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From Mexico to Brazil: Central Atlantic Fisheries Catch Trends and Ecosystem Models

Fisheries Centre, University of British Columbia, Canada

From Mexico To Brazil: Central Atlantic Fisheries catch Trends and ecosystem models

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Director's Foreword

One often hears, when dealing with tropical fisheries, that "there are no data." Usually, this is not true and the complainers are usually persons who have not bothered to look, or at least not beyond conventional sources. A large fraction of standard journals in marine and fishery biology contain articles with tropical contents. Moreover, there is a huge, if gray, literature with valuable information on the state of marine ecosystems and tropical resources in the world, some of these reaching deep into the colonial period, which for many countries ended in the late 1950s and early 1960s. Thus, for the tropics generally, and for the Western Central Atlantic specifically, it is never true that there are no data.

What is true, however, is that the available scattered data are hardly synthesized and rendered coherent and thus useful for resource management and conservation. Thus, every applied project has to start from scratch at great cost, because "they have no data", and every evaluation of the state of resources or of biodiversity is marred by the absence of a sound baseline rooted in well documented accounts of the past.

This report, one of several similar reports by the *Sea Around Us* and *Back to the Future* projects, is devoted to two types of syntheses. One is the reconstruction of catch series, which are crucial in evaluating the present, and enabling a positive future for fisheries. Here, as in previous reports of this kind, the job was to reconstruct catch series, ideally from 1950 on, matching the period covered by the FAO statistics, and thus allowing an improvement of the corresponding countries fisheries data in the *Sea Around Us* database (see www.seaaroundus.org). Note that the comparison between FAO FISHSTAT and 'original' sources undertaken by most of the present reports are in fact comparisons between two 'national' data sets: 1) Data FAO receives from its member countries via national governments; and 2) National data obtained by the authors from sources as close to the initial collection source as possible. Thus, differences and discrepancies between these two sets can tell us a lot about data quality loss.

The other syntheses presented here are food web models of ecosystems of the Central Marine Atlantic. Constructing such ecosystem models requires large amounts of field data. In themselves, such models thus represent syntheses of previously scattered data. Moreover, such models form the basis for the exploration of alternative policies, a topic that has hardly ever been explored in the geographic area covered here.

With the exception of one model recently constructed by one of the editors (E.M.), these models are outdated, having been constructed during and right after a workshop held in 1996, and which I was supposed to have helped co-edit, a job I was previously unable to complete (the other contributions from this 1996 workshop, written in Spanish, will be published elsewhere). These models retain, however, their interest both as syntheses of the knowledge then available and as a starting point for more thorough and updated models.

The Fisheries Centre Research Report series publishes results of research carried out, or workshops held, at the UBC Fisheries Centre. The series focuses on the multidisciplinary problems of fisheries management, and aims to provide a synoptic overview of the foundations, themes and prospects for current research. Fisheries Centre Research Reports are covered by Aquatic Sciences and Fisheries Abstracts and are distributed to appropriate workshop participants or project partners. A full list of the reports is published at the end of this issue. All papers are available as free PDF downloads from the Fisheries Centre's web site www.fisheries.ubc.ca, while paper copies of a report are available on request.

Daniel Pauly
Director
UBC Fisheries Centre
December 2003

FROM MEXICO TO BRAZIL: CENTRAL ATLANTIC FISHERIES CATCH TRENDS AND ECOSYSTEM MODELS

Edited by

Dirk Zeller, Shawn Booth, Elizabeth Mohammed and Daniel Pauly

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PART I: FISHERIES TRENDS

The Global Fisheries Crisis as a Rationale for Improving the FAO's Database of Fisheries Statistics[1]

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ABSTRACT

Global fisheries are in a crisis, and so are the marine ecosystems upon which these fisheries depend. Major policy and management changes are required to halt and reverse the trends that have brought about this situation. Underlying these changes is the need for availability of data sets, pertaining to large areas, that unequivocally demonstrate any large-scale fisheries impacts on marine ecosystems. Not until recently have such secondary data begun to be assembled, although data sets have been available for some time upon which such demonstrations could be based. This applies particularly to the global fisheries statistics assembled and maintained by the Food and Agriculture Organization of the United Nations (FAO), which are assembled by large, arbitrary statistical areas (rather than by ecosystems), and which are not verified against local data sets. The present contribution documents a multi-pronged approach to develop and test a methodology for reconstructing historic catch time series (including misreported catches), and spatially assign these to ecosystems on a large spatial scale. This will serve as baselines for assessing the 'health' of ecosystems, and to evaluate the effects of fishing and management scenarios. Important components of this methodology are a global spatial catch allocation and mapping routine (www.seaaroundus.org), the Ecopath with Ecosim approach and software for constructing food web models of marine ecosystems (www.ecopath.org), and FishBase, an information system on the fish of the world (www.fishbase.org). Along with putting global fisheries data on a spatial ecosystem basis, these tools can greatly contribute to deepening our understanding of the ecosystem services upon which fisheries rely.

INTRODUCTION

In the 1990s, fisheries emerged from their sectoral backwaters, and became one of the environmental concerns of the public at large, at least in the developed countries of the world. This transition in public perception, similar to that involving forestry in the 1980s, was probably due to long established trends suddenly generating media events, e.g., the publication of a report by Alverson and colleague documenting the enormous quantities of by-catch that are discarded by industrial fisheries (Alverson *et al.*, 1994), the collapse of Northern cod (*Gadus morhua*) in Canada (Hutchings and Myers, 1994; Myers *et al.*, 1996; Walters and Maguire, 1996; Myers *et al.*, 1997; Hutchings, 2000), the failed attempt to halt the impending destruction of Southern bluefin tuna (*Thunnus maccoyi*) populations by listing bluefin tuna as an endangered species (Anon., 1996), or the presentation of estimates of the amount of subsidies which contribute to maintaining fishing effort, globally, at levels far exceeding sustainability (Christy, 1997; Garcia and Newton, 1997; Hempel and Pauly, 2002; Munro and Sumaila, 2002; Pauly *et al.*, 2002). These events were only the tip of a gigantic iceberg: fisheries, an industry that had long operated outside of public scrutiny, emerged, to an amazed public, as worse to ocean health than the 'pollution' so much is written about (Dayton *et al.*, 1995). Fishers, whose daring and ingenuity had, for centuries, justified our romantic view of their profession (Kurlansky, 1997), had become cogs in the high-tech machine that almost instantly reduces any stock it touches to a shadow of its former self (Pauly *et al.*, 2002; Christensen *et al.*, 2003; Myers and Worm, 2003).

Particularly important is that 'sustainability', the stated goal of most fisheries management, and enshrined in legislation worldwide, is

[1] An earlier version of this paper was presented at the Fisheries Project Planning Meeting of the Bejier International Institute of Ecological Economics, June 21-23, 1999 in Woods Hole, Mass.

actually a flawed concept. It implies, at best, a maintenance of resources at 'present' levels, usually much below environmental carrying capacity, and, at worst, a gradual erosion of the resource base (Pauly, 1995; Pitcher and Pauly, 1998; Pauly *et al.*, 2002). This is aggravated by 'games' that are played with the logic underlying assessment models. Thus, for example, quickly fishing down newly discovered stocks (such as Orange Roughy, *Hoplostethus atlanticus*) is being justified by surplus-production models, which assume production to be maximized when biomass is reduced to half or less the unfished level. Significantly, however, fisheries are not stopped when the biomass has dropped to half or less the unfished level. Note that we abstain here from probing too deep into the logic of surplus-production modelling and the single-species 'Maximum Sustainable Yield' it implies, earlier criticized by Larkin (1977).

Among professional fisheries scientists, the crisis of fisheries is still often denied. Despite frequent and fashionable references to the need for a methodological 'paradigm shift', many believe, for example, that rigorous quantification of the uncertainties involved in stock assessment, and the communication of the results to fisheries managers in the form of risk assessment would be largely sufficient to resolve the above-mentioned problems. Our key problem, however, is not 'uncertainty', nor lack of knowledge by fisheries managers. Indeed, the problem is not even one of management, but one of public policy. This refers to the excessive role played, in allocation debates, by the users of fisheries resources (i.e., fishing and processing industries) vis-à-vis the true owners of these resources: the citizens (present and future) of the various countries whose fish stocks are being used (Macinko and Bromley, 2002). Resolving this allocation issue requires public involvement, as occurred with, for example, the reclaiming of public waters, long perceived to 'belong' to those who used such waters to cheaply dispose of toxic effluents. Indeed, reclaiming the sea from its abusers will be a key task for humanity in the 21st century; second only to avoiding the massive climatic change that increasing emission of greenhouse gases will give us.

However, informing the public, the true owners of the resources, and the law-makers who represent them, of the true status of the impact of fisheries on ocean health is difficult, as a strong lobby exists which, like the Tobacco Institute with regards to the effects of cigarettes, challenges the obvious to maintain the unacceptable. This implies, among other things, that the data from which the state of the ocean is to be inferred should be transparent and widely available, and thus compelling. An example of the kind of compelling, well articulated case that is meant here is Rachel Carson's *Silent Spring*, which affected public policy via its public impact (Carson, 1962). A step in this direction with regards to the effects of fisheries on our oceans is attempted in Pauly and Maclean (2003).

Developed countries

Fisheries science emerged from the bosom of 'natural history' at the turn of the 20th century, when, following the introduction of steam trawling, coastal catches and catch per effort began to decline in the North Sea and other fishing grounds around the North Atlantic (Cushing, 1988). The scientific response, which included the foundation of ICES, the International Council for the Exploration of the Sea (Went, 1972), is well documented (Smith, 1994), and involved great scientific achievements, notably the development of the first unifying theory in fisheries science, described in Beverton and Holt (1957), and the first functional simulation model of a fisheries resource system (Andersen and Ursin, 1977). This led to Multispecies Virtual Population Analysis (MSVPA), a tool for understanding trophic interactions among exploited species (Daan and Sissenwine, 1991). Similar developments occurred in North America, both on the east and west coasts (Ricker, 1975; Hilborn and Walters, 1992), and in other developed countries and areas, notably Eastern Europe, East Asia and the Southern Hemisphere. Still, it is also in those areas, particularly in the North Atlantic and North Pacific, that ecosystem effects of overfishing are most visible (Pauly and Watson, 2003), notably due to fisheries over time catching species progressively further down the food webs (Pauly et al., 1998; Pitcher, 2001).

Developing countries

The colonial areas which, after the Second World War gradually became what are now called the 'developing' countries of the world, had long traditions of fishing, if mostly at artisanal levels. Since the 1960s, these fisheries have been gradually pushed aside by industrial fisheries, either in the form of distant-water fleets from developed countries, e.g., as in much of West Africa (Kaczynski and Fluharty, 2002), as nominal or real joint ventures, e.g., many tuna fisheries in the South Pacific (Melzhoff and LiPuma, 1983), or in the form of trawler and other fleets owned by local elites (e.g., the trawl fisheries in Southeast Asia) but often subsidized by major development banks, e.g., the Asian Development Bank (Mannan, 1997).

The scientific inputs to these developments, devoted mainly to resource surveys, were minimal (Pauly, 1996a), a reflection of the weak scientific infrastructure of the countries in question. The bulk of the populations exploited by these fisheries have now collapsed, or are much depleted (Silvestre and Pauly, 1997).

However, in retrospect, it appears that more input from the fisheries sciences extant at the time would not have prevented these developments: tropical fisheries science – a derivative of the science prevailing in Europe and North America – was as unequal to its tropical task as its role model was to its temperate task (Pauly, 1998). This, and similar issues related to fisheries in developing countries, are not 'sideshows' that may be ignored when dealing with global fisheries issues: these countries now generate over 50% of global marine fisheries catches (Christensen *et al.*, 1992; Anon., 1995a). Moreover, a very large fraction of their catches enters the world market, increasingly at the detriment of the exporting countries (Atta-Mills *et al.*, 2004).

Time series of catch statistics

The most important information about a fishery is the total catch, by species, over time. Catch statistics are important for three reasons: (1) the gathering of statistics increases knowledge of the fishery (tracking of vessels engaged in fishery, dockside sampling of these same vessels, etc.); (2) total catches determine the scale of fisheries, both within and between sectors, in terms of their size and value; and (3) examining time series of catches allows for first-order assessment of the fisheries over time, and of the status of the species and populations (stocks) upon which the fisheries depend (Caddy and Gulland, 1983; Grainger and Garcia, 1996).

Fisheries catches may be separated into three components: (i) nominal catch, which is reported to (and by) a monitoring agency (e.g., by member countries to the Food and Agriculture Organization of the United Nations [FAO], in the case of global fisheries statistics); (ii) discarded by-catch, the non-targeted part of a catch, often consisting of the juveniles of targeted or other species, caught due to the unselective nature of the gear used, and usually thrown overboard (generally unrecorded) rather than landed (Alverson *et al.*, 1994; Alverson and Hughes, 1996); and (iii) an unreported component, consisting of categories not covered by the reporting system in question, including sport fisheries catches, artisanal fisheries catches and illegal catches (Castillo and Mendo, 1987; Agnew, 2000; Pitcher *et al.*, 2002).

Thus, item (iii) may be composed of catches that a given agency is not mandated to gather and report, so-called 'unmandated catches', and of catches whose value may be maliciously misreported, i.e., 'disreported catches' (Pitcher *et al.*, 2002). A major task, thus, is to estimate IUU catches (Bray, 2000), a task that requires the development of new protocols (Pitcher *et al.*, 2002).

The role of FAO

The role of the Food and Agriculture Organization of the United Nations (FAO) in international fisheries research and management has been considerable, and may be divided into three phases: (1) an early 'North Atlantic Phase', lasting from the post WWII founding of FAO to the mid-1960s, devoted to the development of standardized methodologies, and involving mainly scientists from or in Northern Europe; (2) a 'Developing-Countries Phase', lasting perhaps to the late 1980s, with FAO supporting crucial initiatives in developing countries (workshops, training courses, taxonomic guides, regional commissions); and (3) a 'Global Phase', in which FAO deals with fisheries on a decidedly worldwide basis, reflecting the globalization of fisheries issues: development of the UN agreement on straddling stocks (Anon., 1995b, 1995c), the Code of Conduct for Responsible Fisheries (Anon., 1995a), global evaluation of the status of fisheries (Grainger and Garcia, 1996), etc.

FAO (www.fao.org/fi/default_all.asp, date accessed: 20 November 2003), emphasizes the following elements of its mission: *"to promote sustainable development of responsible fisheries and contribute to food security. To implement this [...], the Fisheries Department focuses its activities, through*

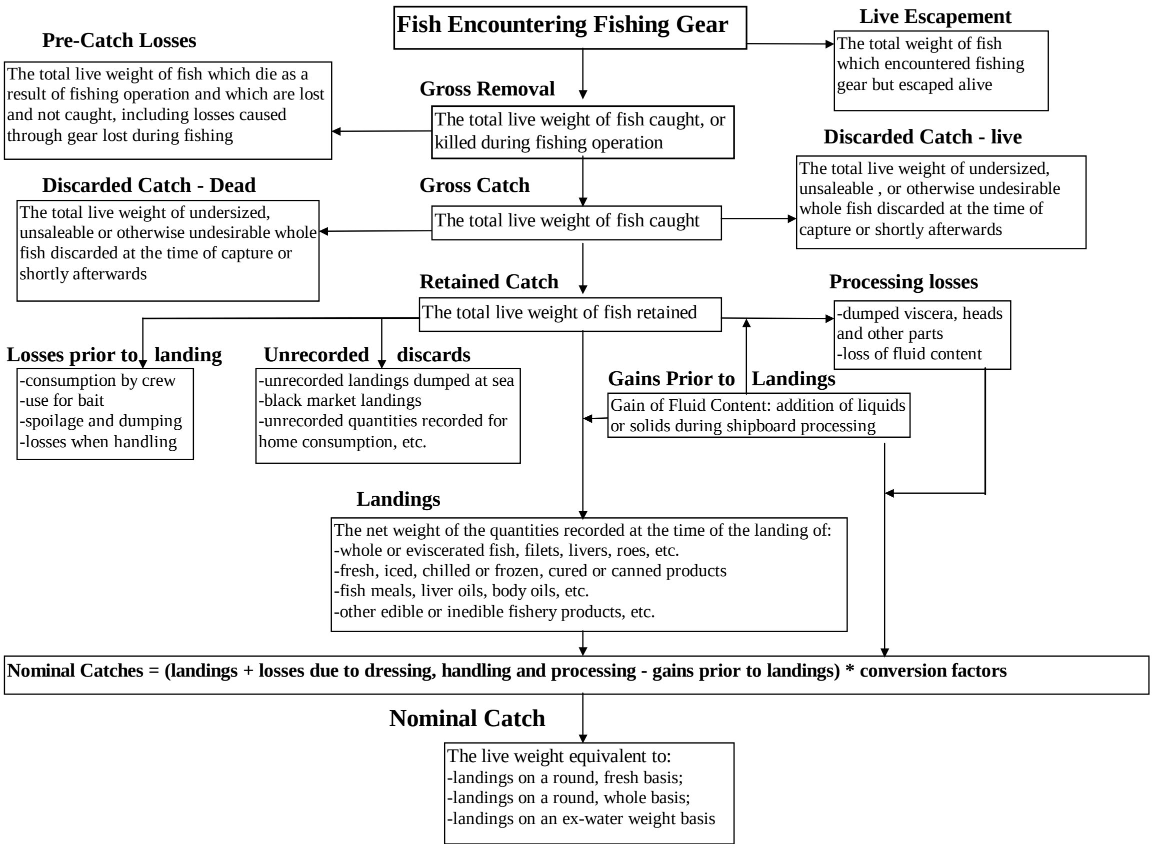

Figure 1: Flowchart of steps involved from 'fishing' (fish encountering fishing gear) to estimation of nominal catch (from the 1994 FAO Yearbook); these steps represent procedures that *should* be used, not necessarily those that are actually used by the entities submitting data to FAO.

programmes in Fishery Resources, Fishery Policy, Fishery Industries, and Fishery Information, on three medium-term strategic objectives:

- *Promotion of Responsible Fisheries Sector Management at the Global, Regional and National Levels, with priority given to the implementation of the Code of Conduct for Responsible Fisheries, Compliance Agreement, International Plan of Action and particular attention paid to the problem of excess capacity and the provision of advice for the strengthening of Regional Fisheries Bodies…*
- *Promotion of Increased Contribution of Responsible Fisheries and Aquaculture to World Food Supplies and Food Security. Following on the outcome of the Kyoto Conference on the Sustainable Contribution of Fisheries to Food Security, the Department focuses on reduction of waste in fisheries (particularly discards) and aquaculture (including its promotion in the context of FAO's Special Programme for Food Security). Support is given to aquaculture development in areas of highest potential or critical need by improving aquaculture resources utilization and integration with agriculture, promoting research as well as protection and rehabilitation of the environment.*
- *Global Monitoring and Strategic Analysis of Fisheries, with priority given to development of databases and analysis of information using modern information systems (e.g. CD-ROM, GIS), and contributing inter alia to the publication of the State of World Fisheries and Aquaculture (SOFIA) on a biennial basis and the Digital Atlas on Agriculture, Forestry and Fisheries".*

Until recently, many fisheries scientists were not fully aware of FAO's role in fisheries, and of the large literature this has generated, largely because, outside of FAO projects, FAO documents are available only through specialized outlets, at relatively high prices. Fortunately, the Internet is changing this, as much of this material is now becoming accessible through the World-Wide-Web. On the other hand, most fisheries scientists and marine biologists are aware of FAO's role in establishing a Code of Conduct for Responsible Fisheries (Anon., 1995a), and in compiling and maintaining global fisheries statistics, although they may not know the underlying mechanisms.

The key steps used by FAO in compiling global catch statistics are summarized here through a graph (Figure 1) adapted from the 1994 FAO Yearbook. Hall (1996) and Alverson and Hughes (1996) discuss the by-catch problem implied in Figure 1, an area of much concern for all involved in fisheries statistics and management, and to the public at large. However, the single most important aspect of the system in Figure 1 and the subsequent adjustments at FAO Headquarters, is that it generates a *global* data set of landings – the only one in the world. Moreover, because so many countries and institutions contribute to it, there is a strong sense of ownership. Rarely does one find any criticism of this system put into print (Chua, 1986), though all practitioners are aware of at least some of its deficiencies, satirized in Mariott (1984), and expanded upon in the next section. As well, the recent discovery of significant over-reporting of fisheries catches by China, which drastically influenced global pattern of catches for the 1990s (Watson and Pauly, 2001) is mentioned in FAO statistical reports, if only tacitly (notably by presenting data with and without China, e.g., Garcia and de Leiva Moreno, 2003).

Earlier proposals for improvement

Critical comments on the FAO datasets are difficult to justify: after all, this is 'all we have got'. On the other hand, it is obvious that the FAO statistical system, even though recently upgraded, is in great need of improvement. For example, the first report of FAO's new 'Advisory Council on Fisheries Research' noted that "*the current statistics collection system is limited to primarily landings and commodity statistics, whereas there is a critical need for data relevant to fleet capacity, participation in fisheries, economic performance and distribution*" (Anon., 1997), which is what Pontecorvo (1988) had asked for over a decade ago. However, collection and standardization of such statistics – except for fish prices - is difficult, and FAO, perhaps rightly, did not follow up on these suggestions, now reiterated in the above-mentioned report, but without reference to Pontecorvo's earlier plea, nor to the lively debate that ensued (Gulland, 1989; Pontecorvo, 1989; Robinson and Christy, 1989). Moreover, while adjuring FAO to emphasize an '*ecosystem perspective on fisheries*', its Advisory Council on Fisheries Research failed to mention the corresponding requirement for its statistical data to be put on an ecological basis (also part of Pontecorvo's plea).

Complementing the FAO monitoring system

It is obvious from this and related documents that the world scientific community must assist FAO in expanding the coverage of its statistical reporting system. There is a need for the international community to create and maintain a relational database compatible with FAO's FISHSTAT database, but which splits over-aggregated time series into finer categories, incorporates previously ignored sport, artisanal and other under-reported catches, and adjusts official figures to account for illegally caught fish.

A crucial element in the gradual evolution of such a database would be an international network of collaborators. These collaborators, many drawn from the academic and conservation communities, would supply the group managing the database (officially or privately) with reports and data sets that would help enrich the database with information presently not covered by FAO. The subsequent publication (through the World-Wide-Web) of otherwise unavailable fisheries data would induce greater transparency overall, and would help FAO in the fulfillment of its mandate to cover global fisheries.

Most importantly, however, this database should re-express the FAO catch statistics, presently aggregated into 18, largely arbitrary 'statistical areas' into catches extracted from marine ecosystems, i.e., into the entities from which this biomass is extracted, and which we would like to see persist as functional entities.

Thus, one way this can be achieved is to create a system that would complement the existing FAO database such that it can be used in ecological contexts, as well as account for those elements (such as illegal fishing), which private groups could follow in greater depth. Attempts to achieve just that are presently underway, e.g., through the *Sea Around Us* project at the University of British Columbia Fisheries Centre (see www.seaaroundus.org), and have already yielded significant results (Watson and Pauly, 2001; Pauly *et al.*, 2002; Christensen *et al.*, 2003; Pauly and Maclean, 2003).

Putting fisheries in their ecosystem context

An ecologically-based stratification, consisting of 56 'biogeochemical provinces' already exist, which can replace the FAO statistical areas (Longhurst, 1998). Being based on satellite oceanography, this stratification relies on the very 'stuff' that generates fundamental differences between ocean provinces: sea surface temperatures and their seasonal fluctuations, and pigments such as chlorophyll and their fluctuations. Marine systems differ from terrestrial systems in that their productivity is essentially a function of nutrient inputs to illuminated layers. This gives a structuring role to the physical processes which enrich surface waters with nutrients from deeper layers, such as wind-induced mixing, fronts, upwellings, etc. Thus, the location, duration and amplitude of deep nutrient inputs into different biogeochemical provinces - as reflected in their chlorophyll standing stocks - largely define the upper trophic level biomasses and fluxes that can be maintained in these provinces (Longhurst, 1998).

The flux of primary production into grazers such as krill, and the subsequent consumption of these herbivores by carnivorous zooplankton and small fishes can be straightforwardly modelled based on the mass balance approach, as can the fluxes into higher trophic levels, all the way to the top predators exploited by fisheries (tuna, billfishes), and those that compete with us (marine mammals). Indeed, the assumption of mass-balance allows quantifying fluxes to and from groups whose biomass is not known, such as deep-sea squids, consumed by sperm whales, and lanternfish, consumed by dolphins. This allows dealing with a type of resource presently not quantified by those evaluating the overall potential of the ocean, and whose estimates are often based on guesswork (Pauly, 1996b), although they involve taxa whose combined biomass has been variously guessed to be in the order of several billion of tonnes.

Mass balance models can be constructed straightforwardly using the Ecopath with Ecosim and Ecospace approach and software, located at www.ecopath.org (Polovina, 1984; Christensen and Pauly, 1992; Walters *et al.*, 1999; Pauly *et al.*, 2000). Thus, the Ecopath-based description of specific ecosystems outlined above can be raised to their corresponding biogeochemical provinces, then to ocean basin scale and finally to the global ocean, taking into account the fraction of coastal waters, shelf, deep ocean, etc. in each of these area. Christensen *et al.* (2003) and Pauly and Maclean (2003) document results obtained through this methodology for the North Atlantic.

This approach combines into a single framework the detailed data sets available at local scales for all ocean provinces (results of historic trawl surveys, acoustic biomass estimates, biomass estimates from single-species assessments, diet compositions analyses, food consumption estimates from laboratory studies, and other data sets, including data in FishBase, see below), and raise these to the level of ecosystems, as required for inferences on the impacts of fisheries. This also allows, using Ecosim, the dynamic simulation module of this software (Walters *et al.*, 1997), to quickly identify, for any ecosystem, the gross features of the management regime required that might optimize catches, given the establishment of marine protected areas (Pauly *et al.*, 2002; Russ and Zeller, 2003), the requirement to protect the food supply of marine mammal populations, and other conservation-relevant constraints (Hempel and Pauly, 2002; Pauly *et al.*, 2002).

FishBase and other biodiversity databases as information systems for fisheries

FishBase (Froese and Pauly, 2000), located at www.fishbase.org, presents key nomenclatural, distributional, biological and other information (including catches, where available) on over 28,000 extant species of finfish. Until 2000, the FishBase CD-ROM included an annually updated version of the global FAO catch database presented above, made accessible through the SPECIES, and

COUNTRIES tables of FishBase. The catch database of the *Sea Around Us* Project is compatible with FishBase, as this enables direct access to the most authoritative nomenclature of fish presently in existence (that of Dr. W.E. Eschmeyer, of the California Academy of Science, also included in, and updated through FishBase). This resolves, in one fell swoop, one of the biggest problems of database covering different taxonomic entities.

However, fisheries (and ecosystems) are not restricted to fishes. Thus, other taxonomic components and data-sources also need to be considered, e.g., through joint initiatives such as the standardization and cross-linking of existing databases currently being undertaken with CephBase (www.cephbase.org), or the creation of new biodiversity data sources such as the Scientific Expeditions Database being developed by M.L. Palomares of the *Sea Around Us* project.

CONCLUSIONS

The world community has made, through FAO, a massive investment to create and maintain a database of global fish catches. This is an investment of great usefulness, and with an even greater potential. To fully realize the potential of this database, however, an additional effort needs to be made to put the time series of catches it contains on an ecosystem basis, and in the process, to verify and amplify its contents (as done in the various contributions in this volume). The first steps in this direction are being undertaken by the *Sea Around Us* Project, the FishBase Consortium and other groups. We hope that these efforts will remove 'lack of data' from the excuses used to justify the state our fisheries are in, and increase public transparency and understanding, leading to increased involvement in public policy by the true owners of ocean resources, the present and future citizens of the world.

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Reconstructing Fisheries Catches and Fishing Effort for the southeastern Caribbean (1940-2001): General Methodology

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Abstract

Time series of fisheries catches and fishing effort from 1942 to 2001 were reconstructed for four island nations in the southeastern Caribbean: Barbados, Grenada and the Grenadines, St Lucia, and St Vincent and the Grenadines. The magnitude and level of species dis-aggregation of reconstructed catches was also compared with existing data in the Food and Agriculture Organization global fisheries database (FAO FISHSTAT). General trends in reconstructed catches, fishing effort, catch per unit area and catch per unit effort were compared for the offshore and inshore fisheries of the respective islands. The present contribution describes the basic methodology applied, while separate, individual country reports in this volume present each country's reconstructed dataset.

Background

Catch and effort data are the basis upon which fish stocks are assessed. These data increase knowledge of fishery operations, indicate the scale of fisheries in terms of size and value, both within and between sectors, and can be used to assess the species and populations upon which fisheries depend (Watson *et al.*, 2000). Yet, especially for developing countries, financial and human resource limitations pose a challenge, even for the collection of this most basic information. In the past, policy decisions were therefore often made in the absence of such information. Management generally aims to regulate either fish catches, fishing effort or both, depending on the future predictions of assessment studies and the social, economic and political climate. Without initial estimates of the status of fish stocks, and time series data on catches, it is very difficult to assess the success of the management strategies implemented.

During the 1980s and 1990s, many islands of the southeastern Caribbean experienced changes in the abundance of reef fish species. Informal reports from fishing communities about declines in overall catch per trip, reduction in individual sizes of fish caught and changes in species composition of the catch reflect this (Mahon, 1990, 1993; Singh-Renton and Mahon, 1996). However, in the absence of catch time series, it is difficult to measure the magnitude of any change. Furthermore, the Fisheries Departments responsible for assessment and management have suffered from staff relocations, insufficient human and financial resources, high turnover of staff, as well as structural damage and loss of important documents by fire. The loss of 'institutional memory' associated with the high staff turn-over contributes to the shifting baseline syndrome (Pauly, 1995). As a result, few existing staff have a full appreciation for the historical changes in fisheries resources prior to their employment.

Starting in 1992, the CARICOM Fisheries Resource Assessment and Management Program has assisted the islands with implementation of a structured statistical data collection system aimed at estimating total landings for assessment and management. Detailed catch, effort and species composition data have been collected, and assessments conducted for the dolphinfish (Parker *et al.*, 2001), wahoo (George *et al.*, 2000) and redhind (Straker *et al.*, 2001) fisheries in the region. It is evident that the data collected are extremely useful in assessing the present status of the fishery. However, they represent only a snapshot of the situation existing in the late 1990s. What is required is an idea of the past condition of the stocks against which the existing status can be compared, and impacts of increased fishing over the study period quantified. It is only when long-termed trends are documented and analyzed that an evaluation of whether further increases in fishing effort would be productive or not is possible.

General developments in data collection and storage systems

Initial attempts at data collection (Brown, 1942a, b, 1945) focused only on fish sold at the major fish markets in the respective islands. An unknown proportion of catches from several landing sites was transported to these markets. Historic data therefore do not adequately reflect total catches, and there is little additional information from which a methodology for estimating total catches using recorded landings could be devised. These data limitations are documented in Hess (1961), Vidaeus (1969 a-d), Villegas (1978) and Chakalall (1982).

A coordinated approach to data collection was the focus of a workshop sponsored by the Organization of Eastern Caribbean States in 1988 (Mahon and Rosenberg, 1988). Associated islands reviewed their data collection systems, identified gaps and proposed strategies for improving coverage of different fishery types (species, gear and fleet). These included total coverage at major sites and sampling of minor sites, the acquisition of purchase receipts from hotels, restaurants and supermarkets, review of export permits/licenses and implementation of logbook programs for semi-industrial and industrial vessels. To date, improvements have been aimed mainly at increased coverage of landing sites, export data and landings from semi-industrial vessels targeting the offshore large pelagics. The project also introduced a computerized data management system. Grenada and the Grenadines, for example, implemented a system for collection of large pelagic species from local and foreign fleets in the early 1980s, a project facilitated under the Enhanced Research Program for Billfish initiated under the ICCAT (Phillip and Isaac, 1994). In 1992, under the CARICOM Fisheries Resource Assessment and Management Program, islands received support for improving their fisheries data collection systems. Data collection focused on those species identified as being commercially important under the following fishery categories (CFRAMP, 1997): large pelagic, deep slope and reef fisheries, lobster and conch fisheries, shrimp and groundfish fisheries. The Trip Interview Program (TIP) was introduced in several islands for storage and management of collected data, and standardization of reporting systems throughout the islands.

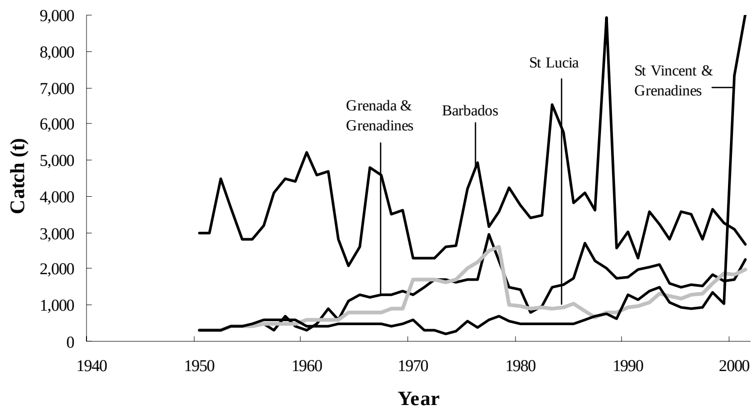
Presently, of the five island states under examination here, only St Lucia has devised a methodology for estimating total catches based on stratified sampling systems. The availability of recorded data since 1995 has facilitated the use of this methodology to estimate total catches. The other islands (St Vincent and the Grenadines, Grenada and the Grenadines, Barbados, and Trinidad and Tobago) have applied fixed raising factors to adjust recorded landings to total catches. These factors are based on general knowledge of fishery development and do not necessarily reflect changes (temporal, spatial, fleet related) in the coverage of the data collection system.

The time periods of available catch data from the Fisheries Departments for the respective islands are as follows: Barbados (1945-2000); St Vincent (1979 –1999); Grenada (1978-2001); St Lucia (1980-2000). In most instances catch data prior to the mid-1990s are highly aggregated, with details available only for those species of commercial importance. Further dis-aggregation of catch statistics is possible from review of reports and papers (published and unpublished), and country raw catch data, the latter are often available in hard copy only. Data for years prior to the time periods mentioned are interpolated using mainly data from Brown (1942 a, b, 1945) and Vidaeus (1969 a-d) as anchor points.

Existing catch data for the region

Catch data from 1950 to the present exists in the Food and Agriculture Organization Fisheries Statistical Database (FAO FISHSTAT) for the respective countries of this study (Figure 1a). Compared to FAO data for northeastern Caribbean islands (e.g., Dominica, St Kitts and Nevis, Antigua and Barbuda, and Montserrat), where most data were reported in a single 'marine fish nei' category (i.e., "not elsewhere identified"), the level of species dis-aggregation in FISHSTAT is reasonable in recent times for the countries of this study (Figure 1b). Nevertheless, a considerable percentage of the overall catch is represented in the aggregate 'marine fish nei' category (Figure 1c), especially for catches in St Vincent and St Lucia. Further, given the numerous species caught in the inshore reef and shelf areas, the level of species dis-aggregation is too low for determining changes in species composition, indicative of over-exploitation.

(a)



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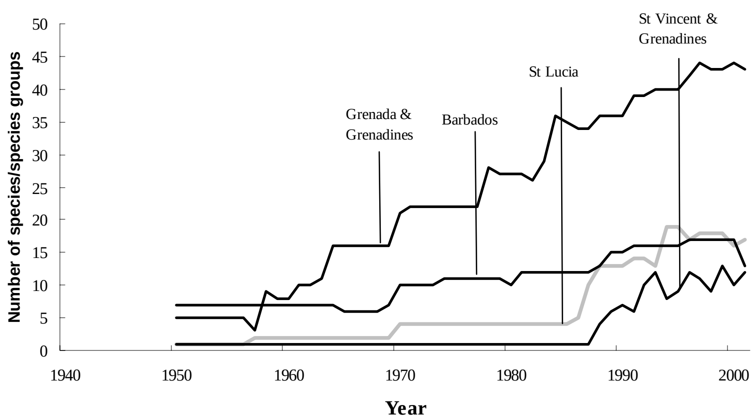

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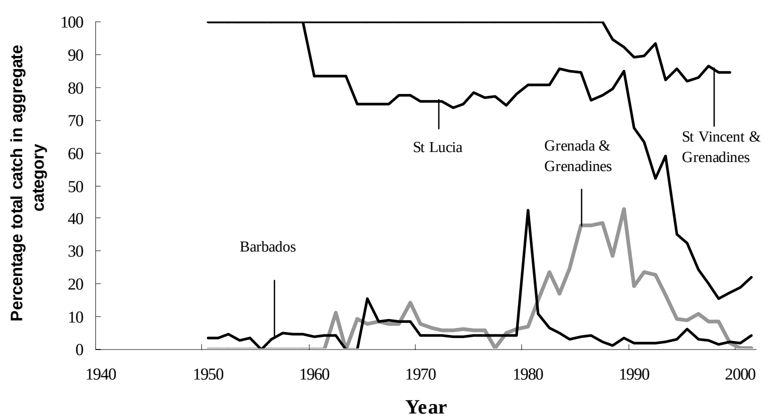

Figure 1: Catches reported by FAO FISHSTAT for four island nations (Grenada and the Grenadine, St Lucia, St Vincent and the Grenadines, and Barbados) in the southeastern Caribbean (a) annual trends in catches; (b) number of species/species groups reported, and (c) percentage of total catch in aggregate (unidentified) category.

The data reported by most countries reflect only nominal catches, and observed trends may be more indicative of changes in the coverage of the data collection systems rather than trends in the abundance of species exploited. Only species of major commercial importance are dis-aggregated in the reported data. Furthermore, the original data sources are often not documented. These limitations affect the utility of the data for examining the impacts of fishing on species diversity, stock assessment, and management or policy formulation. Development of fisheries, therefore, has proceeded in the absence of scientific and technical advice on stock status. This scarcity of information on resource potential and state of exploitation, and resulting difficulties in making rational development plans are not uncommon for tropical small-scale fisheries in general (Gulland, 1979).

GENERAL METHODOLOGY

The general approach for reconstructing a time series of fisheries catches and fishing effort for the period 1942 to 2001 was to use information from historical documents, published and unpublished reports, grey literature, databases and surveys of the Fisheries Departments in the respective islands (see also Pauly, 1998). The methodology and data sources are documented for future reference and trends in reconstructed data are examined based on developments of the fishing industry. A list of Fisheries Departments, other institutions and individuals who assisted in providing data or identified and located documents is given in Appendix 1.

Catches

The available data sources were used to identify 'anchor points', which reflect the actual annual total or taxa specific catches from key information sources. Where estimates from different sources varied, those derived from the most recent methodology and which accounted for unrecorded landing sites, boats and fishing days were used. Alternatively, the estimate most cited in the literature was accepted. When possible, anchor points were adjusted to account for the unrecorded components of the fishery using raising factors identified in the literature. In the absence of additional information, data for missing years were estimated by interpolation. Also, in severely data limited situations, assumptions or inferences were made based on similarities in fisheries of neighboring islands. In some instances data from the FAO FISHTAT database were used. Reconstructed total catches were disaggregated using information on species composition available in the literature, and personal communication with staff of the respective Fisheries Departments.

Where fisheries in a multi-island country differed significantly between islands (e.g., Grenada and the Grenadines), the reconstruction of catches and effort were done separately, for example, for the island of Grenada, which historically targeted mainly large pelagics, and for the islands of the Grenadines, which have historically targeted mainly inshore reef and demersal species. Since there are distinct differences in exploitation levels and resource status between inshore and offshore fisheries, reconstructed data are also analyzed separately for each fishery. The species associated with each fishery were taken from the data provided by the respective Fisheries Departments. The offshore fishery comprises the large, highly migratory pelagics captured mainly with longlines or troll lines. The inshore fishery comprises the reef, shelf and slope fisheries as well as the small coastal pelagic fishery. Attention was also given to reconstructing catches of non-fish species such as marine mammals and turtles (given international conservation concerns), as well as lobster (*Panulirus argus*), conch (*Stombus gigas*) and sea urchins, important in Barbados and St Lucia.

Conversion Factors

It was often necessary to convert reported statistics to an estimate of the associated catch, e.g., in cases where the catch was processed at sea, or when the quantity of turtle shell or whale oil exported was given.

Large Pelagics

For the large pelagic longline fisheries in recent years, conversion factors to estimate total (live) weight were used. Stricter quality controls on the export market necessitate at-sea processing, which may vary from simple removal of gills and digestive organs to removal of fins and bills. The main species are yellowfin tuna (*Thunnus albacares*), swordfish (*Xiphias gladius*), sailfish (*Istiophorus albicans*), blue marlin (*Makaira nigricans*) and white marlin (*Tetrapturus albicans*). Based on the degree of processing (Samlalsingh *et al.*, 1995) appropriate raising

Table 1: Conversion factors applied for onboard processing of fish.

Common Name	Scientific Name	Degree of Processing	Location (FAO Area)	Conversion Factor
Dolphinfish	*Coryphaena hippurus*	Gutted, chilled	–	1.100[a]
Kingfish	*Scomberomorus* spp.	Gutted, chilled	Tobago (31)	1.100
Wahoo	*Acanthocybium solandri*	Gutted, head/tail off, chilled	St Helena (47)	1.300
Tuna	Tunas nei	Gutted, chilled	Liberia (34)	1.100
Albacore	*Thunnus alalunga*	Gutted, chilled	UK (27)	1.125
Yellowfin tuna	*Thunnus albacares*	Gutted, chilled	Mexico (31)	1.100
Atlantic bonito	*Sarda sarda*	Gutted, head off, frozen	Bulgaria (34)	1.320
Sharks/rays/skates	–	Gutted, head off, chilled	Mexico (31)	1.500
Redhind	*Epinephelus guttatus*	Gutted, chilled	Mexico (31)	1.100
Rockhind	*Epinephelus morio*	Gutted, chilled	Mexico (31)	1.100
Snappers, jobfishes nei	–	Gutted, chilled	–	1.100
White marlin	*Tetrapturus albidus*	Gutted; head and fins removed	–	1.140[b]
Blue marlin	*Makaira nigricans*	Gutted; head and fins removed	–	1.140[b]
Swordfish	*Xiphias gladius*	Fins/swords removed, chilled	Cyprus (37)	1.140[b]

a: Assumed; b: Conversion factor based on an estimate of 1.3 for removal of head and gut.

factors available for the species in FAO Area 31 (Western Central Atlantic) were used to convert to whole wet weight (Table 1).

Marine Turtles

Catches or exports of turtles were often reported as number of animals. The mean individual weight of respective species was used to convert numbers to their equivalent weight (Witzell, 1984). Loggerhead turtles (*Caretta caretta*) ranged between 90-180 kg, green turtles (*Chelonia mydas*) ranged between 90-136 kg, and hawksbill turtles (*Eretmochelys imbricata*) ranged between 45-57 kg. While heavy exploitation is expected to result in smaller sizes at capture this was not considered in the present analysis. Hawksbill turtles are favored for export of shell (*bekko*) to Japan. Data were often quoted in weight of shell exported. Two different conversion factors are available: 1 kg of shell per animal (Milliken and Tokunaga, 1987), and 4 kg of scutes per animal (www.tortoise.org.news/1998s28.html). The mean estimate was used along with the corresponding individual weights from Witzell (1984) to convert shell weight to animal weight.

Marine Mammals

Reports from the 1920s and 1930s give data on the quantity of 'blackfish' oil exported. 'Blackfish' is the local name for pilot whale (*Globiocephla macrorhynchus*). The mean quantity of oil produced per whale (13.5 gallons, Brown, 1945), was used to estimate the corresponding number of pilot whales. This estimate differs only slightly from data in Lewis (1964) from which the average quantity of oil produced per whale was 13.79 gallons between 1962 and 1964. The estimates derived are considered lower limits as whale oil was also utilized locally, but not reported, and catches were not limited to pilot whales. For example, the average quantity of oil produced per sperm whale was estimated as 289.3 gallons based on Lewis (1964). Recent estimates of catches are provided as number of animals for selected species (Table 2), and the mean individual weight was used to convert numbers of animals to equivalent weight (Trites and Pauly, 1998).

The movement of catches and landings

In reconstructing fisheries catches the movement of landings has to be considered in relation to the coverage of the data collection program (Figure 2). Except for trawl fisheries, by-catch and discard issues have not been considered as major problems in the region. Most of the gear utilized target specific species, e.g., troll and long lines for catching large pelagics. Though fish-pots may capture species of varying commercial importance, unless a species is poisonous, all of the catch is landed. Beach seines also target specific schools of fish and the bulk of the catch is comprised of species that are either commercially important or used as bait. Further studies are required to ascertain the proportion of the catch kept for personal use or used as bait, both in the line fisheries

Table 2: Mean individual weight for selected species of marine mammals. Source: Trites and Pauly (1998)

Common Name	Scientific Name	Mean Weight (kg)
Bottlenose dolphin	*Tursiops truncatus*	187.5
Atlantic spotted dolphin	*Stenella frontalis*	65.4
Fraser's dolphin	*Lagenodelphis hosei*	95.4
Common dolphin	*Delphinus delphis*	80.2
Spinner dolphin	*Stenella longirostris*	41.3
Dall's porpoise	*Phocoenoides dalli*	61.3
Humpback whale	*Megaptera novaeangliae*	30,408.0
Pigmy killer whale	*Feresa attenuata*	97.5
False killer whale	*Pseudorca crassidens*	578.0
Sperm whale	*Physeter catodon*	6,399.0
Killer whale	*Orcinus orca*	2,281.0
Short-finned pilot whale	*Globicephala macrorhynchus*	643.0

directed at large pelagics and the fishpot fisheries directed at reef and demersal species. Fish sold at major markets have historically been recorded, while those sold on beaches have only recently been incorporated in the data collection system of some islands.

Fishing Effort

Fishing effort was reconstructed separately for the offshore and inshore fishery of each island. The inshore component was further subdivided into small coastal pelagic, and reef, shelf and slope components. This facilitated representation of vessels exploiting more than one fishery type at different times of the year.

Selection of the unit of effort

The main factor influencing the selection of the unit of fishing effort was the availability of information. The most widespread reported unit of effort was 'number of boats'. Also, because of the relative prices in fuel there is a clear preference for vessels with diesel engines of higher horsepower towards exploiting the offshore fishery in recent years (Finlay and Rennie, 1998), while those carrying outboard engines of lower horsepower target inshore resources. Inclusion of engine horsepower is therefore an important factor in estimating fishing effort. There is also a tendency for vessels to target more than one resource type, e.g., those vessels targeting the offshore fishes (flyingfish and associated large pelagics) from November to June usually switch to demersal species from July to October. This switch in targeting and effort can be captured by inclusion of the number of fishing days in the unit of effort. 'Horsepower-days' was therefore selected as the unit of fishing effort. This allowed for comparison of fishing effort among years, countries and fishery types, without adjustments to account for differences in gear, vessel capacity or fishing efficiency. The unit chosen is the sum of the product of number of boats, average horsepower and number of fishing days per year for individual vessel types exploiting a particular fishery. There was no information from which changes in overall number of fishing days per year by the specified vessel types and fisheries could be determined. Hence 'fishing days' was used solely to represent the shift in effort of offshore fleets to the demersal/inshore fishery during the pelagic offseason. Fishing effort was linked to the respective fishery type based on historical information on the associated vessel design, degree of mechanization, and location of landing sites relative to fishing grounds. Temporal changes in these factors were also considered, and non-mechanized vessels utilizing oars and sails, as well as beach seines were assigned a default horsepower of one.

Linking fishing effort to fishery type

The associated fishery types were: offshore (comprising large pelagics and flyingfish caught by troll lines, gillnet and more recently longlines), and inshore (comprising small coastal pelagics caught by beach seines, balahoo seine and gillnets; reef, deep slope and shelf demersals caught by traps and handlines). Specific criteria by which vessels could be assigned to a fishery were obtained from a review of the literature, and included

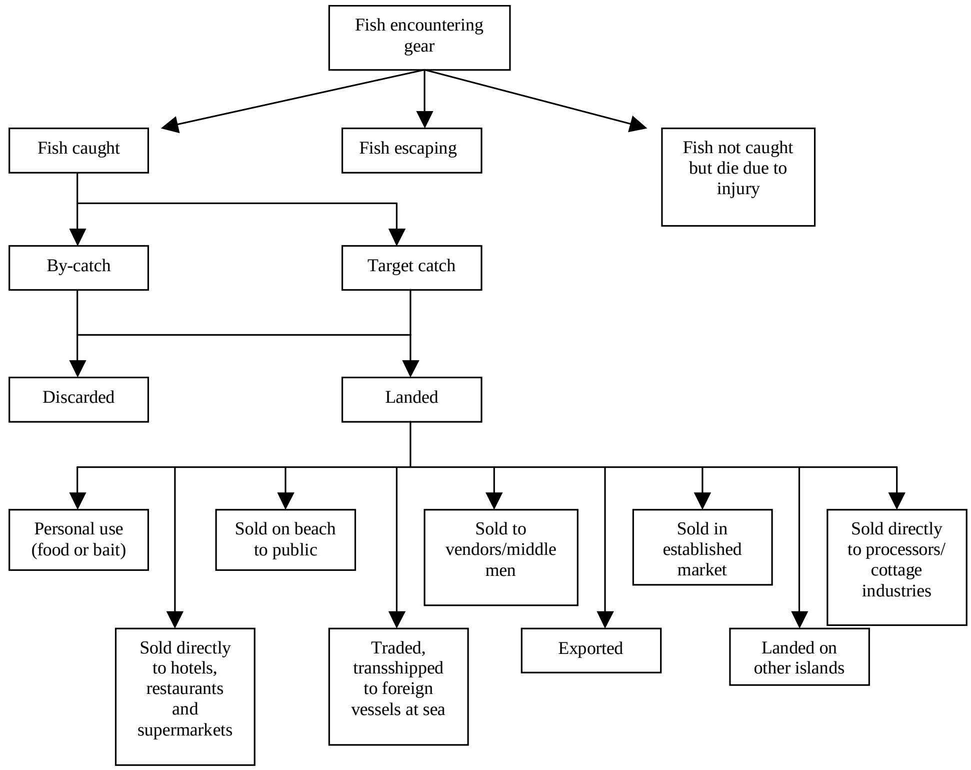

Figure 2: Schematic representation of the movement of catches and landings in four island nations of the southeastern Caribbean.

vessel design and length, degree of mechanization and the location of specific fisheries or fishing areas relative to the coasts, landing sites and mooring sites.

Prior to mechanization (late 1950s) virtually all vessels, regardless of design, fished for inshore and offshore species, though the latter was not yet well developed. Small boats such as canoes and dories were confined to the inshore reef areas, while the larger whalers targeted mainly pelagic fisheries and, during the pelagic off-season, reef and other demersal species. Decked sloops targeted mainly reef, slope and shelf demersals (Brown, 1945, Vidaeus, 1969 a-d). Vessel length, during the pre-mechanization period, also impacted on the fishery exploited and the duration of fishing. Hence whalers, which were typically larger and therefore more stable than canoes, could venture further offshore into rougher waters to target pelagic species, while smaller boats were confined to inshore areas and the respective fisheries. Furthermore, because of greater stability, larger vessels were more likely to fish during the hurricane season (July to October), while smaller vessels would cease fishing. In recent times, semi-industrial launches and pirogues with inboard engines target large, highly migratory pelagic species with longlines, while pirogues with outboard engines target regional large pelagics with troll lines.

Generally, from the late 1950s onwards, an unmechanized vessel was assumed to fish close to shore, either targeting small coastal pelagics with beach seines, gillnets or balahoo nets or inshore reef fisheries with traps and handlines. The degree of mechanization also impacts on the number of fishing days. A mechanized boat is less influenced by sea conditions and therefore would tend to fish during the hurricane season (July to October), when non-mechanized boats either fish closer inshore or stop fishing.

Assigning fishing days to the respective fleets and fisheries

Information on the seasonality of the respective fisheries were used to obtain estimates of fishing days. Vessel mechanization also proved an important factor (Epple, 1977). Non-mechanized vessels are less likely to fish during the hurricane season, especially those located on the windward coasts of the islands.

Table 3: Levels and percentage change in key fishery parameters between 1980 and 1999 for four island countries in the southeastern Caribbean.

Parameter	Grenada & Grenadines		St Lucia		St Vincent & Grenadines		Barbados	
	Offshore	**Inshore**	**Offshore**	**Inshore**	**Offshore**	**Inshore**	**Offshore**	**Inshore**
Reconstructed catch (t): 1980	745	660	549	275	204	397	3211	558
Change in reconstructed catch 1980-1999 (%)	+ 129	- 12	+ 143	+ 36	- 29	+ 64	+ 36	- 31
Reconstructed fishing effort (10^3 Hp-days): 1980	815	302	1254	527	645	1357	2255	1018
Change in reconstructed effort 1980-1999 (%)	+ 598	+ 42	+ 513	+ 133	+ 170	+ 4	+ 339	+ 134
Reconstructed CPUA[a] ($t{\cdot}km^{-2}$): 1980	0.0309	0.3662	0.0341	0.3090	0.0075	0.2048	0.0181	1.4803
Change in CPUA[a] 1980-1999 (%)	+ 129	- 12	+ 118	+ 78	+ 29	+ 64	+ 36	- 31
Reconstructed CPUE (t 10^3 Hp-days): 1980	0.8435	2.0867	0.4707	0.3824	0.2952	0.2753	1.3492	0.5126
Change in CPUE 1980-1999 (%)	- 67	- 38	- 65	- 24	- 52	+ 58	- 69	- 71

[a] CPUA stands for catch per unit area

In the earlier years, the offshore fishery targeted the regional pelagics (small tunas, dolphinfish and mackerels) using troll gear, but expanded to include large, highly migratory species (large tunas and billfishes) caught with longlines from the mid-1980s.

The pelagic fishery has traditionally been seasonal, from November to June, and the associated fleet switches to the demersal and reef fisheries during the pelagic off-season (July to October). During the pelagic season, non-mechanized vessels were assumed not to fish between November and January due to rough sea conditions. Fishing was assumed to occur 15 days per month from February to June (75 days total per year). Mechanized vessels were assumed to fish on average 10 days per month between November and January, and on average 20 days per month otherwise (130 days per year). Specifically for Grenada, vessels on the windward coast were assumed to continue targeting large pelagics from July to October (the hurricane season) on average 15 days per month (excluding one month for vessel maintenance). The total number of fishing days was therefore 175. Semi-industrial longliners operating in earlier years (1982 to 1988) were assumed to function similarly to mechanized boats (Finlay and Rennie, 1998). However, by 1989 these fished year round (Finlay and Rennie, 1998). It was assumed that fishing occurs on average 20 days per month excluding one month each year for vessel maintenance. The associated total number of fishing days was 220. A similar number of fishing days was assumed for like vessels of other islands in recent years.

Non-mechanized vessels targeting the inshore small coastal pelagic fishery were assumed to fish the same number of days each year throughout the period examined. Vessels traditionally target this fishery using beach seines and other nets year round (Finlay, 1996), but peak periods occur from May to October (Brown, 1945). It was assumed that fishing occurred 20 days per month during the peak periods and 10 days per month in non-peak periods, giving a total of 180 fishing days per year.

Generally, vessels targeting the offshore fishery on the windward coasts were also assumed to target the inshore reef, slope and shelf fishery from July to October (excluding one month for vehicle maintenance) at an average of 15 days per month (45 days per year). For fleets targeting this fishery year-round it was assumed that on average fishing occurred 20 days per month from February to October (excluding one month for vessel maintenance) and 10 days per month between November and January. The total number of fishing days was 230.

Analysis of reconstructed data

Details on catch and effort reconstruction of individual island countries are presented in the individual country reports in this volume, and broad patterns are summarized in Table 3. Analyses focused on examining annual trends in reconstructed catches, catch per unit area, fishing effort and catch per unit of effort for the offshore and inshore fisheries of the respective islands. The annual trends, magnitude and level of species coverage of reconstructed catches were compared with data in the FAO FISHSTAT database for the respective islands. Catch per unit area was estimated using the parameters listed in Table 4, assuming that the offshore fishery is confined to the EEZ area and the inshore fishery is confined to the reef, shelf and slope areas.

Table 4: Surface areas for Exclusive Economic Zone, coral reefs, shelves and slopes for islands in the Southeastern Caribbean.

Country	EEZ[a] (km^2)	Coral reef[b] (km^2)	Shelf and slope[c] (km^2)
St. Lucia	18,002	160	522
St Vincent and the Grenadines	27,069	140	1,800
Grenada and the Grenadines	24,153	209[d]	1,595
Barbados	177,346	100	277

a: The Global Maritime Boundaries Database, 2000 Edition. Veridian MRJ Technology Solution. Data modified to include the Territorial Seas. b: ReefBase (Oliver and Noordeloos, 2002). c: Mahon (1993). d: Mean from ReefBase (Oliver and Noordeloos, 2002) and Bacon (1984).

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APPENDIX 1: Institutions and individuals contributing data and literature for catch and effort time series reconstruction.

Fisheries Departments:

St Lucia Fisheries Department: V. Charles (Director of Fisheries); W. Joseph (Fisheries Officer).

St Vincent and the Grenadines Fisheries Department: L. Straker (Fisheries Officer); C. Jardine (Data Manager).

Grenada and the Grenadines Fisheries Department: J. Finlay (Director of Fisheries); J. Rennie (Fisheries Officer).

Barbados Fisheries Department: S. Willoughby (Director of Fisheries); C. Parker (Fisheries Officer).

Other Institutions:

The Organization of Eastern Caribbean States: P. Murray (Data Manager).

The CARICOM Fisheries Resource Assessment and Management Program: S. Singh-Renton (CARICOM Biologist).

The University of the West Indies Libraries at St Augustine (Trinidad) and Cave Hill (Barbados).

The National Archives: St Lucia, St Vincent.

The Library of the Bellairs Research Institute: B. Downey (Director).

The Food and Agriculture Organization: K. Cochrane (FAO Regional Representative for the Caribbean); B. Chakallal (FAO Regional Fisheries Officer for the Caribbean).

The Fisheries Management Information System of the Trinidad Fisheries Department: C. Chan A Shing (Fisheries Officer); A. Maharaj (Documentalist).

Other individuals:

B. Fabres (former Fisheries Officer, Trinidad).

R. Mahon (Fisheries and Environmental Consultant, Barbados)

St. Lucia, Eastern Caribbean: Reconstructed Fisheries Catches and Fishing Effort, 1942-2001

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ABSTRACT

Time series of catch and effort data were reconstructed for the fisheries of St. Lucia in the eastern Caribbean, for the period from 1942 to 2001. Information from historical documents, published and unpublished literature and the St. Lucia Fisheries Department's Statistical databases were used. General trends indicated increasing catches since the 1960s and an exponential increase in fishing effort since 1942. A comparison of reconstructed data with statistics reported in the FAO FISHSTAT database was made and limitations in reconstructed data discussed. Generally, the offshore fishery contributed the greater proportion of the catch, averaging 72% between 1990 and 2001. Between 1989 and 2001 catches increased by 381% and 291% in the offshore and inshore fisheries, respectively. Between 1942 and 2000 fishing effort increased by factors of 257 and 27 in the offshore and inshore fisheries, respectively, and by factors of 4.71 and 1.73 between 1988 and 1999. Catch per unit area has increased by over 300% in both fisheries during the 1990s. Between 1942 and 1999 the catch per unit effort has strongly declined. Throughout most of the 1990s the catch per unit effort of the inshore fishery has exceeded that of the developing offshore fishery.

INTRODUCTION

Study Area

Saint Lucia, situated between 30° and 40°N and 61° and 62°W (Figure 1) is one of the northern Windward Islands. The island is separated from Martinique in the north and St. Vincent in the south by channels about 30 km wide. The submerged insular shelf is very narrow along the western coast (about 0.1 km) and wider (5 km) to the east, north and south (UNEP/IUCN, 1988). The associated Exclusive Economic Zone covers an area of 18,002 km^2 as estimated from data in the Global Maritime Boundaries Database (Veridian MRJ Technology, 2002), while the coastal shelf covers an area of 522 km^2 (Mahon, 1993). Reefs are found on all coasts, but are generally small and most numerous around the east and south coasts, especially around Laborie Bay, Anse Galette and between Savannes Bay and Maria Islands (Villegas, 1979). Those on the windward coast (east) are mainly small patch reefs or broken fringing reef systems and those on the mid-leeward coast (west) are diverse, coral-dominated communities forming an almost solid fringing reef along the narrow slope (Villegas, 1979). The total reef area is 160 km^2 (Oliver and Noordeloos, 2002).The volcanic nature of the island has resulted in reef restriction to the narrow, steeply sloping shelf area. The degree of exposure to the rough Atlantic waters and coastal extent of the shelf determine the physical structure and community composition of the reefs (St. Lucia Fisheries Department, 1995). Those on

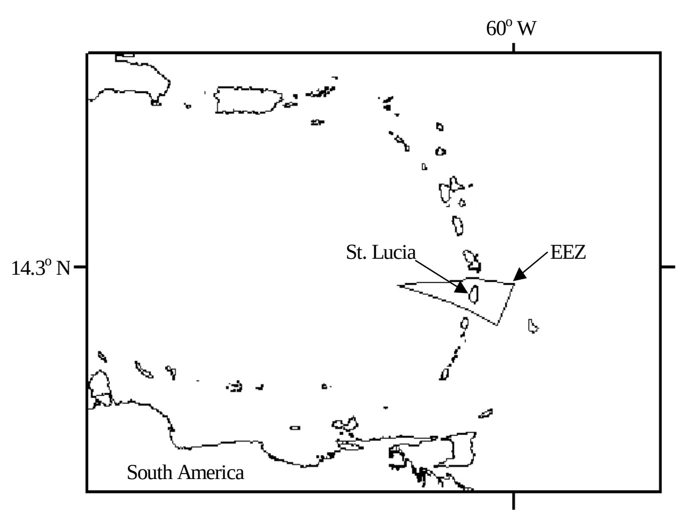


Figure 1. Map of St. Lucia, part of the Lesser Antilles island chain in the south-eastern Caribbean. Shown also is the island's EEZ.

the windward coast are mostly small patch reefs or broken fringing reef systems while those along the mid-leeward coasts are diverse, coral-dominated communities providing an almost solid fringe long the extremely narrow slope (St. Lucia Fisheries Department, 1995). Until 1995, no serious attempts at accurately determining the extent of the reef habitat had been made (St. Lucia Fisheries Department, 1995).

Fishery Development

The fisheries of St. Lucia comprise several components. These include the offshore pelagic fishery targeting flyingfish and large migratory pelagics with gillnets, handlines, troll lines and longlines; the small coastal pelagic fishery targeting mainly small jacks (Carangidae) with beach seines and gillnets; the shallow and deep demersal fishery targeting mainly snappers (Lutjanidae) and groupers (Serranidae) with fish pots and handlines, and the lobster and conch dive fishery. Turtles are caught incidentally in nets, and cetaceans are targeted with harpoons, while seaweeds and sea urchins are harvested by hand.

Pre 1950s

Very little is documented on fisheries prior to the 1950s. Fishing was mainly for subsistence and all boats were unmechanized. There are however, unpublished reports of export trade in hawksbill turtle shells, lobster and whale oil from as early as 1928, 1937 and 1918, respectively.

1950s to 1970s

In the early 1950s, a turtle export trade was established with the United Kingdom (Anon., 1955). The lobster trade was revived, following transportation problems in the 1940s, as Trinidad increased its lobster imports from St. Lucia (Anon., 1955). Reports of the capability to supply the total demand for lobster in Trinidad attests to the possible high catches at the time. The first attempt at boat mechanization, through the introduction of outboard engines, occurred at the ends of the 1950s (Scholz, 1980). The fleet consisted mainly of canoes but the few existing whaleboats were considered more advanced (Smyth, 1957).

Development of the offshore pelagic fishery was promoted to satisfy the local demand for fish, though it was felt that the existing fleet was not operating at its full potential. The government's policy focused on development of all sectors of the fishing industry through the provision of credit for improvement of fishing crafts and gear, granting of duty free concessions on engines and specific fishing gears and improvement of marketing facilities (Vidaeus, 1969). The Fisheries Department, comprising just two staff members, also facilitated the granting of loans to fishers through the Agricultural Development Bank (Vidaeus, 1969).

St. Lucia also allowed the offloading of catches from foreign boats duty-free (Vidaeus, 1969). As a result boats from Venezuela, Martinique and even the US landed their catch in St. Lucia. By the late 1960s crustaceans were exported to Puerto Rico, Barbados and the USA, and frozen snapper to Puerto Rico. It is presumed that this trade is linked to activities of foreign boats. The local retail trade in fresh fish, as well as wholesale and retail trade for frozen and processed fish was regulated by maximum prices enforced by the Government (Vidaeus, 1969). The Caribbean Training and Development Project implemented by the United Nations Food and Agriculture Organization (FAO) between 1965 and 1971 provided technical training in all aspects of industrial fishing and highlighted the possibility of increased catches from the Guyana banks.

In 1967 surface gillnets were introduced to the flyingfish fishery. Previously, dipnets and handlines were utilized (Brown, 1945; Murray and Jennings-Clarke, 1993). About 50% of existing boats were already mechanized, using mainly outboard engines (15-18 Hp). However, rising fuel prices in the late 1960s and early 1970s, affecting about 70% of the fleet (Walters, 1981), along with the fixed fish prices introduced by the government, were limiting factors to fisheries development. It became necessary to introduce more fuel-efficient boats. Assistance was obtained from FAO to train fishers at Vieux Fort to use inboard powered boats and to construct and operate improved fishing gear (Scholz, 1980; Walters, 1983). The associated project also conducted exploratory multi-gear fishing and introduced three boats designed specifically for this purpose. However, despite this support, fishers were reluctant to adopt the new inboard-powered boats because they were slower than those powered by outboard engines and also required a higher initial capital outlay. Further, the lack of market facilities was a discouragement to fisheries development and traditional ties to the canoe were strong (Scholz, 1980). Fishers resorted to using outboard engines of higher horsepower, but rising fuel prices, high maintenance costs and low lifespan of these engines continued to inhibit development.

During the early 1970s the government requested assistance from the Canadian International Development Agency (CIDA) to review the fishing industry and make recommendations for development. The latter included the establishment of cold storage facilities and establishment of a Fisheries Management Unit with responsibility for development of the fisheries sector and the conduct of stock assessment and management research (Walters, 1984). The Unit was established in 1976. Organization of fishers into co-operatives was encouraged to assist with marketing of catches, supply subsidized fuel and duty-free acquisition of fishing materials. Nine such co-operatives were set up in the 1970s (Walters, 1981).

1980s and 1990s

The early 1980s was marked by considerable destruction of fishing boats, engines, and equipment due to hurricane Allen (Fisheries Management Unit, 1981). At the time the fishery was still in the early development phase, mainly artisanal and inshore, utilizing hook and line, beach seines and pots (Matthews, 1983). Though a dramatic change in the industry was not envisaged or advised, efforts focused on careful planning, identifying, and addressing major constraints to development (Matthews, 1983). Existing constraints included the low potential of fishers to adopt new technology, inadequate onshore infrastructure (landing, cold storage, processing), lack of a marketing structure, lack of effective organization among fishers, inefficient boats and fishing techniques and government's price control on fresh fish (Matthews, 1983).

Although the canoe was still the main boat type used, a more efficient boat to target the offshore pelagic fishery was required. Fiberglass pirogues were imported from Trinidad and St. Vincent (Walters, 1981) and the Windward Island Fishing Boat Construction Project, funded by the Caribbean Food Corporation, constructed fiberglass pirogues for sale to St. Lucia, Dominica, St. Vincent and Grenada (Matthews, 1983). Through this project 100 fiberglass pirogues, fitted with either outboard or inboard engines were introduced to the St. Lucia fleet. The marketing system was improved and with assistance from CIDA a fisheries complex, complete with cold storage facilities, was constructed.

The protection of reef and coastal resources has been a major concern. Extensive coral reef management has been undertaken through the co-operative efforts of the Eastern Caribbean Natural Area Management Program (ECNAMP), the St. Lucia Fisheries Department and local groups (UNEP/IUCN, 1988). A 1981 project sought to find solutions to conflicts among various users and to the stresses on critical resources while promoting healthy and sustainable development through a multi-disciplinary approach in the southeastern region (UNEP/IUCN, 1988). This has been used as a case study in integrated coastal zone management.

Through collaboration with other members from the Organization of Eastern Caribbean States (OECS) a Harmonized Fisheries Bill (Walters, 1984) was prepared. This outlined co-operation in fisheries surveillance and enforcement of regulations in the region and mandated that Governments develop and manage fisheries in harmony with the fishing communities. At this time also St. Lucia embarked on a project of diversification of its fishing industry. Through assistance from CIDA, aquaculture projects using tilapia (*Oreochromis mossambicus* and *O. niloticus*), prawns (*Macrobrachium rosenbergi*) and seamoss (*Gracilaria* spp.) were introduced (Walters, 1981). Conservation oriented measures to sustain inshore resources were also introduced. These included a system of marine reserves and fishing priority areas, set up in 1986, and implementation of co-management schemes for the sea urchin (*Tripneustes ventricosus*) fishery (George and Joseph, 1994).

In 1986 a number of coastal marine reserves and fishing priority areas were established. However, prohibition of traditional fishing while allowing Scuba diving resulted in tremendous resource user conflicts. In addition, the level of protection to reef resources was affected by a lack of proper demarcation of fishing priority areas and enforcement (St. Lucia Department of Fisheries, 1995). In 1992 a coordinated approach between the Department of Fisheries and the Soufrière Foundation, with technical assistance from the Caribbean Natural Resources Institute (CANARI) resulted in the formation of the Soufrière Marine Management Area (SMMA) (St. Lucia Department of Fisheries, 1995). This involved zonation of the area according to use and appropriate management with the involvement of user groups. A similar exercise was to be conducted at the Anse la Raye/Canaries coastal areas with support under a USAID/ENCORE project. By the early 1990s there were 20 marine reserves comprising turtle nesting beaches, coral reef areas and mangrove habitats with the use of resources being strictly controlled (St. Lucia Fisheries Department, 1992). The SMMA is a well-documented success story on the usefulness of marine reserves (Hatcher *et al.*, 1995; Roberts *et al.*, 1996; Goodridge *et al.*, 1997). Scuba diving was permitted in these areas, but fishing was prohibited. A joint project with France aimed at conservation and sustainable use of the marine resources within the SMMA was also launched. The project assisted in the construction of a jetty and the introduction of fish attraction devices off the west coast to promote aggregation of offshore pelagic species for the fishery (Pierre, 1999).

By the late 1980s, development of the offshore fishery was evident. Between 1989 and 1992 five 15 m longliners were introduced and an additional 20 boats of 9 m length began exploiting the pelagic fishery (Mahon and Singh-Renton, 1993). Japan assisted with the introduction of fiberglass boats equipped with longlines. Some fishers were trained in the construction and operation of sub-surface tuna longlines, bottom horizontal and vertical longlines with assistance from the Governments of Japan and the France (George, 1999). This has resulted in increased interest in the adaptation and use of these gears from fiberglass pirogues (George, 1999). The fishery is considered as being in a transitional stage, with the capacity and efficiency expected to increase with adoption of improved boats and gear technology (George, 1999). Considerable government subsidies are still provided and a fisheries complex was constructed with financial assistance from Japan. However, fishers are still limited by their ability to self-finance larger boats with advanced gear.

In the 1990s a limited entry system in the conch fishery was implemented through a licensing system, trammel nets were banned for the capture of lobsters, a buy-back scheme for bottom gillnets was implemented and small meshed pots were replaced with large mesh (George, 1999). The sea urchin fishery is also controlled by a licensing system and a co-management system set up for this fishery (Smith and Walters, 1991). Further details on management efforts are available in George (1999) and the Fisheries Department website at www.slumaffe.org.

Fisheries statistical data collection

The first data collection system, set up in the 1960s, sought to resolve disputes between fishers and vendors over selling commission at the main market in Castries rather than management of the resources (Brown, 1945). Data were aggregated across all species so it was not possible to examine species specific changes in the catch. Fish sold at market was supplied mainly from landing sites predominantly out of town. Only about 25% of fish caught off Castries was actually sold at the market. This system of data collection remained unchanged until the late 1970s (Villegas, 1979).

Between the late 1970s and mid-1980s the data collection system was expanded to include landings at nine of the 13 major landing sites (Goodwin *et al.*, 1985; Walters and Oxenford, 1986; Murray *et al.*, 1988). A correction procedure, accounting for non-recorded sites and days in the estimation of total catches from recorded data, was also instituted (Murray *et al.*, 1988) together with a boat registration system (Fisheries Management Unit, 1981). During the late 1980s the OECS instituted a data computerization system to member countries for entry of fisheries catches, fishing effort and other management related data. Currently, information for the 1980s is available only from the Annual Agricultural Reports, based on data submitted by the Fisheries Department. Two relocations of the Fisheries Department and a major fire have contributed to the loss of data collected prior to the 1990s. At an OECS hosted workshop (Mahon and Rosenberg, 1988) plans for upgrading the data collection system were presented (Murray *et al.*, 1988). However, these were not implemented due to financial and human resource constraints.

By the mid-1990s a revised data collection system was implemented (Joseph, 1996) under the CARICOM Fisheries Assessment and Management Program (CFRAMP).

CFRAMP introduced two new databases for computerization of catch and effort data: the Trip Interview Program (TIP) and the Licensing and Registration System (LRS), respectively. Selected landing sites (primary and secondary) were the target of data collection and a system for raising the recorded catch to account for non-enumerated fishing days (at recorded sites) and non-enumerated boats (at non-recorded sites) was derived (Joseph, 1999). Estimates of total catches from 1995 onwards are available from this system. Though reporting is still confined to estimated total catches of the major categories listed previously, with the inclusion of an additional group for snappers, dis-aggregation into the respective species groups is now possible.

Fisheries Policy

In the 1980s the government embarked on a program of increased development of the industry. The overall policy was to increase local production through improved gear and boat technology (Walters, 1981) and to diversify the industry by introducing aquaculture production (Walters, 1984). It was the intention to reduce the quantities of fish imported. There were also improvements in infra-structural facilities, cold storage, marketing and distribution of fish. The fisheries policy since the 1990s is to "promote self-sufficiency through increased production of marine and aquaculture products, and to develop the fishing industry and implement measures to ensure its sustainability" (St. Lucia Fisheries Division Website: www.slumaffe.org; accessed August 12, 1999). Since the inshore resources are found to be depleted, the offshore large pelagic fishery is seen as the avenue for future development (George, 1999). A conservative approach to development also includes the establishment of marine reserves and fishing priority areas and a co-management approach to assessment and management of the sea urchin (*Tripneustes ventricosus*) resources.

The two main bodies of legislation are the Fisheries Act of St. Lucia (Statutory Instrument No. 10 of 1984) and the Fisheries Regulations of St. Lucia (Statutory Instrument No. 9 of 1994) (St. Lucia Fisheries Department, 1999). The latter represents a comprehensive package of revised legislation which was put into effect in 1994. This is discussed in detail in the St. Lucia Fisheries Department publication of 1999 and the associated website: www.slumaffe.org. The Fisheries Act provides for the formation of Local Fishery Management Areas to facilitate more effective management of shelf resources.

METHODOLOGY

Catches

The major sources of information were published and unpublished documents, including reports of the St. Lucia Agricultural Department, the St. Lucia Game Fishing Association, the National Archives, and the St. Lucia Fisheries Department Statistical Database. Where estimates from different sources differed, those derived from the most recent methodology to estimate total landings by accounting for unrecorded landing sites and fishing days (e.g., Joseph, 1999) were used.

Anchor points:

1942: Smyth (1957) provided an estimate of total catch (341 t) for 1942, but gave no details on the methodology for arriving at this figure. This estimate however does not agree with the 1,555 t total catch in Brown (1945). Brown computed a gross estimate of total catch for each boat/fishery type using the associated number of boats, the associated weekly catch rate and number of weeks fishing per year. It is unlikely however, that the estimated catches for the 1940s, derived from an artisanal, unmechanized fleet, would be similar to catches in the 1990s from a still largely artisanal but fully mechanized fleet. This would be the case if Brown's estimate was considered. Thus, the estimate of Smyth (1957) was used in the analysis. However, if over-fishing has occurred (due to industrialization and increased effort), it is possible that declines in catch per unit effort may result in estimates of recent catches that are comparable in magnitude to catches from the early pre-industrialized period.

1956: A total catch of 500 t for 1956 (Salmon, 1958) was used as an anchor point for the respective year.

1960–1968: Catches delivered to the fish market at Castries are available for 1960 to 1968 and range from 80-177 t (Vidaeus, 1969). Cecil (1966) also provided annual recorded landings at Castries for 1961 to 1964 and this was thought to represent one third of total landings. Using this raising factor and data in Vidaeus (1969) and Cecil (1966), total catches were estimated for 1960 to 1968 as

531, 432, 504, 525, 471, 240, 255, 267 and 483 t, respectively.

1981–1994: Estimated total catches by five major species categories: tuna (Scombridae); dolphinfish (*Coryphaena hippurus*); shark (Carcharhinidae); kingfish (*Acanthocybium solandr*i and *Scomberomorus cavalla*); flyingfish (mainly *Hirundichthys affinis*) and snapper (Lutjanidae), and one aggregate category ('other fish') were provided by the St. Lucia Fisheries Department. These were derived by adjusting recorded data to account for non-recorded fishing days and landing sites, using the methodology in Joseph (1999).

1995–2001: The St. Lucia Fisheries Department provided detailed estimates of annual catch for 1995 to 2001, following the methodology of Joseph (1999). Catches were disaggregated into 153 to 171 species or groups in each respective year

First interpolation: Total catches
Annual catches for 1943 to 1955 were estimated by interpolation between estimates for 1942 (Smyth, 1957) and 1956 (Salmon, 1958). Similarly, annual total catches for 1957 to 1959 were estimated by interpolating between estimates for 1956 and 1960 (Vidaeus, 1969). Annual catches for 1969 to 1980 were estimated by interpolation between 1968 (Vidaeus, 1969) and 1981 (Fisheries Department unpublished statistics). The relative contribution of the offshore and inshore fisheries to overall catches was estimated for 1942, 1960 to 1969 and 1981 to 2001 from actual catch estimates as described above. Similar estimates were derived for missing years by interpolation. Along with the overall reconstructed catches for 1943 to 1959 and 1970 to 1979 (estimated by interpolation) the corresponding offshore and inshore components were estimated as the product of the respective proportional contribution to overall catches and reconstructed total annual catch.

Species Composition
The species composition of catches in St. Lucia has not been documented in the past (Vidaeus, 1969). As a result this is either inferred from descriptions of the fishery (Brown, 1945) or assumed to be the same as for neighboring islands, e.g., St. Vincent (Cecil, 1972).

1942: Brown (1945) estimated catches by fleet type, from which the percentage contribution of each fishery type to total catch was computed. Canoes target flyingfish; whaleboats target large pelagics; haul seines and gillnets target coastal pelagics, and troll and pot canoes target both the reef and large pelagic fisheries. It was assumed that 75% of the catch of the troll and pot canoes was attributable to the pelagic fishery since this is the main fishery over 7-8 months of the year, with the other 25% being assigned to the pot fishery. The percentage contribution of the flyingfish, large pelagic, small coastal pelagic (beach seine and gillnet) and reef fisheries were 44%, 16%, 35% and 4.8% respectively. Using the species listed for the large pelagic and small coastal pelagic fishery in Brown (1945), and the list of common and local names in the same document, the species composition of the catches of the respective fisheries was inferred. It was assumed that species caught in each fishery were listed in decreasing order of importance, with the first accounting for 50% of the catch of the fishery. The major species in the small coastal pelagic fishery and corresponding proportional contribution to the total catch are: *Selar crumenophthalmus* (50%); halfbeaks (20%); *Euthynnus alletteratus* (15%); *Thunnus atlanticus* (10%); Cavalli (5%; comprising of equal portions of *Caranx ruber*, *C. latus* and *C. crysos*). The major species in the large pelagic fishery and corresponding contribution to the total catch are: *Coryphaena hippurus* (50%); *Scomberomorus cavalla* (15%); *Acanthocybium solandri* (10%); *Thunnus albacares* (10%); *Thunnus atlanticus* (5%); *Katsuwonus pelamis* (5%); *Makaira nigricans* (2.5%) and *Istiophorus albicans* (2.5%). No information on the species composition of the reef fishery was available. However, consistent with the observation that the species taken in the early stages of fisheries are usually those of higher trophic levels (Pauly *et al*., 1998) it was assumed that catches comprised 50% each of the major snapper and grouper groups.

1960-1969: Cecil (1972) provided a crude estimate of species composition based on personal communication with the Fisheries Officer at the time. Tuna (Scombridae), bonito (*Sarda sarda*) and dolphinfish (*Coryphaena hippurus*) accounted for 40% of the catch; flyingfish (*Hirundichthys affinis*) accounted for 30%; jackfish (*Selar crumenopthalmus*) accounted for 20% and the remaining 10% comprised all other species (mainly reef species). A more detailed species composition was provided for landings in 1966 at the Kingstown market in St. Vincent (Cecil, 1972). At the time the markets at Castries and Kingstown were the only markets existing in the respective neighboring islands. To further disaggregate catches of the broad species groups above, the same species composition at the Kingstown market was assumed. Species were identified by local names. Based on Brown (1945) the associated scientific classification was identified as follows (the name of the species or group used is given in brackets): jackfish – *Trachurops crumenophthalma* (*Selar crumenopthalmus*); gar – *Tylosurus* spp. (Needlefishes- Belonidae); hind – *Petrometropon cruentatus* (*Epinephelus cruentatus*); ocean gar – sailfish, *Istiophorus americanus* (*Istiophorus albicans*); robin (*Decapterus punctatus*); yellowtail – yellowtail snapper (*Ocyurus chrysurus*). Based on the author's general knowledge of local names, dodgers were identified as bigeye scad, *Selar crumenopthalmus* (data combined with jackfish), and red fish assumed to be the queen snapper *Etelis oculatus*. Similarly, amber cavalli was assumed to be the greater amberjack (*Seriola dumerili*) and cavalli was assumed to be the crevalle jack, *Caranx hippos*. Catches of anchovy (Engraulidae) and sprats (Clupeidae) were included under 'herrings and sardines'. This process resulted in disaggregation of tuna catches into yellowfin tuna (*Thunnus albacares*), referred to as 'albacore' and skipjack (*Katsuwonus pelamis*) and the 'other species' category into 21 groups.

1981-1994: The 'other fish' category from 1981 to 1990 was disaggregated into its species components assuming the same species composition of this category for 1990. It was assumed that this species composition remained unchanged over the period.

1990-1994: Recorded data for 1990, 1992 and 1993 were extracted from a discontinued database system introduced under an OECS data management project. The 'other fish' category comprised between 39 (1990) and 81 (1992) species groups in this database. It was used to disaggregate the estimated total catch of the corresponding category into the species components for the respective years. The major assumption is that the species composition of the recorded catches is reflective of the true species composition of catches in the fishery as depicted by the estimated figures obtained from the St. Lucia Fisheries Department. Similarly catches of the aggregate tuna, shark and snapper categories were disaggregated into the respective species based on the species composition of these groups from recorded data for the respective years. Data for 1991 and 1994 were available in the aggregated form mentioned previously. The respective 'other' categories were disaggregated by species using the mean species composition of the same category for 1993 and 1995 as representative of 1994; and for 1990 and 1992 as representative of 1991. Since sharks were not recorded as a separate category in 1991, it was assumed that the species composition of 1990 and 1991 was the same as for 1992. Further, the total shark catches for 1991 was estimated by interpolation between the 1990 and 1992 estimates available from the Fisheries Department.

1995-2001: Data provided by the St. Lucia Fisheries Department was disaggregated into 235 possible species or species groups.

It was difficult to compare reconstructed catches given the vast differences in the species groups represented for the different time periods. Hence, species were aggregated into 61 broad groups across the 1942 to 2001 period. A list of species (local and scientific names) and the associated broad species grouping can be obtained form the senior author. Lobsters and sea turtles were included but cetacean catches are represented separately.

Second Interpolation: Species Composition

Using the aggregated catches represented by 61 species groups, catches of the following species, from 1943 to 1959, were estimated by interpolation between estimates for 1942 and 1960: groupers; halfbeaks; reef jacks; jacks (small coastal pelagics); snappers; billfishes; dolphinfish; flyingfish; pelagic jacks; mackerels; pelgics sharks and tunas. Similarly, catches for the following species between 1970 and 1979 were estimated by interpolation between estimates for 1969 and 1980: barracudas; groupers; reef jacks; jacks (small coastal pelagics); snappers; billfishes; dolphinfish; flyingfish; pelagic jacks; mackerels and tunas. Estimates of marine turtle and lobster catches for missing years were derived as described below. Since it was not possible to estimate catches for all species by interpolation, the difference between the sum of interpolated catches and estimated total catches across all species was attributed to the aggregate category 'miscellaneous marine fish' in the respective years.

Species catch adjustments

Catches of billfishes, tunas, kingfish/wahoo and dolphinfish from 1991 to 2001 were adjusted to incorporate landings from the annual main fishing tournament in St. Lucia. Mahon *et al.* (1994a, 1994b) conducted a detailed analysis of the pelagic fishery, and estimated annual catches of yellowfin tuna for 1980 to 1990. These estimates were used instead of those derived from methods outlined previously. Queen conch (*Strombus gigas*) catch in 1990 was based on Mulliken (1996). The 1993 catch estimate was based on data in George (1997) which incorporated sales at local markets, purchases at the fish market complex (7.54 t) and authorized exports to Martinique (1.95 t). Queen conch catches from 1994 to 1997 were taken from George (1999). A comparison of estimated catches based on George (1997; 1999) and those estimated from the St. Lucia Fisheries Department statistical database is given in Table 1.

Table 1. Estimated catch of Queen conch (*Strombus gigas*) in St. Lucia, 1993-1997, compared between sources.

Year	Catch (t)	
1993	15.91[a]	9.76[c]
1994	19.75[b]	9.95[c]
1995	31.92[b]	8.28[c]
1996	26.80[b]	19.79[c]
1997	24.53[b]	11.09[c]

a: George (1997); b: George (1999); c: St. Lucia Fisheries Department Statistical Database

Catches from sport fishing tournaments

The annual number of fish landed, and associated species composition for 1991 to 1994 (De Beauville-Scott, 1994), and the weight of individual fish species landed for 1996, 1998 to 2000 were available from the unpublished records of the St. Lucia Game Fish Association. The mean individual weight of the landed species was estimated from data for the latter period and used to convert numbers of fish to the corresponding weight for the earlier period, assuming no change in the sizes of fish landed during the 1990s. Species catches for 1995 and 1997 were estimated by interpolation using the catch of the previous and following years.

Estimation of turtle catches

The weight of hawksbill shell exported during 1928 to 1929, 1931 to 1933 and 1935 to 1940 were available from reports of the St. Lucia Agricultural Department (1929, 1930, 1933, 1934, 1938) and Caribbean Commission Central Secretariat (1948). Rebel (1974) gave estimates of green turtle (17.05 t) and hawksbill turtle (10.91 t) obtained from personal communication with C. Matthews. The weight of hawksbill shell exported between 1970 and 1986 were provided in Milliken and Tokunaga (1987) and estimates of turtle catches from 1993 to 1999 were available from the St. Lucia Fisheries Department. Shell weights were converted to the equivalent animal numbers using the conversion factors in Milliken and Tokunaga (1987) and the website www.tortoise.org.news/1998s28.html. The number of animals was converted to the equivalent weight using the mean animal weight in Witzell (1994). Catches for missing years were estimated by interpolation.

Estimation of Marine Mammal Catches

Historically, cetacean catches were not incorporated in the data collection system. Data are available on the quantity (gallons) of blackfish (pilot whale) oil exported from St. Lucia in 1918 (Agricultural Department of St. Lucia, 1918, 1919, 1920), 1920 (Rambally, 2000a), 1924 (Agricultural Department of St. Lucia, 1924), 1926 (Rambally, 2000a), 1928 (Agricultural Department of St. Lucia, 1939), 1931 (Anon., 1932) and 1935 (Rambally, 2000a). The quantities of oil were converted to the equivalent number of animals using the conversion factor in Brown (1945). Estimates of porpoise (mainly *Tursiops truncatus*) catches between 1960 and 1969 were derived using data on species composition in Cecil (1972) and estimates of total marine catches derived from data in Vidaeus (1969). It was assumed that there were no catches of porpoises in 1918 and catches between 1918 and 1960 were estimated by interpolation. Estimates of cetacean catch numbers for 1995 to 1999 were available from the St. Lucia Fisheries Department's unpublished records and Rambally (2000b). The associated species were: bottlenose dolphin (*Tursiops truncatus*), Atlantic spotted dolphin (*Stenella frontalis*), Fraser's dolphin (*Lagenodelphis hosei*), common dolphin (*Delphinus delphis*), spinner dolphin (*Delphinus delphis*), Dall's porpoise (*Phocoenoides dalli*), false killer whale (*Pseudorca crassidens*); short-finned pilot whale (*Globicephala macrorhynchus*), pygmy killer whale (*Feresa attenuata*) and humpback whale (*Megaptera novaeangliae*). Data for 1994 were not disaggregated by species so the same species composition, specific to the respective landings site in 1995 was assumed. Catch numbers were converted to the equivalent weight using the mean individual weight for the respective species in Trites and Pauly (1998). Catches for missing years were estimated by interpolation.

Estimation of lobster catches
The quantity of live lobster exported in 1937 and 1938 was obtained from the 1938 report of the Agricultural Department of St. Lucia. The associated value of the export trade was also provided for 1936 to 1938. Assuming the same average price per unit weight for 1937 and 1938 the weight of live lobster exported in 1936 was estimated. Exports for 1935 to 1941 (Caribbean Commission Central Secretariat, 1948), estimated catch for 1965 to 1967 (Idyll, 1971) and exports in 1968 (Vidaeus, 1969) were also available. Estimated lobster catches between 1981 and 1991 were obtained from the St. Lucia Fisheries Department statistical database. Joseph (2000) gave data on the annual purchases of lobsters at the St. Lucia Fish Marketing Cooperative between 1992 and 1999. A crude estimate of total catch for 1997 was given in George (1999). The ratio of this estimate and the purchase of the Cooperative for the same year was assumed to be the same for each year from 1992 to 1999. Therefore, using data from Joseph (2000) and George (1999), estimates of annual catch of the species for the 1992-1999 period were derived.

Fishing Effort

Data Sources
The unit of fishing effort used in analyses is horsepower-days. Data limitations restricted the estimation of fishing effort to key years for which the required data were available. From these, estimates for missing years were interpolated. Several assumptions were also made based on information in the literature and discussions with staff of the Fisheries Department when there was missing data and the details are given for the respective years. The key years selected and associated information sources were:

1942: Details on the number of boats by landing or mooring site were available from Brown (1945). All boats were unmechanized. A horsepower of one was assumed for all unmechanized boats.

1969: Details on the number of boats by fishery type were available from Vidaeus (1969). Approximately 50% of the boats were mechanized with engines of 15-18 Hp (Vidaeus, 1971).

1972: Data on the number of whalers involved in the fishery for cetaceans was available from Gaskin and Smith (1977). Boat horsepower was taken from Vidaeus (1971), who gave a range of 6 to 33 Hp. The higher estimate was used to provide an estimate of the fleet potential.

1988: The number of boats by type/design were provided in OECS (1989). Boat horsepower were taken from OECS (1993). Canoes, transoms (dories) and whalers carried engines of 36 Hp, 23 Hp and 30 Hp, respectively. It was assumed that pirogues carried engines of 48 Hp, similar to St. Vincent in OECS (1993) and that the single launch carried an engine of 48 Hp as indicated in OECS (1995) for St. Lucia.

1993: Data on the overall number of fishing boats and the percentage composition by type/design was provided in OECS (1993). Associated engine horsepower was available in OECS (1995). Canoes, pirogues, transoms, whalers and launches carried engines of 81 Hp, 67 Hp, 16 Hp, 30 Hp and 48 Hp, respectively.

1994–2000: Data are provided on the number of boats registering each year by their respective landing sites, including the associated boat category (canoe, shaloop, pirogue, longliner, launch etc), boat length and horsepower form the St. Lucia Fisheries Department Licensing and Registration System (unpublished statistics). Since boats do not re-register each year, it was necessary to include the boats for all previous years (from 1993) in the analyses for the post 1993 period in order to give an accurate depiction of fishing effort. The most recent data (1994-2000) facilitates detailed examination of changes in fishing effort. Missing data, e.g., boat length and/or horsepower were estimated as the average of similar boat type and length/Hp operating at the same site, or the average of similar boat types and length/Hp throughout the island.

Linking fishing effort to fishery type

1942: Except for those boats involved in the beach seine, jack seine and other net fisheries, all boats on the leeward coast fished for flyingfish and large pelagics from November to June (Brown, 1945). These boats also targeted inshore demersals using fishpots during the flyingfish off-season. At Castries, six whalers were involved in fishing for large pelagics (trolling) year round. Except for those boats involved in the beach seine, jack seine and other net fisheries, all boats on the windward coast were assumed to fish for inshore demersals year round. In the beach seine, jack seine and other net fisheries it was assumed that twice the number of boats as nets were involved in the fisheries. Usually a large boat (6.67-9.09 m) and a small boat (< 5.67 m) were associated with one net.

1969: There were about 435 boats involved in the handline and pot fishery. Of these, 350 were canoes and assumed to target the large pelagics from November to June and the pot fishery during the pelagic off-season. The remaining 85 were smaller transoms which were assumed to target the pot fishery year-round. About 110 boats were involved in the beach seine fishery and 16 boats (12 at Castries and four at Vieux Fort) involved in whaling. It was assumed that mechanized boats targeted the offshore pelagic fishery. These were estimated at 323 canoes, the remaining 27 canoes and other boats were unmechanized.

1988; 1993; 1994-2000: Based on Murray *et al*. (1988) and personal communication with Fisheries Field Extension Officers, the following inferences were made in assigning boats to fishery type: All transoms and shaloops target the inshore reef resources year-round. However, these boats also fish for coastal pelagic with beach seines. The relative time spent on each fishery is not known. Canoes, pirogues, whalers and launches target the offshore pelagic and flyingfish fisheries from November to June, and the reef, deep slope and bank resources (depending on the landing sites) from July to October.

Longliners target large pelagics year–round. All whalers in 1988 targeted pilot whales only.

Assigning fishing days to the respective fleets and fisheries

The fishing days associated with each fleet type was dependent on the resources targeted and whether or not the fleet was mechanized. Details are provided in the 'General Methods' chapter by Mohammed (this volume). The only exception pertains to whalers operating in the early 1940s. Brown (1945) reported that these fished for large pelagics year round. They were also not mechanized. It was assumed that they fished the same number of days overall each year (120) as boats targeting large pelagics from November to June (75 days) and demersals during the pelagic off-season (45 days). Transoms targeted both the inshore coastal pelagics and reef fishery (Murray *et al.*, 1988). Without a basis for apportioning annual effort into the respective components, it was assumed that these boats targeted the inshore fishery generally, for about 230 days per year. Based on George (1999) and communication with staff of the Fisheries Department (H. Walters, pers. comm.) fishing effort and the number of fishing days in the pelagic fishery had increased in the offshore fishery and decreased in the inshore fishery by the end of the 1990s. To reflect this, pirogues were assumed to fish for large pelagics (offshore fishery) 220 days per year from 1998, and to desist from fishing inshore demersals.

Annual trends in catch per unit area (CPUA) and catch per unit effort (CPUE)

Using reconstructed catches for the inshore and offshore fisheries and the estimates of EEZ (18,002 km^2, Veridian MRJ Technology, 2003), reef (160 km^2, Oliver and Noordeloos, 2002), slope and shelf (522 km^2, Mahon, 1993) areas, a time series of trends in catch per unit area was derived. Catch per unit effort was estimated as the ratio of reconstructed catch (excluding marine mammals) and reconstructed effort for the respective fisheries.

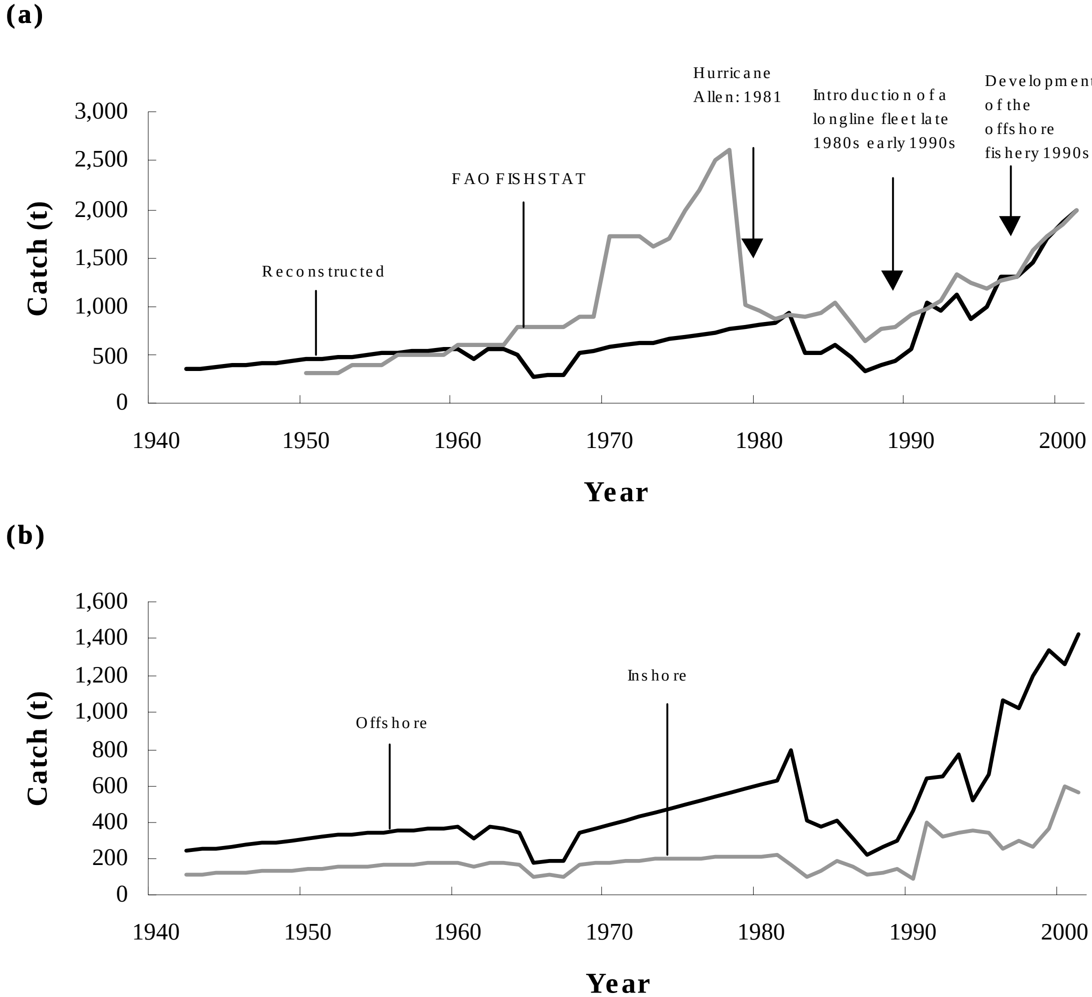


Figure 2: Fisheries catches (t) in St. Lucia. (a) Reconstructed catches (1942–2001) and catches in FAO FISHSTAT (1950–2001), (b) Reconstructed catches dis-aggregated for offshore and inshore fisheries (1942–2001).

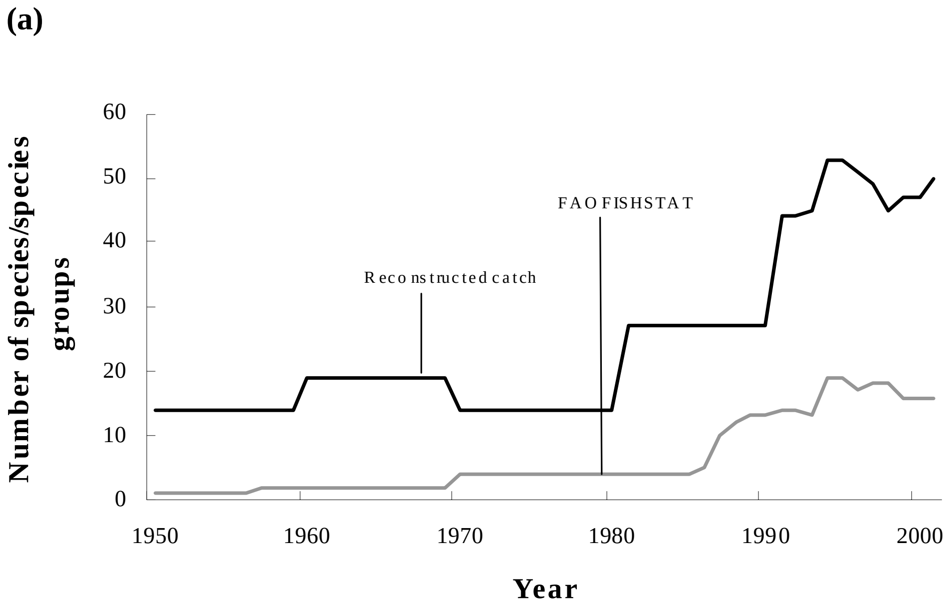
RESULTS

Catches

Reconstructed catches, excluding catches of cetaceans, and corresponding statistics in the FAO FISHSTAT database are presented in Figure 2a. The major difference in catches from the two sources occurred between 1964 and 1980, with data in FISHSTAT exceeding reconstructed statistics by between 145 t in 1980 and 1,700 t in 1977. Differences in estimated catch from the two sources ranged between 323 t and 452 t between 1983 and 1989. The associated fish categories attributed to the higher catches in FISHSTAT are 'miscellaneous marine fish' and 'miscellaneous marine crustaceans'. Reconstructed catches (Figure 2a) indicate a gradual increase between 1942 and 1982 from 349 t to 949 t (172%). This was followed by a sharp decline (54%) to 440 t by 1989. Thereafter, catches increased dramatically from 550 t in 1990 to 1998 t in 2001 (an increase of over 260%).

The offshore fishery contributes a greater proportion to overall catch (Figure 2b), averaging 72% between 1990 and 2001. Catches in the offshore fishery increased by 381%, from 295 t to 1,420 t between 1989 and 2001. Similarly, over the same period catches in the inshore fishery increased by 291%, from 145 t to 567 t.

Overall, a greater number of species are represented in the reconstructed data compared to FAO FISHSTAT, and a higher level of species dis-aggregation was achieved



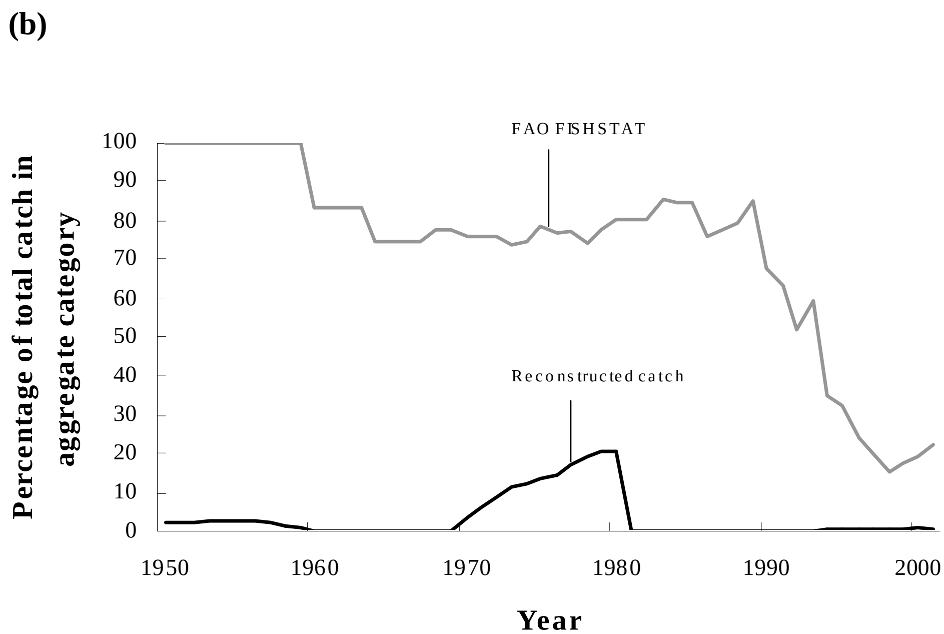


Figure 3: A comparison of reconstructed catch data and statistics in FAO FISHSTAT for St. Lucia between 1950 and 2001: (a) number of species/species groups and (b) percentage of total catch in aggregate category.

in the last decade for both sources (Figure 3a). For most of the time series, a smaller percentage of overall catch was attributed to the aggregate category 'miscellaneous marine fish' in the reconstructed data than that in FAO FISHSTAT (Figure 3b). From 1950 to 1959, all catches in FISHSTAT were recorded as 'miscellaneous marine fish' or 'miscellaneous marine crustaceans'. The percentage of overall catch attributed to this aggregate category declined drastically only during the 1990s, ending at 22% in 2001. The highest proportion of the catch (21%) attributed to the aggregate 'miscellaneous marine fish' category in reconstructed catches occurred in 1980.

Reconstructed catches from the major annual sport fishing tournament in St. Lucia (Table 2) were minimal (less than 3 t) compared to overall landings of the respective species.

Table 2: Reconstructed catches (t) from sport fishing tournaments in St. Lucia (1991-2000).

Species	1991	1992	1993	1994	1995*	1996	1997*	1998	1999	2000
Blue marlin	1.06	0.48	0.48	1.17	1.66	2.16	1.44	0.72	0.80	0.54
Sailfish	0.07	0.03	0.03	0.08	0.07	0.06	0.06	0.07	0.05	0.05
Wahoo	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.06	0.06	0.03
Dolphinfish	0.05	0.02	0.02	0.05	0.03	0.01	0.01	0.01	0.03	0.01
Spearfish	-	-	-	-	-	-	-	0.02	-	-
Tunas	0.06	0.03	0.03	0.06	0.06	0.05	0.05	0.04	-	-
Barracuda	0.16	0.07	0.07	0.18	-	-	-	-	-	-
Mackerel	0.01	0.01	0.01	0.01	-	-	-	-	-	-
TOTAL	**1.43**	**0.64**	**0.64**	**1.57**	**1.84**	**2.25**	**1.60**	**0.92**	**0.94**	**0.63**

* Estimated by interpolation

Table 3: Summary of number of annual of boats and mean engine horsepower between 1994 and 2000. (Data Source: St. Lucia Fisheries Department Licensing and Registration System).

Boat Type	Details	1994	1995	1996	1997	1998	1999	2000
Canoe	No. of boats	196	252	291	302	309	318	337
	Mean Hp	41.01	40.60	40.86	41.38	41.32	41.65	41.37
Pirogue	No. of boats	140	212	242	270	312	363	421
	Mean Hp	69.19	68.21	67.67	67.93	68.94	70.14	71.20
Transom	No. of boats	56	79	85	87	87	92	95
	Mean Hp	20.33	18.97	19.42	20.01	20.01	20.64	20.65
Whaler	No. of boats	3	6	8	8	9	9	12
	Mean Hp	37.00	40.83	38.50	38.50	35.78	35.78	52.25
Shaloop	No. of boats	3	14	25	31	34	36	43
	Mean Hp	24	17.01	13.08	13.89	13.93	14.46	16.52
Launch	No. of boats	2	2	2	2	2	2	2
	Mean Hp	48	48	48	48	48	48	48
Longliner	No. of boats	-	-	2	2	5	7	7
	Mean Hp	-	-	315	315	301	353.71	353.71
Aluminum	No. of boats	1	2	3	3	3	3	3
	Mean Hp	6.50	103.25	135.50	135.50	135.50	135.50	135.50
Yacht	No. of boats	1	1	1	1	1	1	1
	Mean Hp	500	500	500	500	500	500	500
Yaule	No. of boats	-	-	-	3	3	4	4
	Mean Hp	-	-	-	23.63	23.63	21.48	21.48
Total Number of Boats		**402**	**568**	**659**	**709**	**765**	**835**	**925**
Mean Hp		**48.88**	**48.37**	**48.84**	**49.39**	**51.49**	**53.91**	**54.96**

Reconstructed turtle catches reached nearly 25 t in the late 1970s (Figure 4). Between 1928 and 1938 catches were less than 18 t year^{-1} and in the most recent years catches are insignificant. Lobster catches appeared low (less than 10 t) prior to the 1980s, but increased dramatically to 26 t by 2000 (Figure 4). Catches of porpoises were low compared to pilot whales (Figure 5). Porpoise catches were less than two tons throughout most of the 20th century, but increased to almost 9 t by the end of the 1990s. Reconstructed catches of pilot whales (Figure 5) show a peak of almost 45 t in the mid 1920s and have declined to less than 10 t by the late 1990s.

Fishing effort

Considerable increases in the number of canoes and pirogues, and to a lesser extent shaloops and transoms were characteristic of the 1994 to 2000 period as illustrated by data obtained from the St. Lucia Fisheries Department Licensing and Registration system (Table 3). Only whalers and longliners demonstrated any appreciable increases in horsepower.

The annual trend in the number of boats and fishing effort in the offshore and inshore fisheries of St. Lucia between 1942 and 2000 is provided in Figure 6. Generally the number of boats declined between 1942 and the late 1980s but there were substantial increases in the 1990s (Table 3). Potential fishing effort increased exponentially over the period examined. Overall the number of boats in the offshore fishery increased from 411 to 780 between 1942 and 2000 and the corresponding effort increased by a factor of 257 (Figure 6a). Conversely, the number of boats in the inshore fishery decreased from 568 to 493 between 1942 and 2000, while effort increased by a factor of 27 (Figure 6b). Initially fishing effort was greater in the inshore fishery (51 x 10^3 Hp-days compared to 31.1 x 10^3 Hp-days in the offshore fishery), however, the situation was entirely reversed by 2000. In the most recent year fishing effort in the offshore fishery was 9,111 x 10^3 Hp-days compared to 1,390 x 10^3 Hp-days in the inshore fishery. Between 1988 and 1999 the effort in the offshore and inshore fisheries has increased by factors of 4.71 and 1.73 respectively.

Annual trends in catch per unit area (CPUA) and catch per unit effort (CPUE)

Catch per unit area was greater, by one order of magnitude, in the inshore fishery compared to the offshore fishery (Figure 7). The general trend was a gradual increase in CPUA from 0.013 t·km^{-2} in 1942 to 0.044 t·km^{-2} in 1982 in the offshore fishery (Figure 7). The inshore fishery also experienced an increase in CPUA from 0.157 t·km^{-2} in 1942 to 0.313 t·km^{-2} in 1981 (Figure 7). Thereafter, a decline in CPUA was experienced throughout the 1980s in both fisheries. Throughout the 1990s, CPUA increased distinctly, culminating in 2001 estimates of 0.079 t·km^{-2} (394% increase) and 0.832 t·km^{-2} (530% increase) for the inshore and offshore fishery, respectively.

Generally, catch per unit effort declined exponentially in both the offshore and inshore fisheries between 1942 and 1999 (Figure 8a). Initial CPUE in 1942 was 6.616 t per '000 Hp-days and 2.109 t per '000 Hp-days in the offshore and inshore fisheries, respectively (Figure 8a). By 1999 CPUE had declined to 0.167 t per '000 Hp-days and 0.291 t per '000 Hp-days in the respective fisheries, representing a 97.5% and 86.2% decline over the 1942 to 1999 period. The decline in CPUE in the last two decades shows generally higher CPUE in the inshore fishery in the early and late 1990s compared to the offshore fishery (Figure 8b).

DISCUSSION

Catches

Reconstructed fisheries catches for St. Lucia indicated a 172% increase between 1942 - 1982, a 54% decline between 1982 and 1989, and a 260% increase between 1990 and 2001. The offshore fishery has been the greater contributor to overall catches, averaging 72% between 1990 and 2001. Between 1989 and 2001 catches increased by 381% and 291% in the offshore and inshore fisheries, respectively. Increased catches in the offshore fishery are consistent with the development of this fishery, particularly during the 1990s.

The decreased catches during 1965 to 1967 coincide with protest actions by fishers against vendors who offered exceedingly low payments to fishers compared to the prices at which they sold the catch (Vidaeus, 1969).

The difference between reconstructed catches and statistics in FAO FISHSTAT between 1964 and 1980 is most likely due to landings in St. Lucia of catches by foreign boats. The local fishery was not capable of catching such vast quantities of fish, e.g., 2600 t in 1978. Such catches are comparable to those of the present day fleet utilizing engines of higher horsepower and more technically advanced gear. Many have reported on the stagnation of the industry during the 1970s as a result of increasing cost of production associated with rising fuel prices (Walters, 1981), and a lack of cold storage, marketing and distribution facilities (Fisheries Management Unit, 1981). Individuals were reluctant to enter the industry since the price control system, which resulted in reduction of prices to 25% of the allowed maximum when landings were excessive, acted as disincentives to development of the industry (Walters, 1983). Vidaeus (1969) noted the lack of change in number of boats and their distribution around the island since the previous 25 years. At the time however, there were no restrictions, e.g., customs duty, on landings of non-locally registered boats. This was an unusual arrangement in the region. As a result, boats from Venezuela, Martinique and

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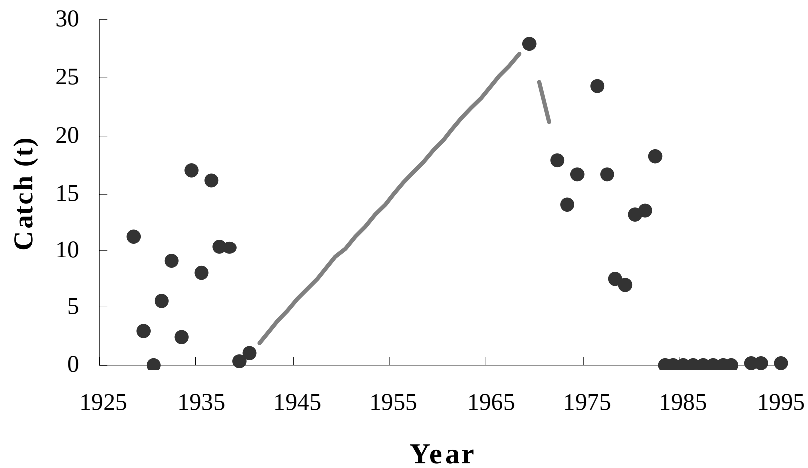

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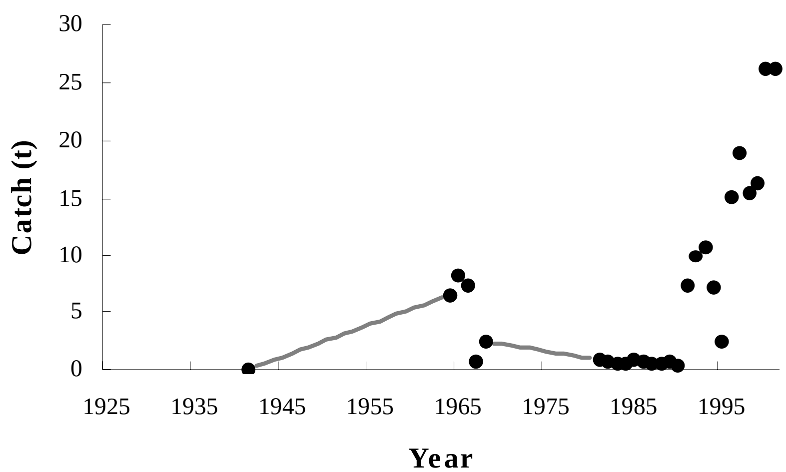

Figure 4: Reconstructed catch (t) of (a) hawksbill turtle (*Eretmochelys imbricata*) from 1928 to 1995 and (b) lobster (*Panulirus* sp.) from 1936 to 2001 in St. Lucia. Solid circles represent reconstructed data and solid lines joining circles are interpolated values.

freezer boats from the United States landed fish in St. Lucia (Vidaeus, 1969). During the late 1960s there was also an agreement between the St. Lucia Marketing Board and a St. Lucian firm allowing for the sale of fish caught by trawlers off the Guyana's via a Guyanese firm. These were usually croaker (*Micropogon furnieri*), whiting (*Malacanthus plumieri*), moonshine (*Selene vomer)* and sea trout (*Cynoscion* spp.).

The differences between reconstructed data and corresponding data in FISHSTAT between 1983 and 1989 are less easily explained. Personal communication with officials of the St. Lucia Fisheries Department yielded no explanation. The methodology accounting for unrecorded fishing days and landing sites (Joseph, 1999) has been applied to recorded data from 1980 onwards, thereby increasing the credibility of the estimates. Other sources of information for this period are based on assumptions regarding the proportion of overall catch recorded at Castries (Walters, 1981, 1983, 1984; Matthews, 1983; Murray, 1984; Goodwin *et al*., 1985), and were therefore not used in the catch reconstruction. The decline in landings however, especially in the late 1980s, is supported by the literature (Mahon, 1990).

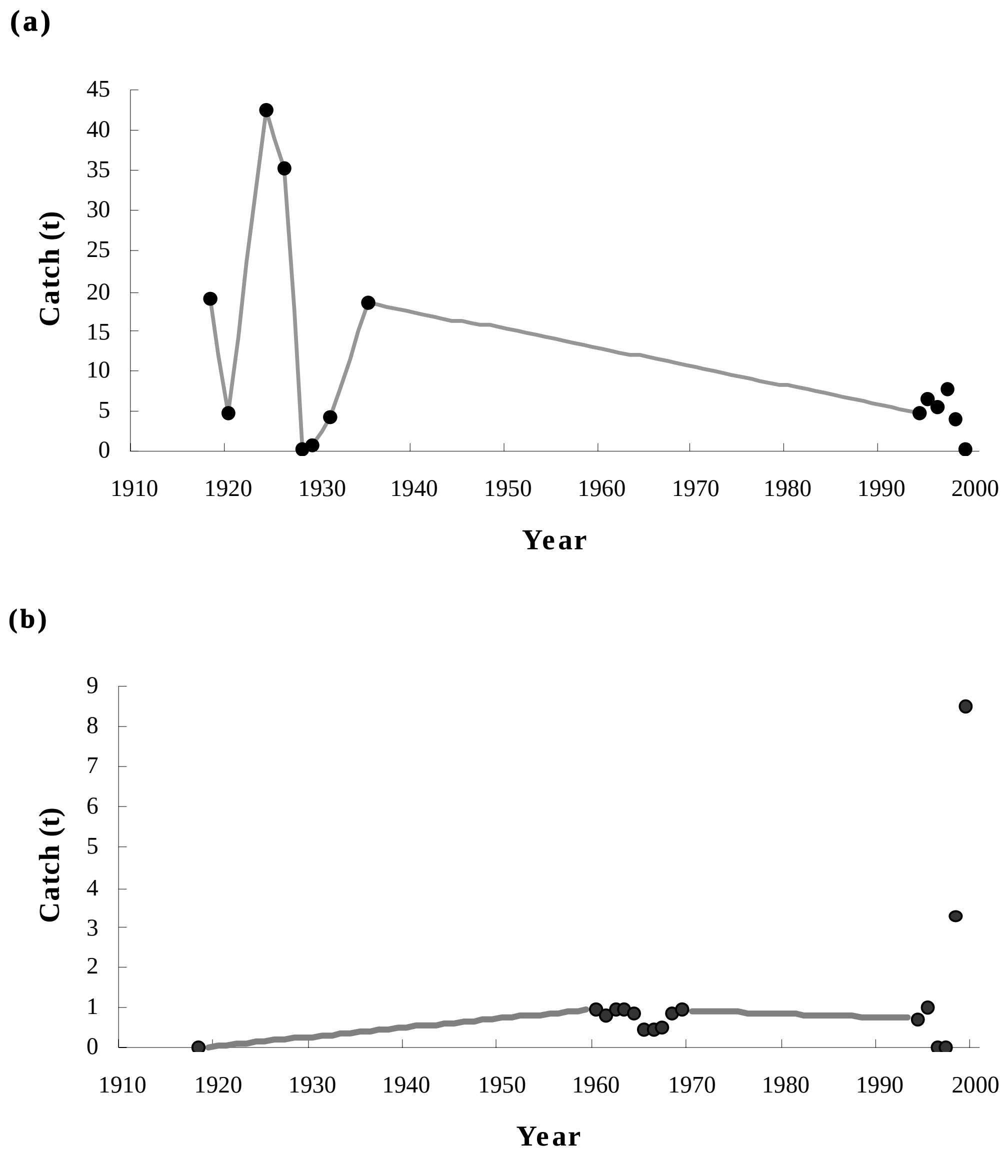

Figure 5: Reconstructed catch (t) of (a) the pilot whale (*Globicephala macrorhynchus*) and (b) porpoises (mainly *Tursiops truncatus*) in St. Lucia (1918-1999). Solid circles represent reconstructed data and solid lines joining circles are interpolated values.

(a)

(b)

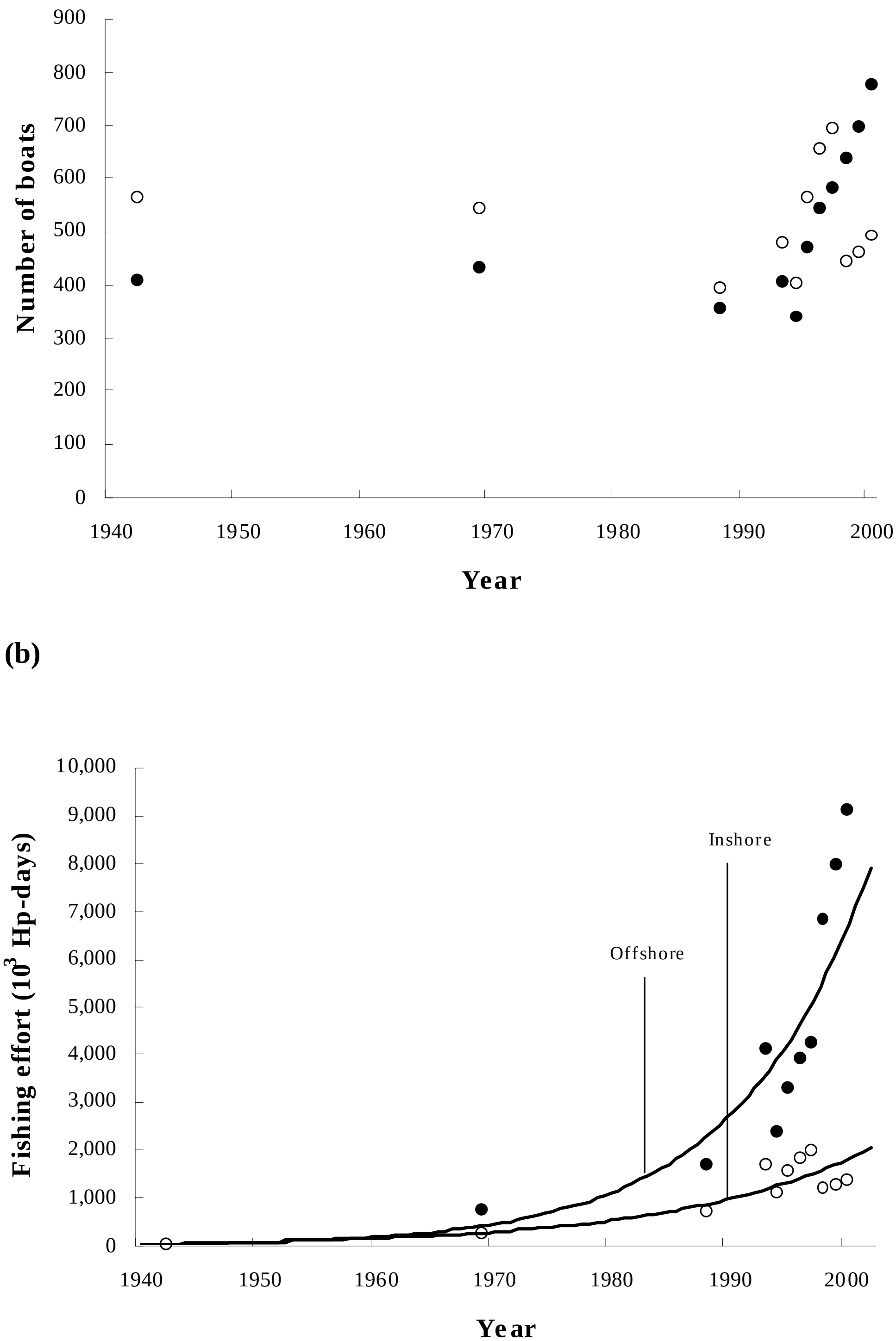

Figure 6: Reconstructed (a) number of boats and (b) fishing effort (10^3 Hp-days) for St. Lucia (1942 – 2000). Solid circles represent the offshore fishery and open circles represent the inshore fishery.

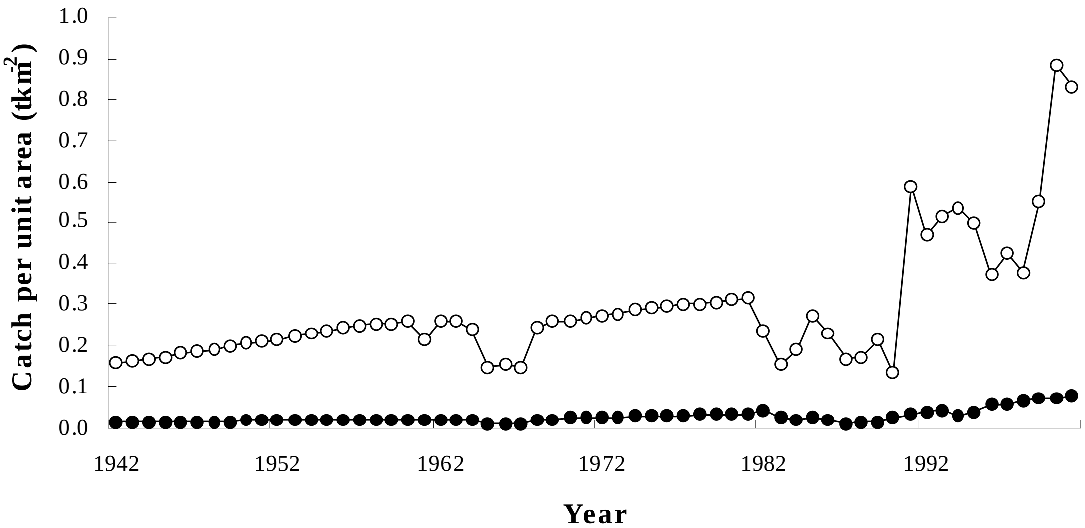

Figure 7: Annual trends in catch per unit area (t km^{-2}) in the fisheries of St. Lucia (1942-2001). Solid circles represent the offshore fishery and open circles represent the inshore fishery.

Similar declines in landings were observed in other islands of the eastern Caribbean, prompting an FAO study to investigate the reasons for such low catches, particularly in the 1987/88 season. Results however, were inconclusive.

The reconstructed data were disaggregated into a greater number of species or species groups than corresponding data in FISHSTAT. There was also a considerably lower proportion of overall catch attributed to the aggregate category of 'miscellaneous marine fish' in reconstructed data. Observations from 1990 onwards are, however, more reliable as these are based on reconstruction from actual data compared to previous years where assumptions of constant species compositions, similarities in species composition with landings in St. Vincent and estimation of annual catches by interpolation were employed. The estimates of annual catches disaggregated into 44 to 53 species or species groups between 1990 and 2001 is a significant improvement on estimates in FISHSTAT, which are disaggregated into some 19 species groups. In addition, reconstructed data for 1995 to 2001 can be further disaggregated into some 235 species or species groups.

The present reconstructed catches represent preliminary estimates. Several limitations to are apparent. These relate to incomplete records of catches in the recreational fishery, lack of data on catches by foreign fleets and the quantities of bait fish utilized locally, incomplete records of species catches in the inshore reef, slope and shelf fishery and the offshore flyingfish fishery and uncertainties in species identification of the catch.

Recreational fishing began in the 1950s (DeBeauville-Scott, 1994). An associated club was formed in 1972 and formally registered as the St. Lucia Game Fishing Association in 1984. The Association organizes informal fishing tournaments on national holidays and a major tournament in October of each year. In 1991 the major tournament was upgraded to an international billfish tournament. Informal tournaments target dolphinfish, tuna, kingfish, wahoo, barracuda and small sharks (H. Otway, pers. comm.). The formal tournament targets larger pelagics such as blue marlin (*Makaira nigricans*), sailfish (*Istiophorus albicans*), white marlin (*Tetrapturus albidus*), swordfish (*Xiphias gladius*) and longbill spearfish (*Tetrapturus pfleugeri*). Catches at informal tournaments are not recorded, while only catches of important species (large tunas and billfishes) are recorded at the major tournament. These were found to be insignificant in this analysis.

Also, catches of small pelagics, e.g., kingfish (*Scomberomorus cavalla*), wahoo (*Acanthocybium solandri*) dolphinfish (*Coryphaena hippurus*), barracuda (*Sphyraena* spp.) and small tunas (Scombridae) taken by tourists are not recorded.

(a)

(b)

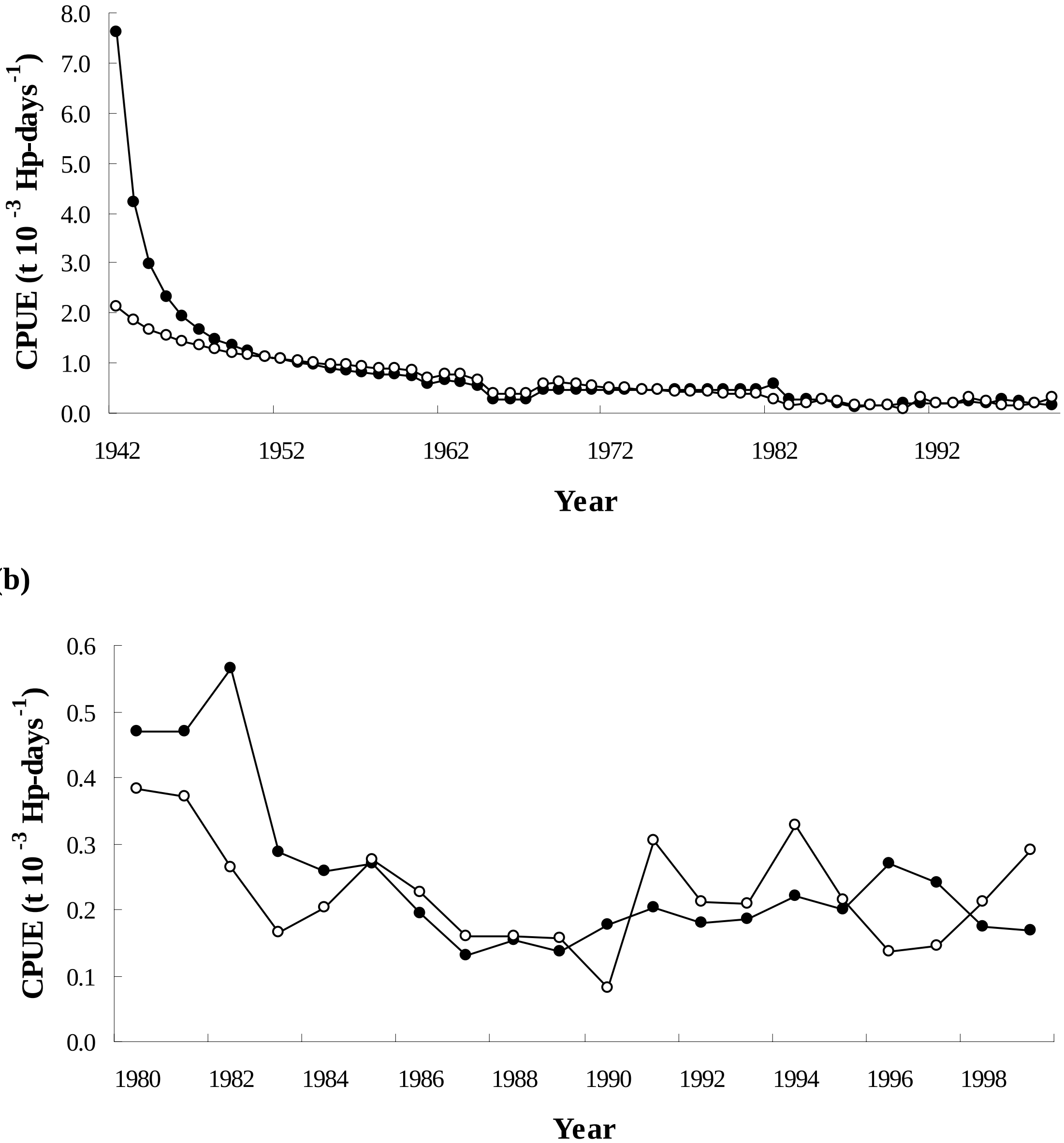

Figure 8: Annual trends in catch per unit effort (t 10^{-3} Hp-days) in the fisheries of St. Lucia (a) 1942 to 1999 and (b) 1980 to 1999. Solid circles represent the offshore fishery and open circles represent the inshore fishery.

In the late 1980s, 12 private charter and sport fishing boats were in operation, the present number is not known. Persons also fish with handlines from shore. The associated catches are not recorded.

Catches of foreign fleets are not available. Vidaeus (1969) alluded to monthly consignments of about 9 t from the Guyanese firm in the 1960s but gave no estimates of landings by fleets from Venezuela, Martinique and the United States. While catches of these fleets are possibly taken outside of St. Lucia's EEZ, fishers from Martinique fish for demersal species in St. Lucia waters and those from Barbados target flyingfish and large pealgics, and US longliners target swordfish in the EEZ of St. Lucia (Murray *et al*., 1988).

The quantities of bait utilized in pot, handline and longline fisheries are not recorded. Popular bait-fish in St. Lucia include anchovy (Engraulidae), pilchards *(Harengula* spp.), sardines (*Sardinella* spp.) silversides (Atherinidae) and thread herring (*Opisthonema oglinum*) (Mahon, 1993). It is unknown whether flyingfish are used as longline bait as is the case in Grenada.

The inshore fishery is not well represented in the data collection system since landing activities are spread across several sites (George, 1999). Important landing sites for lobster and conch are not incorporated in the system (George, 1999). Catches of lobster and conch are either sold to local markets, to hotels or supermarkets directly or exported (either legally or illegally) to Martinique. Only catches sold to markets and exported legally are recorded (Nichols and Jennings-Clark, 1994). Until 1993 it was illegal to export lobster and conch to Martinique (George, 1997). However, up to 5 t were exported illegally in the late 1980s (George, 1997). Currently exports are permitted and are carefully monitored according to regulations of the Convention for International Trade in Endangered Species. Reconstructed landings of lobsters indicate considerable increases in catch throughout the 1990s, starting from almost zero at the end of the 1980s to 26 t in 2001. Important landing sites for reef fish are also not sampled (George, 1999), resulting in underestimation of total catches. Three important landing sites for flyingfish are not incorporated in the data collection system (Murray and Jennings-Clarke, 1993), with similar consequences for estimated total catch as for reef fish.

Information on species composition of the catch was not available prior to 1980. Vidaeus (1969) reported the lack of associated data in the 1960s. Data from 1980 to 1989 were available for only five or six major species groups with all other fish aggregated into one category. There were also uncertainties in species identification arising from differences in vernacular names used by fishers and data collectors (Murray, 1986), and the high diversity of species landed in the demersal fisheries (Gobert, 1995). This renders it almost impossible for data collectors to record reliably the catch composition of most fishing trips at the species level (Gobert, 1995). There are also differences in local names of pelagic species e.g, the blackfin tuna (*Thunnus atlanticus*) is referred to as 'bonito', a common name elsewhere used for *Sarda sarda*; wahoo (*Acanthocybium solandri*) is referred to as 'kingfish', a name normally used for the king mackerel, *Scomberomorus cavalla*. Further, the flyingfish *Cypselurus cyanopterus* is referred to as 'denn' and *Parexocoetus brachypterus* as 'tee-wai' (Murray and Jennings-Clarke, 1993). Rambally (2000b) noted problems with species identification in the cetacean fishery. The Pygmy killer whale is referred to as 'sperm' and the sperm whale as 'sea guap' (Rambally, 2000b). Often, recorded catches of all small cetaceans are grouped and classified as 'blackfish'. This makes examination of species differences or relative contributions to overall catch difficult. Nevertheless, it is evident from the results that the fishery targeting pilot whales has declined considerably. This has been matched by an increased fishery for porpoises, resulting in an almost ten fold increase in catches in recent years compared to the 1960s.

Assignment of some species to the respective fisheries was difficult. This is because juveniles of pelagic species are also captured in the inshore net fisheries. The relative quantities harvested in the offshore and inshore fisheries are not known. As a result, all catches of large pelagic species were attributed to the offshore fishery.

Fishing effort

Reconstructed fishing effort increased exponentially between 1942 and 2000. Overall the number of boats in the offshore fishery increased from 411 to 780 between 1942 and 2000, and the corresponding effort increased by a factor of 257. Conversely, the number of boats in the inshore fishery decreased from 568 to 493 between 1942 and 2000, while effort increased by a factor of 27. Initially, fishing effort was greater in the inshore fishery compared to the offshore fishery, however, the situation was reversed by 2000. Considerable increases in effort in the offshore fishery were observed in the 1990s. This was attributed mainly to increases in the number of boats, since only whalers and longliners demonstrated any appreciable increases in horsepower. The changes in fishing effort reflect what has been documented about general developments in the fishing industry (George, 1999).

There were several constraints in the estimation procedure. Murray *et al.* (1988) noted that all boats were involved in all fisheries. The assignment of fishing boats to the respective fisheries was based on the main fishing method employed, except for boats targeting the inshore reef, slope and shelf fisheries during the pelagic off-season. Uncertainties in the linkages between boats and fishery type, and changes in the number of fishing days between 1942 and 1999 impacted effort estimates.

Apart from Vidaeus (1971), who described fishing effort at Vieux Fort, the number of fishing days is not mentioned elsewhere in the literature. Vidaeus (1971) also noted that activity at Vieux Fort could not be assumed as representative of other sites on the island. While the estimation of the annual number of fishing days can be guided by management regulations such as closed fishing seasons, the lack of surveillance and enforcement results in contravention of these regulations e.g., illegal harvesting of sea urchins (Smith and Berkes, 1991). Hence the number of fishing days so derived would be an under-estimate of the true figure and unsuitable for estimating fishing effort. Further, fishing effort is reconstructed for all components of the inshore fishery collectively. To account for the increased effort directed at the offshore fishery by the pirogue fleet in the late 1990s, the number of fishing days was increased and these boats were assumed to desist from exploiting the inshore fishery, traditionally exploited during the pelagic off-season.

The unit of fishing effort does not allow for investigating changes in gear efficiency as a component of effort. Adaptation of trolling and longline gear for increased catchability, e.g., increasing the number of hooks and number of branch lines for manually operated gear (vertical and horizontal longlines) or the use of mechanized gear in larger boats (George, 1999) is not incorporated in the unit of effort. The same applies to the use of Scuba for capture of lobster and conch in deeper water. Fishing effort of foreign fleets, e.g., boats from Barbados, Martinique or the United States is not incorporated in this analysis.

Annual trends in catch per unit area (CPUA) and catch per unit effort (CPUE)

The higher magnitude of CPUA in the inshore fishery is expected, given that inshore resources are concentrated within a narrow shelf area, representing approximately 3% of the entire EEZ. CPUA has increased throughout the 1990s by 394% and 350% in the offshore and inshore fisheries, respectively. The increase for the offshore pelagic fishery is consistent with the targeted development of that fishery, instituted to preserve the remaining inshore resources. The overall fishing effort directed at these resources has declined in recent years, although the long-term trend demonstrates an exponential increase between 1942 and 1999. This decline in effort along with the system of marine reserves implemented from the late 1980s may have contributed to increases in biomass which are reflected in the associated catches of the remaining boats in the fishery. It is interesting to note that the incentive system in St. Lucia, and to a certain extent management regulations (the use of trammel nets has been banned), discourages development of the inshore fleet targeting reef and other demersals.

Generally, catch per unit effort declined exponentially in both the offshore and inshore fisheries between 1942 and 1999. The decline in CPUE in the last two decades showed generally higher CPUE in the inshore fishery in the early and late 1990s compared to the offshore fishery. This is despite measures taken to develop the offshore fishery. The changes in effort account for these differences. Between 1988 and 1999 the effort in the offshore fishery has increased by a factor of 4.71 compared to 1.73 for the inshore fishery. The considerable increase in overall effort, mainly due to increasing number of boats, increases the competition for fish within the EEZ, manifested in declining CPUE. The decline in CPUE of the inshore fishery is less marked because the situation is quite the opposite to that in the offshore fishery, i.e., fewer boats are now exploiting this fishery.

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Barbados: Reconstructed Fisheries Catches and Fishing Effort, 1940-2000

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ABSTRACT

A time series of catch and effort data was reconstructed for the fisheries of Barbados between 1940 and 2000, based on information from the Barbados fisheries statistical data collection system, published and unpublished reports, and the Barbados fishing boat registration system. Reconstructed catches indicate considerable inter-annual variability with peaks in 1966 (7,908 t) and 1991 (7,563 t) and a slight increasing trend between 1970 (4,081 t) and 2000 (5,003 t). Offshore catches were higher than inshore catches by one order of magnitude. Catches by day-boats and moses boats (dinghies of 3-6 m length, manual propulsion or low-Hp outboard engines) declined by 68.5% between 1967 and 2000, while catches of the ice-boat and longlining fleets increased by 2,647% between 1979 and 2000. Overall, flyingfish contributed up to 89% of total catch, with an annual average of 59% over the sixty year period. The number of boats exploiting the offshore and inshore fisheries increased by 66% and 176%, respectively. Potential effort increased exponentially in both fisheries and was consistently higher in the offshore fishery. Fishing effort increased by a factor of 384 in the offshore fishery and 65 in the inshore fishery. Annual catch per unit area (CPUA) was higher in the inshore than offshore fishery, with high inter-annual variability. CPUA ranged between 0.04 t·km^{-2} (1966, 1991) and 0.015 t·km^{-2} (1985, 1989) in the offshore fishery, and between 2.24 t·km^{-2} (1992) and 0.54 t·km^{-2} (1991) in the inshore fishery. Annual catch per unit effort between 1966 and 2000 declined by 85% and 73% in the offshore and inshore fisheries, respectively. A comparison of reconstructed data with reported statistics incorporated in the FAO FISHSTAT database was made.

INTRODUCTION

Study Area

Barbados is the most easterly of the West Indian islands (Figure 1). It is situated at 13°N and 59°W, and its Exclusive Economic Zone (EEZ) covers an area of 177,346 km^2. The continental shelf is narrow, the 100 fathom line (~180 m) varying between 0.8 and 2.6 nautical miles offshore (Brown, 1942), and covers an area of 277 km^2 (Mahon, 1986). The deeper and broader sections of this narrow insular shelf occur off the northeast and northwest coasts. An isolated off-shore bank, locally known as the 'London Shallows' exists off the southeast coast (Brown, 1942). Actively growing coral reefs are restricted to the west (leeward) coast, between Bridgetown in the south and Shermans, 16 km to the north. Total reef area is 100 km^2 (Oliver and Noordeloos, 2002).

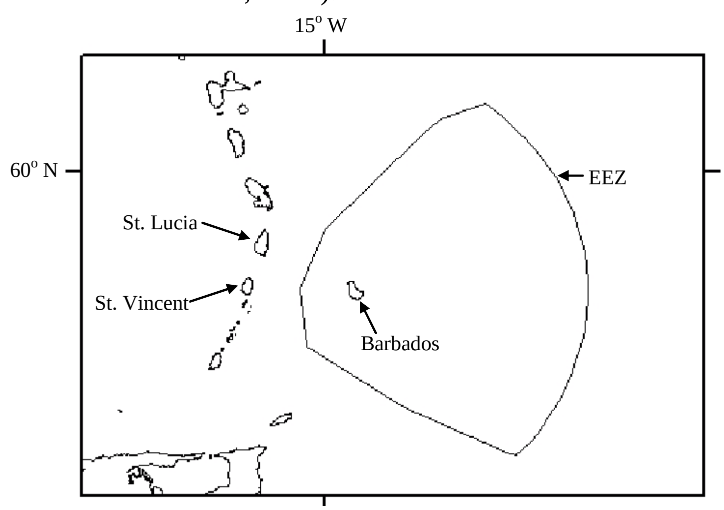

Figure 1: Map of Barbados, Lesser Antilles Islands. Also indicated are the 200 nm EEZ, and the nearest neighbouring islands.

Fishery Description

Detailed descriptions of fisheries development in Barbados are provided in Brown (1942), Hess (1966), Vidaeus (1969), Chakalall (1982), Cecil (1999) and Parker (2000). The fisheries resources are grouped into nine categories for management by the Barbados Fisheries Division. Two of these categories relate to offshore resources, the large pelagic fishery targeting dolphinfish (*Coryphaena hippurus*), tunas (Scombridae), kingfish (*Scomberomorus cavalla* and *Acanthocybium soalndri*), swordfish (*Istiophorus albicans*) and sharks (Carcharhinidae) with handlines, troll lines or longlines, and the flyingfish fishery targeting mainly the four-winged flyingfish (*Hirundichthys affinis*) with gillnets, handlines and dip nets. The inshore fishery is comprised of the shallow shelf reef fishes, the deep slope fishes, coastal pelagics, sea urchins, turtles, lobsters and conch. Shallow shelf reef fisheries target parrotfish (Scaridae) and surgeonfish (Acanthuridae) using fish pots, nets and spear guns, while the deep slope fisheries target mainly snappers (Lutjanidae) and groupers (Serranidae) with fish pots and handlines. The coastal pelagic fishery targets herrings (Clupeidae), jacks (Carangidae) and small tunas with handlines, troll lines, seine and cast nets. Sea urchins (*Tripneustes ventricosus*) and queen conch (*Strombus gigas*) are hand collected, while turtles (mainly the hawksbill *Eretmochelys imbricata*) are caught with entangling nets, and lobsters (*Panulirus argus*) with fish traps and hand spears. There has been a moratorium on turtle capture since 1998.

Pre 1950s

In 1944 the Fisheries Division, with responsibility for management and development of fisheries, was formed. Prior to this, a system of fish price control was instituted in 1942 to ensure that fish was affordable to all sections of society. At this time, the fishing fleet was unmechanized, relying on sails and oars for propulsion (Brown, 1942). The fleet was thought to operate below capacity and the introduction of troll gear was promoted to increase catches (Brown, 1942). Mechanization of the fleet was dependent on the increased spatial and temporal availability of flyingfish (Brown, 1942), the most important species in terms of bulk of catches. Brown (1942) noted the historical decline in catches of the species in 1928, 1930 and 1933. Flyingfish was traditionally caught using hook and line, or dipnets when plentiful. In 1947 the more efficient gillnet was introduced (Hess, 1966). Following successful fishing trials in the early 1950s, this gear was widely adopted. The turtle fishery was lucrative until the early 1950s, but the illegal harvest of eggs on the beaches was thought to result in the decline of the fishery (Hess, 1961). Prior to the 1950s only one fish market (primary landing site) was established in 1946 at Cheapside in Bridgetown.

1950s to 1980s

The second fish market in Barbados was constructed at Oistins in 1950. The following year a natural disaster, and in 1955 hurricane Janet caused extensive fleet damage (Parker, 2000). However, the high number of trees felled by the storm provided the opportunity for extensive fleet development, as these served as a source of timber for boat construction. The government also promoted boat mechanization by facilitating the acquisition of loans (Vidaeus, 1969). A safer, more stable boat was designed (day-boat or launch) and by 1954 boat mechanization commenced (Rose, 1954). Another fish market was constructed at Speightstown in 1954 and 200 t cold storage provided in Bridgetown. However, the existing cold storage was still inadequate and proved a major problem facing the industry since catches were low during the flyingfish off-season (July to October). As a result, fishers also limited their daily catches in favor of returning to the landing site early when there was less competition for sale of their catch. Solutions for short and long term storage of fish were suggested at the time (Rose, 1954).

Although development efforts focused on increasing landings, this was not matched by similar improvements in handling, distribution, marketing and storage (Hess, 1966). In the 1960s government's policy promoted the local fishing industry and welfare of the fishers through improved landing facilities. Although unsatisfactory repayment of loans resulted in the suspension of the scheme in 1964, fishers still benefited from the duty free concessions on fishing gear, diesel engines and spare parts, and subsidization of fuel (Vidaeus, 1969). It was also evident that, even though the larger mechanized boats initially operated at a profit, this margin decreased as the number of similar boats entered the fishery. The initial capital investment and operating costs of these boats were greater than the smaller boats, yet the production was similar (Hess, 1966). The government price control system ended in 1972. In 1963 an American-owned company began operations in Barbados. The company caught shrimp off Brazil, and exported the processed catch to the US (Parker, 2000). By 1973 this offshore fleet was well established (Kreuzer and Oswald, 1978), comprising some 20 trawlers with on-board cold storage (Baker, 1976).

During the 1970s, the National Development Plan and policy of the Barbados Development Bank (BDB), newly instituted in the early 1970s and responsible for granting loans to fishers, promoted the use of fishing boats fitted with ice-holds (Parker, 2000). These boats became known as ice-boats, with the first being introduced in 1976. During the 1980s the BDB's promotion of development of the offshore fishery resulted in tremendous increase in the number of ice-boats as well as the introduction of a longlining fleet towards the end of the decade. Increasing trip costs and competition for sale of catch with ice-boats resulted in the conversion of day-boats to ice-boats by inclusion of an ice-hold (Parker, 2002). Ice-boats increased the range of exploitation to up to 550 km offshore (Berkes and Shaw, 1986), and were equipped for trips of up to 2 weeks duration. The 1980s was marked by considerable improvement in market facilities, with the construction of a fisheries complex at Oistins in 1983 and another at Bridgetown in 1986 (Parker, 2000).

1990s

Expansion of the offshore fleet continued into the 1990s. Significant efforts were placed on improving fisheries management initiatives, with the enactment of the Fisheries Act (1993), the drafting of fishery-specific management plans (Anon., 1999) and the enforcement of related fisheries regulations in 1998 (Parker, 2000). Exploitation of sea urchins, whose fishery collapsed in 1987, was banned, and a co-management approach instituted for future management. During this decade, there were considerable increases in the number of boats in all fleets except day-boats which were in the process of conversion to ice-boats. Other infrastructure developments included the construction of the Weston fish market at Reids Bay, formerly a ‘secondary landing site’ (secondary landing sites are equipped with a shed and running water for processing and selling of fish). The tertiary site at Six Men’s Bay had grown in importance as fishers avoided the congestion at the nearby Speightstown market (tertiary sites have no sheds or running water). By 2001 the government planned to construct a market at Six Men’s Bay, Payne’s Bay and a fisheries complex at Speighstown to meet the demand of increased catches.

Fisheries Statistical data collection

Barbados differs from the rest of the southeastern Caribbean islands of this study in that it instituted a fisheries statistical data collection system in the 1940s, from which a long time series of recorded data are available. Initially, the quantity of fish landed at Bridgetown was recorded and later the system was extended to include landings at Speightstown and Oistins. The management of the three markets was handed over to the Marketing Division of the Ministry of Agriculture in 1954, while the Fisheries Division of the same Ministry retained responsibility for small secondary sites (referred to as ‘sheds’). This division of responsibility persists to date. At the time, however, the reliability of statistics collected at the sheds was low (Rose, 1954).

By the early 1960s, data were collected at the three markets (Bridgetown, Oistins and Speightstown) and eight secondary sites (beach sheds). The quantities landed were estimated visually and excluded landings during late evening, early morning, Sundays and bank holidays (Rose, 1954; Hess, 1966). The associated gear was also not recorded (Hess, 1966). Recorded landings were assumed to represent one third of total landings (‘one third’ assumption) from some 25 landings sites around the island (Hess, 1961), but there was no scientific basis for this assumption. Some fishers avoided landing at the markets to circumvent payment of toll fees. As a result, catches may have been sold across boats. There was also no system for ensuring non-duplication of records, particularly for catches sold at one market and resold at another. By the late 1960s, catches from several fishing centres along the coast were delivered to the main markets. However, the same assumption that recorded catches represent one third overall total catch was still used in deriving estimates of total catch (Vidaeus, 1969). There was little improvement in the data collection system throughout the 1970s and 1980s. Despite developments in the fishing industry, the ‘one-third’ assumption was still utilized well into the late 1980s (Chakalall, 1982; Oxenford, 1990).

In the late 1980s, Barbados participated in a workshop to improve fisheries data collection systems in the region, hosted by the Organization of Eastern Caribbean States (Willoughby *et al.*, 1988). Deficiencies in the data collection system were identified, such as non-inclusion of landings from recreational fishing and inadequate coverage of landing sites important for non-fish species. The workshop proposed an improved data collection system, incorporating total census at primary and secondary sites and stratified sampling at tertiary sites, collection of purchase slips from hotels, restaurants and supermarkets to estimate lobster catches, and implementation of a logbook system for offshore and charter fleets (Willoughby *et al.*, 1988).

Under the CARICOM Fisheries Resource Assessment and Management Program (CFRAMP) restructuring of the data collection program in line with recommendations of the OECS workshop of 1988 was undertaken. Data are collected at four primary sites (Bridgetown, Oistins, Speightstown, Weston), seven secondary sites (Conset Bay, Tent Bay, Martins Bay, Skeetes Bay, Fitts Village, Paynes Bay and Half Moon Fort) and ten tertiary sites. Data are recorded at primary and secondary sites five days per week. Since data collectors at the secondary sites reside in the vicinity of landing operations, most of the landings at these sites are captured by the system. Tertiary sites are sampled on a rotational basis. Computerized data management systems were also introduced by the CFRAMP for fisheries catch and effort statistics (Trip Interview Program) and licensing of fishers and boats (Licensing and Registration System).

Since 1997, the 'one third' assumption has been revised. A raising factor of between 1.2 and 1.6 is applied to recorded catches of all species, except tuna and swordfish, for which it is believed that a total census of landings is taken. It is envisaged that greater quantities of total landings would be captured by the data collection system as the Government moves towards increased development of the industry through provision of larger markets or fisheries complexes (primary sites) with increased cold storage and freezing capabilities. Presently (2000-2002), markets were constructed, though not yet operational, at Skeetes Bay and Consett Bay, while another market was under construction at Paynes Bay. There are also plans to construct markets at Six Men's Bay, Half Moon Fort and a complex at Speightstown.

Fisheries Policy

The general fisheries management and development policy seeks to "ensure the optimum utilization of the fisheries resources in the waters of Barbados for the benefit of the people of Barbados", (Anon., 2001). Specific management plans have been developed for the respective fisheries. The policy for the offshore large pelagic resources is to maximize catches for national and regional fishers, within conservation guidelines, and to ensure fair and equitable distribution of resources. For the flyingfish fishery, the objective is to establish a catch and effort regime aimed at long-term sustainability, optimal economic and social return, and an acceptably low-risk of economic or social disruption as a result of inter-annual variability in catches. The policy for inshore shallow-shelf reef resources is to rebuild fish populations to levels capable of satisfying the requirements of both the commercial fishery, and recreational or tourism non-harvest uses, in order to obtain social and economic benefits from the resource. A precautionary approach to achieving sustainable yield for local consumption is proposed for the deep slope and bank fisheries, while policy aims to optimize catches of target species in the coastal pelagic fishery to meet the demands for bait fisheries, while minimizing by-catch of reef species. Policy aims to rebuild populations of sea urchins and assess the status of queen conch populations as well as institute a co-management arrangement with fishers to maintain population levels that can sustain long term optimum yields for social and economic purposes. For lobsters, the policy is to promote sustainable harvest of the resource for domestic use and the local tourism market aimed at long termed maximum economic gain. Protection, conservation and recovery of sea turtle populations is the management objective.

METHODOLOGY

Catches

Barbados has a long time series of landings data, either hand-written, printed summaries or computerised details of landings by boat trip. There are however, inconsistencies in the level of species disaggregation of landings and aggregation of landings across boat types. Data collected at the primary sites provide the greatest level of detail as far as segregation of species. The associated categories are flyingfish (*Hirundichthys affinis*), dolphinfish (*Coryphaena hippurus*), kingfish (*Scomberomorus cavalla* or *Acanthocybium solandri*), shark (Carcharhinidae), tuna (Scombridae), billfish (Istiophoridae), jacks (Carangidae), crevalle jack (*Caranx hippos*), bonito (*Sarda sarda*), pot fish, any other variety (AOV), brim or queen snapper (*Etelis oculatus*), snappers (Lutjanidae), any other variety of deeper water species (mainly Lutjanidae and Serranidae). Market data are available as monthly summaries of landings as well as the associated categories and numbers of boats. Data for secondary sites during the 1970s are available as monthly summaries of landed weights but aggregated across categories/species, while more recent data (from 1981 onwards) are available in the same species categories as the markets. Catch data from recreational fishing tournaments were also provided by the Barbados Game Fishing Association for the period 1992 to 2001.

Since each fleet is characterized by differences in either level of activity, trip length, fishing area, landing sites or main species targeted, catches are reconstructed separately for each fleet, depending on availability of information with the annual catch represented by the sum of individual fleet catches. To correct for missing data, it was assumed, where possible, that all boats of a similar category operating within the same administrative region (parish) exploit the same resource and exhibit the same level of activity.

Day-boats (Launches) and Moses Boats

Except for recent years (1994 to 2000), available catch data for both fleets were aggregated. Although effort (number of boat trips) is recorded separately, it is difficult to disaggregate annual or monthly catches accordingly. As a result, catch reconstruction was conducted for both fleets combined. These fleets make daily fishing trips, are not equipped with on-board cold storage facilities and do not fish in offshore waters outside the EEZ. While the day-boat fleet targets large pelagics mainly, it exploits the inshore demersal and reef resources during the pelagic off-season. The moses fleet (dinghies of 3-6 m length, manual propulsion or low Hp outboard engines) targets mainly inshore demersal and reef and coastal pelagic species. Target species are dependent on proximity of mooring sites to fishing areas and landing sites since this fleet carries engines of low horsepower.

Anchor Points: Total Catch

Anchor points are estimates of total catch either taken from the literature or estimated from recorded statistics on fisheries landings.

1940: Brown (1942) provided an estimate of 454 t total catch in 1940.

1950 – 1992: Annual total catch was estimated as the sum of catches across all parishes. Annual catch at each parish was estimated as the product of average catch per boat and number of registered boats. The average catch per boat was estimated using data at recorded sites. Representative sites for each parish at which data were collected are: Oistins; Skeetes Bay; Pile Bay, Bay Street, Cheapside Market and Bridgetown Complex; Paynes Bay and Reids Bay; Speightstown; Half Moon Fort; Martins Bay and Consett Bay; and Tent Bay. It was assumed that a complete census is taken at recorded sites, that all boats registered at a particular site land catches at that site only and that the average annual catch per boat at recorded sites is representative of all other non-recorded sites within the respective parish. Using the point estimates of number of boats at all landing sites (recorded and non-recorded) in 1942 (Brown, 1942), 1954 (Rose, 1954) and 1963, 1973, 1983, and 1993 (Fisheries Department Boat Registration System), and estimating missing values by interpolation, the annual number of boats registered at each recorded site between 1950 and 1988 was derived. The number of registered boats at each parish was estimated as the sum of registered boats at all landing sites, whether recorded or not, within the parish.

Between 1950 and 1953 data were available for the Oistins landing site only. As a result, the average catch per boat at recorded sites in 1954 was assumed the same for similar sites during the 1950 to 1953 period. Because of gaps in the data, it was assumed that boats at adjacent parishes function similarly and therefore will land similar quantities and species. Hence, between 1964 and 1973, the annual catch per boat at St Joseph (not recorded) was assumed the same as that for St John, while the 1992 catch per boat at St John (not recorded) was assumed the same as that for St Joseph. This procedure enabled estimation of total catches for parishes for which no data were collected, as well as disaggregation into the respective species components (see below). Since no records of boats at Cheapside Market were available in most of the data sources consulted, the number of boats at Bridgetown was used in the calculations. Because of the close proximity of these sites it is assumed that the same boats land at these two sites.

Between 1984 and 1989 considerably fewer boats were recorded at the sites in St Michael. There was also the anomaly of more boats recorded than registered at St Michael during 1992. It was assumed that boats at the neighbouring parish of St James also land at St Michael, to use the fisheries complex facilities constructed in 1986 in Bridgetown. Thus, average catch per boat across both sites was used in calculations. A considerably lower coverage of landing sites was observed from 1989 to 1991 compared to earlier and later periods. Hence, it was not possible to estimate the average catch per boat from data for the respective years and sites. This was therefore estimated by interpolation between the 1988 and 1992 estimates.

1994-2000: Computerised data on landings from individual boat trips were provided by the Barbados Fisheries Department. The greatest level of disaggregation was available for this most recent time series. Information for each recorded trip included the catch weight by individual species, date of catch/landing, landing site and the associated boat. The recorded data were used to estimate total monthly landings, for each boat category and parish (as opposed to individual landing site) and then summed across all months, boat categories and parishes to derive the annual total. Although landings data were available separately for each landing site, the Fisheries Department's boat registration records were aggregated for all landing sites within a parish, hence constraining the level of spatial detail of this analysis. Based on similarities of operations of moses boats and day boats, which both make daily trips, fish closer inshore, and land at sites adjacent to the fishing areas, the same procedure was used for estimation of total landings.

Since recorded data did not represent a total census, total catches for the recorded landing sites/parish/boats were estimated by Equation 1:

$$Tc_{\text{parish, boat type, month}} = \text{Mean CPUE} \times \text{FD} \times \text{BR}$$

Where FD is the assumed number of Fishing Days and BR is the number of Boats Registered.

Herein, the basic assumptions are that:

- The CPUE by boat type and month is the same for recorded and non-recorded boats of the same type in similar months;
- That all boats in a parish fish each month; and
- That the average number of fishing days per month of each boat type from recorded data is the same for similar boats that are not recorded in other parishes.

For each parish, month and boat type the following details were extracted: catch of each species and total across all species; the number of fishing days; the number of fishing boats; fishing effort, as the product of number of boats and fishing days (boatdays); and mean catch per unit effort (CPUE), where CPUE = total catch/number of boatdays. The mean CPUE by boat type and month (across all parishes) and the number of registered boats by parish and type were also estimated, based on the Fisheries Department database. Missing monthly mean CPUE values by parish and boat type were estimated using proportional differences between adjacent months from mean monthly CPUEs calculated for different boat types.

Equation (1) was also used to estimate total catches for non-recorded parishes and boat types assuming that mean CPUE for the particular boat type across all parishes was representative for non-recorded sites. Missing values of monthly mean CPUE by boat type for across all parishes were estimated using the proportional difference between adjacent months from mean CPUEs calculated for different boat types across all years (1994-2000). The same procedure was followed for estimating missing cells for average number of fishing days.

The above procedure generated estimates of total catch by parish, month and boat type, which accounted for changes in seasonality of fishing and frequency of trips due to weather or market conditions. Catches were subsequently summed across all months to provide an annual total for day-boats and moses boats.

First interpolation: Total catches

Data were available from the Cheapside market in 1942 and the Bridgetown market in 1947 and 1948. However, records were incomplete and could not be used to estimate total catch. Thus, estimates of total catch from 1941 to 1949 were interpolatied between values for 1942 (Brown, 1942) and 1950 (reconstructed). Similarly, annual total catch for 1993 was estimated by interpolation between the reconstructed annual estimates for 1992 and 1994.

Species composition

Generally, species composition was estimated directly from recorded data, and species identification was clarified by Fisheries Division staff (Table 1).

1940 – 1963: Data were only available for up to four landing sites over this period. Thus, composition was estimated using recorded data for all sites combined. The species composition for 1940 and 1941 was assumed the same as for 1942.

1964 – 1992: The average composition of catches at recorded sites of each zone was used to disaggregate the zonal catch into its species components. No data on species composition were available for sites in Zone 3 between 1964 and 1981. During this period, the annual species composition of catches recorded at Oistins (the nearest recorded site) was used. Speightstown was the only landing site for which data were available for 1989. Hence species composition at this site was applied across all sites. Similarly for 1990, the mean species composition at the two recorded sites, Speightstown and Cheapside markets, was applied across all landing sites.

1994 – 2000: The annual species composition from recorded catches was used to disaggregate estimates of total catch of the day-boat fleet into component species. Since day-boats target

Table 1: Species names (taxonomic and common/local) used for disaggregation of reconstructed catches for Barbados.

Scientific Name	Common/Local Name
Hirundichthys affinis	Flyingfish
Coryphaena hippururs	Dolphin
Scomberomorus cavalla; Acanthocybium solandri	Kingfish, Wahoo
Acanthocybium solandri	Wahoo
Scombridae	Mackerel
Sphyraena barracuda	Barracuda
Carcharhinidae	Shark
Thunnus alalunga	Albacore
Thunnus albacares	Yellowfin Tuna
Katsuwonus pelamis	Skipjack Tuna
Scombridae	Tuna
Istiophorus albicans	Sailfish
Tetrapturus albidus	White Marlin
Makaira nigricans	Blue Marlin
Several billfish species	Billfish
Xiphias gladius	Swordfish
Large pelagics unidentified	AOV Large pelagic
Etelis oculatus	Brim
Rhomboplites aurorubens	Snapper
Lutjanidae; Lutjanus synagris, Lutjanus mahogoni	Other snapper
Epinephelus adscensionis	Rock Hind
Epinephelus guttatus	Red hind
Carangidae	Jacks/Johns
Caranx ruber	Cavally
Sarda sarda	Bonito
including conch *Stombus gigas*	Marine molluscs nei[a]
including lobster *Panulirus argus*	Marine crustaceans nei[a]
Mainly hawksbill, *Eretmochelys imbricata*	Turtles
Scaridae	Parrotfish
Haemulidae	Grunts
Holocentrus rufus, Holocentrus adscensionis	Squirrelfish
Cantherhines pullus, Cantherhines macrocerus	Filefish
Chaetodon striatus, Chaetodon capistratus	Butterflyfish
Myripristis jacobus, Plectrypops retrospinis	Soldierfish
Serranidae	Grouper
Acanthuridae	Surgeonfish
Pomacanthus paru	Angelfish
Lactophrys polygonius, Lactophrys triqueter	Cowfish & Trunkfish
Bodianus rufus, Bodianus pulchelles	Hogfish
Pseudopeneus maculatus	Goatfish
Microspathodon chrysurus, Stegastes spp.	Damselfish
Abudefduf saxatilis	Sergeant major
Gymnothorax ocellatus	Spotted moray
Scorpaena plumieri plumieri	Spotted Scorpiofish
Chilomycterus antillarum	Web burrfish
Tylosurus spp.	Garfish
Balistidae	Triggerfish
Canthidermis maculatus	Turpit
Unidentified seine caught fish	AOV Seine
Unidentified pot caught fish	AOV potfish + AOV
Snappers (Lutjanidae) and groupers (Serranidae)	AOV Deep
Unidentified fish	Ninnins

[a] nei = not elsewhere included

mainly large pelagics (and the demersal fishery during the flyingfish 'off-season') regardless of their port of registration, the species composition was computed across all parishes. Moses boats generally target inshore resources (small coastal pelagics and reef species), as a result the species composition of the catch may vary at different landing sites. Recent records also show the tendency for some boats to target large pelagics. Since computation of species composition across all parishes may skew the individual species catches towards large pelagics, and underestimate the catches of inshore species, this was computed separately for each parish, and catches of like species summed across parishes to provide the total annual catch by species.

Second interpolation: Species composition
The species composition for 1943 to 1946, 1954 to 1956, and 1993 were estimated by interpolation between the estimates for the years immediately preceding and following these periods.

Ice-boats and Longliners
Ice-boats were introduced in the late 1970s, and their catches are offloaded directly at processing plants or to consumers at unmonitored landing sites. During the 1980s, landings of this fleet were not recorded by the Fisheries Division. Longliners were introduced in the late 1980s. Both boat types make fishing trips of between nine and 28 days duration (Parker, 2002), and are equipped with cold storage facilities. Since they fish in specific offshore areas, regardless of their home port or landings site, no differences in CPUE is expected for boats of similar type among landing sites. It is however, impossible to determine the number of fishing days from recorded data (date) as these are indicative of offloading operations rather than fishing. Since this process may span several days, the total catch is recorded in batches, corresponding to the quantity offloaded on the respective days. Because of the differences in nature of activity and interpretation of recorded data, a different methodology was employed for estimation of total catches by ice-boats and longliners compared to day-boats and moses boats.

Anchor Points: Total Catch
1979 – 1993: Estimates of annual total catch for this fleet were derived using the methodology of Mahon (1990a, b), who assumed an average of 14.5 trips per year with an average of 1808 kg per trip. Mahon estimated total landings as the product of catch per trip, number of trips per year and number of boats. Since there were discrepancies in the number of boats estimated in this study, maximum estimates in Mahon (1990a, b) and Anon. (1986) were used. Using information on the number of longliner boats operating each year (R. Mahon, pers. comm.), and assuming the same annual catch per boat as 1994 estimates of total annual catch were derived for 1988 to 1993.

1994 – 2000: Monthly catch per boat (C_{BM}) and monthly number of boats recorded (B_{RM}) were extracted from the fisheries landing database. Using the total number of unique boats of each type recorded in the respective year (T_{RY}), the fraction operating each month was estimated (B_{RM}/T_{RY}). Based on the overall number of registered boats by type, available in the Fisheries Department Licensing and Registration database, the number of boats operating each month (B_{AM}) was estimated, assuming the same proportion from recorded data. The total monthly catch was estimated as the product of the average catch per boat and the number of boats operating (C_{BM} x B_{AM}). Monthly catches were summed for an estimate of total catch.

First interpolation: Total catches
Annual total catch of ice-boats for 1990-1993 was estimated by interpolation between estimates for 1989 and 1994.

Species composition
1979 – 1993: No data were available for the ice-boat fleet. Mahon (1990a, b) assumed a species composition of 60% flyingfish and 40% large pelagics after Hunte and Oxenford (1989). However, data for 1993 indicated other species (including demersals) in the catch, with flyingfish accounting for 67% and large pelagics for 25% of overall catch. Due to the uncertain nature of species composition for the earlier period, the same species composition was based on the 1994-2000 data.

Data on species composition of the longliner fleet was not available for 1988 to 1993. Thus, the species composition for 1994 was assumed for this period, and species composition for 1994 to 2000 was taken directly from recorded data.

Catches from sport fishing tournaments
The recreational fishing industry has grown over the years, particularly because of its association with tourism and the introduction of local and international fishing tournaments. Raw data sheets, with details on catch weight by boat, were provided by the Barbados Game Fishing Association for the period 1992-2001. A change in the level of detail recorded was evident.

Records of earlier years provided information on individual fish weights by species, with a total weight for those fish below the size limit, summed for each species. It is not known when this method of recording changed, however by 2000 only the weights of those fish meeting the minimum weight criteria for the competition were recorded. While additional information indicated the overall number of fish caught by each boat, no information was provided on the fish caught that were not satisfying the minimum weight criterion.

Species catch adjustments

Between 1970 and 1990, catches of kingfish (*Scomberomorus cavalla*), yellowfin tuna (*Thunnus albacares*), skipjack tuna (*Katsuwonus pelamis*) and billfish (Istiophoridae) were taken from Mahon and Singh-Renton (1993). Since some species are taken by all fleets, catches were disaggregated according to the species composition by fleet of the reconstructed data. Given that ice-boats began operations in 1979 and longliners in 1988, it was assumed that all catches prior to 1979 were attributed to day-boats and moses boats only, and that catches from 1979 to 1987 were attributed to day-boats, moses and ice-boats. Catches from 1988 to 1990 were attributed to all fleets. Catches of yellowfin tuna from 1970 to 1978 were attributed solely to day-boats and moses boats. However, from 1979 to 1988 yellowfin tuna catches were attributed solely to ice-boats. From 1988 onwards, catches of yellowfin tuna were divided between ice-boats and longliners according to species compositions in the initial data. Similarly, all catches of skipjack tuna were attributed to day-boats and moses. The 1991 yellowfin tuna catch was taken from Mahon *et al.* (1994), and was disaggregated among fleets as previously described.

Swordfish (*Xiphias gladius*) catches from 1994 to 1998 were provided by R. Mahon (pers. comm.), who investigated the swordfish fishery of Barbados and estimated catches which exceeded reconstructed data in most years. Catches were distributed to respective fleets based on the contribution of each fleet to total catch and the percentage composition of each fleet in the overall catch in the initial reconstructed data.

Data for kingfish (*Scomberomorus cavalla*) and Wahoo (*Acanthocybium solandri*) were grouped because of uncertainty in species identification (wahoo is referred to as 'kingfish' in Barbados). Also, the estimated catch of 'bigfish' for 1981 and 1982 (166 t and 6 t, respectively) was assumed to be incorporated in estimates of yellowfin tuna and billfishes from Mahon and Singh-Renton (1993).

Because of the extended trip lengths of ice-boats and longliners, it was assumed that some degree of processing occurred on board. Using conversion factors for the relevant species based on the degree of processing (Mohammed, General Methodology, this volume), species landed weights were adjusted to the corresponding whole weight.

The species composition of billfish for 1988-1991 was taken from Oxenford (1994); assuming no differences across fleet types, this was applied across catches for all relevant fleets. Sailfish and spearfish accounted for 73% of overall billfish catch, while blue marlin and white marlin accounted for 18% and 9%, respectively. Recreational tournament catches were disaggregated by the respective billfish species (white marlin, blue marlin, sailfish). The species composition of billfishes caught commercially from 1992 to 2000 was disaggregated into the species components based on the composition of the recreational catch. The same species composition was used to disaggregate the individual fleet (moses boats, day-boats, ice-boats and longliners) catches.

An 'AOV' (any other variety) category comprising mainly fish caught in pots was listed as a separate category to 'AOV potfish' or 'Potfish'. Since all three categories refer to the same fishery, reconstructed catches were combined into one 'AOV Potfish' category. Information on species composition of artisanal pots used in the commercial fishery was available for 1986, 1990, 1991 and 1996 from D. Robichaud and R. Mahon (pers. comm.) and Robichaud *et al.* (1999). The species composition for 1987-1989 and 1992-1995 was estimated by interpolation, while species composition for 1997-2000 was assumed the same as 1996.

There were no records of catches of molluscs, e.g., Queen conch (*Strombus gigas*) or crustaceans, e.g., spiny lobster (*Panulirus argus*) in the literature or databases consulted for this study. The respective catches in FAO FISHSTAT were therefore included as presented.

Estimation of flyingfish caught as bait

Longliners utilize flyingfish as bait. The associated catches of flyingfish are not accounted for in the data collected at landing sites. Estimation of annual landings of flyingfish caught as bait uses information on the number of hooks per main line from R. Mahon (pers. comm.), the mean individual weight of flyingfish (0.15 kg) from personal observation and an assumed 110 fishing days per year (conservative estimate since longliners have the potential to operate about 220 days per year). However, R. Mahon (pers. comm.) outlined the slow start-up of activities and ongoing maintenance problems for this fleet. Since introduction of longliners to the fishery in 1986 the number of hooks has increased from 200 per mainline to about 400 (R. Mahon, pers. comm.). The number of hooks per mainline between 1986 and 1999 was estimated by interpolation. It was assumed that hooks were baited once each fishing day and that one flyingfish was used per hook. The estimated annual quantity of flyingfish utilized as bait was taken as the product of number of hooks per mainline, number of fishing days, the mean individual weight of flyingfish and the number of longliners estimated from the Fisheries Department's boat registration system.

Estimation of turtle catches

Fishing is mainly for the hawksbill turtle, though a few green turtles are also taken (Ingle and Smith, 1949). In the 1940s, about 50-60 men harvested turtles between March and July each year using nets, and catches between 1945 and 1948 were taken from Ingle and Smith (1949). Assuming that these were all hawksbill, with a mean individual weight of 51 kg (Witzell, 1994) the equivalent weight was computed. Using annual data on the number of hawksbill turtles associated with quantities of 'bekko' exported to Japan (Milliken and Tokunaga, 1987) and mean individual weight from Witzell (1994), estimates of the weight of hawksbill caught between 1970 and 1986 were derived. Turtle catches were interpolated for years without data.

Fishing Effort

Boats were categorized as sail and/or oar boats, moses boats, day-boats or launches, ice-boats and longliners. In 1947, under the Fishing Industry Control Act, a boat registration system was implemented. This system requires annual re-registration of all boats and continues to date. The Fisheries Department keeps hard copies of these records from 1960 to the present time. In 1995 a Licensing and Registration System was introduced under the CARICOM Fisheries Resource Assessment and Management Program.

Data Sources

Point estimates (representing a single year) were derived for each decade between the 1940s and 1990s. The main data sources were Brown (1942); Rose (1954); Fisheries Department unpublished boat registration statistics available on hard copy for the years 1964, 1974, 1984 and 1994; and the Fisheries Department unpublished statistics available in the Licensing and Registration System for 1995-2000. Fishing effort for years with missing data was estimated by interpolation.

1942: Brown (1942) provided data on the number of boats by size, landing site and fishery, which led to a preliminary identification of landing areas associated with each fishery. Flyingfish and associated large pelagics are caught off all coasts. Since this is the major fishery, there are no clear distinctions in the associated boat designs as all boats target flyingfish. The associated number of boats is 340; while 52 of these target the brim and red fish fishery during the flyingfish off season (July to September). Boats utilising pots to capture demersal and reef species include the large row boats on the west (24) and south east (40) coasts and some small row boats on the west coast (85). It is assumed that large oar boats target the flyingfish and large pelagics fishery from November to June. Some of the small row boats on the west coast target the pot fishery all year, thus it is assumed that these are the boats for which pot fishing is listed as the main fishery (46). It is also assumed that the other 39 small oar boats target the pot fishery during the hurricane season only. The 107 castnets and nine beach seines targeted the inshore small coastal pelagic fishery which also acts as a source of bait. It is assumed that all boats were unmechanised, roughly corresponding to one horsepower.

1952: The number of boats by mooring site and parish, as well as the association of boats to fishery type was available from Rose (1954). There were 400 boats involved in the flyingfish fishery, 18 of which were mechanized with average engines size of 23 Hp (Parker, 2000). During the hurricane season (July to October), only 66 of the flyingfish boats operated in addition to the 18 mechanized ones. It was assumed that these target demersal resources. The inshore pot fishery was exploited by 600 fishers during hurricane season. Based on a mean crew of six (Rose, 1954), the equivalent number of boats was estimated at 100.

1963, 1973, 1983, 1993: Data were available in hard copy from the Fisheries Department's unpublished statistics, and computerized for this analysis. A list of boats and the associated mooring site, length, and engine details, i.e., whether inboard or outboard, brand and horsepower, were extracted for the respective years. The boat registration system requires annual re-registration. However, some fishers may have neglected to register their boat, yet continued to fish (illegally) during the year selected for analysis. Following a review of registration records for the year immediately preceding and following the selected year, boats found to have registered during these years were assumed to have fished during the selected year, and therefore were included. Mean horsepower was estimated from the same database.

1988: Data were available on the number of boats, by type, from Willoughby *et al.* (1988). Engine horsepower was estimated by interpolation between estimates for 1984 and 1994, with resulting estimates of 20 Hp, 53 Hp and 167 Hp for moses, day launches and ice launches, respectively.

1994-2000: Data were available on boat registration, parish, boat length and horsepower and boat type from the Fisheries Department's licensing and registration system (LRS).

Linking fishing effort to fishery type

In Barbados, there is a clear distinction between boat type and the associated fisheries. Prior to mechanization, all boats targeted the flyingfish and large pelagic fishery from November to June/July. During the pelagic off season, some targeted the pot and handline fishery (smaller boats and dinghies or moses boats) to catch bream (*Etelis oculatus*) and other snappers, while others targeted the sea urchin fishery (Brown, 1942; Rose, 1954). Willoughby *et al.* (1988) linked boat design to fishery type. Following mechanization, day-boats targeted the offshore fishery (flyingfish and large pelagics) from November to June, and switched to inshore shallow and deepwater demersals during the hurricane season (coinciding with the flyingfish off-season) from July to October. Ice-boats were designed specifically for targeting the offshore fishery, but were assumed to operate similar to day-boats until 1994, when they targeted the offshore pelagic fishery year round. Longliners target the offshore large pelagic fishery year round, catching flyingfish either incidentally or as bait. During the flyingfish off-season these boats continue targeting large pelagics. Moses boats target inshore shallow and deep water demersal and reef species mainly, though in recent years (1995-2000) records indicate a switch to the offshore pelagic fishery, particularly in the parishes of Christ Church, St John and St Peter.

Assigning fishing days to the respective fleets and fisheries

The assignment of number of fishing days was based on the fishery type and level of fleet mechanization as outlined in Mohammed (this volume). It was assumed that until 1994 ice-boats targeted the offshore pelagic fishery from November to June (130 days), and inshore demersal, reef and slope fisheries from July to October (45 days). Thereafter, ice-boats targeted the offshore pelagic fishery all year (220 days). Moses boats targeted both components of the inshore fishery (small coastal pelagics, and reef, slope and shelf) year round. Based on Mohammed (this volume), 230 fishing days was assumed and this was apportioned equally to each component of the inshore fishery. Between 1995 and 2000, moses boats at Christ Church, St John and St Peter targeted the offshore pelagic fishery. It was assumed that these boats operated similar to the day boats. Longliners target the offshore pelagic fishery year round (220 days).

Annual trends in catch per unit area (CPUA) and catch per unit effort (CPUE)

Using reconstructed catches and estimates of the EEZ (177,346 km^2), reef (100 km^2), and slope and shelf areas (177 km^2), a time series of catch per unit area (CPUA) was derived. The EEZ area was considered offshore and the reef, slope and shelf areas as inshore. Catch per unit effort (CPUE) was estimated as the ratio of reconstructed catch and reconstructed effort for the respective fisheries. Missing data on fishing effort were estimated by interpolation between reconstructed estimates for specific years.

RESULTS

Catches

A literature review indicated considerable variability in estimates of catches from different sources (Figure 2). Both, reconstructed data and statistics for Barbados in the FAO FISHSTAT indicate considerable inter-annual variability in catches (Figure 3a). Between 1950 and 2000, catch statistics in FISHSTAT varied between 2,101 t (1964) and 6,523 t (1983), with an unusually high catch of 8,929 t in 1988. Greatest deviation between reconstructed catches and FISHSTAT statistics occurred pre-1960 and post-1990. Except for the 1990s, periods of peak catches coincided in both data sources, although magnitude differed.

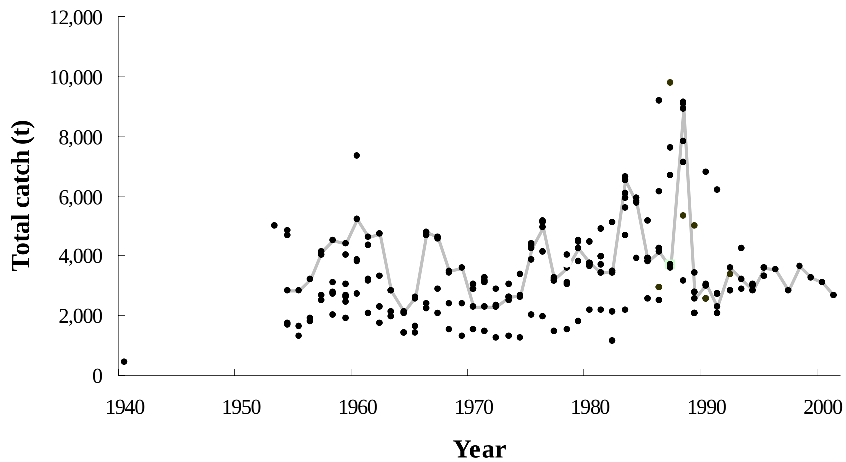

Figure 2: Estimates of total catch for Barbados from a literature review. Sources: Brown (1942); Howard (1950); Rose (1954); Fiedler *et al.* (1957); Smyth (1957); Bair (1962); Vidaeus (1969); Villegas (1979); Kreuzer and Oswald (1978); Chakalall (1982, 1992); St. Hill (1984); Berkes and Shaw (1986); McConney (1987, 1996); Anon. (1990); Oxenford (1990); Willoughby *et al.* (1990); Prescod *et al.* (1991); Prescod (1996); and the Barbados Fisheries Division. The line indicates data from FAO FISHSTAT for Barbados.

Reconstructed statistics indicate periods of peak catches in 1966 (7,908 t) and 1991(7,563 t). There is also a slightly increasing trend from 1970 (4,081 t) to 2000 (5,003 t), with annual catches fluctuating between 2,886 t (1985) and 7,562 t (1991). Inter-annual variability is evident in both the offshore and inshore fisheries (Figure 3b). Offshore catches were higher than inshore catches by one order of magnitude, and varied between 7,394 t (1966) and 2,670 t (1985), while inshore catches varied between 204 t (1991) and 843 t (1992). A comparison of catches between artisanal (day-boats and moses boats) and semi-industrial (ice-boats and longliners) fleets between 1964 and 2000 indicates an overall 68.5% decline in catches of the artisanal fleet, from a high of 7,889 t in 1967 to a low of 2,482 t in 2000 (Figure 4). Conversely, from 1979 to 2000, catches of the semi-industrial fleet have increased from 105 t to 2,884 t, a 2,647% increase. Overall, flyingfish contributed up to 89% of the total catch, with an annual average of 59%.

Over the 50 year period catch statistics in FISHSTAT were disaggregated into up to 20 species/groups, while reconstructed catches were disaggregated into 37 species/groups (Figure 5a). The percentage of overall catch attributed to the FAO aggregate category (‘Miscellaneous Fishes nei’) remained at or below 5% in most years for data in FAO FISHSTAT (Figure 5b). Notable exceptions occurred between 1965 and 1970 when this increased to 15%, and in 1980 when 42% of overall catch was attributed to the aggregate category. In reconstructed statistics the greatest contribution of the aggregate category, comprising ‘AOV seine’, ‘AOV large pelagics’, ‘AOV potfish’, ’AOV’ and ‘ninnins’, to total catch was 9% in 1968 and 1981. In other years this category contributed at most 7% to overall catch (Figure 5b).

Catches of large pelagics from recreational tournaments were insignificant compared to commercial catches. Between 1992 and 2001, landings from tournaments declined from about 11 t to 2 t (Table 2). Catches of flyingfish as bait for the longline fishery has increased from 7 t in 1986 to 205 t in 2000 (Table 3). Marine turtle catches increased from 5 t (1945) to 20 t (1970), followed by a general decline (Figure 6).

Fishing Effort

The number of boats in the offshore fishery ranged between 370 (1984) and 631 (2000) over the sixty year period (Figure 7a). No definite trend towards increased numbers of boats was observed in the earlier period (1940 to 1988), with the overall increase between 1940 and 2000 being 66%. The number of boats exploiting the inshore fishery ranged between 184 (1952) and 878 (2000), with a 176% increase between 1940 and 2000 (Figure 7b). Generally, effort increased exponentially between 1940 and 2000, with effort in the offshore fishery far exceeding that in the inshore fishery. The 2000 estimate was 11,667 x 10^3 Hp- days for the offshore fishery,

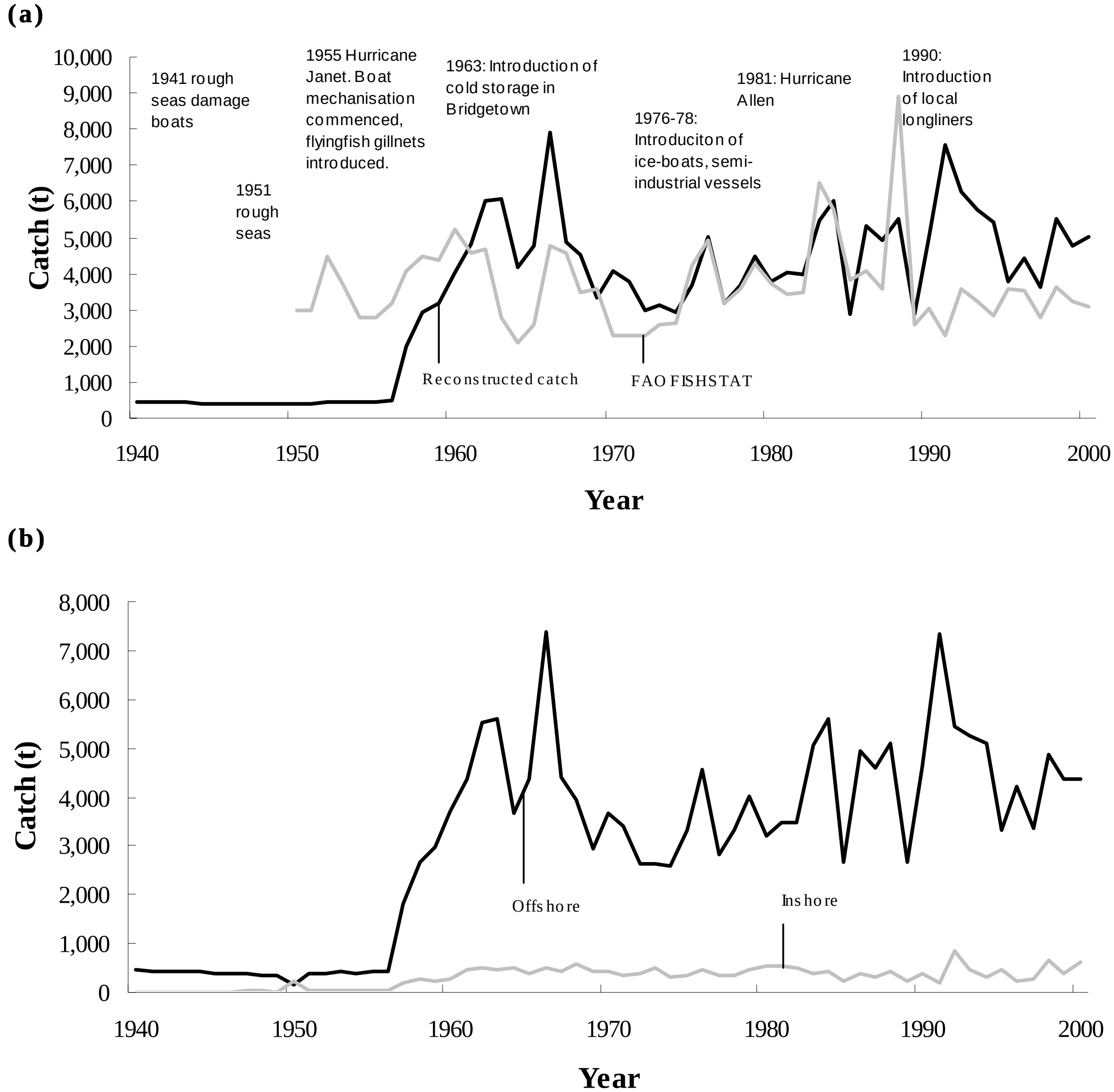

Figure 3: Catches in Barbados: (a) reconstructed catches (1940 – 2000) and FAO FISHSTAT (1950-2001); (b) reconstructed catches dis-aggregated for offshore and inshore fisheries (1940-2000).

compared to 2,690 x 10^3 Hp-days for the inshore fishery.Over the 60 year period, fishing effort increased by a factor of 384 and 65 in the offshore and inshore fishery, respectively. This increase was more pronounced in the most recent years (1994 to 2000) for both fisheries.

A summary of number of boats and mean engine size by boat type between 1963 and 2000 (Table 4) indicates a general increase in the overall number of boats and engine size. The increase in numbers of boats is attributed mainly to increases in moses and ice-boats, and longliners to a lesser extent in recent years. However, the number of day-boats has gradually declined over the period.

Annual trends in catch per unit area (CPUA) and catch per unit effort (CPUE)

Generally CPUA was greater, by about two orders of magnitude, in the inshore compared to the offshore fishery (Figure 8). Between 1956 and 1962, both fisheries experienced considerable increases in CPUA, from 0.13 t·km^{-2} to 1.30 t·km^{-2}, and from 0.002 t·km^{-2} to 0.031 t·km^{-2} in the inshore and offshore fisheries, respectively. Thereafter, CPUA remained relatively stable, although still varying between years.

Catch per unit effort in the inshore fishery was considerably lower than in the offshore fishery (Figure 9). Two different patterns in CPUE were observed in both fisheries between 1940 and

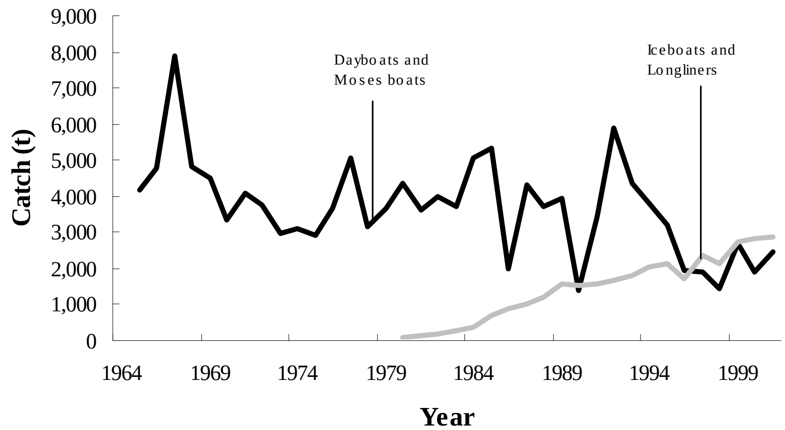

Figure 4: A comparison of annual reconstructed catches for artisanal boats (day-boats and moses boats), and semi-industrial boats (ice-boats and longliners) from 1964 to 2000.

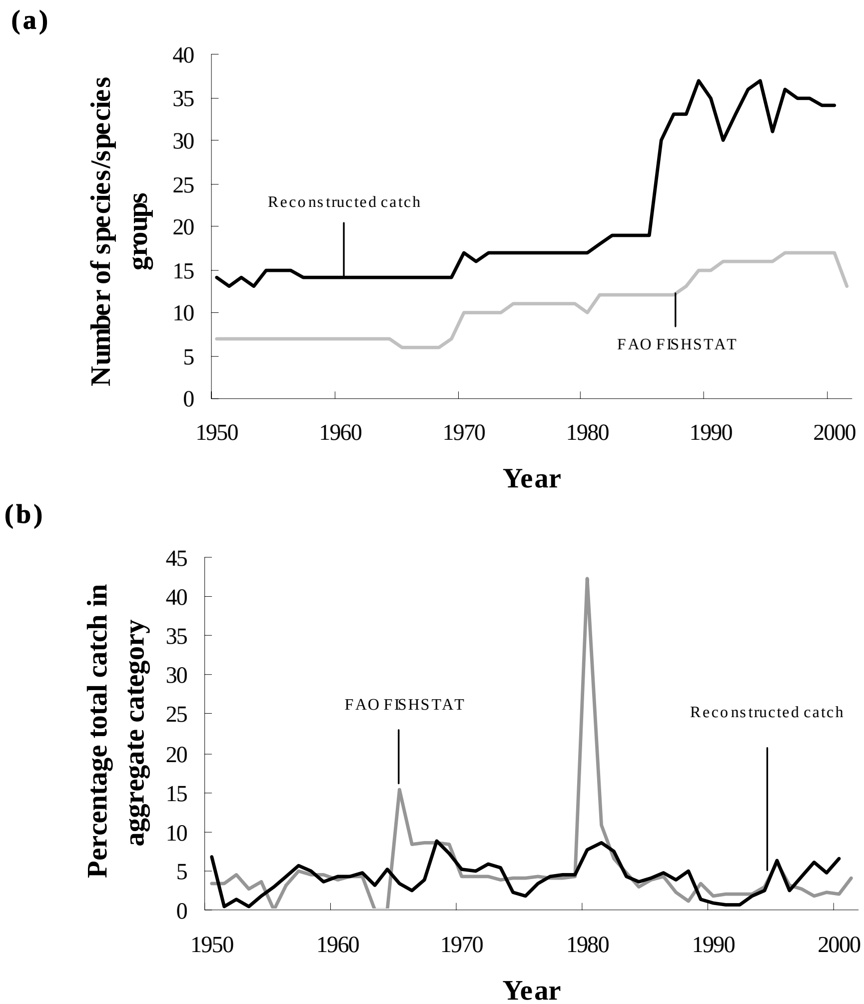

Figure 5: A comparison of reconstructed catch data and statistics in FAO FISHSTAT for Barbados between 1950 and 2000: (a) number of species/species groups and (b) percentage of total catch in aggregate category
.

Table 2: Catches (t) from recreational fishing tournaments (1992 – 2001).

Year	Dolphin-fish	Wahoo	Sailfish	White marlin	Blue marlin	Yellowfin tuna	King-fish	Other pelagics	Total
1992	6.21	3.62	0.32	0.08	0.40	0.12	-	0.04	10.79
1993	2.82	4.26	0.18	0.10	0.59	0.01	-	0.03	7.99
1994	3.42	1.99	0.15	0.03	0.47	0.19	-	0.05	6.30
1995	4.11	3.58	0.07	0.08	0.75	0.18	-	0.13	8.89
1996	5.33	4.88	0.05	0.04	1.06	0.08	0.02	0.11	11.58
1997	3.84	1.15	0.29	-	0.35	0.08	-	0.01	5.72
1998	1.79	0.70	0.11	0.02	0.32	0.06	-	0.01	3.02
1999	1.18	0.96	0.07	-	0.10	0.05	-	0.02	2.37
2000	0.54	0.44	0.05	0.02	0.43	0.04	-	0.13	1.66
2001	0.81	0.48	0.05	0.07	0.70	0.17	-	-	2.30

1952. Catch per unit effort in the inshore fishery increased from 0.176 x 10^{-3} t·Hp-days^{-1} in 1940 to 1.60 x 10^{-3} t·Hp-days^{-1} in 1952, while offshore CPUE declined from 14.74 x 10^{-3} t·Hp-days^{-1} to 1.59 x 10^{-3} t·Hp-days^{-1} over the same period. An unusually high inshore CPUE in 1950 was attributed to high catches of queen snapper (*Etelis oculatus*). Generally between 1956 and 1966, CPUE increased from 0.79 x 10^{-3} t·Hp-days^{-1} to 5.29 x 10^{-3} t·Hp-days^{-1} in the offshore fishery. Over the same period, the increase in CPUE was much smaller for the inshore fishery, from 0.20 x 10^{-3} t·Hp-days^{-1} to 0.86 x 10^{-3} t·Hp-days^{-1}. Thereafter, CPUE declined to 0.38 x 10^{-3} t·Hp-days^{-1} and 0.23 x 10^{-3} t·Hp-days^{-1} by 2000, for offshore and inshore fisheries, respectively.

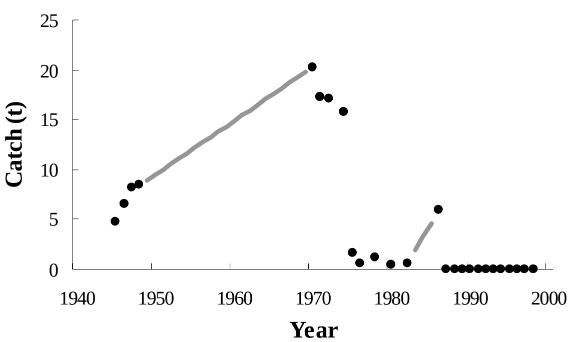

Figure 6: Reconstructed catches of hawksbill turtle (*Eretmochelys imbricata*) in Barbados (1945 – 1998). Solid circles represent reconstructed data and solid lines are interpolated values.

DISCUSSION

Catches

Our review of the literature showed that most authors neglected to indicate the methods used for arriving at their estimates of total catch, while others simply quoted recorded data or estimates of total landings from other documents. This has resulted in tremendous variation in the figures presented, making it difficult to ascertain which estimate is most representative of true catches. Often, there were discrepancies in estimates even within the same document. Traditionally, annual total catch has been estimated by raising recorded landings by a factor of three (Rose, 1954; Vidaeus, 1969; Chakalall, 1982; Oxenford, 1990). These estimates have been submitted for inclusion in the FAO FISHSTAT database between 1950 and 1996. The methodology, however, gives no consideration to changes in the coverage of the data collection system, associated infra-structure development and changes in fleet characteristics. While some have criticized the methodology used to adjust recorded data to total catch (Hess, 1961; Vidaeus, 1969; Chakalall, 1982; Oxenford, 1990), there has been little effort to provide an alternative approach. Mahon (1990a, b) estimated catches of flyingfish and dolphinfish by the day-boat and ice-boat fleets between 1962 and 1989, using information on the catch per trip, number of boats and an assumed number of trips per year. The resulting catches showed an increase from 1,750 t in 1962 to 7,104 t in 1989. This trend is not reflected in the data of FAO FISHSTAT (reported to FAO by Barbados) nor the present reconstructed statistics. It also does

Table 3: Estimated catch of flyingfish caught as bait (1986-2000).

Year	Number of hooks per main line	Number longliners	Estimated catch (t)
1986	200	2	6.60
1987	214	2	7.07
1988	29	3	11.31
1989	243	3	12.02
1990	257	3	12.73
1991	271	6	26.87
1992	286	9	42.43
1993	300	10	49.50
1994	314	13	67.41
1995	329	13	70.48
1996	343	19	107.49
1997	357	24	141.43
1998	371	24	147.09
1999	386	29	184.56
2000	400	31	204.60

Table 4: Number of boats (N) and mean engine horsepower (Hp) in the Barbados fishery (1963-2000).

Boat Type	Details	1963	1973	1983	1993	1994	1995	1996	1997	1998	1999	2000
Day-boat	N	484	370	356	303	327	326	316	301	301	288	290
	Hp	18	25	53	56	53	52	52	54	54	62	62
Moses	N	71	51	82	208	250	271	290	320	333	401	434
	Hp	13	15	19	20	21	21	21	23	25	26	27
Ice-boat	N	-	-	12	75	89	100	120	134	144	145	156
	Hp	-	-	174	173	159	158	161	160	167	173	192
Longliner	N	-	-	-	10	13	14	19	24	24	29	31
	Hp	-	-	-	348	262	265	302	308	314	334	325
Pirogue	N	9	15	2	-	-	-	-	-	-	-	-
	Hp	185	156	115	-	-	-	-	-	-	-	-
Total N		564	436	452	596	679	711	745	779	802	863	911

not indicate the high inter-annual variability in catches documented in the literature (Mahon *et al.*, 1982). While Mahon (1990a, b) represented inter-annual variability in the estimates of catch per trip for day-boats, he assumed a constant estimate for the ice-boats from 1979 to 1989. He also assumed no change in the number of day-boats over the time period examined, however, our reconstructed fishing effort shows otherwise.

The methodology used in this study assumed similar average annual catches per boat for all non-recorded sites within a parish as for the corresponding recorded sites, and estimated an annual total catch for each parish based on the number of registered boats. This estimate was disaggregated into species components based on the composition of catches at recorded sites within the parish. This process accounts for site-specific differences in species composition. The reconstruction over the most recent period (1994 to 2000) provides a more refined methodology, accounting for between-site differences in average annual catch rates of the respective fleets, the associated number of fishing days and number of boats. The species composition is estimated separately by parish for the moses fleet only, because of recent trends towards targeting offshore pelagics instead of the traditional inshore reef and shelf demersals and coastal pelagics.

There are however, some limitations, based on the assumptions made in the present study. For the earlier period (1940 to 1992), it was assumed that a total census of landings at recorded sites was taken, and that only boats registered at the respective sites landed there. Vidaeus (1969), however, commented on the limitations of the data collection system in the 1960s, and indicated that, at the time, early morning and late evening catches were not recorded. Double recording of landings being taken from one market to another occurred, and catches sold at beaches were also not recorded. Hence, recorded data may not represent a total census at the respective landing sites. Bair (1962) reported on the movement of fishing boats, particularly during the early months of the year, when seas on the windward coast are rough. At this time, boats from Tent Bay relocated to Bridgetown, and those from Foul Bay operated from Crane, Silver Sands or Oistins. Between December and March, boats from Crab Hill also moved to Speightstown or Half Moon Fort. These movements of boats were not considered in the reconstruction analysis, because estimations were made annually. It may be possible however, to refine the estimates of total catch accordingly, if annual changes of movements of boats throughout the entire study period are known. Another limitation is that estimates of catches were not derived for months with missing data. This is largely due to uncertainty in interpretation of statistics, i.e., whether a blank or zero entry reflects no catch taken on the fishing trip, no fishing trips made or that catches were not recorded.

The reconstructed statistics can be refined further by disaggregation of catches taken by fishing pots according to the species composition after Wilson (1983) and Selliah (2000). These documents were not available during the course of this study. Estimation of recreational catches, apart from tournament catches, may also be possible using data in Antia *et al.* (2002). Future research will focus on estimating adjustment factors for historic data which can account for the difference in methodology used, compared to the most recent period (1994 to 2000). Catches by foreign fleets may also be estimated using data by fishing area from the International Commission for the Conservation of Atlantic Tunas (ICCAT) for the relevant fleets.

A comparison of reconstructed catches and FISHSTAT statistics indicated major deviations between the two data sources in the pre-1960 and post-1990 periods. While few data points

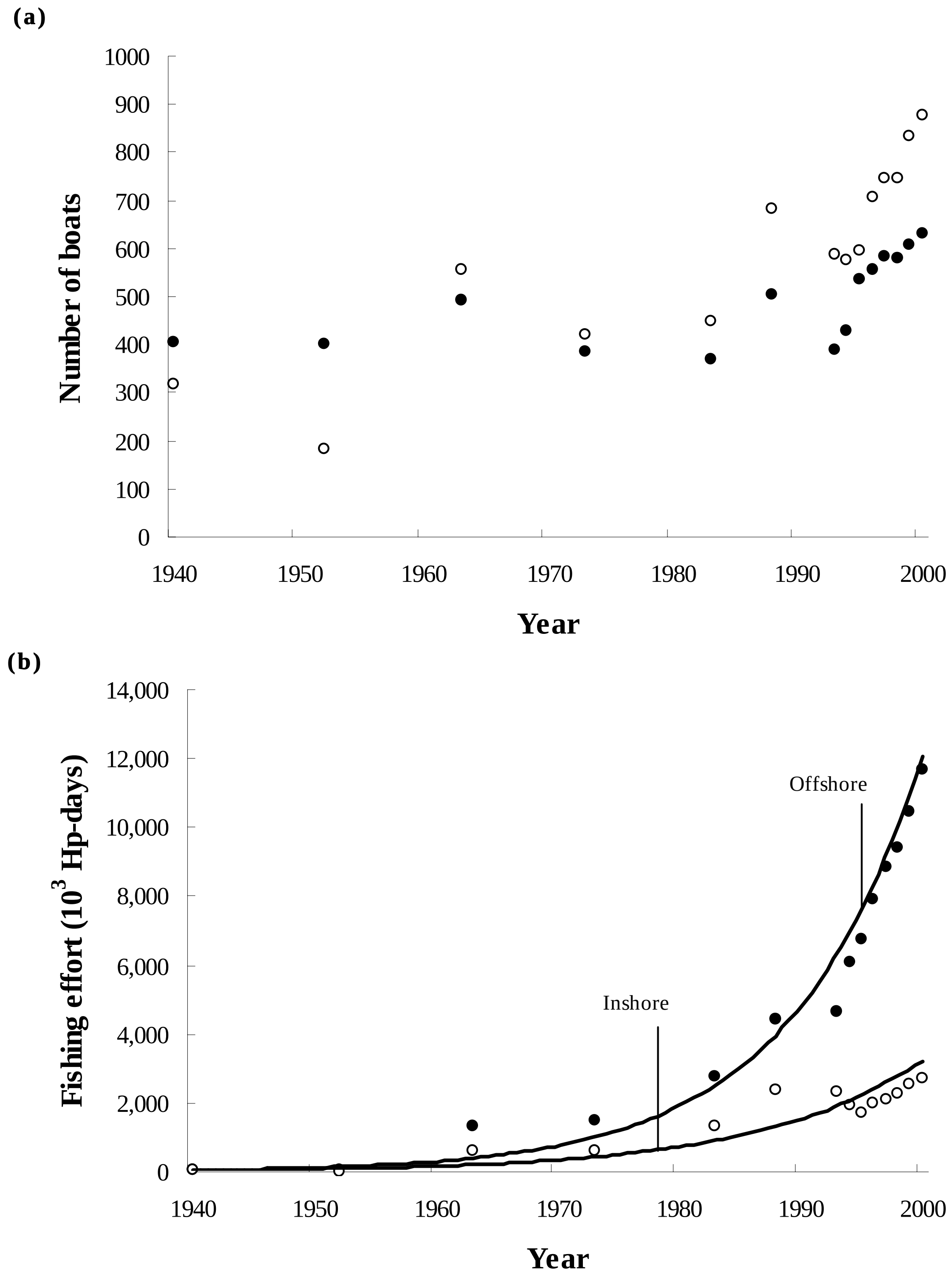

Figure 7: Reconstructed number of boats (a) and fishing effort (b) in the Barbados fisheries (1940 to 2000). Solid and open circles represent the offshore and inshore fishery, respectively.

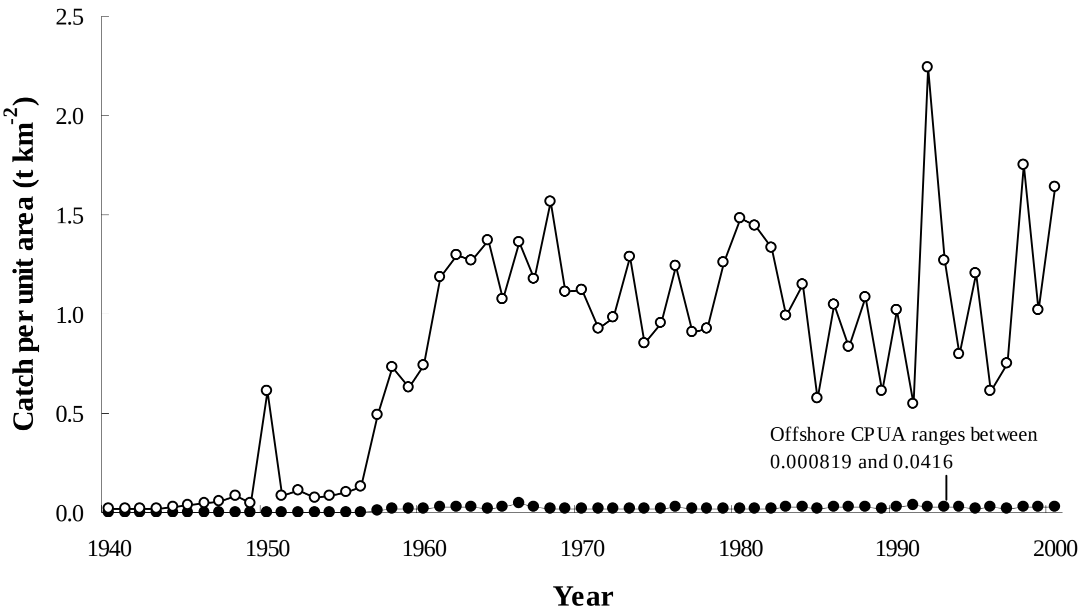

Figure 8: Annual trends in catch per unit area (t·km^{-2}) in the fisheries of Barbados (1940 – 2000). Solid and open circles represent offshore and inshore fishery, respectively.

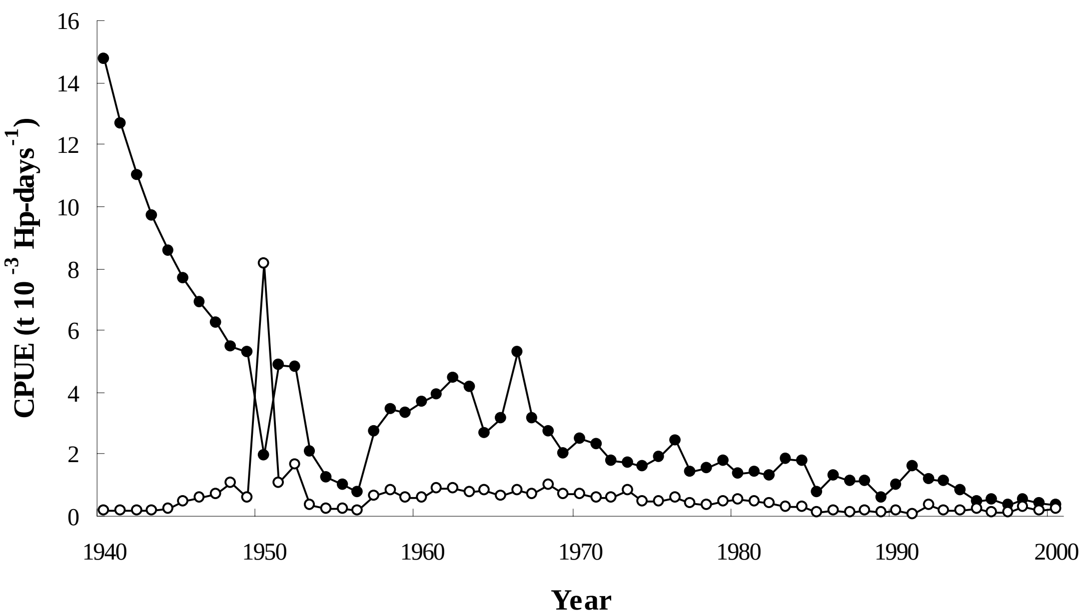

Figure 9: Annual trends in catch per unit effort (10^{-3} t·Hp-days^{-1}) in the fisheries of Barbados (1940 – 2000). Solid and open circles represent offshore and inshore fishery, respectively.

exist for the earlier period, it is evident that a combination of gillnet introduction in the flyingfish fishery, and complete mechanization of the fleet by the end of the 1960s resulted in considerable increases in catches (Hess, 1966).

Hess (1966) commented on the increased productivity per boat and per crew member since the mid-1940s. He cited Hall (1955), who estimated an increase in average daily catch per boat from 150 to 240 flyingfish, and a fivefold increase in overall catch with the introduction of gillnets. An increase in reconstructed catch is evident from the mid-1950s, however, the magnitude of this increase far exceeds the fivefold estimate. This increase is also not reflected in the trends in FISHSTAT statistics, which do not indicate any increases, outside of the normal inter-annual variation, which may be considered a result of technological development at the time. Further, the catches in FAO FISHSTAT seem high, ranging between 2,800 t and 4,500 t in the mid to late 1950s, for a fleet that was experiencing the initial transition from sail to engine power at the time. There are, however, factors which also contributed to a decline in catches, including price control on fish between 1942 and 1972 (Parker, 2000), the lack of cold storage facilities resulting in fishers limiting their catch (Parker, 2002), and increasing cost of fishing due to vessel mechanization and rising fuel prices in the 1970s. The extent to which specific factors contributed to a net increase in catches is not known.

For the post-1990 period, greater confidence is placed on estimates derived from reconstructed data, because of the considerations outlined above. Since 1997, the Fisheries Department has applied a raising factor of 1.2, instead of the traditional three, to estimate total catch from recorded data. It is interesting to note that the Planning Division of the same Ministry has applied a raising factor of 1.6 to the same data in its estimation of total catches. Further, data from tertiary sites have not yet been incorporated in the Fisheries Division's estimates of total landings. Tertiary sites are important landing sites for pot and small coastal pelagic fisheries, and the estimates of landings for these fisheries are therefore underestimated by the Fisheries Department. In contrast, landings at these sites were considered in the present study.

Bair (1962) alluded to the possible influence of environmental factors on catches. He noted the increase of 2,550 t between 1959 and 1960, which could not be attributed to technological developments alone. This increase, however, is not reflected in reconstructed data nor the FAO FISHSTAT. The introduction of cold storage facilities may explain the increase in catches to a peak in 1960. The decline that followed is consistent with the global period of rising fuel prices in the early 1970s. The introduction of ice-boats in the late 1970s and longliners in the late 1980s have contributed to an overall increase in catches over the years. However, there have been periods of tremendous fluctuation. One such period occurred 1988-1989, when the fishing community reported a tremendous decline in catch rates, prompting a detailed study to investigate the reasons for and impacts of the decline (Mahon 1990a, b). There was no unusual environmental factors or foreign fleet activity identified in the region which explained the decline. It seems that fishers responded in this manner because 1989 was a year of low abundance that immediately followed a year of unusually high abundance. The decline is reflected in FAO FISHSTAT with the 1988 catch of about 9,000 t plummeting to 2,500 t by 1989. A somewhat smaller decline is reflected in reconstructed statistics. This, however, is not unusual, compared to the normal inter-annual variability. In fact a decline of greater magnitude appears to have occurred between 1984 and 1985. R. Mahon (pers. comm.) indicated that two US longliners landed catches in Barbados during 1988, possibly accounting for the high 1988 observed catch. However, this does not entirely explain the 1988 peak. Reconstructed catches indicate higher variability in annual catches, which is consistent with observations in Hunte and Oxenford (1989).

In spite of the refinements mentioned earlier, there are still several limitations in the data presented here. These relate to incomplete records of catches in the recreational fishery, lack of data on catches by foreign fleets, quantities of bait fish and sea urchins utilized in inshore fisheries, and catches in the inshore reef, slope and shelf fishery. Juvenile large tunas and small tunas are also caught in the inshore fishery. However, the associated proportion of total catch is not known. As a result, all catches of these species were attributed solely to the offshore fishery. Although there is by-catch in several fisheries, nearly all fish are landed, so discarding is not a problem.

The recreational fishery has grown because of its association with tourism. By 2000 there were 12 charter boats (R. Mahon, pers. comm.), targeting barracudas, tunas, wahoo, dolphinfish and billfish, and with the capacity to fish 25-50 km offshore. Catches of these and smaller recreational vessels are not recorded. Catches from fishing tournaments are also incomplete, since individuals which do not meet the minimum size requirements are not recorded. Furthermore, foreign fleets from the US and Asia are reported to fish in the EEZ of Barbados (Cecil, 1999). It may be possible to estimate the magnitude of foreign fishing using catch data available, by fishing area, from ICCAT. Bait is also utilized in the fishpot fishery, but the associated species and quantities are not recorded. Traditionally, the data collection system has also not incorporated landing sites of importance to the lobster and conch fishery.

Fishing effort

The number of boats in the offshore fishery ranged between 370 (1984) and 631 (2000) over the sixty year period. No definite trend towards increased numbers of boats was observed between 1940 and 1988, however, the overall increase between 1940 and 2000 was 66%. The number of boats exploiting the inshore fishery ranged between 184 (1952) and 878 (2000), with a 176% total increase. Generally, effort in the offshore fishery far exceeded that in the inshore fishery, increasing by a factor of 384 in the offshore fishery and 65 in the inshore fishery. This increase was more pronounced in recent years (1994-2000) for both fisheries, and results from increases in number of boats (except day-boats) and engine size.

The recent decline in number of day-boats reflects their conversion to ice-boats. These boats were considered over-mechanized for their size (Parker, 2000). The main advantage of increasing horsepower was to enable boats to return from fishing prior to the closure of markets and arrival of ice-boats. Ice-boats were found to flood the markets resulting in declining prices which adversely affected the day-boat fleet (Horemans, 1988). Increasing horsepower eventually led to economic inefficiency (Oxenford and Hunte, 1998) and finally to conversion to the more efficient ice-boat fleet.

The unit of fishing effort used here allowed comparison across fishery and fleet types regardless of gear types. As a result, the increase in fishing efficiency associated with the introduction of gillnets for the capture of flyingfish in the 1950s, and the introduction of longlining gear in the late 1980s are not reflected in this analysis. Neither is the increase in effort directed at specific inshore resources, e.g., lobsters, conch and sea urchins, which may be measured by the number of fishers rather than boat or gear units. Further, boat mechanization is reported to have extended daily fishing time by about two hours. Although the increase in boat horsepower associated with introduction of the ice-boats and longliners is incorporated in the unit of effort, the increased range of fishing, including areas inaccessible by the artisanal fleet of Barbados and other islands, is not considered.

Annual trends in catch per unit area (CPUA) and catch per unit effort (CPUE)

Generally CPUA in the inshore fishery was greater, by about two orders of magnitude, then in the offshore fishery. Between 1956 and 1962, both fisheries experienced considerable increases in CPUA. Thereafter, CPUA remained stable but showed high inter-annual variability. The higher inshore CPUA is a result of concentration of the resources within a narrow shelf and reef area. Compared to the entire area considered in this study for Barbados, the inshore component accounts for only 0.15% of the total area. The increase in CPUA between 1956-1962 quite likely results from increased catches due to boat mechanization and introduction of gillnets in the flyingfish fishery. Essentially, factors accounting for the trends in catches also explain the trends in CPUA. From the late 1970s onwards, however, CPUA seems over-estimated. Introduction of the ice-boat and longline fleets have considerably increased the fishing range. Ice-boats can fish as far as 650 km offshore. They operate as far south as Trinidad and Tobago, and Grenada (Potts *et al.*, 1988; R. Mahon, pers. comm.). Longliners also operate in the EEZ of the windward islands, e.g., St Vincent and the Grenadines (Morris *et al.*, 1988), and St Lucia (Murray *et al.*, 1988), in the Atlantic waters outside the Barbados EEZ and as far south as Surinam and Guyana. Some boats are also reported to fish as far as the southern coast of the Dominican Republic. This increase in fishing range is not incorporated here.

Generally CPUE in the inshore fishery was considerably lower than in the offshore fishery. Between 1956 and 1966, CPUE increased dramatically in the offshore fishery, while the increase in CPUE was much smaller for the inshore fishery. Between 1966 and 2000, CPUE decreased exponentially, with a drastic 85% decline in the offshore fishery, and a 73% decline in inshore CPUE over the same period.

Factors contributing to the increase in CPUE between 1956 and 1966 include the introduction of the gillnet in the flyingfish fishery and loans for boat mechanization during the previous decade, along with government subsides on gear and fuel (Hess, 1966). The decline in CPUE from the late 1960s is consistent with increasing fishing effort associated with offshore and inshore fisheries. This increase in effort is not balanced by similar increases in catch. As indicated earlier, the over-mechanization day-boats was solely for the purpose of achieving greater speeds, thereby reducing return time to the markets and winning the intense competition for the sale of the catch (Parker, 2000). However, this also indirectly contributed to an increase in fishing time and overall fishing effort. Flyingfish account for the major portion of the catch (about 60%), and as such has a great influence on overall CPUE. It is also a major prey of the dolphinfish (Oxenford and Hunte, 1998) and other large pelagics. The abundance of flyingfish is also highly influenced by environmental conditions (Mahon, 1986). McConney (1996) identified several economic, social and ecological factors impacting on estimates of CPUE. However, it is difficult to identify which of these exerts the greatest influence on CPUE at any point in time.

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Grenada and the Grenadines: Reconstructed Fisheries Catches and Fishing Effort, 1942-2001

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Abstract

An annual time series of catch and effort data are reconstructed for the period from 1942 to 1002 for the fisheries of Grenada and the Grenadines, Eastern Caribbean. Information from historical documents, published and unpublished literature and the Grenada Fisheries Department's Statistical Databases was used. Offshore catches of Grenada increased by a factor of 8.6, from 256 tonnes in 1981 to 2,205 tonnes in 2001. Between 1987 and 2001 inshore catches declined from 1,062 t to 400 t, 62% of the 1987 estimate. Offshore catches in the Grenadines were small (17 t average from 1985 to 2001) compared to inshore catches (2,576 t average between 1985 and 2001). However, inshore catches declined drastically from about 700 t in 1986 to as low as 74 t in 1999, 89% the 1986 estimate. A comparison of reconstructed data with data in the FAO FISHSTAT is made and limitations in reconstructed data discussed. Generally a greater number of species are represented in reconstructed data than corresponding information in FAO FISHSTAT. Fishing effort has increased from 1942 to 1999 in both the offshore and inshore fisheries of Grenada (factors of 411 and 21 respectively) and the Grenadines (factors of three and 10 respectively). The corresponding time series of effort and catch per unit effort are presented and discussed as well.

Introduction

Study Area

Grenada lies on the Grenadines shelf and is the southernmost island of the Lesser Antillean chain (UNEP/IUCN 1988), (Figure 1). Its dependencies include some twenty low-lying islands, including Carriacou and Little Martinique. The associated Exclusive Economic Zone and territorial waters comprise an area of 24,153 km^2 (Global Maritime Boundaries Database, 2000) with a continental shelf area of 1,595 km^2 (Mahon, 1993). Total reef cover is estimated at 209 km^2 [mean of estimates in ReefBase (Oliver and Noordeloos, 2002) and Bacon *et al.* (1984)]. The insular shelf within the 100-fathom line on the west coast is extremely narrow, averaging about 926 m while off the east coast it is broader, ranging from 4,630 m in the southeast to 13,890 m in the northeast (Brown, 1945).

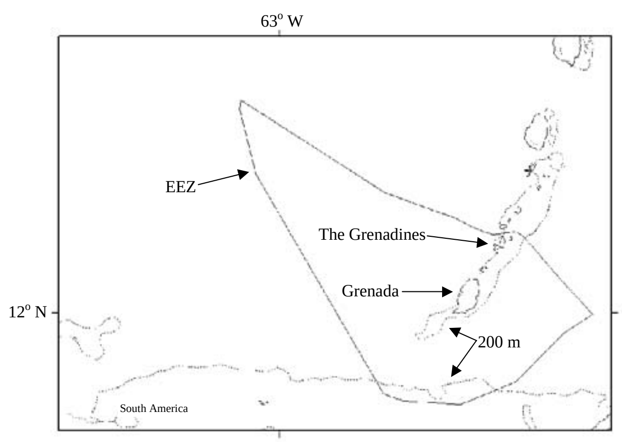


Figure 1: Map of Grenada and the Grenadines, showing the EEZ as well as the 200 depth contour.

Fisheries Development

There is little documentation on the Grenada fisheries prior to the 1980s. Up until 1974, Grenada and the associated Grenadines were British colonies and received assistance from the colonial Development and Welfare Programme. Fisheries development occurred under the administration of the Director of Fishery Investigations in the British West Indies.

Pre 1950s

Prior to the 1950s most of the fishing in Grenada and the Grenadines was of a subsistence nature and targeted mainly the inshore coastal areas (Epple, 1977). Brown (1945) gives a detailed account of fisheries in the Windward and Leeward islands. In Grenada, he noted four major fisheries in the early 1940s: the 'driving' flyingfish and associated large pelagic fishery (caught using the 'ligne dormante' or by trolling); the directed large pelagic fishery; the beach seine fishery for small coastal pelagics, and the hand-line fishery for demersal species. The hand-line fishery operated mainly off the Grenadines. Game fishing was also thought to be quite significant, especially between January and June in the Windward islands (Brown, 1945) because of its association with development of tourism. Already in the early 1940s, Brown (1945) alluded to the depletion of inshore stocks, particularly in the Leeward islands and proposed development of the pelagic offshore and deep water fisheries. All indications are that vessels at the time were all powered either by wind (sail) or oars. However, a significant change occurred after World War II when inexpensive inboard gasoline engines were imported from Europe (Epple, 1977). These were fitted on double-enders or whalers (the design being introduced with the development of whaling in the mid nineteenth century) and pirogue type boats (popular mainly in Trinidad and Grenada). At this time also the government instituted price controls on fish to ensure affordability by all sections of society, even in times of low supply.

1950s to 1980

During the decade from the late 1950s to the early 1960s the government provided loans of up to US$25,000 from the Commonwealth Welfare Program (Vidaeus, 1969) to encourage the mechanization of the fleet. In fact, Grenada was cited as the most advanced in vessel mechanization throughout the Windward islands (Hess, 1961). In 1953, fish-pots were introduced and the Fisheries Department commenced experimentation with outriggers to catch large pelagics by trolling and gillnets to catch flyingfish (Caribbean Commission Secretariat, 1955). Prior to this time, dipnets were used to catch flyingfish for human consumption and as bait for the large pelagic fishery. By the end of the 1950s, gillnets were adopted by the fleet (Hess, 1961). Vidaeus (1969) attests to the consistent popularity of the beachseine, handline and pot fisheries throughout the 1960s. He further noted that the only exports were some 2.7 - 3.6 t of crustaceans (i.e., lobsters) exported annually in the early 1960s. The Grenadines exhibited a greater dependence on demersal fisheries. Beach seining activity was concentrated on the west and north coasts of Grenada and some 15-20 landing areas were being utilized. There appeared to have been a distinct separation in the area of operation of the different fleet types existing at the time. The small row-boats exploited the handline and pot fishery close inshore at depths of 10-15 fathoms. 'Whalers' using handline and pots fished further offshore (10-15 miles) at depths of 30-40 fathoms. They also utilized 'troll' lines when journeying to and from the fishing ground. 'Sloops' utilized both handlines and troll lines. These vessels concentrated more on demersal species and fished further up the Grenadines to St. Vincent. There were also directed lobster and conch fisheries presumably off the south and north coasts of Grenada. By 1969, another government loan scheme was implemented, which provided duty free loans on engines, gear and fishing equipment.

Epple (1977), writing after independence from British rule (1974), gives a detailed account of the impacts of motorization of the fleet, with particular reference to the landing site at Grenville, on the east coast. The most obvious change was the extension of fishing grounds and the increase in fishing time, especially with the reduction in travel time to and from the fishing grounds. Vessels were better equipped to withstand unfavorable sea conditions and this resulted in an increase in the number of possible fishing days. A change in species composition of the catches was also evident, as vessels previously targeting hind, grouper and various reef fish switched, once mechanized, to large pelagics such as blackfin tuna, bonito and billfish (Epple, 1977). Other impacts are related to changes in the marketing system, pattern of vessel ownership, migration of boats, the creation of new economic roles and relationships, the entry of entrepreneurs into the fishery (as boat owners) and a distinct preference for motorized boats by younger fishers while the older ones continued to target inshore demersal and reef resources.

During the 1970s, the industry, however, was still characterized by small artisanal vessels and traditional fishing gear. The marketing structure remained simple, fish being sold at beaches, in the markets or in villages by vendors. Processing was very limited and there was little government support for further development, especially in the area of on-shore cold storage facilities. The 1970s therefore represented a period of stagnation in fisheries development. Retail price control was still in effect and fish catches declined considerably during the late 1970s early 1980s. The fish export policy allowed the granting of export licenses on an *ad-hoc* basis, for species that were abundant and/or unpopular (Peña and Wirth, 1979). Such a situation made it more difficult to acquire a license for dolphinfish, kingfish or tuna than for flyingfish or red hind (Peña and Wirth, 1979). This implies, therefore, that at this time, the landings of large pelagics was still considerably less than demersal/reef species, deep slope and shelf species.

1980s

The period from 1979 to 1984 was marked by tremendous political instability. In 1979, an attempt began to set up a socialist state in Grenada. Four years later, the United States, supported by Jamaica and the Eastern Caribbean States intervened militarily. Finally, in December of 1984, a general election established a new democratic government (Finlay, 1991). Hurricane Allen also struck in 1980 (Finlay, 1991). The extent of hurricane damage on vessels or reef fisheries is uncertain, though considerable impact of an earlier hurricane (Janet, in 1955) on the fleet in Barbados is documented (Barbados Fisheries Department Website, 2000).

Finlay (1990, 1991) also attributed the dramatic decline in landings between 1980 and 1983 to a decline in capitalization in the industry, a lack of government maintenance of on-shore refrigeration holding facilities and the age of the fleet. Another reason for the decline in catches was a reduction in skilled labour associated with the artisanal fleet as a number of the highly skilled fishers opted to work on four semi-industrial vessels donated by Cuba in 1980. These vessels, however, were not equipped for catching a wide range of species, and were fraught with maintenance problems, resulting in substantial reduction in fishing days (Finlay, 1991). The introduction of this fleet however, signaled a new era in the development of fisheries in Grenada: the introduction of longline fishing through he transfer of skill and technology to Grenadian fishers. Initially, however, fishers were very cautious at expanding such a fleet because of the initial high investment costs, the large catches that would be required to ensure profitability, the possible decrease in wholesale fish prices as a result of increased supply, the possible competition with the artisanal fleet and the absence of a proper infrastructure.

From 1982 on, the government invested heavily in the fishing industry through the Artisanal Fisheries Development Project (scheduled to be of 5-6 years duration), a US$ 2.7million project, instituted with financial assistance from the Caribbean Development Bank (Finlay 1990), the International Fund for Agricultural Development (IFAD) as well as technical assistance support from the Venezuelan investment fund (Finlay, 1991). Government’s policy focused on increasing fish catches and employment in the industry and reducing fish imports. Among the associated developments were the rehabilitation and expansion of facilities at fishing centers and markets, provision of gear and equipment at duty-free prices and institution of a marketing infrastructure to guarantee the sale of fish (even in times of excessive supply). Price control was, however, still in effect for fish sold on the retail market. Loans were also provided for fleet expansion and development or motorization. The use of outboard engines gained popularity among the artisanal vessels because of the speed this allowed and smaller investment costs compared to inboard engines. Further, by the mid-late 1980s, vessels involved in longlining set to sea with two instead of one outboard engine (Samlalsingh *et al.*, 1995). However, Finlay and Rennie (1989) identified a considerable number of unutilized fishing days despite motorization of the fleet. They attributed this to the high operating costs associated with the outboard engine (used on boats involved in trolling) and indicated the reluctance of fishers to go to sea unless there was a high likelihood that the catches would be high. Nevertheless, fishing with longlines became popular with the artisanal fleet on the west coast.

In 1984, the FAO provided technical assistance to Grenada through its Regional Seas Law Advisory Programme in drafting harmonized Fisheries Laws and regulations tailored to the management needs of the OECS states (Finlay, 1990). Fisheries management in Grenada was thereafter guided by the Grenada Fisheries Act #15 of 1986, and the Grenada Fisheries regulations SRO #9 of 1987.

Apart from the increases in local effort, the Grenada government (unlike that of other

OECS countries) promoted the legalization of foreign fishing and granted licenses to seven US longliners to fish for large pelagics (swordfish, *Xiphias gladius*; yellowfin tuna, *Thunnus albacares*; bigeye tuna, *Thunnus obesus*; and others) within Grenada's EEZ in 1988 and 1989 (Samlalsingh *et al.*, 1995). Also, an unspecified number of locally-based vessels (14-17 m) were licensed to fish for large pelagics; five of these operated out of Grenada (Finlay, 1991). Between 1986 and 1989, a major decrease in landings of large pelagic species was observed (Finlay, 1990). This prompted an investigation of the likely causes under the CARICOM Fisheries Resources Assessment Program. However, the results were inconclusive (Mahon *et al.*, 1990).

By the end of the decade, semi-industrial longliners specifically targeting tuna and swordfish were introduced; there was also a clear preference for inboard diesel engines because of the lower fuel costs compared to outboard engines (Finlay, 1990, 1991). These longliners, capable of ice storage, made fishing trips of several days duration. Very little is documented on fishing in the Grenadines except a decrease in exports to Martinique in late 1980s (Finlay, 1991).

Fisheries development in the 1980s was a result of tremendous government investment and subsidisation of the industry, which contributed to the 'dependency syndrome' of the industry (Finlay, 1990).

1990s

Finlay and Rennie (1998) give a detailed account of fisheries development in the 1990s. The highlight of this period was the tremendous investment in expansion and development of the longline fleet (commencing in the late 1980s) and deregulation of retail fish prices. In 1991 the Japan International Cooperation Agency (JICA) donated eight longliners (10.9 m long and cold storage of 2.4 cubic meters with inboard diesel engine of 70Hp) to the Grenada government. Fishing by seven of these started in 1992 (Samlalsingh *et al.*, 1995). By the mid-1990s, almost the entire west coast pirogue trolling fleet, without any modifications to the vessel design, size (mainly 8 m) or outboard engines, converted to longlining (Samlalsingh *et al.*, 1995). The use of outboard engines, however, continued to result in high operating costs. This prompted the government's formulation of a 'Fishing Vessel Modernization Plan' in 1994, aimed at encouraging fishers to convert from the outboard to more economical inboard engines (Senga, 1995). However, the high initial investment required for inboard engines had been a major deterrent in the conversion of the fleet. With the fleet modernization plan little emphasis was placed on increasing vessel sizes beyond the size of the existing semi-industrial fleet (10-11 m), since this would result in trips longer than the current 3-4 days duration, thereby compromising the quality of the fish brought back for export (Senga, 1995). This has been the reason for the higher prices obtained for tuna caught by the Grenadian fleet compared to the US fleet, which is comprised of larger vessels which stay out at sea for longer time periods. Also, an increase in vessel size will further increase capital and operational costs and would be unattractive to fishers.

Pirogues targeting large pelagics have traditionally restricted fishing activity to the months between November and July (coinciding with the flyingfish fishing season), fishers believing that large pelagics were no longer abundant on the fishing grounds after July. However, the semi-industrial longline fleet fished year-round and demonstrated the occurrence of tuna in what had been called 'off-season' months. The tunas (mainly yellowfin tuna) could be located further offshore (60-80 km) in deeper waters during this period. It should be noted, though, that sea conditions during the hurricane season (July to September) are not conducive to fishing by the smaller (8 m) boats at these distances (Senga, 1995). Fishing trips by the pirogues using longlines now extended to 12 instead of 8 hours and between two and four trips were made per week while the semi-industrial longliners made trips of between 1-4 days duration. Semi-industrial vessels fished in the same areas as pirogues (at least during November to June), and therefore the catches of the two fleets were of similar species composition (yellowfin tuna and Atlantic sailfish, *Istiophorus albicans*). However, less swordfish were caught by the semi-industrial vessels, and less blue marlin, *Makaira nigricans* by the pirogues (Samlalsingh *et al.*, 1995). The year round and increased landings of yellowfin tuna, swordfish and sailfish also prompted increased investment in fish processing and exporting. The latter was also facilitated by improved air transportation to the US, the main export market for yellowfin tuna and swordfish. By 1998, in addition to the ten small processing plants for smaller migratory pelagic species and for lobsters, sea eggs and sea moss, there were four main export packagers for tunas and swordfish. It is not surprising also that given the decline in demersal fisheries in the Grenadines, fishers began switching to longline fishing. This represents an historic move away from the traditional demersal fisheries of these islands.

A less obvious impact of the development of the longline fishery is the change in importance of flyingfish, a traditional food fish, to one of bait in the longline fishery. In fact, the decreased abundance of flyingfish during the months July to September has been known to severely affect longline fishing (Samlalsingh *et al.*, 1995). In an attempt to assist development of the longline fleet, the Japanese provided bait in the form of 700 kg of frozen squid and sea robin to the Government of Grenada, for sale to fishers during the summer months of 1992. There was also a change in fisheries from a subsistence activity to an export oriented one. By the 1990s much of the local consumption consisted of imported processed fish (canned sardines, mackerel, dry/salted cod, smoked herring) which appeared to satisfy the traditional taste and preferences of the Grenada population, while local catches were mainly exported (Finlay and Rennie, 1998).

Fishery developments were matched by significant strides towards fisheries management and compliance with international law. Through the CARICOM Fisheries Resource Assessment and Management Program catch data are submitted to the International Commission for Conservation of Atlantic Tunas (ICCAT) for assessment of billfishes and tuna. The general policy is for expansion of the offshore pelagic fishery, which is perceived as having the greatest potential for expansion in the Caribbean (Mahon, 1990; Chakallal, 1986; Mahon and Singh-Renton, 1992; Finlay, 1991; Finlay and Rennie, 1998).

Fisheries Statistical Data Collection

Grenada was reported to be one of the better equipped countries for fisheries landings data collection in the Caribbean region during the 1960s (Vidaeus, 1969). At the time there were six data collectors who recorded information at five of the six parishes in Grenada: St Georges (fish market), St John (all bays from Halifax to Dothan); St Marks (Victoria fish market and neighboring bays, Duquesne and David Bays); St Patricks (Sauteurs fish market) and St Andrews (Grenville fish market). Landings in the parish of St Davids, and landings of lobsters and turtles were estimated by the Fisheries Officer. The system however, did not incorporate landings in the associated Grenadines, except for that portion landed at the Grenville fish markets. This system of data collection continued into the 1980s.

By 1988 there were improved or new government fish markets at Victoria, Gouyave, St Georges (Melville Street and the Carenage), Grenville and Sauteurs (Finlay *et al.*, 1988). At these sites, the throughput of fish was recorded along with catches for each fishing trip. There existed, however, several sites without markets where data were not collected. These ranged from small landing beaches with only a few boats, through areas where substantial catches of conch and lobster were landed, to points in the Grenadines where substantial amounts of fish were transshipped from fishing boats to trading boats for export to Martinique. Thirteen trading boats operated at the time. The reliability of information obtained from this source was compromised by considerable under-reporting in applications for export permits to avoid high duty fees on landings in Martinique. At this time, the Organization of Eastern Caribbean States hosted a workshop aimed at improving data collection systems in the respective islands (Mahon and Rosenberg, 1988). The plan for Grenada (Finlay *et al.*, 1988) included a total census at major markets, a sampling program for other sites, collection of purchase slips from hotels and restaurants (for lobster, conch and choice fish), review of export licenses, implementation of a logbook system for launches, recreational and charter boats and procedures for estimating foreign catches. Limitations in financial and human resources have, to date, hindered the implementation of this plan.

In the late 1980s, a data collection system was implemented under the Enhanced Research Program for Billfish, initiated under the ICCAT (Andrews, 1990). In addition to data collection at fish landing centers (Gouyave, St John's, Melville Street Market, St George's), the Ministry of Industrial Development and Fisheries was responsible for collecting data from foreign fishing vessels under joint venture arrangements with local investors.

Although there were plans to implement an Observer Program on board these vessels (Andrews, 1990; Samlalsingh *et al.*, 1995), these were not implemented, again due to lack of finances and human resources.

In the early 1990s, under the CARICOM Fisheries Resource Assessment and Management Program, the data collection system was expanded to include landings at Hillsborough in Carriacou, one of the Grenadine islands. More intense efforts were placed on recording catches at the markets. A review of detailed catch statistics provided for 1997 indicate data collection at Grenville market, Melville Street market, Gouyave, Sauteurs, Du Quesne, the artisanal fisheries project, Carriacou and Petit Martinique and eight processors.

It is difficult to pinpoint the gaps in the catch data because of the inconsistency in coverage of the landing sites from year to year. However, it is possible to highlight some of these from discussions with Fisheries Department personnel. Firstly, all fish landed at the markets is recorded. Large pelagics attain the highest prices and are always sold to vendors at markets. After 1995, large pelagics (mainly yellowfin tuna, swordfish and sailfish) have been sold to processing plants and this information is captured in the data collection. By-catch, consisting of billfish, dolphinfish, kingfish and wahoo, are sold to vendors at the markets and these quantities are therefore recorded. Some of the demersal catches are transported to the markets (e.g., Grenville) and are recorded. However a small but unknown proportion is also sold, without records, to the public on the landing beach or to hotels. A major gap exists for landings of the dive fishery which target lobster and conch (mainly the south coast) as these catches are either sold directly to hotels or restaurants, or exported. In these cases data are not recorded though information on the latter may be derived from export statistics. An unknown proportion may also be sold to vendors who may in turn sell at the markets (therefore recorded) or in villages (not recorded). Despite minimum size regulations for the species, there exists a market for undersized lobsters.

Fisheries Policy

A shift in the approach of government to fisheries management was also evident, as Grenada, along with other countries of the Organisation of Eastern Caribbean States, embarked on a program in 1986, with legal assistance from the FAO, to enact a program of harmonized fisheries management legislation. The general fisheries policy focuses on development of the offshore fleet (Finlay and Rennie, 1998).

Objective

The main objective of the present study was to assemble a time series of catch and effort data for Grenada and the Grenadines from 1942 to 2001.

METHODOLOGY

General aspects of the methodology for reconstruction of fisheries catches and fishing effort are discussed in Mohammed (2003).

Fisheries Catches

Catches are reconstructed separately for Grenada and the Grenadine islands north of Grenada for two reasons:
Firstly, the difference in species caught - Traditionally fishers from Grenada target medium sized regional pelagics (small tunas and mackerels) and small coastal pelagics such as scads and jacks, with demersal and reef fisheries being of lesser importance (with the exception of lobster and conch fishing off the south coast). Fishers in the Grenadines have targeted mainly demersal and reef species because of the greater expanse of shallow shelf surrounding these islands. Further, most of the catches do not enter the local market systems but rather are traded with the French Overseas Department of Martinique. This traditional market exerts a tremendous influence on the relative quantities of the various species caught.

Secondly, the quality of the available data – A time series of catch statistics is available from the Fisheries Department since 1978. These statistics are however, confined to Grenada. Up until the mid-1990s, the only available information for the Grenadines was derived from Grenada export and Martinique import statistics. As a result the catch and effort reconstruction is severely limited by unavailability of data for the Grenadines.

Grenada

The essential data sources, for the pre-1980 period, are Brown (1945); Smyth (1957); Vidaeus (1969) and Giudicelli (1978). These data are used as anchor points to define the limits of total annual catches. The Fisheries

Department provided detailed information on annual fish catches by species for the period 1978 to 1999. While this information is collected in sufficient detail to facilitate a more informed estimation of catches by fishery and vessel type, limitations in human resources for data computerization have resulted in the use of data summarized on a weekly basis by market/landing site and species. These data are computerized and annual summaries produced by site and species. Many authors have commented on the limitations of the data collection program which focuses on quantities of fish at the main markets only (Vidaeus, 1969; Chakallal, 1997). Kawaguchi (1985) indicated that apart from the six main markets, where data are collected, there are approximately 25 smaller fish landing areas scattered across Grenada (and 6 across Carriacou), where data are not collected. However, based on observed developments in the fishery, the Fisheries Department has applied adjustment factors to recorded data at markets in Grenville, Melville Street, Gouyave, Victoria, Sauteurs as well as 12 processing/exporting plants (in operation in the 1990s) to estimate total landings. From 1978 to 1998 an adjustment factor of 1.75 was used for all species caught in Grenada. However, from 1998 a smaller adjustment factor (1.4) was utilized for tunas, dolphinfish and billfishes while the 1.75 was applied to records of other species.

Since the Grenada Fisheries Department provided data on combined catches for Grenada and the Grenadines, it was necessary to separate these accordingly. This process was simple since most of the catches reported in the aggregate categories ‘other fish’ or ‘marine fish not elsewhere identified (nei)’, are from the Grenadines. However when these statistics were compared with Martinique import statistics from the Grenadines, there were considerable differences.

Anchor points:
Total catches for the respective years were taken from the following documents: 1942 (Smyth, 1957); 1956 (Salmon, 1958); 1959 to 1968 (Vidaeus, 1969); 1974 to 1975 (Giudicelli, 1978); 1977 (Villegas, 1978); 1978-2001 (unpublished statistics of the Fisheries Department). Estimates provided by the Fisheries Department for 1978 to 2001 included catches in Grenada and exports from the Grenadines to Martinique combined. The difference between total catches and Grenadine exports provided an estimate of catches from Grenada only. Brown (1945) presented a crude estimate of total catches (947 t) for 1942. This figure was much greater that the estimate of 182 t provided by Smyth (1957). Since the latter estimate more closely matched the statistics provided to the FAO it was the preferred anchor point.

First Interpolation: Total catches
Total catches from 1943 to 1955 were estimated by interpolation between the estimates for 1942 and 1956, obtained from the literature. This procedure was also used for estimating total catch for the period 1957 to 1958 and 1969 to 1973 using the anchor points for 1956 (Salmon, 1958) and 1959 (Vidaeus, 1969) and 1968 (Vidaeus, 1969) and 1974 (Giudicelli, 1978) respectively; and for 1976 using the anchor points for 1975 (Giudicelli, 1978) and 1977 (Villegas, 1978).

Some adjustments were made to the anchor points from Giudicelli (1978) since these were quoted as “estimated” figures. This followed, after examination of statistics in Peña and Wirth (1979) who presented both recorded (1,043 t) and raised estimates (3,189 t) for 1978. These statistics were compared to data provided by the Fisheries Department for the same year (1,962 t). The gross discrepancy between the two estimates is attributed to the raising factor used. The Fisheries Department utilizes a raising factor of 1.75. The recorded catch for 1978 according to the Fisheries Department statistics is 1,072 t, quite close to the 1,043 t reported by Peña and Wirth (1979). The raising factor used by these authors (3.0) appears excessive at a time when there is reported to be tremendous lack of investment in fisheries (Finlay, 1991). A review of the literature gives no indication of any factors which would affect the manner in which data were previously collected, and therefore there is no basis for a change in raising factor in computation of total catches. Since the figures presented by Giudicelli (1978) are estimates, it is believed that the same raising factor (3.0) utilized by Peña and Wirth (1979) was used. The data in Giudicelli was therefore adjusted accordingly (applying a raising factor of 1.75 instead), to derive catch estimates of 1,341 t and 1,458 t for 1974 and 1975 respectively.

Second Interpolation: Species Composition
The issue of uncertainty in species identification particularly in earlier years

(Vidaeus, 1969) arises because it is common in data collection either to refer to certain species by local names or to misidentify species (especially the tunas). Vidaeus (1969) listed the following species/groups: jacks, bonito, grouper, ballahoo, cavalli, sprats, albacore, long gar, tuna, flyingfish, herring, red fish, hind shark, shark, dolphin, kingfish, round robin and other fish. The bigeye scad, *Selar crumenophthalmus*, has historically, and continues to be referred to as 'jacks'. Further, since there was a distinct category for sharks, and since there is no known species of shark called 'hind shark' (see www.fishbase.org), it was assumed that 'hind shark' refers to the red hind (*Epinephelus guttatus*, Serranidae). Also, blackfin tuna have historically been mis-identified as albacore, *Thunnus alalunga*, or bonito, *Sarda sarda*, and as such landings of these species were grouped into one category 'blackfin tuna' (*Thunnus atlanticus*). 'Long gar' is the local name for flat needlefish (*Ablennes hians*). For earlier years, the 'herring' category was assumed to represent all other herring species except *Harengula clupeola* and *Opisthonema oglinum*, both of which are reported as separate categories. Both 'red fish' and 'other fish', (Vidaeus, 1969), represent a mixture of perch-like fishes, most often a combination of snapper (Lutjanidae), coney (*Cephalopholis fulva*, Serranidae) and redhind (*Epinephelus guttatus*, Serranidae). For the pre-1978 period, this aggregate category was divided among the three species/groups based on the proportion in the recorded catches of 1978. Hence snapper was comprised of 85% 'redfish' and 37% 'other fish'; redhind was comprised of the category 'hind shark' and 56% 'other fish' and coney was comprised of 15% 'red fish' and 75% 'other fish'. In the post 1978 period the catches of 'marine fish nei' was divided among the three species/groups based on their relative proportions in the recorded catches for the respective years.

Using information on species catches for 1964, 1965 and 1967 (Vidaeus, 1969) and the corresponding annual total catches recorded, an estimate of species composition was derived for each year. In the absence of additional information, the species composition for 1964 was assumed to apply throughout the period 1942 to 1964. For the same reason the species composition of 1967 was assumed to be the same for 1966 and 1968. The species composition between 1968 (Vidaeus, 1969) and 1978 (AFP) was interpolated and used to estimate individual species catches (product of species composition and total catch) using the interpolated estimates of total catch for the respective years.

Adjustment for at-sea processing

Catches of yellowfin tuna, swordfish, sailfish, white marlin and blue marlin from 1992 onwards were adjusted to account for at-sea processing using conversion factors for estimating whole wet weight based on different degrees of processing as indicated in Mohammed (2003) of this report. Yellowfin tuna are gutted at sea and the head, caudal and dorsal fins of sailfish and swordfish are also removed (Samlalsingh *et al.*, 1995). A small proportion of the catch may be attributable to the trolling fleet (and therefore may not be subjected to the strict quality control of longliners supplying foreign markets). As a result the degree of processing may be different for the two fleets. However, since this is a minute quantity of the overall catch (the trolling fleet targeting mainly dolphinfish, mackerels and smaller tunas), it is assumed that all catches of the respective species are attributable to longliners and are processed in the manner described above.

Catches from sport fishing tournaments

Catch data from the annual Spice Island Billfish Tournament (Grenada Fisheries Department, unpublished data) were available for 1992, 1994, 1996 and 1998. Blue marlin, white marlin, sailfish and yellowfin tuna are the main species captured. Estimates for 1993, 1995, 1997 were derived by interpolation between the previous and following years for which data were available.

Estimation of quantities of flyingfish and round robin used as bait

With the development of the longline fleet, commencing in the early 1980s, flyingfish became a popular bait fish for this fishery targeting large pelagics. However, since the flyingfish caught as bait are utilized at sea there are no records of the associated quantities, neither are there records of the quantity of round robin utilized as bait during the flyingfish offseason. Hence a crude estimate is derived for pirogue and semi-industrial longliners as follows:

$$Q = B \times H \times W \times D \qquad ...1)$$

where *Q* is the total weight of flyingfish or round robins utilized as bait each year; *B* is the number of longliners fishing; *H* is the mean number of hooks per vessel; *W* is the mean individual weight of the fish; and *D* is the number of days fishing. The number of longliners (pirogue and semi-industrial) and associated number of fishing days per year are taken from the effort reconstruction component of the present study. Since point estimates for these parameters are available for the years 1982, 1988, 1993, 1995, 1997 and 1999, data for the missing years were estimated by interpolation. No data were available for 2000 and 2001. Hence the same number of boats as that operating in 1999 was assumed for these years. The mean number of hooks is taken from Samlalsingh *et al.* (1995) and the mean individual weight of flyingfish was based on field observations of the author.

The main assumptions in arriving at this estimate are:

1. That mean individual flyingfish weight is 0.15 kg and that each hook is baited with one flyingfish only;
2. That mean individual weight of round robin (utilized as bait from July to October) is the same as for flyingfish;
3. That all hooks are baited once per fishing day regardless of the vessel type;
4. That the number of vessels and fishing days per year are equivalent to that in the effort reconstruction component of this analysis; and
5. That flyingfish is the only species used as bait during the months of November to June. Semi-industrial longliners which fish year round, use other species (e.g., round robin) during the flyingfish 'off-season', July to October, for a total of 30 fishing days.

The quantities of flyingfish utilized as bait is computed separately for pirogues and semi-industrial longliners because of differences in the nature of fishing operations. During the early to mid-1980s, pirogue longliners carried a mainline of 2.5 km and approximately 45 hooks baited with flyingfish (Samlalsingh *et al.*, 1995). Lines were set at depths of 27-54 m and one gear set was made per trip, the vessel staying with the set longline until retrieval. Fishing occurred during the traditional surface pelagic fishing year (November to June) and was constrained by the lack of flyingfish bait from July to October. Modifications by the late 1980s resulted in fishing at greater depth (45-54 m) but the mainline remained at 2.5 km. Hence it is assumed that the same number of hooks (45) is utilized on a trip. Semi-industrial longliners (also referred to as short-stay longliners in Samlalsingh *et al.*, 1995) utilize a hand operated reel for retrieving the line. The mainline is 6 km and the number of hooks about 110-150 (Samlalsingh *et al.*, 1995), the upper limit is used in the analysis. Hooks are set at depths of 45-90 m. Trip length has increased in terms of hours per day for these vessels but this is not reflected in the effort reconstruction. Further, since this fleet targets large pelagics year-round, flyingfish is utilized as bait from November to June while round robins are used from July to October.

Estimation of marine turtle catches

A traditional fishery for turtle exists for local consumption. There was also an export trade in the early 1900s to the value of UK£ 400 per year (Duerden, 1901). Prior to World War II, a trade in live turtles to the United Kingdom existed, and some 180 turtles (each over 82 kg) were shipped annually (Rebel, 1974). A trade with Barbados and Trinidad also existed with some 694 green turtles (*Chelonia mydas*), 279 hawksbill turtles (*Eretmochelys imbricata*) and 2 loggerhead turtles (*Caretta caretta*) being shipped to these two countries in 1948 (Rebel, 1974). Data from Witzell (1984) was used to convert numbers of animals to the equivalent weight as described in Mohammed (this volume). Thus, an estimated 92.9 t was landed in 1948. Rebel (1974) also provides landing estimates of 11.4, 12.5, 13.6 and 32.3 t in 1964, 1965, 1967 and 1969 respectively (the former three estimates were taken from Rebel, 1974 who cited a personal communication from J.L. Dibbs; these also corresponded with data in Vidaeus, 1969). There was however, a discrepancy in the 1969 estimate with Vidaeus (1969) who quoted 13 t. Grenada also exported hawksbill shells, 'bekko', to Japan (Meylan, 1984; Milliken and Tokunaga, 1987). Approximately 499, 132, 59, 9, and 7 kgs of shell were exported in 1973, 1975, 1977, 1980 and 1981 respectively (Milliken and Tokunaga, 1987). Data from Milliken and Tokunaga (1987), Witzell (1984) and the website www.tortoise.org.news/1998s28.html were used to convert hawksbill shell weight to the equivalent animal weight as described in Mohammed (1993). Minimum estimates (since only one species of turtle considered here) of 10.18, 2.69, 7.50, 1.20 and 0.9 t for 1973, 1975, 1977, 1980 and 1981 respectively were derived. The only discrepancy with Fisheries Department data is for 1981 with an estimated 3 t landed, this higher estimate was used in the analysis. Data for missing years were estimated by interpolation. In 1993, an international ban under the Convention for International Trade in Endangered Species (CITES) was imposed on the bekko export trade.

The Grenadines

Anchor points:
Fewer anchor points were derived from the literature for the Grenadines compared to Grenada. These are for 1942 (Brown, 1945), 1980 to 1994 (Chakallal *et al.*, 1997), 1984-2001 (Unpublished fish export statistics for the Grenadines) and 1999-2001 (Fisheries Department unpublished estimates of fish catches).

First interpolation: Total catches
1942: Some adjustment to the estimate provided in Brown (1945) was necessary after the discrepancy with data provided by Smyth (1957) was observed for Grenada. Based on the proportional difference in statistics provided by the two authors for Grenada, the estimate provided by Brown (1945) for the Grenadines was scaled down to 48 t for 1942.

1984 – 1999: There was an overlap in time coverage (1984-1994) of data on Martinique imports from the Grenadines (Chakallal *et al.*, 1997) and Grenadine export data from the Grenada Fisheries Department (unpublished statistics). The data from the two sources were inconsistent. Given a general tendency to underreport, and the need for a precautionary approach, the higher of the two estimates in any given year was used in calculations to arrive at estimated total catch for the Grenadines. In the absence of species composition data, it was assumed that it was from 1985 to 1999 the same as that for Martinique imports from the St Vincent Grenadines (SVG) report (Chakallal *et al.*, 1997, Table 40, p. 55). This was used to disaggregate the Martinique import or Grenadine export statistics into the following broad species categories: reef/demersal fish; large pelagics; seine fish; mixed fish; lobster; conch and other fish. The estimated quantities in the various broad species categories exported to Martinique can also be represented as a proportion of total catches: 85% of the finfish catch; 60% of catches from the dive/shell fishery and 10% of catches from the subsistence fishery (Finlay, 1990). It was assumed that the categories reef/demersal fish, large pelagics, seine fish and mixed fish (from SVG export) combined were analogous to the “finfish” category in Finlay (1990), the lobster and conch categories in the SVG export were assumed analogous to the “dive/shell fishery” (in Finaly, 1990) and the other fish category in the SVG export analogous to the “subsistence” fishery in Finlay (1990). The disaggregated catches from the Grenadine export/Martinique import statistics was raised accordingly to 100% for the respective species groups (in Finlay, 1990) and these were summed across groups each year to provide estimates of total annual catches for the Grenada Grenadines from 1980 to 1999.

Subsequent data provided by the Fisheries Department on estimated catches from 1989 to 1999 were inconsistent with the estimates derived above. Again, the higher of the two estimates was used as representative of total catch.

1943-1979: Annual total catches for the period 1943 to 1979 were estimated by interpolation between the estimate for 1942 (modified after Brown, 1945 and Smyth, 1957) and the estimate for 1980 (derived as described above).

Second interpolation: Species composition
Dis-aggregation of estimated annual total catches involved a two step process. The first involved dis-aggregation of estimated total catches into the broad groupings defined for the Martinique import statistics (Chakallal *et al.*, 1997) from the St Vincent Grenadines (reef/demersal fish; large pelagics; seine fish; mixed fish; lobster; conch and other fish). It was assumed that the relative contribution of each group to the total imports was the same as the relative contribution to estimated total landings each year. The categories which correspond with the fisheries in this study, are the reef/demersal, large pelagic, lobster and conch fisheries. It was assumed that the seine fish category was analogous to the small coastal pelagic fishery (of this study) and that the ‘mixed fish’ and ‘other fish’ could be grouped into a general ‘other fish’ category for this study.

The second step involved further dis-aggregation of the respective fishery catches into the individual species within each fishery. Information on the species composition of the Grenadines fishery was sparse. Details were available for 1999, from the Fisheries Departments first estimation procedure of total landings. From this the species composition was computed separately for each fishery. Using this species composition, the estimated fishery catches were dis-aggregated into the respective species catches. There was some overlap between the reef/demersal fishery and 'other fish' category. It was assumed, based on a list of preferred species for Martinique trading vessels (Chakallal *et al.*, 1997, Table 35 p. 48), that the reef/demersal fishery comprised parrotfish (Scaridae), red hind (*Epinephelus guttatus*, Serranidae), coney (*Cephalopholis fulva*, Serranidae), snappers (Lutjanidae) and groupers (Serranidae) while the 'other fish' category (Finlay, 1990) comprised smaller, lesser important reef species such as grunts (Haemulidae), triggerfish (Balistidae), squirrelfish (Holocentridae), goatfish (Mugilidae), sand tilefish (*Malacanthus plumieri*, Malacanthidae), horse-eye jack (*Caranx latus*, Carangidae) and doctorfish (Acanthuridae). Without a basis for identifying changes in species composition over the period, it was assumed that the composition remained the same for the respective fishery types from 1980 to 1999.

A crude estimate of the relative contribution of each fishery type to total catches was available in Brown (1945). At that time there was no fishery for large pelagics. Catches from beach haul seines were taken to represent the small coastal pelagic fishery and catches from decked sloops, whaleboats and other boats to represent the reef, shelf and slope fishery in the present study. These catches were scaled down according to the procedure described above for the 1942 total catch anchor point. The species composition and individual species catches over the period 1943 to 1979 were estimated by interpolation between the estimated values for 1942 and 1980.

Fishing Effort

The Unit of Fishing Effort

The unit of fishing effort used in the analysis was horsepower-days. The rationale for its selection is discussed in Mohammed (this volume).

Data Sources

Data limitations restricted the estimation of fishing effort to key years for which the required data were available. From these, estimates for missing years were interpolated. Several assumptions had to be made when data was missing, and details are given for the respective years. These assumptions were based on information in the literature and discussions with staff of the Fisheries Department. The key years selected and associated information sources were as follows:

1942: Data were presented by Brown (1945) on the number of boats by design (decked sloop, whaler, sail/row boat), and number of gear units for beach seine and gillnets at landing sites on the leeward (15 sites) and windward (7 sites) coasts as well as for three Grenadine islands (Carriacou, Petit Martinique, Isle Ronde). At the time, all boats except for the decked sloops were un-mechanized. It was assumed that these vessels were fitted with inboard engines of the lowest horsepower (10 Hp) mentioned in the literature for that time. Brown (1945) also gives details from which the number of days fishing could be inferred.

1969: Information on the number of boats by design (sloops, mechanized; whalers, mechanized; whalers, unmechanized; canoes/pirogues, mechanized; canoes/pirogues, unmechanized; transumes; seine boats; balahoo seine boats) for Grenada and the Grenadines were taken from Table 21 in Videaus (1969). Assignment of vessels to fishery types and estimation of likely number of fishing days was derived using information on the description of the fisheries given in Vidaeus (1969). Mechanized vessels at the time carried engines of 5-10 Hp. It was assumed that the smaller canoes carried engines of 5 Hp, while the larger whalers carried engines of 10 Hp.

1982: Information was provided in hard copy by the Fisheries department through their unpublished vessel census of engine type (inboard or outboard), brand and horsepower for each vessel in the fleet. The associated parishes (St Andrews and St David; St Georges; St Johns; St Marys and St Patrick) at which the individual vessels landed, and their catch, was also given. For the Grenadines, information was provided for Carriacou only. As a result the reconstructed fishing effort for the Grenadines is likely an under-estimate. Further, it was possible to ascertain the vessel type based on information about the engine. Hence all sail powered vessels were categorized as sloops, those fitted with outboard engines as pirogues, those with inboard engines of the Seagull brand as dories/open boats and those fitted with inboard diesel and gas engines of the non-Seagull brand as double-enders. Data were computerised and missing values for vessel horsepower were derived by comparison of data for other vessels of similar design and engine type and brand, within the same parish or the entire island. Additional information on the longline fishery (number of pirogues and semi-industrial vessels and associated engine horsepower) was taken from Samlalsingh *et al.* (1995). For other vessels, average engine horsepower was computed directly from census data.

1988: Data on the number of vessels by design (double-ender, launch, pirogue, sloop, whaler) was provided by landing site for Grenada (29 sites) and the Grenadine islands of Carriacou, Petit Martinique and Isla Ronde (total of 10 sites) (Finlay *et al.*, 1988). A qualitative description of the importance of each fishery type to the respective vessel designs was given in Table 1 of the same reference. This was useful in assigning vessels to fishery type, and in estimating the number of fishing days for vessels targeting different fisheries at different times of the year. Information on vessel horsepower was taken from Mahon (1988).

1993: Information was provided on the number of vessels at selected landing sites, the total number of vessels at the respective parishes and the associated engine type (inboard or outboard) by Senga (1993). The associated horsepower for different vessel types was taken from OECS (1995).

1997: Computerized information on a fishery survey conducted in 1997 was available from the Fisheries Department as was the associated report summary (Straker and Jardine, 1998). The details given for each vessel included information on the associated parish, vessel design, engine brand and associated horsepower and number of fishing days per week. The survey targeted all parishes in Grenada (St George, St Patrick, St Andrew and St John, St Mark and St David). However, data for the parishes of St Mark and St David could not be located. The survey also did not cover the Grenadine islands. The mean horsepower was computed directly from census data once the vessels were linked to the respective fisheries.

1999: Computerized information was also provided on vessel characteristics (design/type, length, horsepower, engine type), as well as the associated landing sites and target fishery from the Fisheries Department's 'Trip Interview Program'. The fishery types specified were: coral reef; inshore pelagics; large offshore pelagics; small offshore pelagics; lobster/conch; slope and shelf; spiny lobster. The 'large offshore pelagics' was assumed to be the longline fishery and the 'small offshore pelagics' the trolling fishery. Further, the 'inshore pelagics' was assumed to be the small coastal pelagic fishery usually targeted with beach seines. For the purposes of this analysis, the 'spiny lobster' and 'lobster and conch' fisheries were grouped with the 'coral reef' fishery in the inshore demersal reef category. Missing values on vessel characteristics were estimated by comparing information at same landing site for vessels of a similar type, horsepower, length and fishery type. Mean horsepower was computed directly from information in TIP for each vessel type exploiting the respective fisheries.

Linking fishing effort to fishery type

Specific criteria based on vessel design and length, degree of mechanization and the location of specific fishing areas relative to the respective coasts, landing and mooring sites were identified from a review of the literature to facilitate linking of fishing effort to fishery type. This is described in Mohammed (this volume).

Specifically for the Grenadines, the assumption that from the late 1950s onwards, all unmechanized vessels fished inshore, does not hold since until the mid-late 1990s virtually all vessels, whether or not mechanized, targeted inshore reef, offshore deep slope and shelf and coastal pelagic species (Finlay and Rennie, 1998). Since introduction of longlines in the 1980s, all pirogues and semi-industrial vessels with inboard engines (which are of higher horsepower than outboard engines) were assumed to target large highly migratory pelagics offshore using longlines. Pirogues with outboard engines were assumed to target the regional pelagics (small tunas, mackerels and dolphinfish) with troll lines. Although there are vessels with inboard engines targeting regional pelagics, these are in the minority.

The topography off the respective coasts influences the types of fisheries that can occur. Since the west (leeward) coast of Grenada is characterized by a narrow shelf, deep waters are close to shore. Therefore, large pelagics can be caught without sailing too far offshore. It is therefore assumed that vessels at the parishes of St Georges, St John and St Mark, off this coast, target large pelagics (using troll lines prior to the 1980s and converting to longlines through the mid-1980s into the 1990s). Also, the sandy shore, sheltered bays, calmer seas and fewer reefs make this coast popular for catching small coastal pelagics with beach seines, and so the unmechanized vessels along this coast are assumed to target this resource.

The east (windward) coast is lined by many fringing reefs and the shelf area is wider than that on the west coast. Since the waters off this coast are rougher, it is assumed that all vessels from the parishes of St Patrick, St Andrew and St David targeted mainly demersal reef resources during the pre-mechanization period. Since mechanization there has been an increase in the number of vessels targeting large pelagics using troll gear on the east coast (mainly those from Grenville which is a sheltered bay allowing vessels good landing conditions). The reef resources, however, are still exploited and it is assumed that unmechanized vessels target them year-round while mechanized vessels do so only during the pelagic off-season.

The south coast is characterised by reefs and deep waters close to shore because of the narrow shelf area. Consequently, boats on this coast (St Gerges and St David), are assumed to target both large pelagics and reef demersals. As for the east coast, the main target fishery is determined by the degree of mechanization. Boats at landing sites between Woburn and Calliste also target lobster and conch fisheries.

The north coast of Grenada is characterized by an expansive shelf area. Vessels in the parishes of St Patrick area are assumed to target large pelagics and demersal shelf and slope species, with reef species also taken, if to a lesser extent. As in other areas, it is assumed that unmechanized vessels target inshore resources year-round while mechanized vessels do so during the pelagic off-season.

The expansive shelf area of the north coast is shared with the Grenadines islands of Carriacou, Petite Martinique and Isla Ronde. Traditionally the fisheries targeted by these islands are the reef, deep slope and shelf demersals and, to a lesser extent, the small coastal pelagic fisheries. It is only with the depletion of demersal resources that some of these vessels have started converting to longlining in the 1990s (Finlay and Rennie, 1998). The species targeted in the Grenadines are dictated by the demand of the Martinique market, and to a lesser extent the Guadeloupe market, to which most of the catch is exported.

The assumptions made above are considered to hold throughout the period covered by this study. Detailed notes on assumptions and inferences made are given in Appendix 1.

Assigning fishing days to the respective fleets and fisheries

A review of the literature provided no information from which changes in the annual number of fishing days for the respective fisheries could be quantified, though Epple (1977) noted an increase in number of fishing days as a result of mechanization. The pelagic fishery has traditionally been seasonal, from November to June, and the associated fleet switches to the demersal and reef fisheries during the pelagic –off-season (July to October). The number of fishing days associated with each fishery for this fleet provides a possible way of accounting for the division of annual total effort between the two fisheries.

Large pelagic fishery

Vessels targeting this fishery in the pre-mechanization period were assumed not to fish between November and January due to rough sea conditions. Fishing was assumed to occur 15 days per month from February to June (75 days total per year). Vessels targeting this fishery on the windward coast were also assumed to target inshore demersals from July to October (excluding one month for vehicle maintenance), at an average of 15 days per month (45 days per year). Mechanized vessels were assumed to fish on average 10 days per month between November and January, and on average 20 days per month otherwise (130 days per year). Those on the windward coast are assumed to continue targeting large pelagics from July to October (the hurricane season), on average 15 days per month (excluding one month for vessel maintenance). The total annual number of fishing days is therefore 175. Mechanized vessels on the east coast (pirogues involved in longlining) virtually cease fishing from July to October since the tuna are believed to move further offshore in deeper waters and are inaccessible to this fleet (Finlay and Rennie, 1998). Because of high fuel costs, it is also uneconomical for this fleet to travel to the north and south coasts where demersal and reef resources could be targeted during the pelagic off-season (Finlay, 1991). The estimated number of fishing days for this fleet is thus 130 days per year. Since the semi-industrial longliners on the west coast can track the tunas into deeper waters from July to October they are able to fish year-round (Finlay and Rennie, 1998). It is assumed that fishing occurs on average 20 days per month excluding one month each year for vessel maintenance. The associated total number of fishing days is thus 220. An exception to this occurred in the earlier years (1982-1988), when these vessels targeted reef demersals (Finlay *et al.*, 1988) during the pelagic off-season. It is assumed that, at that time, the large pelagic fishery was ran an average 130 days per year and the demersal and reef fishery 45 days per year (15 days per month from July to October excluding one month for vessel maintenance).

Small coastal pelagic fishery

Unmechanized vessels targeting small pelagics were assumed to fish the same number of days each year throughout the study period. Vessels traditionally target small pelagics using beach seines and other nets year round (Finlay, 1996), but the peak period is from May to October (Brown, 1945). It was assumed that fishing occurred 20 days per month during the peak period and 10 days per month during the non-peak periods, giving a total of 180 fishing days per year. An exception to this occurred in 1997, when the actual number of fishing days was computed at 234 for canoes/transumes from survey data. This was assumed the same for vessels in 1999. This observation is consistent with the expansion of this fishery from subsistence level (provider of bait for the demersal and regional pelagic fishery) to a bait supplier for the offshore fishery for large pelagics.

Demersal reef, shelf and slope fisheries

Unmechanized vessels on the east (windward), south-east (from Calliste to Woburn), south, southwest and north coasts (Victoria and Sauteurs) are assumed to target this fishery year round. On average fishing is assumed to occur 20 days per month from February to October (excluding one month for vessel maintenance) and 10 days per month between November and January. The total number of fishing days is thus 230. Mechanized vessels, which target these resources during the pelagic off-season, are assumed to fish 10 days per month from July to October (excluding one month for vessel maintenance), for a total of 30 days per year.

Annual trends in catch per unit area and catch per unit effort

Using the reconstructed catches for the inshore and offshore fisheries of Grenada and the Grenadines and the estimates of EEZ, reef, slope and shelf areas in Mohammed (2003), a time series of trends in catch per unit area was derived. Catch per unit effort was derived for the Grenada fisheries as the ratio of reconstructed catch and reconstructed effort for the offshore and inshore components. Fishing effort being derived for specific years, missing data were estimated by interpolation between these estimates.

RESULTS

Fisheries catches

The reconstructed catch data for all species combined is presented in Figure 2 for Grenada and the Grenadines. This includes estimated annual catches for the Grenadines derived from Grenadine export and Martinique import statistics (Table 1), catches from billfish fishing tournaments between 1992 and 1998 (Table 2), catches of flyingfish and round robin for use as bait between 1982 and 1998 (Table 3), and catches of turtles between 1942 and 1998 (Figure 3). A comparison of the existing data in the Food and Agriculture Organization FISHSTAT database for Grenada with reconstructed catch data of this study (Figure 2a) indicates major deviations from the mid-1950s to mid 1960s, 1972 to 1977 and 1985 to 2001.

Overall catches increased between 1955 and 1965 from 512 t to 1,444 t, remained stable at between 1,300 t to 1,600 t thereafter until the mid-1970s, early 1980s, when there was a

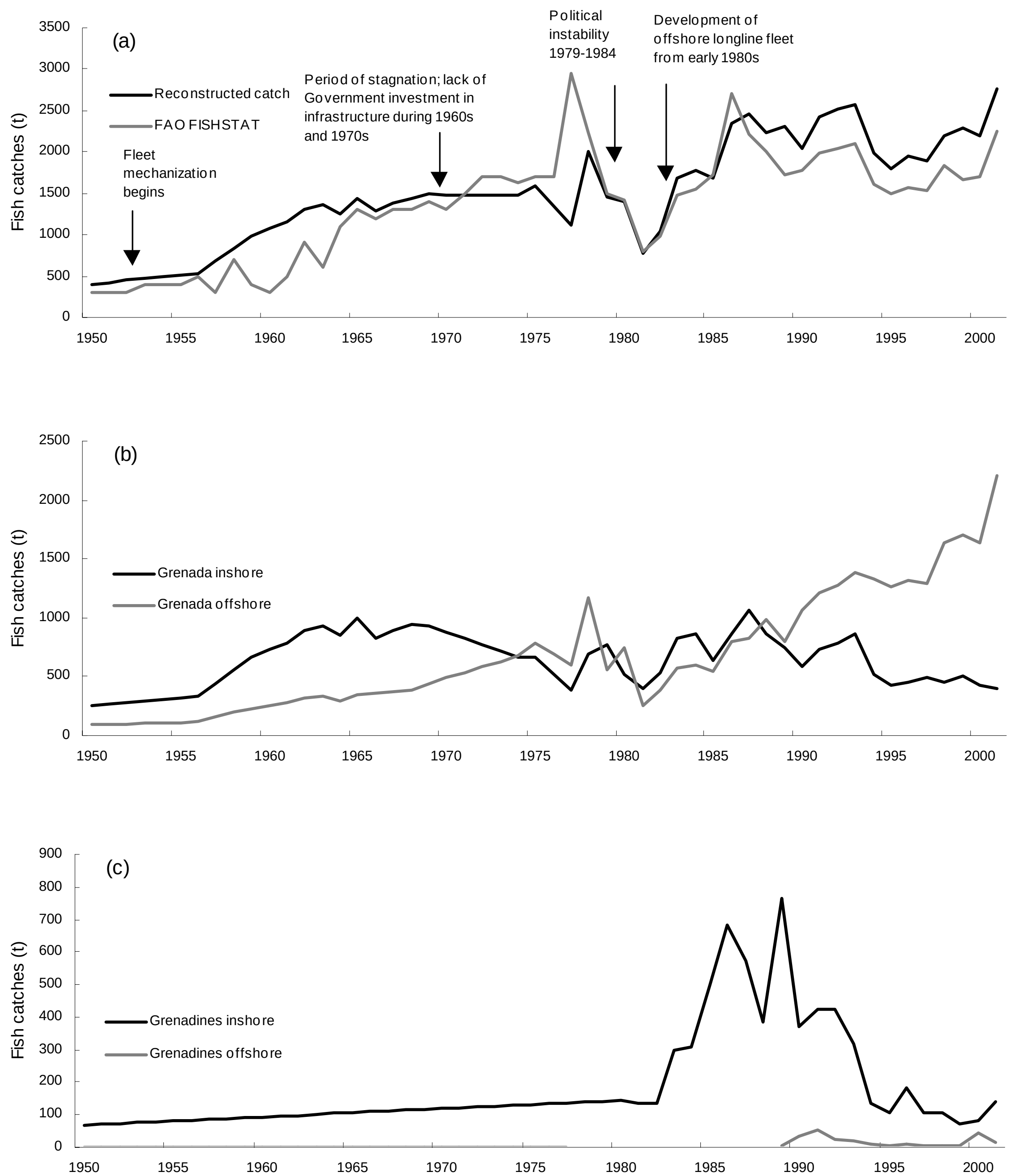


Figure 2. Fisheries catches reconstructed from reported data for (a) Grenada and the Grenadines combined; (b) Grenada; (c) the Grenadines (1950-2001).

Table 1. Estimated annual catches for the Grenadines derived from Grenadine export and Martinique import statistics: 1980 to 1999.

Year	Catch (t)	Year	Catch (t)
1980	144	1990	403
1981	134	1991	479
1982	133	1992	450
1983	297	1993	339
1984	306	1994	141
1985	501	1995	112
1986	688	1996	195
1987	571	1997	113
1988	384	1998	110
1989	768	1999	176

Table 2: Catches (t) landed at annual billfish tournaments in Grenada (1992-1998).

Year	Blue marlin	Sailfish	White marlin	Yellowfin tuna	Total catch (t)
1992	0.05	2.80	0.36	0.00	3.21
1993	0.23	1.84	0.19	0.06	2.31
1994	0.40	0.87	0.02	0.13	1.42
1995	0.23	1.20	0.05	0.06	1.54
1996	0.05	1.53	0.08	0.00	1.66
1997	0.32	1.17	0.05	0.00	1.54
1998	0.59	0.82	0.02	0.00	1.43

Table 3: Estimated quantities of flyingfish and round robin utilized as bait in the longlining fishery. Quantity caught = number of boats x number of fishing days x number of hooks utilized per trip x mean individual weight of fish. Pirogue longliners and semi-industiral longliners use mainlines with 45 and 150 hooks respectively (Samlalsingh *et al.*, 1995). The mean individual weight of flyingfish was estimated at 0.15kg based on field observations. The same mean weight was assumed for flyingfish and round robin. Catches in bold were estimated by interpolation.

Year	Pirogue longliners			Semi-industrial longliners				Total Flyingfish caught as bait (t)
	Number	Fishing days	Flyingfish caught as bait (t)	Number	Fishing days	Flyingfish caught as bait (t)	Round Robin caught as bait (t)[a]	
1982	25	130	21.94	4	130	11.7	-	33.64
1983	-	-	-	-	-	-	-	**58.70**
1984	-	-	-	-	-	-	-	**83.75**
1985	-	-	-	-	-	-	-	**108.81**
1986	-	-	-	-	-	-	-	**133.87**
1987	-	-	-	-	-	-	-	**158.93**
1988	183	130	160.58	8	130	23.4	-	183.98
1989	-	-	-	-	-	-	-	**194.59**
1990	-	-	-	-	-	-	-	**205.20**
1991	-	-	-	-	-	-	-	**215.82**
1992	-	-	-	-	-	-	-	**226.43**
1993	225	130	197.44	11	160	39.6	14.85	237.04
1994	-	-	-	-	-	-	**16.20**	**222.02**
1995	-	-	-	-	-	-	**17.55**	**207.00**
1996	-	-	-	-	-	-	**18.90**	**191.98**
1997	138	132	122.96	15	160	54.00	20.25	176.96
1998	-	-	-	-	-	-	**30.38**	**217.51**
1999	171	130	150.05	30	160	108.00	40.50	258.05

a: It was assumed round robins are targeted 60 fishing days per year.

drastic decline from about 1,900t to 700 t. This was followed by a period of significant increases to about 2,476 t in 1993, until the mid to late 1990s (Figure 2a) when catches declined to 1,469 t in 1997. Thereafter catches continued to increase, reaching to about 2,900 t in 2001. The offshore catch of Grenada increased from 256 t to 2,205 t (a factor of 8.6) between 1981 and 2001 (Figure 2b). Catches in the inshore fishery declined from 1,000 t in the mid to late 1960s (Figure 2b) to about 400 t in 1977, and fluctuated between 381 t and 1,062 t between the late 1970s to 1987. Between 1987 and 2001 inshore catches declined from 1,062 t to 400 t, a decline of 62% of the 1987 estimate. Offshore catches in the Grenadines (Figure 2c) were very small (17 t average between 1985 and 2001) compared to inshore catches (2,576 t average between 1985 and 2001). However, inshore catches declined drastically from about 700 t in 1986 to as low as 74 t in 1999, 89% the 1986 estimate. Subsequently catches have increased to 139 t in 2001.

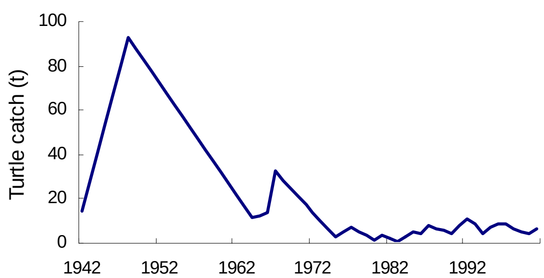


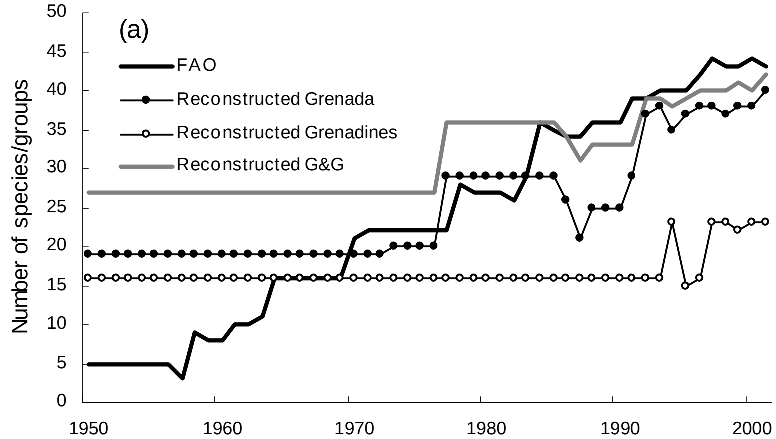
Figure 3. Reconstructed catch of sea turtles (hawksbill: *Eretmochelys imbricata*; green turtle: *Chelonia mydas*) in Grenada (1942-1999).

A comparison of the number of species or species groups and percentage of overall catches attributed to the aggregate category 'marine fish nei' as represented in FISHSTAT and reconstructed statistics of this study are provided in Figure 4. A greater number of species were represented in reconstructed data between 1950 and the mid-1990s (Figure 4a). The number of species or species groups represented in FISHSTAT increased from five (Atlantic moonfish, flyingfishes nei, redhind, scads nei and snappers, jobfishes nei) in 1950 to 43 in 2001. Overall a greater number of species or species groups were represented in Grenada catches (19 to 40 species/groups) compared to catches of the Grenadines (16 to 23 species/groups). In recent years (1994 to 2001) however, the number of species or species groups in FISHSTAT exceeded those in reconstructed data by three species/groups. A comparison of species in the reconstructed data and FAO attributed the differences to a splitting of the 'king mackerel and wahoo' category of this study into the individual species components in FISHSTAT and inclusion of three additional species or species groups: scaled sardines, scads nei, and surgeonfishes. As well, Albacore (*Thunnus alalunga*) and bonito (*Sarda sarda*) are not represented explicitly in reconstructed data, though they are in FISHSTAT. Reconstructed catches were disaggregated among all possible species with no catches attributable to an aggregate category. However, up to 45% of overall catches in the FAO data were attributed to 'marine fish nei' between the early 1960s and 2000 (Figure 4b), with considerable inter-annual variability over the period.

Estimated annual catches for the Grenadines between 1980 and 1999, derived from Grenadine export and Martinique import statistics (Table 1) indicate a considerable increase in catches from just over 100 t in 1982 to a peak of 768 t in 1989. Catches declined thereafter, reaching as low as 110 t in 1998, and increasing to 176 t the following year. Catches from the annual Spice Island Billfish Fishing Tournament (Table 2) were very small, 1.0 – 3.1 t, compared to the commercial fishery. Estimated annual catches of flyingfish utilized as bait (Table 3) have increased from about 50 t in 1982 to over 250 t in 1999. Similarly catches of round robin (Table 3) have increased by a factor of 2.7 between 1993 (14.9 t) and 1999 (40.5 t). Reconstructed catches of turtles (Figure 4) reflect significantly higher catches in earlier years, in particular 1948 and 1967. Catches in recent years have remained below 20 t.

Fishing effort

Fishing effort was calculated using information on the reconstructed number of boats for each fishery type, the associated mean horsepower and number of fishing days each year (raw data can be obtained from the author). Figure 5 indicates the key features in development of fisheries in Grenada and the Grenadines. Generally there has been an increase in fishing effort in both the offshore and inshore fisheries of Grenada (by factors of 411 and 21 respectively) and the Grenadines (factors of three and 10 respectively. In Grenada the number of boats exploiting the offshore fishery has increased linearly while effort has increased exponentially. During the last two decades,



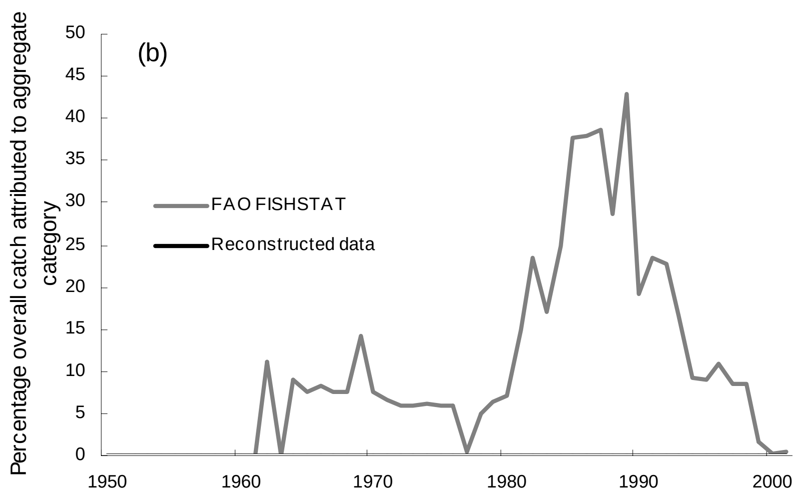


Figure 4. A comparison of reconstructed catch data and statistics in FAO FISHSTAT for Grenada and the Grenadines between 1950 and 2001: (a) number of species/species groups and (b) proportion of overall catch attributed to the aggregate category 'marine fish nei'.

the effort in the offshore fishery of Grenada (Figure 5a) has increased sevenfold from 748 x 10^3 Hp-days in 1982 to 5,273 x 10^3 Hp-days in 1999, while the corresponding numbers of boats (Figure 5a) has increased by a factor of 1.6, from 250 to 390 in the same years. Conversely, between 1982 and 1999, the number of boats targeting the inshore fishery in Grenada (Figure 5b) decreased by a factor of 1.4, from 185 to 136, although overall fishing effort has increased by a factor of 2.5, from 89 x 10^3 Hp-days to 223 x 10^3 Hp-days. In the Grenadines, the number of boats targeting the offshore fishery (Figure 5c) has decreased by a factor of 1.5 between 1982 and 1999, from 80 to 55, while the corresponding effort has increased by a factor of 3.3, from 272 x 10^3 Hp-days to 895 x 10^3 Hp-days. Although the number of boats targeting the Grenadines inshore fishery changed little between 1982 and 1999, the effective effort peaked in 1988 at 691 x 10^3 Hp-days and declined considerably thereafter to 226 x 10^3 Hp-days in 1999.

Annual trends in catch per unit area (CPUA) and catch per unit effort (CPUE)

Overall the annual CPUA was greater, by about one order of magnitude, for the inshore than the offshore fisheries of Grenada and the Grenadines (Figure 6). Generally CPUA in the offshore fishery increased between 1942 and 2000. Between 1981 and 2001 CPUA increased by a factor of nine, from 10.6 x 10^{-3} t·km^{-2} to 93 x 10^{-3} t·km^{-2}. The maximum 93x 10^{-3} t·km^{-2}) in the offshore fishery was observed in 2000.

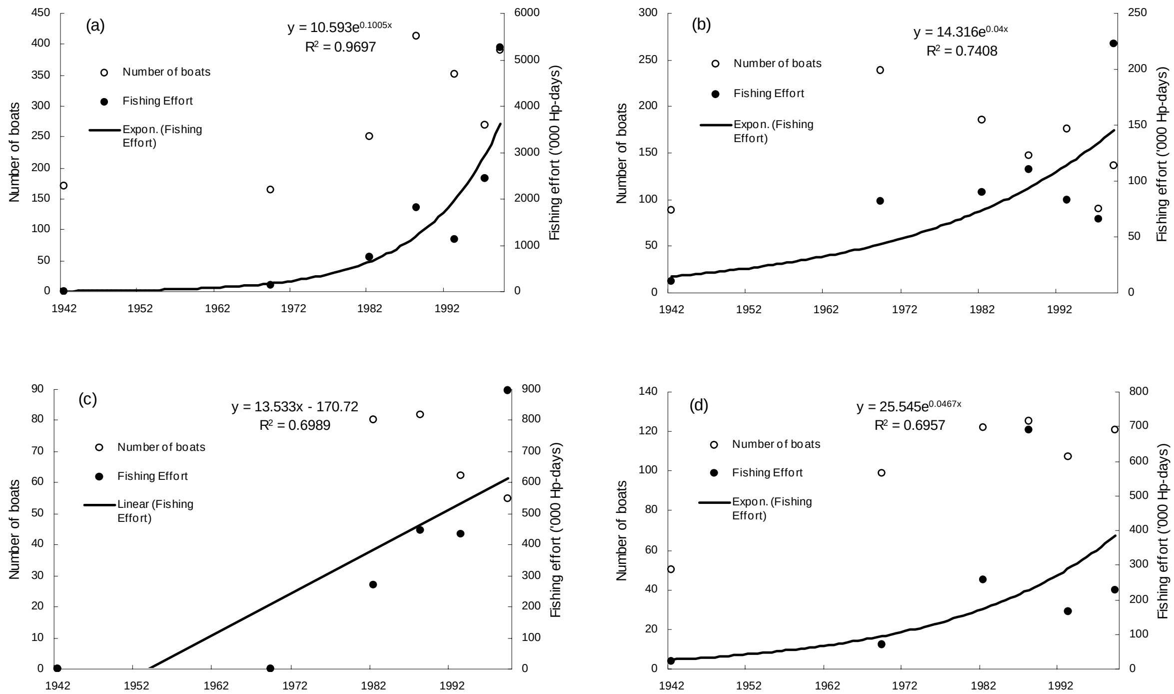


Figure 5. Reconstructed fishing effort for the Grenada (a) offshore and (b) inshore fisheries; the Grenadines (c) offshore and (d) inshore fisheries (1942-1999).

Two peaks in CPUA were observed in the inshore fishery, in 1965 (612 x 10^{-3} t·km^{-2}) and 1987 (905 x 10^{-3} t·km^{-2}). Recently CPUA in the inshore fishery has declined considerably, from 654 x 10^{-3} t·km^{-2} in 1993, to 360 x 10^{-3} t·km^{-2} in 1994 and has remained below 350 x 10^{-3} t·km^{-2} throughout the latter half of the 1990s.

Generally CPUE was greater in the inshore fishery than the offshore fishery of Grenada and the Grenadines (Figure 7). Initial CPUE in 1942 was 5.33 t per thousand Hp-days and 3.69 t per thousand Hp-days in the inshore and offshore fisheries respectively. These declined to 4.37 t per thousand Hp-days and 1.54 t per thousand Hp-days in the respective fisheries by 1957. Although the general pattern in both fisheries was a decline between 1942 and 1999 (92% and 76% in the offshore and inshore fisheries respectively), there was a notable increase in CPUE during the late 1950s, and considerably high CPUEs throughout most of the 1960s. CPUEs in the 1960s ranged between 6.74 and 8.23 t per thousand Hp-days in the inshore fishery and between 2.67 and 3.23 t per thousand Hp-days in the offshore fishery. CPUE in the offshore fishery declined thereafter, reaching a low of 0.269 t per thousand Hp-days in 1981. This increased only slightly to 0.897 t per thousand Hp-days by 1993 and declined again to 0.28 t per thousand Hp-days '000 Hp-days by 1999. CPUE in the inshore fishery also declined rapidly from the highs of the 1960s, ranging between 2.64 t per thousand Hp-days (1982) and 1.56 t per thousand Hp-days (1988) during the 1980s. A peak in CPUE occurred in the mid-1990s ranging between 4.72 t per thousand Hp-days in 1993 and 9.02 t per thousand Hp-days in 1997. However, CPUE declined again towards the end of the decade to only 1.3 t per thousand Hp-days.

DISCUSSION

Fisheries catches

Catches in the Grenada offshore fishery increased by a factor 8.6 between 1981 (256 t) and 2001 (2,205 t), while catches in the inshore fishery declined by 62% between 1987 (1,062 t) and 2001 (400 t). Offshore catches in the Grenadines fishery were insignificant compared to the catches of the traditional inshore fishery. However, inshore catches declined drastically from about 700 t in 1986 to as low as 74 t in 1999, 89% the 1986 estimate. Subsequently catches have increased to 139 t in 2001.

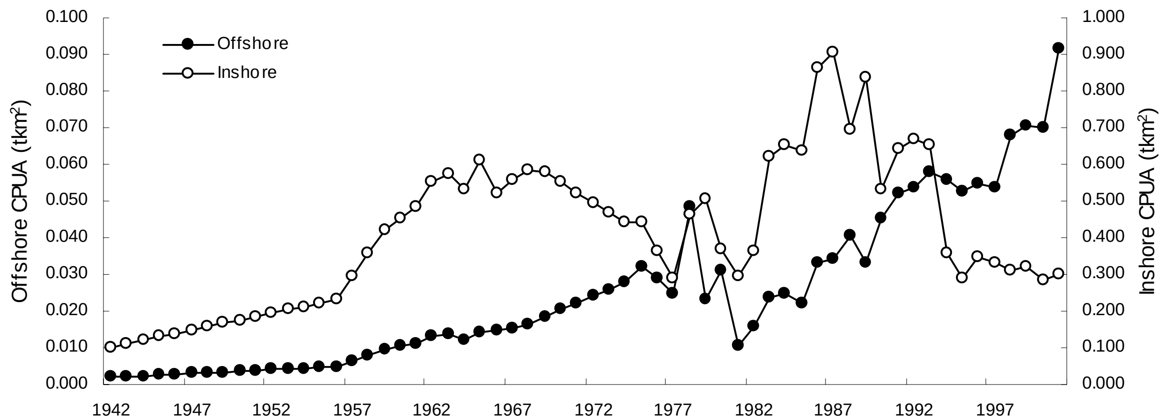


Figure 6. Annual trends in catch per unit area (t·km^{-2}) in the fisheries of Grenada and the Grenadines (1942-2000).

A comparison of annual catches in the Food and Agriculture Organization FISHTAT database and reconstructed catches of this study showed major differences from the mid-1950s to mid-1960s, 1972 to 1977 and 1985 to 1999. Since the information sources used to derive catch estimates submitted to the FAO are not known, it is difficult to comment on the reasons for these differences. A review of the literature however, provided no support for the high catches listed in FISHSTAT for Grenada and the Grenadines during 1977 and 1986. Deviations in the most recent period are attributed mainly to the quantities of flyingfish used as bait in the longline fishery.

Overall catches increased between 1955 and 1965 from 512 t to 1,444 t, remained stable at between 1300 t to 1600 t thereafter until the mid-1970s, early 1980s, when there was a drastic decline from about 1,900 t to 700 t. This was followed by a period of strong increases to about 2,500 t in 1993, until the mid to late 1990s when catches declined to about 1,500 t in 1997. Thereafter catches continued to increase, reaching to about 2,900 t in 2001.

Overall, the increased catches from the mid-late 1950s reflect the initial attempts at fleet mechanization and the associated provision of loans for fisheries development (Vidaeus, 1969). Despite these efforts, however, fisheries stagnated during the mid-1960s to mid-1970s. Several factors may have contributed to this: stricter collateral requirements, resulting in fewer loans being granted by the government; lack of government's support for infra-structural development (including provision of onshore cold storage facilities); a system of retail price control which acted as a disincentive to increase exploitation given the associated increases in fishing (fuel related) costs and the large quantities of imported processed fish. Videaus (1969) estimated that between 1960 and 1968 annual imports represented between 1.64 and 2.76 times domestic landings. This apparent preference for imports, for salted fish in particular, originates from a long tradition of consuming salted cod and smoked herring from northern countries.

The decline in catches between 1979 and 1984 coincides with the political events mentioned above. They impacted negatively on tourism, an industry that accounted for a significant proportion of total fish consumption, and was a major incentive to fishers. The result was a reduction in catches of demersal (including lobster and conch) and large pelagic species which would have otherwise been sold to hotels (Finlay, 1991). This decline was mitigated in 1982 when the government launched the US$2.7 million Artisanal Fisheries Development Project (Finlay, 1990).

A semi-industrial longline fleet was also introduced and the artisanal inshore fleet began conversion to the offshore fishery. Cuba provided technical assistance in the longline fishery and efforts were concentrated in Grenada. Only recently has this extended to the Grenadines. The main species targeted are yellowfin tuna, sailfish and swordfish. Greater efforts were focused on development of the offshore fishery. This accounts for the increased catches from the mid -1980s

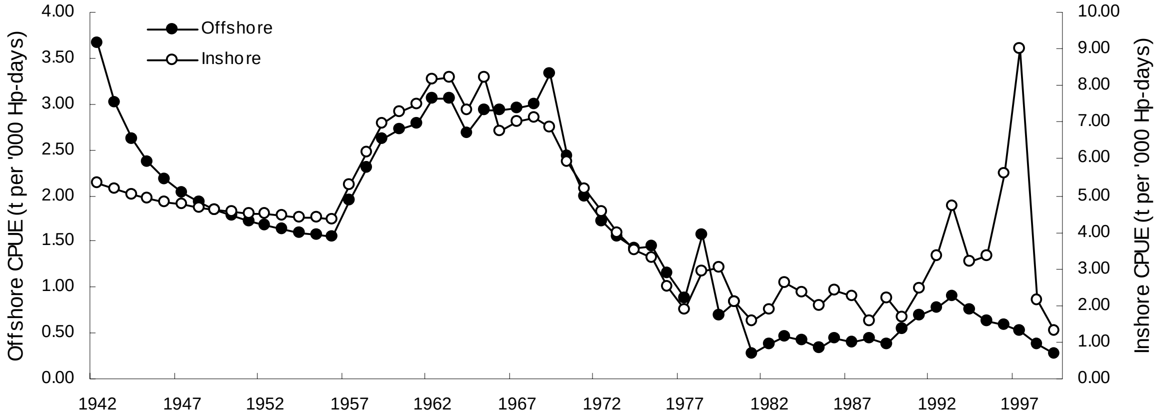


Figure 7. Annual trends in catch per unit of effort (t per '000 Hp-days) in the fisheries of Grenada and the Grenadines (1942-1999).

onwards, which, according to Finlay (1991), was attributed mainly to the artisanal fleet fishing in the Caribbean Zone. Attempts to decrease fishing operation costs through the Fishing Vessel Modernisation Plan (Senga, 1995) in 1994 would also have added to the profitability of the venture. The increased catches are also supported by reports of increased fishing range, and increased duration of the fishing season (from seven to twelve months) of semi-industrial vessels (Samlalsingh *et al.*, 1995).

The 1997 decline in catches (clearly seen in the data for Grenada) results from a regional fish-kill which resulted in closure of fisheries in Grenada and Grenadines. More recent catches show an immediate recovery of the industry.

The reconstructed catches for Grenada reflect a shift in relative importance of the inshore and offshore fisheries. Until 1975 the inshore fishery accounted for a greater proportion of overall catch, but by the mid to late 1980s, the offshore fishery proved to be the greater contributor, and continues to do so at the present time. Catches in the inshore fishery appear relatively stable in recent years. The reasons for this shift in relative importance of the inshore and offshore fisheries are mainly due to the perceived depletion of inshore resources and governments policy to develop the offshore fishery in response to this. The increased jurisdiction provided under the United Nations Convention on the Law of the Sea (1982), and introduction of new longlining technology and more fuel efficient vessels, provided an avenue for geographical expansion of fishing operations targeting high-priced pelagic species to supply the export market. Fishing has therefore changed from a subsistence activity, or for national food production, to one that is export oriented. In the 1990s most of the fresh fish production in was traded overseas (USA, French Martinique, Barbados) and a high proportion of local consumption consisted of imported fish and fish products (Finlay and Rennie, 1998).

There were vast differences in the 1948 and 1967 reconstructed catches of turtles when estimated from information in the literature specific to turtles, compared to estimations using information on species composition and total catch across all fisheries and species, in the general literature. Quite possibly, the estimates of mean weight or weight of shell per turtle used to estimate landed weights from numbers of turtle are incorrect. Further verification of these estimates is required. Also, catches estimated from exported shell weight are minimum estimates since only shell of the hawksbill turtle are exported, while catches of other species (especially the green turtle) are not well recorded.

The reconstructed catches for the Grenadines were incomplete for the pre-1984 period. This is reflected in a sudden increase in catches around the mid-1980s. While the Artisanal Fisheries Project would have promoted an increase in catches it is difficult to establish whether the increase observed is due solely to fisheries development or to improvements in the data collection system, though the latter is more likely. The traditional importance of the inshore fishery is reflected in the broad species composition of the reconstructed catch and the significantly higher overall catch compared to the offshore fishery. Assuming that catches were around 700-900 t in the late 1980s then the drastic decline in catches of the inshore fishery from the early 1990s offers some evidence for overexploitation of these resources. However, successive devaluations in the Venezuelan Bolivar in the late 1980s made the Martinique market more lucrative to Venezuelans and contributed to increased competition for the market (Finlay, 1991) and may also explain the decline. Finlay (1991) reported on the associated decline in exports to Martinique, the traditional market for fisheries in the Grenadines. Further, reconstructed catches using Grenadine export and Martinique import data are quite possibly over-estimates because Finlay (1990) also indicated that 10% of beach seine catches from Grenada are exported to Martinique, though this is not considered in the present analysis.

The reconstructed catches presented in this report are preliminary and should be considered minimum estimates. There are several data limitations. These are associated with the recreational fishery, foreign catches, inadequate data collection on the inshore fishery and associated high level of species aggregation, the increased exploitation of flyingfish as bait to support the longline fishery and the lack of a method for estimating total catches from recorded data in Grenada and the Grenadines.

Catches from the three-day recreational fishing tournament are incomplete, as only the main target species are reported. Other species of lesser importance (small tunas, mackerels and dolphinfish), are also caught, but the data are not recorded. There is also some uncertainty as to whether the data recorded accurately reflects the total catches of target species (C. Isaac, Fisheries Department, pers. comm. 2001). Further, catches of the recreational fishery (excluding fishing tournaments) and the tourist-associated charter boat fisheries are not included. These operate year round and target reef species, and smaller pelagics with regional distributions. A system for collection of these data does not exist and arriving at a crude estimate is difficult, as basic information, e.g., on the number of vessels involved in the fishery, is not available.

Catches of the seven US longliners licensed to fish for large pelagics between 1988 and 1989 in Grenada waters (Samlalsingh *et al.*, 1995) were not recorded and are therefore not included in the analysis. The same is true for the four vessels donated by Cuba to the Grenada government, which targeted large pelagics and sharks in the early 1980s. Further, foreign fishing (legal and illegal) is also almost unavoidable given the proximity of the southeastern Caribbean islands. The associated catches are either not documented or incorporated in the landing statistics of another island. Information concerning the latter is usually not shared among islands.

Catches of the inshore fishery (in particular reef, shelf and slope demersals and lobster and conch resources) are known to be grossly underrepresented in the recorded statistics for Grenada, as important landing sites for these fisheries are not incorporated in the data collection system. As well, lobster and conch are also delivered directly to hotels upon landing, and therefore by-pass the data collection system implemented at the major markets. Also, recorded landings of the inshore fishery are aggregated across several species making it difficult to determine the level of individual species exploitation. This is particularly true for reconstructed catches for the Grenadines.

The flyingfish fishery has also been relegated to a ‘bait fishery’ status, supporting the developing longline fishery. The quantities utilized as bait are not recorded. For other countries of the southeastern Caribbean (Barbados and Tobago), this is a major commercial fishery, with a resource base that is distributed and shared regionally. The associated implication of non-recording of catches is an underestimation of the level of exploitation of the species and the associated ecological impacts since flyingfish is a natural prey of the large pelagic species targeted by the longline fishery.

A method for estimating total catches based on recorded landings and the number of boats operating in the respective fisheries has not yet been developed nationally. Estimates of total catches provided by the Grenada Fisheries Department for the period 1978 to 2001 are derived by applying a fixed raising factor to recorded data, based on general knowledge of the structure of the fisheries and their development. Except for the offshore pelagic fishery, this factor has remained unchanged since 1978. This confounds the interpretation of catch statistics and estimation of depletion of inshore fisheries.

Fishing effort

The increase in fishing effort of the offshore fishery in Grenada is consistent with development of the longline fleet targeting mainly yellowfin tuna, sailfish and swordfish. The exponential increase in effort, as opposed to the linear increase in number of boats, results mainly from the use of engines of higher horsepower since the mid-1980s. This also explains why the overall effort in the offshore fishery in the Grenadines has increased despite a decline in the number of boats involved in the fishery, and highlights the dangers of monitoring solely the number of boats as an indication of fishing effort. Though the increased effort in the Grenadines fishery is consistent with the literature (Finlay and Rennie, 1998), the number of boats is expected to increase given the conversion of the inshore fleet to offshore fishing. Improvements in vessel and fishing technology must also be considered. Increases in fishing effort are matched by an increased geographical range of fishing (Finlay, 1990). Development and expansion of the large pelagic fishery is reflective of the future fisheries policy of Grenada and the Grenadines.

Despite overexploitation and depletion of inshore resources, however, the fishing effort deployed in Grenada has increased. This is due, as in the offshore fishery in the Grenadines, mainly to the use of engines of higher horsepower (the overall number of boats has in fact decreased). Data for the inshore fisheries in the Grenadines are difficult to interpret. They suggest that the inshore fishery has remained purely artisanal, with a low effort. The associated number of boats has increased gradually over the years. However, changes in the number and types of gear deployed are not incorporated in the estimate of effort. These certainly would have contributed to increases in effort and the consequent decline of the resources.

Annual trends in CPUA and CPUE

Overall the annual CPUA was greater, by about one order of magnitude, for the inshore than the offshore fisheries of Grenada and the Grenadines. This is expected since the inshore resources are concentrated over a narrow shelf and the reef areas represent only about 7% of the EEZ. Generally CPUA in the offshore fishery increased between 1942 and 2000. This is consistent with development of this fishery, particularly from the early 1980s onwards, when CPUA increased by a factor of nine. Two peaks in CPUA were observed in the inshore fishery in 1965 and 1987. The associated increases in CPUA leading to these peaks coincide with major developmental periods, firstly the introduction of vessel mechanization in the late 1950s and the Artisanal Fisheries Development Project, which commenced in 1982. Recently CPUA in the inshore fishery has declined considerably, from 654 x 10^{-3} t·km^{-2}in 1993, to 360 x 10^{-3} t·km^{-2} in 1994 (45% the 1993 estimate) and has remained below 350 x 10^{-3} t·km^{-2} throughout the latter half of the 1990s. This is a clear signal of overexploitation.

Catch per unit of effort was greater in the inshore fishery than the offshore fishery of Grenada and the Grenadines. Although the general pattern in both fisheries was one of decline between 1942 and 1999 (92% and 76% in the offshore and inshore fisheries respectively), there was a notable increase in CPUE during the late 1950s, and considerably high CPUE throughout most of the 1960s (ranging between 6.74 and 8.23 t per thousand Hp-days in the inshore fishery and between 2.67 and 3.23 t per thousand Hp-days in the offshore fishery). This coincides with the initial period of vessel mechanization, which promoted considerable increases in catches as vessels could then exploit a greater area and were less affected by adverse weather conditions. CPUE in the offshore fishery declined thereafter, reaching a low of 0.269 t per thousand Hp-days in 1983. This increased only slightly to 0.897 t per thousand Hp-days by 1993, coinciding with development of the longline fishery, but declined again to 0.28 t per thousand Hp-days by 1999.

The CPUE of the offshore fishery has declined between 1993 and 1999. Though catches continue to increase, so too has effort, through the introduction of bigger vessels utilizing more powerful engines, with a higher initial capital investment. Results reflect the general situation across the entire fleet. The economic implications will vary among the individual vessels, depending on the types of engines used, the associated fuel consumption and the catch per trip. This decline in CPUE could be offset financially by increasing prices for the associated species on the foreign market. Management of the large pelagic fisheries is the responsibility of the International Commission for the Conservation of Atlantic Tunas (ICCAT). Hence ICCAT quota regulations, which limit the catches, and the corresponding fleet development (more boats of higher horsepower and increased horsepower of existing boats) may also account for the declining CPUE in this fishery. Normally, under these circumstances, fishing should become unprofitable. However, these vessels have larger inboard diesel engines, with considerably lower fuel costs than outboard gasoline engines, and they supply the more lucrative export markets and local hotels instead of traditional local markets. As a result economic gains (dependent on foreign market prices) would encourage increased investment despite the declining CPUE.

CPUE in the inshore fishery has also declined rapidly from the highs of the 1960s, ranging between 2.64 t per thousand Hp-days (1982) and 1.56 t per thousand Hp-days (1988) during the 1980s. This decline in CPUE of the inshore fishery is consistent with claims of overexploitation and depletion (Mahon, 1990, 1993; Singh-Renton and Mahon, 1996). A peak in CPUE occurred in the mid-1990s ranging between 4.72 t per thousand Hp-days in 1993 and 9.02 t per thousand Hp-days in 1997. However, CPUE declined again towards the end of the decade to only 1.3 t per thousand Hp-days. Further investigation is required to explain the mid-1990s peak.

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APPENDIX 1:

Interpretation of data for fishing effort reconstruction for Grenada and the Grenadines (1942-1999).

Grenada

1942:

It was assumed that sailboats on Leeward coast (114), except those from Sauteurs and Victoria, and sailboats on the windward coast (48) fish for flyingfish and large pelagics (inshore). Whalers at Gouyave (6) and Marigot (3) also targeted large pelagics, the differences being that vessels on the leeward coast cease fishing after June while those on the windward coast (48) target inshore reef demersals from July to October. Beach seines (16) and gillnets (7) targeted small coastal pelagics and an equivalent number of boats is assumed. It is assumed that the vessels from Sauteurs (2 whalers and 4 sailboats) and Victoria (12 sailboats) target inshore reef demersals year round.

1969:

It was assumed that mechanized whalers (95); unmechanized whalers (60), and canoes (9) target large pelagics and flyingfish by trolling. The mechanized whalers however, also target deep water demersals (30-40 fathoms). Coastal pelagics are taken by beach seines (35) and balahoo seines (6) and a similar number of boats was assumed. Inshore reef demersals are assumed to be targeted by unmechanized canoes (30) and transumes (130). The decked sloops (4) and mechanized whalers (95) target deep demersals, however the latter do so during the months of the pelagic 'off-season' while the former do so year-round.

1982:

In the early 1980s there were 25 pirogues using longlines and 4 semi-industrial vessels donated by Cuba also involved in the longline fishery (Samlalsingh *et al.*, 1995). These were assumed to target large pelagics from

November to June and the semi-industrial vessels assumed to catch reef demersals from July to October. It was also assumed that the vessels with outboard engines (121 pirogues and 16 dories) targeted large pelagics by trolling and were involved in fishing for inshore reef demersals during the pelagic off season. The double-enders (83 inboard, mean Hp is 19; 1 outboard, mean Hp is 12) are also assumed to target large pelagics from November to June but do not exploit the reef and demersal fisheries. The number of boats involved in the coastal pelagic (44) fishery were estimated by interpolation between data for 1969 and 1988.

Mean horsepower was computed from the vessel census data. A crude estimate of the range in horsepower during the late 1970s is as follows: whalers were either mechanized by sails or 10-35 Hp engines; canoes and transumes were either mechanized by sails or outboard engines and sloops were either mechanized by 50 to 100 Hp engines (Giudicelli, 1978).

1988:
Based on the qualitative description of the preferred fishery types of the respective vessels a number of assumptions were made: launches (8) were assumed to target large pelagics and flyingfish mainly (November to June) and catch inshore demersals during the large pelagic off season (July to October) and pirogues on the west and east coasts (except those between Woburn and Calliste) assumed to target large pelagics and flyingfish. Further, pirogues on the west coast utilise longlines and those on the east coast utilize troll lines. It is important to separate those utilizing different gear types because of the differences in vessel horsepower. Vessels between Woburn and Calliste (Woburn 17; Lance Aux Epines 3; True Blue 7; Calliste 31) target inshore demersals including lobster and conch (Finlay *et al.*, 1988) as well as seamoss from July to October. The single sloop is assumed to fish for deep water demersals based on the specialization of these vessels in previous years. Further it was assumed that whalers (13) fish for large pelagics (mainly) and inshore reef species with same fishing pattern as launches. There were 45 beach seines targeting the small coastal pelagic fishery; the equivalent number of boats was assumed.

Mean horsepower was taken from Table 1 of Mahon (1988). Estimates for pirogues, launches and sloops were 28, 58 and 101 Hp, respectively. No information on vessel horsepower was provided for whalers. An estimate was derived from interpolation between values for 1982 (vessel census) and 1993 (OECS, 1995). The horsepower of pirogues longlining was taken from Samlalsingh *et al.* (1995).

1993:
It was assumed that vessels with inboard engines target large pelagics with longlines (8 in St Georges and 3 in St Andrews); that all vessels on the west coast (parishes of St Georges – 143; St Johns – 76; and St Marks – 6) carrying outboard engines target large pelagics by longlining; that vessels on the east coast (parishes of St Patrick – 10; Andrews – 75 and St Davids – 31) carrying outboard engines target large plagics with troll lines; other vessels (assumed to be unmechanized) target either the small coastal pelagic fishery (72 on the west coast) or reef demersal (56 on the east coast). Two exceptions to the latter are vessels at Victoria and Sauteurs (48 combined) from where reef demersals are targeted year round by both mechanized and unmechanized vessels.

Mean vessel horsepower was taken from OECS (1995). Estimates for double-enders, pirogues, launches, and sloops were 36, 40, 130 and 120 respectively. The whaler category is not explicitly mentioned in the main data source. However, because of the similar activity with pirogues it is presumed that these two vessel types are combined under the pirogue category and the higher horsepower of the two was used in the analysis.

1997:
Information was extracted from the computerized information of the vessel census by simple querying in Microsoft Access. It was necessary to estimate the number of boats landing at the two parishes (St Mark and St David) for which data were not provided. The assumption was made that the relative number of boats at these two parishes compared to the rest of the island was the same in 1997 as for 1999. Details were available for this year from the Fisheries Department Trip Interview Program. It was estimated that 26 vessels (4 unmechanized, 20 with outboard engines and 2 with inboard engines) landed at these two parishes. It was also necessary to separate the statistics for each parish to account for differences in the

fishing activity on each coast (St Mark is on the north west coast where the typical fishery is for large pelagics (longlining) and St David on the south east where typical fisheries are for large pelagics (trolling) and reef demersals). Based on the relative number of vessels utilizing different engine types at the 2 parishes in 1999, it was estimated that in 1997 there were 9 vessels at St Mark (2 unmechanised; 5 with outboard engines and 2 with inboard engines) and 17 vessels at St David (2 unmechanised and 15 with outboard engines) in 1997. Several assumptions were made in order to assign vessels to fishery types, based on the location of the parishes along the coast. The reconstructed number of vessels is as follows: 'Pirogue (trolling)' comprises 99 pirogues (outboard), 1 double-ender (outboard) and 15 pirogues (outboard) reconstructed for St David. 'Pirogues (longlining)' comprises 10 canoes (outboard), 1 dory (outboard), 1 double-ender (outboard), 112 pirogues (outboard), 8 pirogues (inboard), and 6 vessels (5 outboards and 1 inboard) estimated for St Mark. 'Launches longlining' totals 15. Unmechanized vessels targeting coastal pelagics are listed under 'Canoes, transumes (unmechanized)' and total 31 [canoes (6), dory (2), double-ender (10), pirogue (11) and 2 vessels estimated for St Mark]. Vessels involved in inshore reef fisheries include 19 pirogues (outboard) representing vessels from landing sites between Calliste and Woburn which target these resources during the pelagic off-season and 11 unmechanized vessels (1 dory, 1 double-ender, 7 pirogues) under the heading 'Canoes, transumes (unmechanised)' which target this fishery year round.

Mean horsepower was computed directly from vessel census data for the different vessel types, once the vessels involved in each fishery were identified. The respective fishing days were computed directly from census information.

1999:
The relevant information was extracted by simple querying of the information obtained from the Trip Interview Program in MS Access. The large pelagic fishery was exploited by vessels of several types carrying either inboard or outboard engine. While the type of engine tremendously affects fishing costs, for this analysis, all vessels of a similar type were grouped regardless of engine type (though details by engine type are available in the associated worksheet). The category 'pirogues (longlining)' includes 16 pirogues (inboard), 154 pirogues (outboard) and 1 dory (outboard). The 3 doublenders (inboard) are involved in longlining. Also the category 'semi-industrial longliner/launch' includes 7 launches (inboard); 18 longliners (nf); 3 longliners (nm) and 1 sloop (inboard). The category 'pirogues (trolling)' comprises 1 dory (outboard), 7 pirogues (inboard) and 171 pirogues (outboard). Only 2 launches are involved in trolling (1 inboard and 1 outboard). Data for all unmechanized vessels for a particular fishery type were grouped. Five unmechanized pirogues were listed for the pelagic longline fishery and 5 vessels (1 dory and 4 pirogues) for the pelagic troll fishery. Coastal pelagics are exploited by 17 unmechanized boats (9 are pirogues and 8 are seine boats) as well as 16 pirogues (outboard), 2 dories (outboard) and I unidentified mechanized boat listed under 'beach seine and gillnet'. Inshore demersals are exploited by 8 unmechanized 'sailboats' (2 canoes, 1 dory and 4 pirogues), as well as 47 pirogues (outboard) and 2 dories (outboard). Offshore demersals are exploited by 8 unmechanized boats (1 dory, 6 pirogues and 1 seineboat), 33 pirogues (outboard), 1 dory (outboard) and 1 seineboat (outboard). Mean horsepower was computed directly from information in the Trip Interview Program once the vessels participating in each fishery was identified.

The Grenadines

1942:
Historically, the Grenadines have concentrated fishing on reef and demersal species (Brown, 1945). It is assumed that before the introduction of launches in 1982, all effort was directed at the small coastal pelagic, reef demersal and deep slope and shelf demersals. The beach seines (2) targeted small coastal pelagics and it is assumed that an equivalent number of vessels were involved. Whalers (19) and canoes (23) targeted demersal reef resources and the sloops (6) targeted deep slope and shelf demersal resources. All vessels were unmechanized except the sloops for which it is assumed that they were fitted with inboard engines of 10 Hp.

1969:
No details are given for the small coastal pelagic fishery, i.e., number of seines. It is assumed that the unmechanized vessels target the inshore reef resources. These comprise transumes (50) and whalers (26).

The mechanized sloops (6) and whalers (17) target deep slope and shelf demersals year round. The horsepower of whalers is given as 5-10 Hp, the higher limit is used. It is assumed that sloops carry diesel engines of 10 Hp.

1982:
The number of vessels is the main data source is an underestimate, as Petite Martinique and Isla Rhonde were excluded from the census. Using the 1998 data and assuming that the tow islands contribute the same proportion to the overall total number of boats it was estimated that 113 boats existed in all the Grenadine islands in 1982. Further, assuming the same relative proportion of the different vessel types as in 1988, it was estimated that there were 17 launches, 63 pirogues, 24 sloops and 9 double-enders. In assigning vessels to fishery types, the same pattern as for 1988 was assumed. Mechanized vessels with outboard engines (63 pirogues) targeted large pelagics by trolling and exploited the inshore reef fishery during the pelagic 'off-season' (typically from July to October). The launches were assumed to target the large pelagics from November to June and the deep shelf and slope demersals from July to October. The sloops (24) targeted the offshore shelf and slope demersals year round while the double-enders targeted the small coastal pelagic fishery (seine fishery) mainly but also exploited the reef demersals from July to October.

Mean horsepower was estimated directly from data provided for pirogues. There was no information available for sloops in the census data. Kawaguchi (1985) noted that inboard diesels of about 32 Hp are installed in larger boats or as auxiliary propulsion for larger sailing schooners. This was assumed applicable to the sloops. The horsepower of launches and double-enders was assumed to be the same as for 1988.

1988:
Vessel types were assigned to the corresponding fishery types based on Mahon (1988). It was assumed that the launches (17) and pirogues (65) fished for large pelagics mainly and inshore reef demersals during the pelagic off-season. The double-enders (9) were assumed to fish mainly for coastal pelagics and for reef demersals between July and October. The sloops (25) are assumed to target deep slope and shelf demersals year round as they have traditionally done. Mean horsepower was taken from Table 1, of Mahon (1988).

1993:
It was assumed that the 62 boats (with outboard engines) target the large pelagics from November to June and the inshore reef demersals from July to October. The 42 unmechanized vessels were assumed to target inshore reef demersals year round and the 3 vessels with inboard engines taken to represent the sloops, which traditionally target the offshore demersals. Mean vessel horsepower was taken from OECS (1995). The 62 mechanized vessels were assumed to be pirogues (40 Hp) and the sloops carried engines of 120 Hp.

1999:
Computerized information from the Trip Interview Program was queried in MS Access to extract the relevant information. In the large pelagic fishery vessels were grouped according to whether they were involved in trolling or longlining, rather than engine type. For categories with few vessels, these were often grouped with other categories when the fishing pattern was similar. Vessels targeting large pelagics with troll lines included 3 launches (2 double-enders and 1 launch); 27 pirogues (2 with inboard and 18 with outboard engines and 7 vessels of unknown category) and 1 unmechanized sloop. Vessels utilizing longlines included 8 launches; 12 pirogues (6 with inboard and 6 with outboard engines); 1 unmechanized pirogue and 3 double-enders. The coastal pelagic fishery was targeted by 2 pirogues (one each carrying an inboard and outboard engine). The inshore reef fishery was exploited by 13 mechanized pirogues (outboard engines); 2 unmechanized pirogues and 1 unmechanized sloop. The offshore demersals were targeted by: 2 dories (outboard engines); 3 pirogues (inboard engines); 88 pirogues (outboard engines); 9 unmechanized pirogues and 1 sloop (inboard engine). Mean horsepower was estimated directly from information in the Trip Interview Program for the respective vessel categories.

St. Vincent and the Grenadines: Reconstructed Fisheries Catches and Fishing Effort, 1942-2001

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ABSTRACT

Time series of catch and effort data were reconstructed for the fisheries of St. Vincent and the Grenadines for the time period 1942 to 1999. Information was obtained from the St. Vincent Fisheries Department's Statistical databases, from historical documents, and from published and unpublished literature. General trends indicated increasing catches since the 1960s and an exponential increase in fishing effort since 1942. A comparison of reconstructed data with reported statistics incorporated in the FAO FISHSTAT database was made, and limitations in reconstructed data are discussed. Generally, catch per unit area (CPUA) for both offshore and inshore fisheries increased over the 58-year period, but considerable inter-annual variability was observed for 1977 onwards. Catch per unit of effort (CPUE) declined exponentially between 1942 and 1999 in the St. Vincent offshore and in the Grenadines inshore fisheries. Compared to other fisheries, CPUE has been consistently higher in the St. Vincent inshore fishery, which operates during the pelagic off-season. Although a decline in catch per unit effort was experienced from the mid 1970s to late 1980s, this has increased again in the 1990s, though at levels substantially below the pre-1975 period.

INTRODUCTION

Study area

St. Vincent is the youngest of the major volcanic islands in the Windward group of the Lesser Antilles (Figure 1.). It lies between Grenada and St. Lucia, due west of Barbados (UNEP/IUCN, 1988). Dependencies of St. Vincent include some 28 rocky islands extending south and including Bequia, Mystique, Canouan, Union and Little Vincent. The Exclusive Economic Zone of St. Vincent and the associated Grenadines occupies an area of 27,069 km^2 (Veridian MRJ Technology, 2000). Total reef habitat is estimated at 140 km^2 (Oliver and Noordeloos, 2002) and slope and shelf area at 1,800 km^2 (Mahon, 1993).

Fishery development

Fisheries in St. Vincent and the Grenadines are multi-gear and multi-species. Detailed descriptions are provided in Brown (1945), Vidaeus (1969), Chakallal (1982), Matthes (1984) and Morris (1991, 1992, 1993, 1995). The reef, slope and shelf fisheries are targeted by handlines, bottom-set longlines, fish pots, spear guns and trammel nets. These capture species such as snappers (Lutjanidae), groupers (Serranidae), parrotfish (Scaridae), squirrelfish (Holocentridae), grunts (Haemulidae), surgeonfishes (Acanthuridae) and triggerfish (Balistidae). The small coastal pelagic fishery utilizes beach seines and cast nets, and captures species such as jacks (Carangidae), herrings (Clupeidae), silversides (Atherinidae), anchovies (Engraulidae), balahoo (*Hemiramphus* spp.)

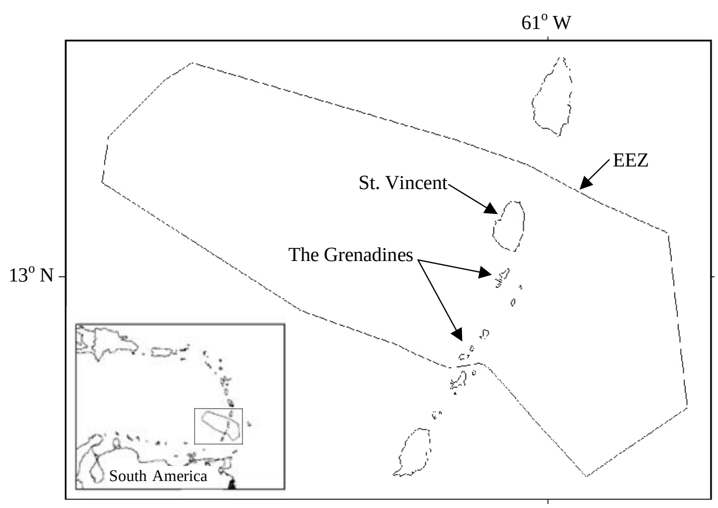


Figure 1: Map of St Vincent and the Grenadines in the Lesser Antilles of the southeastern Caribbean. Indicated also is the EEZ.

and robins (*Decapterus* spp.). Large pelagics like tunas (Scombridae), billfishes (Istiophoridae), dolphinfish (*Coryphaena hippurus*), wahoo (*Acanthocybium solandri*), sharks (Carcharhinidae) and swordfish (*Xiphius gladius*) are caught by troll and surface longlines. Non-fish species such as lobster (*Panulirus argus*), conch (*Strombus gigas*) and sea urchins (*Tripneustes ventricosus*) are taken by divers. A small traditional whaling industry utilizing gun harpoons is also operating out of Barrouallie and Bequia (Grenadines), targeting mainly short-finned pilot whales (*Globiocephala macrorhynchus*) and humpback whales (*Megaptera novaeangliae*), respectively (Brown, 1945; Rack, 1952; Vidaeus, 1969; Adams, 1971, 1973; Caldwell and Caldwell, 1971, 1975).

There is a clear distinction between the various fisheries of importance to St. Vincent and the Grenadines. The dominant fisheries in St. Vincent are the trolling and longline fisheries targeting large pelagics, the beach seine fishery targeting small coastal pelagics and the taking of humpback whales, which are landed at Barrouallie (Chakalall, 1982). Handlining for snappers and groupers, the lobster and conch fisheries and whaling for short-finned pilot whales, which are landed in Bequia, are more popular in the Grenadines (Chakallal, 1982).

Pre 1950s

Little is documented on fisheries in St. Vincent and the Grenadines prior to the 1950s. Whaling was the first important fishing industry, which was established by Americans in the early 1860s (Adams, 1971), and by 1875 a local whaling station was established in Bequia, one of the Grenadine islands. Although the industry declined in the 1920s, it contributed substantially to the knowledge and technology of boat building and sailing, later required for exploiting fin fish (Adams, 1971). Commercial exploitation of fish and shellfish was insignificant until the 1940s, mainly because of a small and unreliable markets for fish. The main source of protein was derived from cheap, salted cod from Newfoundland (Kurlansky, 1997). The small demand for fish in Bequia resulted in little momentum to develop the fishing industry (Adams, 1980). Canouan exported small quantities of processed fish to Kingstown, but transport difficulties associated with the distance between the islands limited trade. Fishing was mainly at the subsistence level in Union Island, although there was some export of turtle shell to Trinidad and processed fish to Grenville (Adams, 1980).

In 1940 the government enacted a price control on fish (Adams, 1985), whereby wholesale and retail prices were set according to a grading system for landed fish. The measure was implemented to ensure the affordability of fish to low income people. However, it was thought to encourage a black market in the selling and buying of fish and to act as a hindrance to the development of the industry (Adams, 1985).

Fishing activity declined considerably during World War II as fishers sought alternative employment on military bases. At the end of the war, there was a mass entry to the fishing industry (Adams, 1980), the only readily available employment. Under the jurisdiction of the Agriculture Department, a ‘fisheries administration’ was created in 1946 with the hiring of one person. This situation prevailed until 1982, when the Fisheries Division was created. Tremendous dissatisfaction with marketing conditions at the main market in Kingstown resulted in the sale of catches, particularly by fishers from the Grenadine island of Canouan, to Grenada. The higher prices and fewer restrictions in Grenada were added incentives to this activity (Agricultural Department, unpublished report, 1949). At the time retailing activities by fishers were prohibited in St. Vincent and the Grenadines, a regulation that was later rescinded. The price control on fish was lifted in 1946.

By the end of the 1940s, Canouan emerged as an important island for salting of fish catches (Agricultural Department, 1949), mainly demersal species caught with bank lines and fish pots. Several reports of fish trading between the Grenadines islands and Martinique indicate this activity as commencing in the late 1940s (Adams, 1971) or early 1950s (Agriculture Department, unpublished report, 1951). Lobster, conch, turtles and demersal fish were sold to boats from Martinique.

In early 1946, an assistance scheme for the development of the shark industry in Barrouallie was implemented, but this was short lived (3 months) due to lack of technical supervision. By the end of the 1940s, there were also demonstrations on the use of trammel nets and construction of the first purse seine net (Agricultural Department, unpublished report, 1948). Though trammel nets later became very important in the Grenadines demersal fishery, purse seines are limited to beach seining (Chakallal, 1982).

1950s to 1980

Grenadines

Little is documented on fisheries during the 1950s. However, the trade between the Grenadines and Martinique acted as an incentive to increased fishing. Between 1955 and 1958 nearly 227 t of fish was exported to Martinique (Adams, 1980). Conch fishing became an important activity on Union Island (Grenadines), stimulated by the strong demand in Grenada and Trinidad, growing unemployment and the observed high abundance in nearby waters (Adams, 1970). Throughout most of the 1950s and 1960s conch caught at Union Island was sold to Grenada (Adams, 1980) and Trinidad (Adams, 1970). During the 1960s this fishery was the most important economic activity on Union Island (Mahon, 1987), although, by the early 1970s virtually all conch was sold to Martinique (Adams, 1980). The resource was rare in the northern Grenadines (Bequia and Mystique) and by 1966 the resource was already showing signs of depletion in established fishing areas due to overfishing (Adams, 1970).

Fishing in the 1960s was still mainly a subsistence activity with most fishers operating on a part-time basis (Vidaeus, 1969). Activities at Canouan received government support through the introduction of a cold storage facility and construction of a loading jetty in Canouan in 1960 (Agricultural Department, 1961). Iced and salted fish were purchased from the island and sold in the main market at Kingstown in St. Vincent and in Grenada. An auxiliary sloop was introduced in 1962 to transport ice to Canouan and purchase iced fish from the island. The sloop also transported fish to neighbouring islands of St. Lucia and Dominica (Lewis, 1964). By 1964 however, fishers had reverted to drying and salting fish for sale in St. Vincent or Grenada. Bequia had emerged as an important trading island for lobster and demersal fish and two trading schooners from Martinique were sent to the Grenadines each month for this purpose (Lewis, 1964).

The government's policy of increased fish production was manifested in its participation in a joint program sponsored by the United Nations Development Program (UNDP) and the Food and Agriculture Organization (FAO). The Caribbean Fishery Development Project supported market development and the training of fishers (Vidaeus, 1969). Financial assistance was provided through a loan scheme initially implemented by the Agricultural Department in the early 1960s which was taken over by the St. Vincent Agricultural and Co-operative Bank in 1969. This offered duty-free privileges for the purchase of engines, timber (for boat construction) and gear. However, there were problems with the efficient implementation of the scheme (Vidaeus, 1969). In 1963, a four-fold increase in the catches of blackfish (short-finned pilot whale) over the previous year was attained through the introduction of mounted harpoon guns (Lewis, 1964).

A fisheries development program was instituted in association with the Ministry of Overseas Development in the United Kingdom beginning in the early 1960s, which included infrastructure development in Canouan and cold storage and ice facilities at Kingstown. The government also granted licenses to companies in the French Antilles facilitating the purchase of fish from the Grenadines at guaranteed prices. This arrangement did not last very long, however, and was eventually abandoned. In addition to Martinique, fish from the Grenadines (Canouan and Bequia) were sold to Guadeloupe (Vidaeus, 1969).

St. Vincent

Most fishing off St. Vincent was conducted off the west and south coasts at which there were ten 'fishing centers'. Facilities at the 'fishing centers' included, at most, a shed used as the fish market and running water. No fuel facilities were available. Fishing on the windward (east) coast was insignificant and there were no fishing centers. Three of the fish markets (Chateau Belair, Layou and Calliaqua) were the property of the Town Board, while the main market in Kingstown was administered by the St. Vincent Marketing Board. The price control implemented in 1940 was discontinued (Vidaeus, 1969). However, a new fish marketing scheme was implemented in the Kingstown market in 1969: the market had the sole buying authority and guaranteed a fixed price to fishers, based on a new pricing structure. The intention was to relieve the fishers of dependency on 'middle-men' and thereby promote increased fishing and a better supply of fish to the public.

In the early 1970s, only 6.13% and 14.8% of the fleets in St. Vincent and the Grenadines, respectively, were motorized (Cecil, 1972). Although it is reported that engines were being used 15-18 years previously, the bulk of the engines were acquired starting in the early 1960s.

The blackfish (pilot whale) industry also started to decline in the 1970s (Adams, 1973). This was attributed to reduced interest by potential fishers, increased evasion of whales from the motorized boats (sound), world inflation and associated high fuel and equipment costs, and the 1972 US Marine Mammal Protection Act which prohibited the export of high priced melon oil to the US. By the mid-1970s depletion of lobsters and turtles was apparent (Agricultural Department, 1975) and the extension of closed seasons for these resources were being considered.

In the 1970s, the government sought to decrease the substantial imports of processed fish by increasing local fish catches. In addition to increasing the number and technical capability of staff, improved methods of fish harvesting, greater monitoring of duty-free importation and other incentives such as fuel subsidies, establishment of fishing co-operatives and revitalization of the blackfish (pilot whale) industry were also to be introduced. International assistance was sought to address inadequate cold storage and processing capabilities (Agricultural Department, 1975). Efforts to set up fishing co-operatives continued throughout the late 1970s (Agricultural Department, 1979). The smuggling of lobsters, fish and conch from the Grenadines by boats from Martinique was a major on-going problem, especially since the activity was supported by local fishers who obtained high prices for their catch (Agricultural Department, 1979).

1980s

In August 1980 Hurricane Allen caused fleet and gear damage of about US$ 26,000. Altogether 31 boats were affected and beach seines and fish pots were destroyed (Agricultural Department, 1980). At this time fishers were also complaining about the sharp increases in fuel prices and the lack of a proportional increase in fish prices (Agricultural Department, 1980). This resulted in a decline in fishing activity. Exports from the Grenadines were particularly affected as only 2 boats operated in 1980. Apart from high fuel costs, the high costs of engines and scarcity of spare parts were also contributing factors for the substantial decline in fishing activity. At this time, several resources were already showing signs of over-exploitation (Matthes, 1984). Conch catches were limited with exports going primarily to Martinique (Mahon, 1987). The use of Scuba gear and faster boats utilized in the fishery suggested that greater effort was required to extract the catch from depleted populations (Chakallal, 1982). Smaller sizes of lobsters in the catch and unavailability in shallow waters suggested a similar fate of this resource. Fishers responded by fishing in deeper waters. The whaling industry was also in decline.

The general consensus was that demersal resources, excluding lobster and conch, could withstand an increase in artisanal fishing effort (either by increasing the number of boats or the efficiency of existing methods). However, industrialization of the fleet was not recommended until the status of the resource was determined. The pelagic fishery was thought able to accommodate an increase in fishing effort, though under controlled conditions to avoid population declines in transboundary stocks. Unlike neighboring islands, the flying fish fishery was not important in St. Vincent and the Grenadines. This fishery was seen as another avenue for development (Chakallal, 1982).

Attempts to set up fishing co-operatives mostly failed, with only those under the guidance/control of the fisheries administration being successful. A loan scheme was still in effect, and engines and gear were provided free of duty. However, facilities at the major fish market in Kingstown were in disrepair and there was no organized marketing scheme. Wholesale and retail prices were still under government control (Morris, 1984). Fishing activity was still largely for subsistence as most fishers operated part-time, and had alternative sources of employment (Matthes, 1984).

Japanese assistance commenced in 1987 and was aimed at development of offshore fisheries, domestic distribution, export systems, and training of fishers (St. Vincent

Fisheries Department, 1999). These came to fruition in the 1990s.

1990s

A joint project funded by the government of St. Vincent and the Grenadines and the Canadian International Development Agency was implemented in the early 1990s (St. Vincent Fisheries Department, 1999). The project aimed to support and enhance the St. Vincent and the Grenadines fisheries institutional capacity, community self-help activities and organizations, and to allow sustainable growth of the industry.

Significant development was also achieved through a Japanese Grant Aid Program. This included the upgrade of facilities at the main market at Kingstown (Morris, 1992) and construction of fisheries centers at Union Island, Canouan, Bequia and Calliaqua (St. Vincent Fisheries Department, 1999). In 1991 five new 12.5 m multi-gear vessels equipped with longline and trolling gear were acquired from Japan (Mahon and Singh-Renton, 1992). This marked the establishment of a tuna longline fleet resulting in escalation of the importance of large pelagic resources such as tuna, billfish and shark in the 1990s (Morris, 1992, 1995). Research and management support to assess the status of pilot whales and the bottlenose dolphin were also sought from the Japanese Grant Aid Program. Another program in collaboration with St. Lucia and Grenada aimed at assessing the status of the warsaw grouper (*Epinephelus nigitus*).

Fisheries were still predominantly small-scale and artisanal (Morris, 1995) with most vessels being open and powered by outboard engines. However, by the end of the 1990s considerable infrastructure development had occurred in the Grenadines (Paget Farm, Britannia Bay, Mystique, Friendship, Clifton) and Calliaqua in St. Vincent (Straker *et al.*, 2001). Similar facilities were planned for Barrouallie and Chateaubelair. The improvement and establishment of facilities and the increased harvesting of off-shore fisheries are indicative of the future developments in the fisheries sector.

Fisheries statistical data collection

Prior to 1992 data collection was confined to landings at the major market at Kingstown and exports from the Grenadines to Martinique. The Barrouallie Fisherman's Co-operative Society had historically recorded captures of whales and porpoises (Adams, 1973). In the 1960s fish landings at the market represented 60% of total landings throughout St. Vincent and the Grenadines (Vidaeus, 1969). In 1988 plans were formulated under the Organization of Eastern Caribbean States (OECS) for a revised data collection system (Morris *et al.*, 1988). This revised data collection system was implemented in 1992 under the CARICOM Fisheries Resource Assessment and Management Program (CFRAMP) and is still in effect. A system of random stratified cluster sampling was implemented at seven zones, with catch and effort data recorded at representative sites within each zone. Landing sites are categorized into primary, secondary and tertiary sites based on the number of fishing boats landing regularly at the site, the amount of fish landed and the level of infra-structure development (Straker *et al.*, 2001). At Kingstown and Barrouallie there are two primary sites, 14 secondary sites and 20 tertiary sites. Data are also collected from trading vessels operating in the Grenadine/Martinique fish trade. Total landings are estimated by applying a raising factor to account for days when data are not recorded. A licensing and registration program is in effect and an inventory of distant water fishing vessels registered with St. Vincent and the Grenadines is maintained. The Trip Interview Program (TIP), a data management program introduced under the CFRAMP, is presently being used for data entry, management and analysis.

Fisheries policy

The fishery policy in the 1980s focused on the provision of jobs in the industry by upgrading the performance of existing fishermen and improving services and facilities (Andersen *et al.*, 1983). St. Vincent, being a member of the Organization of Eastern Caribbean States (OECS), has also enacted the harmonized fisheries legislation. Presently the three pieces of legislation governing fisheries management include: the Maritime Areas Act No. 15/1983 declaring an Exclusive Economic Zone; the Fisheries Act No. 8/1986 for the promotion and management of fisheries and related matters and the Fisheries Regulations for regulation of foreign fishing licenses, fish processing establishment licenses, fishery conservation measures, fish aggregation devices and fisheries research. The aim of policy in the 1990s was to promote sustainable utilization of all fishery resources within the EEZ (Morris, 1992). Policy promoted the gradual development and expansion of a national offshore fleet, while ensuring the legal framework existed to protect the smaller artisanal boats that traditionally targeted the same species.

Objectives

The main objective of the present study was to assemble a time series of catch and effort data for St. Vincent and the Grenadines.

METHODOLOGY

Catches

Most available data were from recorded landings at the fish market in Kingstown. Fish from throughout St. Vincent (but mainly the leeward coast) and the Grenadines were transported to this market. Information in Brown (1945) and Vidaeus (1969) was used to disaggregate recorded catches into the respective components for St. Vincent and the Grenadines. Landings attributed to St. Vincent accounted for 50% in the early 1940s to 60% from the late 1950s to late 1960s (Vidaeus, 1969). It was assumed that minimal landings from the Grenadines were transported to St. Vincent after the late 1960s as the fish trade with Martinique was well established after this point (Chakallal *et al.*, 1997). Landings at the Kingstown market were reported to represent 50% of the overall landings in St. Vincent during the early 1940s to mid-1960s; 60% from the mid to late 1960s and declined steadily from 45% in the late 1960s to 29% in 1995.

St. Vincent

Anchor Points

1942: Smyth (1957) provided total annual catch estimates of 181 t Brown (1945) derived a crude annual estimate of 1,684 t (67% attributable to St. Vincent with the remaining 33% to the Grenadines).

1948-1949: Recorded landings at the Kingstown Fish Market were available in the reports of the Agricultural Department. Data were adjusted accordingly to represent total catches in St. Vincent only, assuming that the recorded data represented 50% of total landings in St. Vincent. The report of 1949 also provided data for landings at Layou and Calliaqua which were estimated to represent 3.4% and 6.4% of the total, respectively.

1958-1968: Recorded landings at the Kingstown market were available in Vidaeus (1969). Data for 1959 to 1964 matched those in the Colonial Report (Part I) of 1964/65 (Anon., 1965). Data for 1962 to 1964 matched those in the Fisheries Report of Lewis (1964). Recorded data in the Colonial Report exceeded that from other sources for 1965. This higher estimate was used in calculations. It was assumed that 60% of recorded landings were from catches by the St. Vincent fleet and that recorded catches represented 60% of the overall total for the island.

1975-1981: Chakallal (1982) provided data on fish landings at the Kingstown Fish market. He assumed this represented 45% of the total fish catch in St. Vincent, which was used in estimation of the associated annual total catch. The St. Vincent Fisheries Department's Statistical Database also provided data on landings at the Kingstown Fish Market from 1979 to 1981. However, these estimates were lower than those stated in Chakallal (1982), and were also lower than estimates from the Agricultural Department for 1979 and 1980. The higher estimates were used in subsequent analyses.

1982-1999: Data were obtained from the St. Vincent Fisheries Department's Statistical Database. Prior to 1993, data consisted solely of landings at the Kingstown Fish Market and exports, mainly from the Grenadines Islands. Beginning in 1993, data sources consisted of 1) a total census of landings at the Kingstown Fish Market; 2) data from 36 additional landings sites obtained from a random stratified cluster sampling system; and 3) fish exports. It was assumed that landings at the Kingstown Fish Market accounted for 45% of total landings in St. Vincent prior to 1985. Since data on landings at the Kingstown market were not available for 1993 and 1994, the estimated total landings for 1995 (which utilized data for both the Kingstown market and other landing sites) was used to estimate the relative contribution of catches from the Kingstown Fish Market (46.6%) to the overall total. The relative contribution of landings at the Kingstown Fish Market to overall total landings in St. Vincent between 1986 and 1994 was estimated by interpolation between the 1985 and 1995 values. This was used to derive estimates of total annual catch for 1985 to 1992 from recorded data at the market.

First Interpolation: Total catches

Total catches from 1943 to 1947 were estimated by interpolation from estimates for 1942 (Smyth, 1957) and 1948 (Agricultural Department, 1948). The same procedure was used to estimate the total catch for the periods 1950 to 1957 and 1969 to 1974.

Second Interpolation: Species Composition

There was no documentation on species composition prior to 1967. Brown (1945) derived a crude estimate of total catch by fleet. Although the estimate was not used in the actual catch reconstruction because of uncertainties associated with the magnitude of total catch and respective fleet catches, it was used to apportion the 1942 catch into the respective offshore and inshore components. It was assumed that catches from part-time fishing comprised solely of inshore species, harvested during the pelagic off-season. Vidaeus (1969) provided information on the species composition of landings/catches at the Kingstown Fish Market in 1967 and 1968. This comprised of 12 species: robin (*Decapterus macarellus*), jacks (*Selar crumenophthalmus*), skipjack tuna (*Katsuwonus pelamis*), redfish (Serranidae and Lutjanidae), hind (*Epinephelus guttatus*), dolphin (*Coryphaena hippurus*), spratt (*Harengula pensacolae*), ballahoo (*Hemiramphus balao*), dodger (*Decapterus punctatus*), bonito (*Thunnus atlanticus*) and barracuda (Sphyraenidae). All other species were grouped in an aggregate category accounting for 6-14% of the total. The species composition between 1969 and 1978 was estimated by interpolation of estimates for 1968 (Vidaeus, 1969) and 1979 (based on the Fisheries Department's Statistical Database on recorded catches at the Kingstown Fish Market). The proportion of total catch attributed to the offshore and inshore fisheries between 1943 (Brown, 1945) and 1966 was interpolated, using data from Brown (1945) for 1942 and Vidaeus (1969) for 1967. The corresponding estimates of offshore and inshore catch were calculated as the product of the respective annual proportion of total catch and the total catch estimated previously. Between 1979 and 1992 the species composition from recorded data at the Kingstown Fish Market was assumed representative of total catches. In all instances, the actual species weights were estimated using the associated species composition and total catch estimated. Annual estimated total landings by species were available for 1993 to 1999 from the St. Vincent Fisheries Department.

Estimation of marine mammal catches

Barrouallie is the main site from which marine mammals are targeted in St. Vincent. Catches include mainly blackfish and porpoises. Comprehensive descriptions of the fishery are provided in Brown (1945), Rack (1952), Videaus (1969), Adams (1971, 1973), and Caldwell and Caldwell (1971, 1975).

Pilot Whales: The number taken was estimated based on 'fish oil' exports (assuming the oil was derived only from pilot whales) or from landings at Barrouvaille. In 1944 about 596 gallons of blackfish oil were shipped to Trinidad, Barbados and Grenada (Brown, 1945). Using the mean quantity of oil produced per whale (14 gallons; after Brown 1945), a minimum of 43 animals were estimated to be taken. This was converted to the equivalent weight using the mean individual weight of 0.64 tonnes for short-finned pilot whales (Trites and Pauly, 1998). The annual report of the Agricultural Department (1946) indicated 1,627 gallons of fish oil was exported in 1946. Similar reports for 1948 and 1949 indicated 135 and 272 pilot whales caught in the respective years. Approximately 937 and 293 gallons of oil were exported to Trinidad in 1960 and 1961, respectively (Agricultural Department, 1960, 1961). Using the conversion after Brown (1945) and Trites and Pauly (1998) the equivalent weight was estimated. Caldwell and Caldwell (1975) provided estimates of annual numbers of blackfish landed at Barrouallie from 1962 to 1974. Except for 1964 and 1965 these estimates exceeded the annual numbers for 1962 to 1968 in Vidaeus (1969), and for 1962 to 1964 in Lewis (1964). Chakallal (1982) gave an estimate of 125 animals. The higher estimates were used. The annual reports of the Agricultural Department for 1979 and 1980 indicated 25 and 23 blackfish landed in the respective years. Records of the St. Vincent Fisheries Department indicated the quantity of blackfish oil exported from 1986 to 1999. Using the conversion factor after Lewis (1964), the corresponding number of whales was estimated and converted to the equivalent weight using the mean weight from Trites and Pauly (1998).

Sperm Whales: The 1949 annual report of the Agricultural Department provided an estimate of the number of sperm whales caught in the respective year while Vidaeus (1969) gave estimates for 1962 to 1968. Corresponding weights were estimated using a mean individual weight of 18.5 tonnes (Trites and Pauly, 1998). Lewis (1964) also provided estimates of sperm whale catches from 1962 to 1964, although only the estimate for 1963 was used as this was greater than that provided in the Agricultural report. Caldwell and Caldwell (1975) provided estimates of landings at Barrouaille between 1967 and 1974. Estimates for 1967 and 1968 were, however, lower than those provided by Vidaeus (1969). Consequently, the higher estimates were used.

Other Whales: Caldwell and Caldwell (1975) provide estimates of killer whales (*Orcinus orca*) and false killer whales (*Pseudorca crassidens*) landed at Barrouallie between 1967 and 1974. Landings of porpoises at the Kingstown market between 1972 and 1974 are also provided. This comprised several species but the spinner dolphin (*Stenella longirostris*) accounted for a large portion of the catch. The reports of the Agricultural Department for 1979 and 1980 provided estimates of 18 and 15 dolphins landed in the respective years. The weight of porpoise caught between 1979 and 1999 were available from the St. Vincent Fisheries Department's statistical database.

Estimation of marine turtle catches

Four species of turtles are present: the green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), leatherback (*Dermochelys coriacea*) and loggerhead turtle (*Caretta caretta*) (Matthes, 1984). Only the green and hawksbill are regularly fished, either by net or harpoon. The quantity of turtles exported between 1935 and 1946 was taken from the Caribbean Commission Central Secretariat (1948). The fishery is based mainly on green and hawksbill turtles with approximately 65 to 70% of the total catch coming from Bequia (Rebel, 1974). There is no market data available for the green turtle so it was assumed that all exports were hawksbill turtles with a mean weight of 51 kg (Witzell, 1994). Exports of hawksbill shell ('bekko') from 1974 to 1986 were taken from Milliken and Tokunaga (1987). Assuming 1.15 kg of shell per individual (Ogren, 1989) the corresponding numbers of turtles was estimated. For the periods 1987 to 1989 and 1992 to 1999, data were from the Fisheries Department's statistical database and pertain mainly to the export of turtle meat. No conversion factor is available to translate this into total weight of turtles caught.

The Grenadines

Anchor Points

1942: Smyth (1957) provided an annual estimate of 205 t for the Grenadines.

1949: Assuming the same relative contributions of St. Vincent as in 1942, and using the 1949 estimate of total catch for St. Vincent (Agricultural Department, 1949), an estimate of 265 t was derived for the Grenadines.

1958-1968: Vidaeus (1969) provided data on recorded landings at the Kingstown Fish Market, 40% of which was assumed to be landed by boats from the Grenadines. Based on a crude estimate of total annual landings of the respective fleets using assumed catch rates for the respective islands (Vidaeus, 1969), St. Vincent and the Grenadines accounted for 55% and 45% of the total landings, respectively. Total annual landings in the Grenadines were estimated using the relative percentage contributions and estimates of total landings derived for St. Vincent. It was assumed that Grenadine landings at the Kingstown market were also accounted for using this method. Recorded landings at the Kingstown market accounted for 35-49% of total annual catches in the Grenadines using this method.

1975-1980: Chakallal (1982) gave exports of fish from the Grenadines derived from statistics of the Fisheries Division, Ministry of Agriculture, Trade and Tourism. Specific limitations of the data include the disregard of fish consumed locally, the non-inclusion of unofficial exports and the inaccuracy of weights which are usually estimated by eye rather than measured directly. Export data for 1979 was taken from the Annual report of the Agricultural Department for the respective year (120 t) as this slightly exceeded the estimate for the corresponding year in Chakallal (1982). Export data for this period represent minimum estimates as these include exports from Union Island but exclude exports from Bequia and Canouan. Fish exports represented about 60% of total catch (Matthes, 1984), hence recorded exports were adjusted accordingly to represent total catch. Based on raised estimates for 1993 (provided by the St. Vincent Fisheries Department), Union Island accounted for 38.54% of total catches from the Grenadines. Export data were adjusted accordingly to account for landings at Bequia and Canouan in total catch estimates for 1979 and 1980.

1981-1994: Data were available from two main sources. Firstly, the Statistics Bureau of Martinique Customs summarized in Chakallal *et al.* (1997) gave estimates of fish imports from St. Vincent and the Grenadines from 1981 to 1993. Secondly, records of the St. Vincent Fisheries Department statistical database provided data on fish exports from 1984 to 1994. Based on Matthes (1984) and Morris *et al.* (1988), fish exports were assumed to account for 60% of total landings of seine and demersal fish caught in the Grenadines. Exports from St. Vincent were assumed negligible. Annual catch was estimated by adjusting export data accordingly. Except for 1989 and 1993, data from Chakallal *et al.* (1997) exceeded corresponding estimates in the Fisheries Department Statistical Database. In all instances the higher estimates were used, consistent with a precautionary approach to assessment.

1995-1999: Estimates of total catch were provided by the St. Vincent Fisheries Department for 1995 to 1999. These estimates were derived from recorded data for 15 sites in the Grenadines (Admiralty Bay; Friendship Bay; Lapompe Bay; Lower Bay; Paget Farm; Shipping Bay; Trading Vessels; Ashton; Canouan; Clifton; Palm Island; Petit Martinique; Petit St. Vincent; Saline Bay and Union Island). Recorded data were adjusted to account for non-enumerated days.

First Interpolation: Total Catches
Annual total catches for 1943 to 1948 were estimated by interpolation between the 1942 estimate (Smyth, 1957) and the 1949 estimate (Agricultural Report, 1949). Similarly, estimates were derived for 1950 to 1957 and 1969 to 1974 using the anchor points described previously.

Second Interpolation: Species Composition
Pre 1984: No data are available upon which the species composition of the catch could be estimated.

1984-1991: Export data were disaggregated for specific groups only. These included lobster, conch, whelk (*Cittarum pica*), turtle and tri-tri (*Sicydium plumieri*), while all other fishes were aggregated into one category. No data were available from which the aggregate fish category could be disaggregated into its species components. Based on Chakallal *et al.* (1997) the species preferred by trading vessels from Martinique are snapper, redhind, grouper, butterfish/coney (*Cephalopholis fula*), caca belly/parrotfish (*Sparisoma aurofrenatum*), mackerel, cavalli (*Caranx* spp.), jacks and robins.

1993-1999: Export data are disaggregated into the respective species groups. There is however, a high level of aggregation in 1993. Exports of large pelagics, including yellowfin tuna (*Thunnus albacares*), swordfish and bigeye tuna (*Thunnus obsesus*) were assumed to have originated from St. Vincent (Morris, 1995).

Estimation of marine mammal catches
Humpback whales (*Megaptera novaeangliae*) are caught off Bequia in the Grenadines. The annual number of whales caught from 1898 to 1938, and 1950 to 1984 were taken from Price (1985) and were based on the amount of oil produced. The 1979 estimate concurs with that provided by the report of the Agricultural Department for the respective year. Weights were estimated using a mean individual weight of 30.408 tonnes (Trites and Pauly, 1998). Brown (1945) indicated that no whales were caught between 1940 and 1944, while three were killed in 1945. The 1982 annual Agricultural report indicated two whales were harpooned in that year.

Fishing Effort

The Unit of Fishing Effort
The unit of fishing effort used in the analysis was horsepower-days. The rationale for its selection is discussed in a general methodology report by Mohammed (this volume).

Data Sources
There were several sources of information, however, only those which enabled separation of effort for St. Vincent from the Grenadines were used.

1942: Estimates of the number of boats by size as well as the number of gear units (beach seines, jack seines and gillnets) used at several landing sites along the windward (seven sites) and leeward coasts (21 sites) of St. Vincent, and seven sites in the Grenadines was provided in Brown (1945). The number of whale boats at Barrouaille and Bequia was also given.

1949: The 1949 annual Agricultural report gave data on the total number of boats in St. Vincent as well as Bequia, Canouan, Mayreau and Union Island. The associated number of whales boats, beach seines and fishermen was also provided.

1959: Adams (1971) estimated six whaleboats at Bequia, targeting humpback whales.

1968: Data were extracted from Vidaeus (1969) from a description of the respective fisheries and gave the number of boats involved in the handline and pot fishery in St. Vincent and the Grenadines (Bequia, Canouan, Mayreau, Union Island, Mystique). The relative quantity of mechanized and unmechanized boats was also provided and the number of beach seines given.

1971: Adams (1971) estimated nine whaleboats at Barrouallie, targeting pilot whales and porpoises.

1981: Chakallal (1982) provided data from an artisanal fishery survey in St. Vincent and the Grenadines. Specifics on the number of vessels by size and design (fiberglass pirogue, planked or dug-out canoe), the number of mechanized boats and the corresponding number of fishers for 18 landing sites in St. Vincent, and the Grenadine islands of Bequia, Canouan, Mayreau and Union Island. The number of flyingfish nets, beach seines, ballyhoo nets, trammel nets, cast nets and turtle nets was also provided. Based on Matthes (1984) mechanized vessels carried outboard engine of 25-40 Hp average, while Morris (1984) gave a range of 25-55 Hp. An estimate of 40 Hp was used. Matthes (1984) indicated inboard engines of 40-70 Hp average. An estimate of 70 Hp was used.

1999: Data were available from the Fisheries Department's Licensing and Registration System. Details on vessel type, engine type, engine horsepower and port of operation were used. Missing data on vessel type and engine horsepower were estimated by comparing information on vessel length at similar sites and for similar fishery types. Mean horsepower was estimated directly for specific vessel types in St. Vincent and the Grenadines. In St. Vincent the mean horsepower of pirogues (commercial), pirogues (sport), canoes, bow and stern vessels, and semi-industrial longliners was 65, 438, 45, 51 and 241, respectively. The same mean horsepower of canoes and bow and stern vessels was estimated for the Grenadines. However, the mean horsepower of commercial pirogues (n = 59), sport pirogues (n = 500), semi-industrial longliners (n = 172) was different. Sloops and mechanized double-enders in the Grenadines carried engines of 50 and 32 Hp, respectively.

Linking fishing effort to fishery type

1942: Based on a description of the respective fisheries in Brown (1945) the St. Vincent fleet consisted of 285 boats. Eighty-four boats and 42 beach seines operated year round in the small coastal pelagic fishery (Brown, 1945) on the leeward coast of St. Vincent. These were divided equally among large and small boats. It was assumed that all other boats targeted flyingfish and large pelagics from February to May, and demersal resources during the pelagic off-season. These comprised 81 small boats and 120 large boats. The two whaleboats in St. Vincent (Barraouallie) targeted the pilot whale and porpoises. All boats were unmechanized.

In the Grenadines there were 127 boats. The large pelagic fishery was unimportant. Based on the number of beach seines, 11 small boats and 11 large boats targeted the coastal pelagic fishery, year round. The remaining boats (42 small boats and 63 large boats) exploited the demersal fishery year round. The four whaleboats in Bequia (Grenadines island) targeted humpback whales (Brown, 1945). All boats were unmechanized.

1949: There were 180 boats in St. Vincent and 124 in the Grenadines all of which were unmechanized. In St. Vincent 32 boats targeted the small coastal pelagic fishery (based on the number of beach seines). It was assumed that the remaining boats (148) targeted large pelagics from December to June and demersal resources during the pelagic off-season. In the Grenadines, 24 boats targeted the small coastal pelagic fishery and the remaining boats (100) targeted the demersal resources.

1969: There were 30 beach seines in St. Vincent. The associated number of boats was 60, all unmechanized. Of the 275 boats involved in the handline/pot fishery (large pelagics and demersals), 35 were mechanized and 240 unmechanized. It was assumed that these fished with the same pattern as in previous years (i.e., targeting demersal resources during the pelagic off-season).

In the Grenadines there were 20 beach seines and 40 associated boats. There were 227 boats involved in the handline and pot fishery, 52 of these were mechanized and 175 unmechanized. It was assumed that all vessels targeted demersals (on reef, shelf and deep slope) year round. There were 12 boats involved in whaling. Four of these were based in Barrouallie (involved in whaling for pilot whale) and carried inboard motors. It was assumed that the remaining eight boats operated out of Bequia and targeted humpback whales. No information was available on the horsepower of mechanized vessels. An estimate of 25 Hp was assumed.

1981: In St. Vincent a total of 508 boats existed. Of these, 179 were over six meters and the remainder (329) were smaller. The large boats comprised 38 fiberglass boats, 107 planked boats and 34 canoes. The smaller boats comprised four fiberglass pirogues and 325 planked boats. Of the total number of vessels only six were powered by inboard engines and 121 powered by outboard engines. There were also two flyingfish nets, 64 beach seines, 19 ballyhoo nets, 13 trammel nets, 25 cast nets and four turtle nets. Based on the number of beach seines it was assumed that 64 of the 107 large planked boats and 64 of the 325 small planked boats were involved in this fishery. All vessels were unmechanized. It was also assumed that other nets were utilized occasionally by the same boats utilizing beach seines. All other boats were assumed to target mainly pelagic species during the associated season and demersals during the pelagic off-season. Of the large planked boats not involved in the beach seine fishery (43), six were assumed to carry inboard engines and the remaining 37 outboard engines. The fiberglass boats (large and small), canoes and 15 of the small planked boats were assumed to carry outboard engines, while the remaining 246 small boats were assumed to be unmechanized.

In the Grenadines a total of 305 boats were recorded, 95 of which were planked and over six meters and the remaining 210 were smaller. There were 126 mechanized boats, seven of them carrying inboard engines, and the remainder carrying outboards. There were 27 beach seines, 66 trammel nets, 175 cast nets and 61 turtle nets combined in the respective Grenadine islands. It was assumed that 27 of the large planked vessels and 27 of the small planked ones were involved in beach seining year round. These were all unmechanized and assumed to utilize the other net types as well. The remaining boats (68 large planked and 183 small planked) targeted the demersal fishery (125 were unmechanized, 119 carried outboard engines and seven carried inboard engines). It was assumed that seven of the large planked boats carried inboard engines and the remaining 61 carried outboards, while 58 of the small planked vessel carried outboard engines and the remaining small vessels (125) were unmechanized. There were also five whalers at Barrouallie targeting pilot whales and two at Bequia, targeting humpback whales. It was assumed that all beach seine boats were unmechanized.

1999: Vessels were assigned to fishery type based on data in Morris *et al.* (1988) assuming the same conditions as the late 1980s. In St. Vincent double-enders utilize beach seines only, while pirogues utilize mainly troll gear to capture large pelagics and target demersals during the pelagic 'off-season'. The bow and stern vessels and canoes target the same resources as pirogues. Launches or semi-industrial vessels target large pelagics year-round utilizing both troll and longline gear. In the Grenadines, double-enders target mainly demersals (shallow and deep water) using traps and handlines. These vessels also utilize beach seines. Since they troll and fish for conch only occasionally, the associated effort was considered negligible and therefore not incorporated. Pirogues are not linked to a specific fishery, but it is assumed that these use troll gear for large pelagics mainly, and fish for demersals during the pelagic 'off-season'. Sloops fish for demersals and bow and stern vessels target mainly lobster, conch and utilize beach seines. Whalers target mainly humpback whales. In 1999 only one semi-industrial launch operated from the Grenadines. It was assumed that these targeted offshore pelagic fishery. Also, there were five pirogues involved in the recreational fishery in St. Vincent and one in the Grenadines. These were assumed to target pelagics as well.

Assigning fishing days to the respective fleets and fisheries

Recreational pirogues were assumed to fish from January to July, on weekends only. The total number of fishing days was 56. Double-enders, and bow and stern vessels in the Grenadines were assumed to fish year round, on average 20 days per month from February to October (excluding one month for vessel maintenance) and 10 days per month between November and January. The total number of fishing days using this method was calculated to be 230. The 230 fishing days were divided equally between the small coastal pelagic and the demersal reef and slope fishery components of the inshore fishery. The same was assumed for 1988. Semi-industrial vessels were all assumed to be involved in longline fishing for large offshore pelagics year round and that fishing occurred on average 20 days per month excluding one month each year for vessel maintenance, leading to a total of 220 fishing days. Unpowered double-enders, bow and stern vessels, dories and pirogues were assumed to target the beach seines fishery for small coastal pelagics in St. Vincent, year round.

Humpback whales are targeted by fishers from Bequia, from January to May, but mainly around March and April. It was assumed that whaling occurred 12 days per month in March and April and 6 days in other months leading to a total of 42 fishing days. Pilot whales are hunted by fishers from Barrouallie between May and September. It was assumed that fishing occurred 12 days per month, giving a total of 60 days.

Annual trends in catch per unit area (CPUA) and catch per unit effort (CPUE)

Using reconstructed catches for the inshore and offshore fisheries and the estimates of the EEZ, reef, slope and shelf areas in the methodology report by Mohammed (this volume), a time series of trends in catch per unit area was derived. Catch per unit effort was estimated as the ratio of reconstructed catch and reconstructed effort for the respective fisheries. Data for missing years were estimated by interpolation between point estimates for years based on the literature.

RESULTS

Fisheries catches

Estimated total catches for St. Vincent and the Grenadines are presented in Figure 2. Since St. Vincent operates an open register for foreign vessels, catches are reported for several regions, including the north Atlantic and Pacific regions. Only catches in the western central Atlantic region are presented here, since these reflect catches of the local St. Vincent and the Grenadines fleet. Reported catches in FAO FISHSTAT exceeded reconstructed catches between 1954 to 1971 by four to 262 t. Reconstructed catches between 1971 and 1987 were consistently higher than data for corresponding years in FISHSTAT, but exceeded reconstructed catches in the early 1990s and late 1990s. Generally, reconstructed catches from the late 1980s mirrored reported catches in FISHSTAT.

Overall, reconstructed catches increased by over 194% between 1962 and 1999. Reconstructed catches remained generally low (below 500 t) and constant between 1942 and 1969 (Figure 2a), but increased between 1969 and 1975 from 496 t to 878 t. Considerable variability was observed thereafter, with reconstructed catches ranging between 602 t in 1980 and 1,605 t in 1994. Catches in the St. Vincent inshore fishery far exceeded those from the offshore fishery from the late 1960s, throughout the 1970s and in the most recent years (Figure 2b). Catches in the inshore fishery have ranged between 400 t and 800 t between 1995 and 1999. The majority of the catch in the Grenadines was from the inshore fishery (Figure 2c). The general trend is a decline from the early 1950s to late 1970s, followed by a considerable and sudden increase in the early 1980s. Catches declined thereafter, from about 811 t in 1981 to 88 t in 1997.

Excluding marine mammals and turtles, reconstructed catches are reported for up to 91 species/groups. Several of these groups, however, remain very broad, e.g., ‘snappers’ or ‘groupers’. Catches for St Vincent were disaggregated from the late 1960s, beginning with 11 groups and increasing to 70 species/groups by 1994 (Figure 3a). Fewer species/groups were represented for the Grenadines, beginning with 5 groups in 1986 and increasing to 25 groups by 1998 (Figure 3a). Reported catches in FAO FISHSTAT was disaggregated into considerably fewer categories, beginning with four groups in 1988 and increasing to a maximum of 13 groups in any one year (Figure 3a). The proportion of the catch reported in aggregate category declined from the early 1980s (Figure 3) from about 69% to less than one percent in 1999.

Reconstructed catches of marine mammals (Figure 4) indicate considerable historical catches of humpback whales (over 1,550 t in

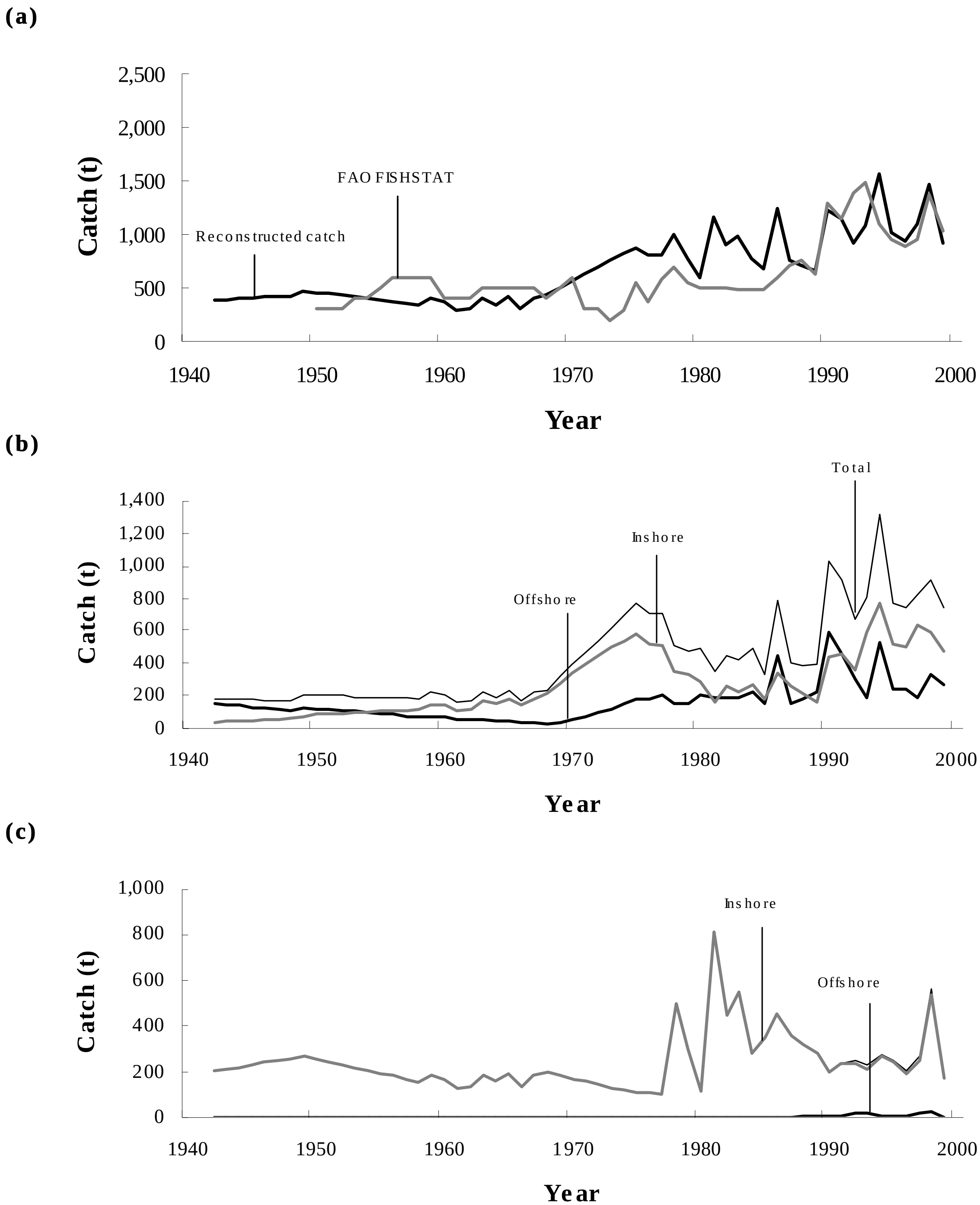
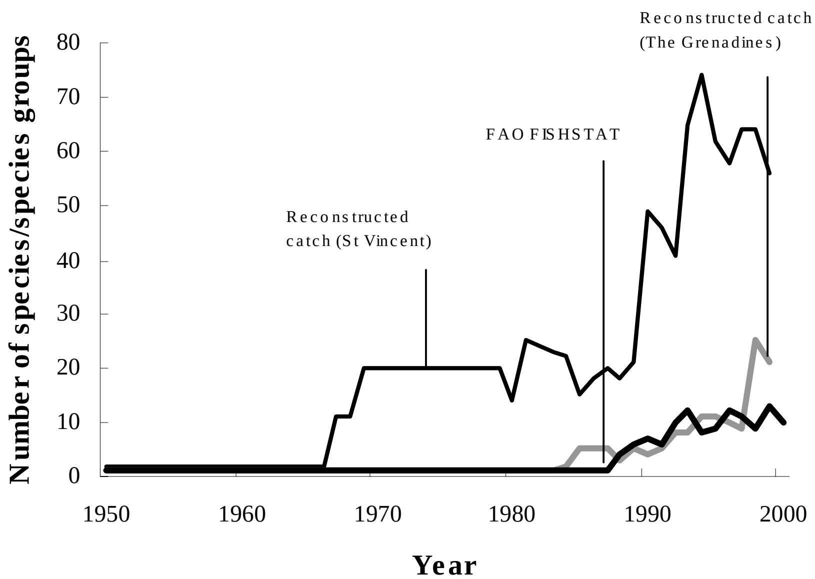


Figure 2: Catches (t) in St Vincent and the Grenadines (a) Reconstructed catches (1942–1999) and catches in FAO FISHSTAT (1950–1999), (b) Reconstructed offshore and inshore catches in St Vincent (1942–1999) and (c) Reconstructed offshore and inshore catches in the Grenadines (1942–1999).

(a)



(b)

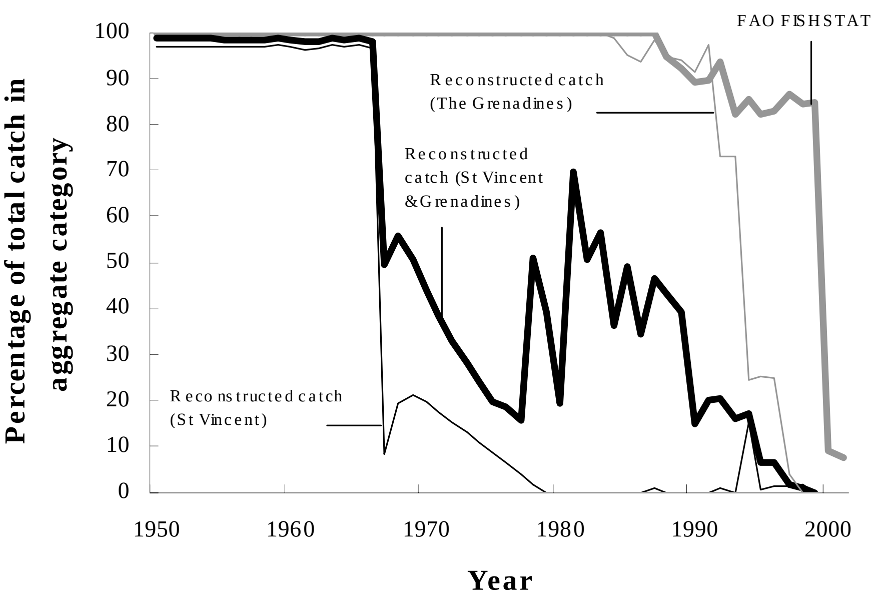


Figure 3: A comparison of reconstructed catch data and statistics in FAO FISHSTAT for St Vincent and the Grenadines between 1950 and 1999: (a) number of species/species groups and (b) percentage of total catch in aggregate category.

1898). This declined in the early 1900s where catches remained below 365 t and declined from about 300 t in the late 1920s to only 30 t by the late 1930s. Thereafter, catches fluctuated between zero and about 152 t until 1984. No catches have been reported since then. Catches of pilot and other whales and porpoises were reconstructed for a shorter time period (late 1940s to 1999). High catches, in excess of 100 t were experienced for both pilot whales and other whales and porpoises during the late 1950s to late 1960s, but this has declined over the years to less than 25 t in the last decade for both categories. Reconstructed catches of marine turtles (Figure 5) indicate considerable inter-annual variability. Between 1935 and 1945 catches varied between 0.4 t and 20 t. In the later period (1975 to the present) annual catches remained below 12 t and in some years, no catches were reported.

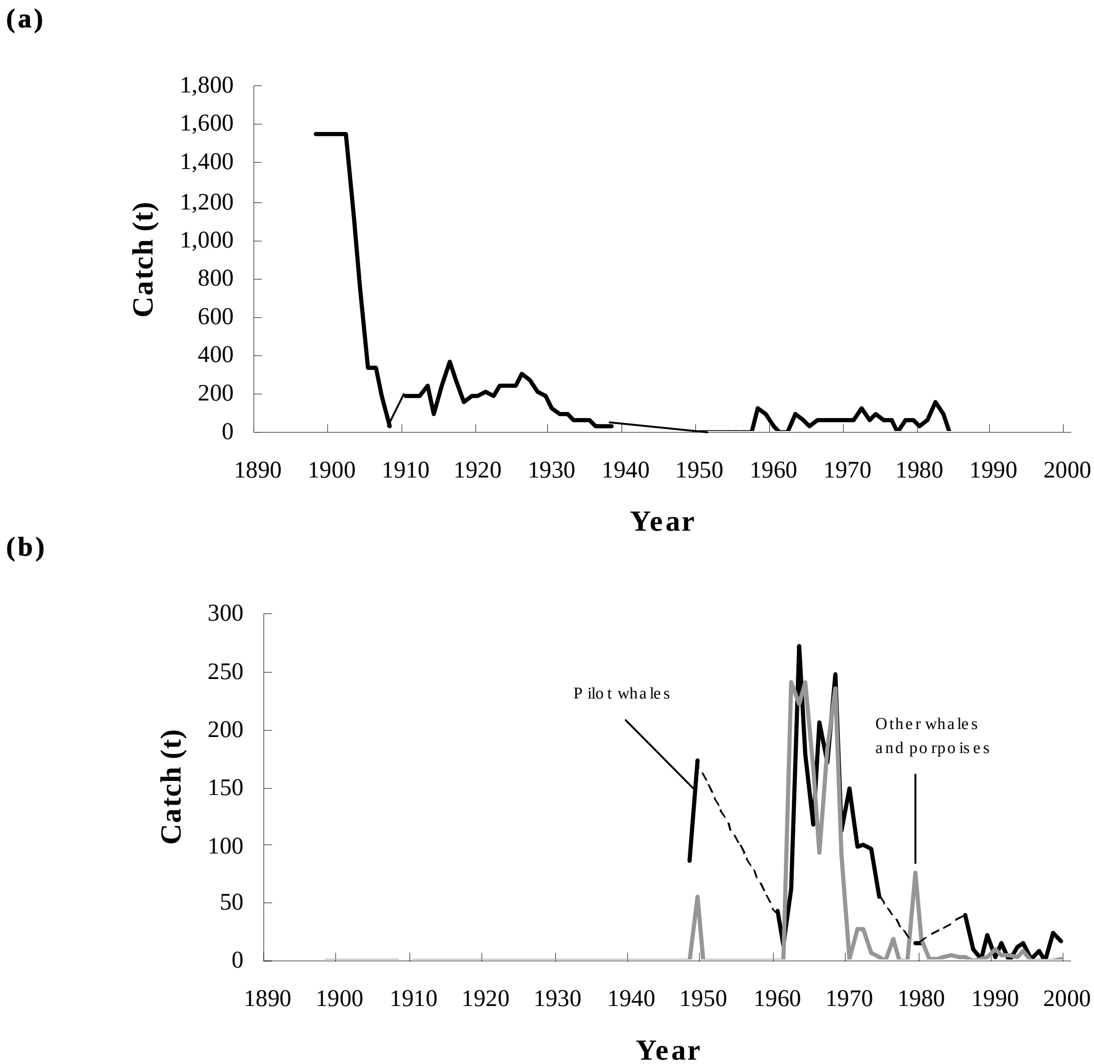


Figure 4: Reconstructed catches (t) of (a) humpback whales and (b) other whales and porpoises in St Vincent and the Grenadines (1898-1999). Dashed lines represent interpolated values.

Fishing Effort

Reconstructed fishing effort is represented in Figure 6. Effort in the St. Vincent offshore fishery was comparable in magnitude to effort in the Grenadines inshore fishery. Effort increased by a factor of 115 in the St. Vincent offshore fishery, and by a factor of nearly 19 in the St. Vincent inshore fishery between 1942 and 1999. In the Grenadines offshore fishery effort increased by a factor of 11 between 1981 and 1999 and by a factor of 35 in the inshore fishery, between 1942 and 1999. The increase in effort was more pronounced in recent years. Fishing effort is observed to increase by a factor of 2.35 from 739,000 Hp-days to 1,736,000 Hp-days in the St. Vincent offshore fishery between 1981 and 1999 (Figure 6c). Similarly, effort in the inshore fishery increased by a factor of 1.68, from 283,000 Hp-days to 476,000 Hp-days over the same period (Figure 6c). The corresponding number of boats decreased from 380 to 174 and from 508 to 286 in the offshore and inshore fisheries, respectively. The offshore fishery in the Grenadines remained unexploited until the mid-1980s and effort has not increased throughout the 1990s (11,000 Hp-days, Figure 6c). In the inshore fishery, effort has decreased from 1,246,000 to 1,024,000 Hp-days between 1981 and 1999 (Figure 6c). The number of boats has decreased from 305 to 191 over the same period. Between 1981 and 1999 effort directed at the humpback whale off Bequia has decreased from 760 to 380 Hp-days (Figure 6c), while effort in the Barrouallie fishery for pilot whales and porpoises has remained relatively constant at between 720 and 1,200 Hp-days.

Trends in catch per unit area (CPUA) and catch per unit effort (CPUE)

Annual trends in CPUA and CPUE are shown in Figures 7 and 8, respectively. Generally, CPUA was higher in the inshore than offshore fishery. There was a gradual decline between the early 1940s to early 1960s (Figure 7) from 0.0054 t·km^{-2} to as low as 0.0007 t·km^{-2} in the offshore fishery. Catch per unit area remained relatively stable in the inshore fishery during this time, ranging between 0.123 t·km^{-2} and 0.192 t·km^{-2}. Throughout the 1960s and 1970s the CPUA increased considerably from 0.143 t·km^{-2} in 1966 to 0.340 t·km^{-2} in 1975 in the inshore fishery, and from 0.0007 t·km^{-2} to 0.007 t·km^{-2} in the offshore fishery. Although there is a general increase in CPUA in both fisheries, considerable inter-annual variability is observed from 1977 onwards. Catch per unit area in the most recent five years ranged from 0.0195 t·km^{-2} to 0.007 t·km^{-2} in the offshore fishery and 0.780 t·km^{-2} to 0.371 t·km^{-2} in the inshore fishery.

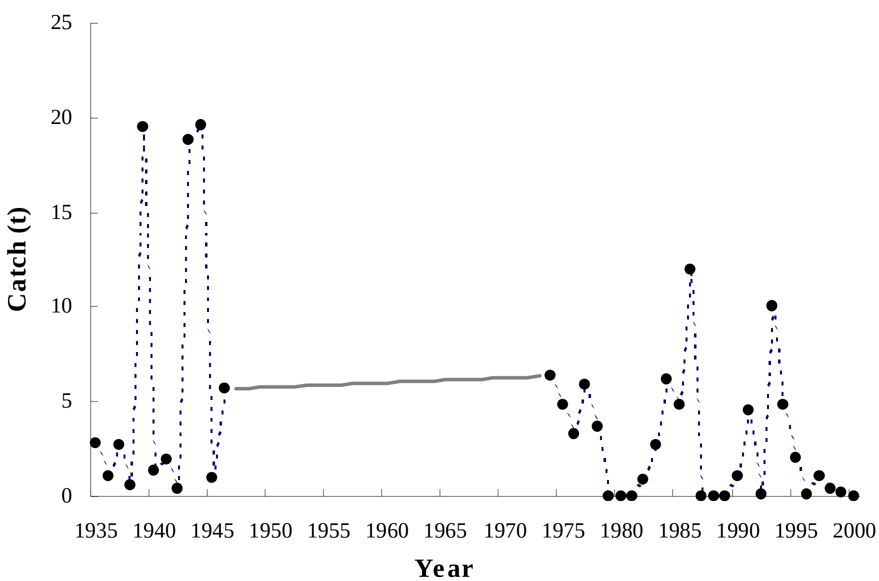


Figure 5: Reconstructed catch (t) of marine turtles in St Vincent and the Grenadines (1935-2000). Solid circles represent reconstructed data and solid lines joining the circles are interpolated values.

A pattern of exponential decline in CPUE was observed for all fisheries examined (Figure 8). Except for the St. Vincent offshore fishery, CPUE was found to increase between 1942 and 1949. Catch per unit effort in 1949 was greatest in the St. Vincent offshore fishery (11 t per thousand Hp-days) compared to the St. Vincent inshore (6.13 t per thousand Hp-days) and Grenadine inshore (9.70 t per thousand Hp-days) fisheries. The decline in CPUE is more pronounced in the Grenada offshore and Grenadines inshore fisheries, compared to the St. Vincent inshore fishery. The most recent (1999) estimates of CPUE are 0.15 t, 1.0 t and 0.31 t per thousand Hp-days for St. Vincent offshore and inshore, and the Grenadines inshore, respectively.

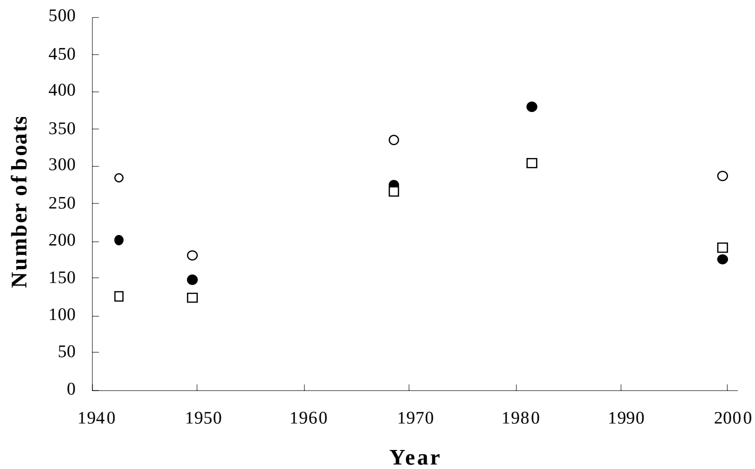
Discussion

Fisheries catches

Reconstructed catches indicate a general increase from the mid-1960s onwards, with an increase of over 190% between 1962 and 1999. This increase was attributed mainly to increased landings in the St. Vincent inshore fishery. Vessel mechanization began in the late 1950s (Cecil, 1972), and throughout the 1960s there were financial incentive programs to encourage fishery development. Reconstructed data for the late 1950s and throughout the 1960s was lower than data in FISHSTAT for corresponding years. This may be due to underestimation in this study, but is more likely due to the inclusion of catches by foreign fleets in data submitted to the FAO. Vidaeus (1969) reported on activities of foreign vessels during this time, however, there is no documentation on the magnitude of the catches or the associated fishing areas. Despite tremendous inter-annual variability, increasing catches throughout the 1980s reflect the government's efforts to increase local fish catches and employment in the fishing industry (Chakallal, 1982). The higher catches reported to the FAO in the late 1990s, compared to reconstructed data can only be accounted for by inclusion of catches of foreign vessels registered in St. Vincent and fishing in the western central Atlantic. St. Vincent has an open vessel registry, with vessels fishing in the Pacific, and North and South Atlantic.

Declining catches in the 1990s concur with studies by Straker (2001). He indicated that the institutional and technical development

(a)



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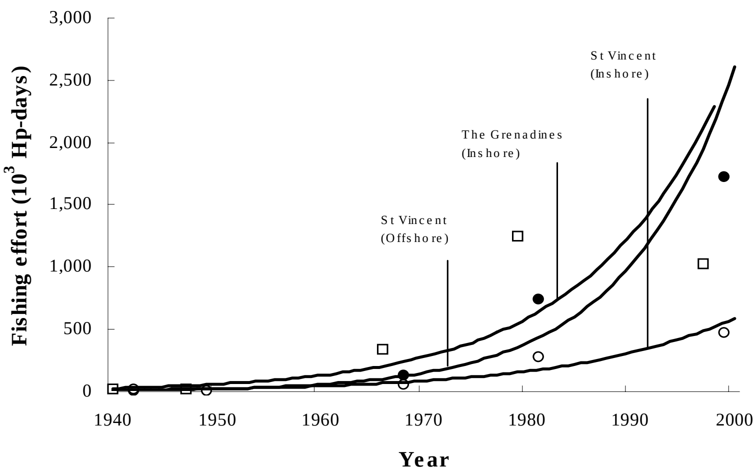

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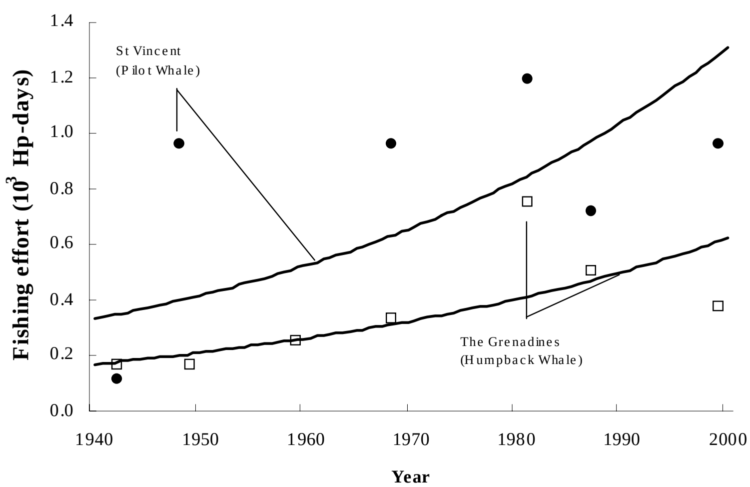

Figure 6: Reconstructed (a) number of boats, (b) fishing effort (10^3 Hp-days) in the fisheries of St Vincent and the Grenadines and (c) fishing effort (10^3 Hp-days) directed at marine mammals (1942–1999). Except for (c) solid and open circles represent the offshore and inshore fisheries of St Vincent respectively and solid and open squares represent the offshore and inshore fisheries of the Grenadines respectively. In (c) solid circles represent effort in the St Vincent pilot whale 'fishery' and open squares represent the Grenadines humpback whale 'fishery'

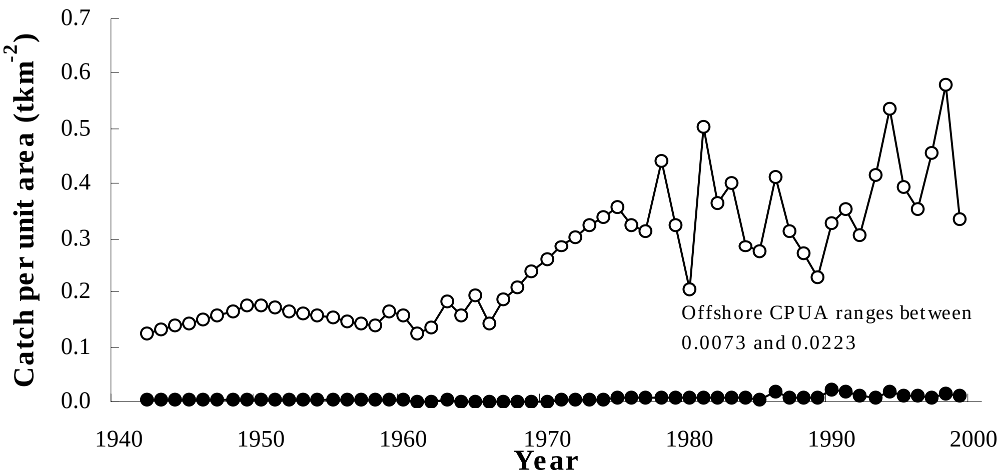

Figure 7: Annual trends in catch per unit area ($t \cdot km^{-2}$) in the fisheries of St Vincent and the Grenadines (1942-1999). Solid circles represent the offshore fishery and open circles represent the inshore fishery.

along with improved infrastructure, distribution and marketing of fish in the early 1990s promoted additional entry to the fishing industry. This was manifested as an increase in effort and associated increase in catch. By the late 1990s, however, catches began to decline. The refinement in the data collection program and procedures for estimating total catch since the early 1990s may also account for the observed pattern. However, it seems that other factors may have contributed to the decline as the local industry was unable to meet the increasing demand, resulting in increased fish imports throughout the period (Straker, 2001). The decline in catches in the 1990s was offset by increasing fish prices to the extent that the value of landings had actually increased throughout the 1990s (Straker, 2001).

Despite reports of the greater importance of the offshore fishery to St. Vincent (Brown, 1945; Vidaeus, 1969; Chakallal, 1982; Morris, 1984) results suggest that the inshore fishery is the greater contributor to overall catches, especially throughout the late 1960s and 1970s as well as in the late 1990s. The inshore fishery comprises both the small coastal pelagic fishery and the demersal, reef, slope and shelf fishery. Traditionally the small coastal pelagic fishery has contributed significantly to catches landed at the main market in Kingstown (Vidaeus, 1969) and still do (Straker, 2001). Catches in the offshore fishery have increased since the early 1970s but given recent developments in the 1990s (introduction of semi-industrial longliners) catches have not reflected this. Reconstructed catches for the Grenadines indicate considerable decline from 1982 onwards.

A longer time series of reconstructed catch data, disaggregated by the respective species components, is available compared to current data for St Vincent and the Grenadines in the FAO FISHSTAT. From the late 1960s reconstructed catch data were disaggregated into the respective species components while all reported data between 1950 and the late 1980s incorporated in FAO FISHSTAT were assigned to a single aggregate, unidentified category. Reconstructed catch data are also disaggregated into a greater number of species groups (up to 91 for St Vincent and the Grenadines combined) compared to reported data in FAO FISHSTAT for St Vincent and the Grenadines (a maximum of 13 species/species groups represented in any given year). A smaller percentage of annual total catch is attributed to the aggregate, unidentified category in reconstructed data compared to current catch statistics in FAO FISHSTAT. This level of dis-aggregation is attributed mainly to the fisheries of St Vincent, since the species composition of catches from the Grenadines, prior to the early 1980s, have not been quantified in the literature examined. Nevertheless, reconstructed data in general, represent a considerable improvement in terms of the number of species groups reported and breakdown of the aggregate, unidentified fish category, compared to current data in FAO FISHSTAT for St Vincent and the Grenadines.

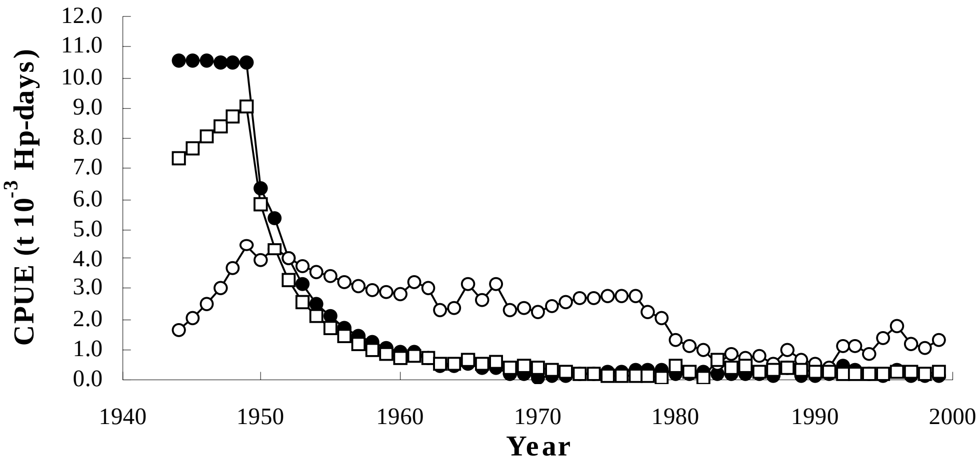

Figure 8: Annual trends in catch per unit effort (t·10^{-3} Hp-days) in the fisheries of St Vincent and the Grenadines (1942-1999). Solid and open circles represent the offshore and inshore fisheries of St Vincent respectively and open squares represent the inshore fishery of the Grenadines.

Reconstructed catches of marine mammals show considerable decline in catches of pilot whales from the late 1960s onwards. Catches of humpback whales have been declining since the early 1900s with estimates of about 400 t, to less than 100 t in recent years. Morris (1984) confirmed the decline in the fishery for humpback whales since effort had not increased between 1974 and 1984 and there was no indication of future increases in effort. He stated further that overseas markets for oil had declined drastically due to pressure from both conservation groups as well as the signatories of Convention on International Trade in Endangered Species (CITES). Hence, the pilot whale fishery is on the decline with no indication that the whaling industry would ever attract more than the four boats presently involved. Reconstructed catches of marine turtles showed inter-annual variability in catches, which ranged between zero and 13 t between 1975 and 1999.

Our reconstructed catches represent preliminary estimates at this time, as several limitations in the data exist. These relate to recreational fishing, discarding, quantities caught as bait, landings of fish caught in St. Vincent and the Grenadines at other islands, foreign fishing and under-estimation of catches in components of the inshore fishery.

In the 1980s, at least 8,000 tourists visited St. Vincent and the Grenadines each year (Matthes, 1984). A considerable portion was involved in unlicensed sport fishing with fishing rods, spears and nets (Matthes, 1984). Some tourists fished commercially and sold the catch to local and foreign hotels. These catches, however, are not documented. Unlike other Caribbean islands, there were no charter boat operations in St. Vincent or the Grenadines in the 1990s (Morris, 1991), although there were several private sport fishing boats.

Several species of fish are discarded at sea (Adams, 1985), either because of size or preference for other species. Based on the types of species discarded, it appears that this practice is common in all fisheries The trammel net fishery which targets snapper, grouper, cavalli, shark, barracuda and turtle off the Grenadines is regarded as unsustainable (Chakallal, 1982). Since these nets capture everything in their path and are lifted every 12 hours, those fish caught early are unfit for export. This accounts for about 50% of the catch, of which one-fifth is unfit for human consumption and discarded, while the rest is sold locally or processed by salting and drying (Chakallal, 1982). There are no records of the quantities of fish discarded. In the Grenadines, preference for specific species by Martinique traders may result in up to 40% of the landings remaining unsold, and much may be dumped because of lack of suitable transport to St. Vincent (Andersen *et al.*, 1983). Historically, only export data have been recorded and therefore the quantities dumped are not incorporated in the data.

Bait is utilized in the longline, pot and handline fisheries. Usually dwarf herring (*Jenkinsia* spp.), pilchards (*Harengula* spp.), round scad (*Decapterus* spp.), sardines (*Sardinella* spp.), silversides (Atherinidae) and thread herring (*Opisthonema oglinum*) are used as bait in St. Vincent and the

Grenadines (Mahon, 1993). Although catch rates from directed exploratory fishing in the 1970s are available (Wagner, 1974) these do not give an indication of the associated quantities utilized as bait.

Apart from catches of finfish, lobster, conch and whelks caught in the Grenadines and traded illegally with Martinique, catches are also sold in St. Lucia, while catches from Bequia are also taken to Kingstown market in St. Vincent, and a portion of catches from vessels operating off the north leeward and northeast coasts (Fancy, Owia, Sandy Bay) of St. Vincent are sold in St. Lucia (Matthes, 1984). Records of these catches, if they do exist, are incorporated in the landing statistics of the island to which the catch was sold. Ryan (1999) indicated trading of beach seine catches in St. Vincent with vessels of Martinique, Dominica and St. Lucia and trading of catches in the Grenadines with vessels from Martinique and seine boats or charter boats from Grenada or Carriacou. These data are not recorded in landings data.

Catches of foreign fleets fishing in the waters of St. Vincent and the Grenadines either do not exist or are incorporated in the landing statistics of the country to which the fleets belong. In the 1960s vessels from Martinique fished off the Grenadines and supplied entrepreneurs from Martinique (Chakallal *et al.*, 1997). The activity was illegal and there are no accompanying records. Such activity is also known off Grenada and Carriacou (Peña and Wirth, 1979). Fishers from Martinique also fish for large pelagics (especially tunas) in the EEZ of St. Vincent and the Grenadines (Andersen *et al.*, 1983), as do distant water longliners, including US swordfish boats as well as Venezuelan pole and line boats, and purse seiners (Morris, 1991). Large, deep-water snappers (*Etelis oculatus*) occurring on the slopes at 80-180 m were fished occasionally by boats from Barbados (Morris, 1991). In the Grenadines, fishers from Grenada have traditionally fished for demersal finfish, lobster and conch in the waters of St. Vincent and the Grenadines and until the early 1990s continued to do so (Morris, 1991). Boats from Barbados and St. Lucia also target flyingfish and large pelagics within the EEZ of St. Vincent and the Grenadines. There is also evidence of St. Vincent fishers catching pilot whales in the territorial waters of St. Lucia (Cecil, 1972). If landed in St. Vincent then these are incorporated in the landings data for St. Vincent and represent an over-estimate of harvests from waters of St. Vincent and the Grenadines.

Catches in the inshore fishery, specifically the demersal component as well as lobster, conch and turtles are under-estimated. Data were particularly lacking for the Grenadines where, until the mid-1990s, data were available only on fish exports to Martinique. The quantity of catches consumed locally was not recorded. The species composition of the catch was not known, though it was possible to separate exports of finfish from shellfish. Export weights were estimated by eye. Exports of processed fish were not adjusted to whole weight since the associated species was not known. Also, conch exports refer to meat only, i.e., were not corrected to represent whole weight. There are also reports of ongoing illegal trading with Martinique confirming that export data are minimum estimates at best. This made analyses on the Grenadines fishery impossible. Catches of turtles are under-estimated, representing shell exports of one species only (hawksbill) in most instances. Further, the quantity of marine turtles caught on land when they come ashore to lay eggs, is not recorded.

Fishing effort

Reconstructed fishing effort increased exponentially for all fisheries. Effort increased by a factor of 114 in the St. Vincent offshore fishery, and by a factor of 18.6 in the St. Vincent inshore fishery between 1942 and 1999. In the Grenadines offshore fishery effort increased by a factor of 11 between 1981 and 1999 and in by a factor of 35.42 in the inshore fishery, between 1942 and 1999. The increase in effort is attributed to increases in the horsepower of engines rather than number of boats. In fact in all fisheries the number of boats was found to decline in all fisheries between 1981 and 1999.

Changes in effort due to the introduction of the gun harpoon in the whaling fishery during the 1940s, use of Scuba gear in the demersal lobster and conch fisheries in the 1980s and possibly increased numbers of fish pots or handlines used are not incorporated in the unit of effort. Such detail however, is not available (Straker, 2001). Andersen *et al.* (1983) noted that engines were used as auxiliary power, suggesting that they were not utilized on all fishing trips. As such the reconstructed effort more accurately represents potential effort rather than actual effort. Prior to 1999 all reports indicated that vessels involved in the beach seine fishery (inshore) were unmechanized. However transoms (flat bottom boats), which carry outboard engines of 14-115 Hp, were responsible for the high mobility of beach seine units around the islands and for towing other fishing boats associated with the seine unit from one fishing area to another, and to transport the catch to the market. A seine unit was reported to comprise a seine net, a flat transom boat or pirogue and two double-enders. Mechanized boats were not considered in the effort of the beach seine component of the inshore fishery.

The assumption of constant fishing days was used purely to represent the division of effort by boats targeting both the offshore and inshore fisheries each year. However, the introduction of mechanization, government financial incentives and infrastructure development over the period examined would have contributed to changes in the number of fishing days. In the Grenadines, adverse weather conditions, strong tides and the absence of trading vessels all affect the number of fishing days in the Grenadine Islands (Chakallal *et al.*, 1997). Assumptions regarding effort directed at whales do not consider the time spent on the 'look-out' for whales. Adams (1980), commenting on the handline fishery in the Grenadines, indicated that the decision on whether or not a fishing trip is feasible is dependent on a number of highly variable physical and cultural factors; namely weather conditions, current and tide, immediate financial needs of the fisher, access to fish markets and the demand and price for the associated species.

Annual trends in catch per unit area and catch per unit effort

Generally, CPUA has increased, reflecting responses to fisheries development, over the period examined. Further investigation is required to explain the inter-annual variability from the mid-1970s to late 1990s. The CPUA in the inshore fishery was higher by one order of magnitude than that in the offshore fishery. This higher inshore CPUA is expected given the concentration of the associated resources over a narrow shelf area. CPUE has declined exponentially in all fisheries since 1952. Higher CPUE in the St. Vincent inshore fishery is influenced by the high catches of small coastal pelagics and associated low effort, since all vessels were assumed unmechanized. The development of the longline fishery, which utilizes coastal pelagic species as bait, may account for the higher CPUEs in the inshore fishery during the late 1990s.

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Trinidad and Tobago: Preliminary Reconstruction of Fisheries Catches and Fishing Effort, 1908-2002

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Abstract

This paper describes the methodology used for the reconstruction of time series data on fisheries catches and fishing effort in Trinidad and Tobago from 1908 to 2002. The work described here is ongoing and preliminary in nature. Data are reconstructed separately for both islands and are fleet specific. Sources of information and data are listed and preliminary results provided. Major limitations to the reconstruction exercise are also discussed.

Introduction

Trinidad and Tobago are located at the southern end of the eastern Caribbean island chain (Figure 1) on the continental shelf off Northeast South America, some 8 miles east of Venezuela. The islands lie downstream of the outflow of 17 South American rivers, including the Amazon and Orinoco, and at the confluence of major ocean currents such as the North Equatorial current (Fabres, 1983). This has influenced species diversity and marine habitat types, which range from coral reefs to muddy bottom, brackish water. Not only has this contributed to the high productivity of surrounding waters, particularly around Trinidad, but it has also limited the extent of coral reefs, which are more abundant off Tobago.

Fishery development in Trinidad

Pre 1950s

There is little documentation on fisheries in Trinidad and Tobago prior to the 1940s. In fact, fisheries attracted little attention following the establishment of the Department of Agriculture in 1908, within which fisheries administration was imbedded (Anon., 1929). From Vincent's (1910) account of fisheries on the north-western coast of Trinidad, sport fishing seemed more popular than commercial fishing at the time. Commercial fishing was mainly of a subsistence nature. One central market existed in Port of Spain. Despite the high retail price of fish, the fishers were disadvantaged by the low prices they received from the 'middle-men', which may have acted as disincentive to fisheries development. Despite the apparent abundant resources around Trinidad (Vincent, 1910), development of the fishing industry was further hindered by lack of capital and inappropriate technology. As a result, Trinidad was dependent on imported processed fish, mainly from Canada and Venezuela (Vincent, 1910).

By the early 1940s imports had increased to 650,000 UK£. Compared to other colonies in the British West Indies, Trinidad and Tobago suffered the most severe depletion of market availability of fresh fish at the onset of the Second World War (Brown, 1942), due to gear shortage, transportation problems and lack of infrastructure. Moreover, the situation was exacerbated by the transfer of labor from the fishing industry to the more lucrative military bases in Trinidad, and the exclusion and closure of fishing areas in military training areas. The control of local fish prices also acted as a disincentive to development (Brown, 1942).

Figure 1: Map of Trinidad and Tobago, showing 200 nm EEZ, as well as its nearest neighbor, Venezuela.

To increase food security following WWII, a development program was implemented. Fleet mechanization was promoted with the introduction of outboard engines (Anon., 1948), larger vessels were constructed, and more fuel-efficient inboard engines introduced (Anon., 1947). Fishing trials were conducted with a variety of gear types, e.g., trammel and shark nets, otter trawl, bottom-longline (palangue), multiple troll lines, long lines, purse seines, and drift- and gillnets (Stockdale, 1945; Anon., 1947; Anon., 1948). Existing fishing gears were considered antiquated (Hunt, 1949), and a subsidization program considered to promote the adoption of more efficient gear (Anon., 1947). The supply of gear was improved, and efforts focused on increasing the industry's awareness of related regulations and promotion of co-operative organizations in the industry (Anon., 1948). The development program also included trials in fish processing, and experimentation with extraction of shark liver oil (Anon., 1946), as well as introduction of nets for the capture of turtles (Anon., 1947). Fish depots were established at Toco, Matelot, Grande Rivière, Sans Souci and Cumana and ice storage promoted through market guarantee. Despite these developments, however, the fishing industry was still largely of a subsistence nature by the late 1940s. Already then, however, there were reports of environmental concerns associated with the high level of discards from the beach seine fishery targeting shrimp, and pollution from the petrochemical and agricultural industries in the Gulf of Paria. The shrimp fishery, particularly off Cedros, had expanded considerably following WWII due to relocation of fishers displaced for the construction of a military base.

1950 - 1980

During the 1950s, development efforts initiated earlier continued. Subsidization of the industry increased, with the introduction of a fuel tax rebate system in 1956 facilitated under the Fishing Industry Assistance Regulations of 1952, and a loan scheme in 1957 to promote the entry of more boats in the fishery (Director of Agriculture, 1958). Improved infrastructure at the Port of Spain fish market and fishing facilities at Carenage, Toco and Blanchisseuse occurred throughout 1956. The use of small outboard motors with lower operation costs was promoted (Anon., 1958). A 1957 survey identified the lack of adequate harbor facilities as a major constraint (Anon., 1958). The adoption of arrow-head fish-pots (early 1950s), and trawl nets (1954) were the major gear introductions in the 1950s, and an 18 m motor launch acted as a mother-ship for five artisanal trawlers operating in the Gulf of Paria (Anon,. 1958).

Due to the development of the fishery off the south coast increased catches of fish were realized. This accounted for about 28% of total landings by the 1960s (Kenny and Lagois, 1961; Vidaeus, 1970). The fleet still consisted mainly of artisanal pirogues, most of which were mechanized as a result of duty free engine imports. A single, large sized trawler commenced operations in the Gulf of Paria, but contributions to overall landings were negligible. At this time also severe marketing problems acted as a disincentive to development, causing some fishers to limit their catches. Most boats operating off the south-western peninsula switched from targeting fish to shrimp, as they began to exploit the waters in the channel between Trinidad and Venezuela (Vidaeus, 1970). The establishment of a shrimp processing plant at Cedros, which provided a guaranteed shrimp market, and boat servicing facilities, promoted development of the shrimp fishery. Shrimp, being a high priced commodity, also made the switch in target species more profitable. A locally owned company, International Fisheries Ltd, provided landing and processing facilities for some 60 international trawlers, mainly of American origin, which fished along the continental shelf off the north-east coast of South America, as well as three locally owned large trawlers which caught shrimp off the Guianas. Following a temporary termination of the loan scheme for artisanal vessels in 1966, the development of the fleet of large trawlers (over 21 m) was promoted through a similar incentive. By 1972, however, the loan scheme for artisanal vessels, and, to a lesser extent, vessels targeting the deep-sea fishery, was re-instituted (Anon., 1973).

Between 1966 and 1972, fuel rebate subsidies amounted to over 570,000 US$ (Anon., 1973). Correspondingly, the exemption of purchase tax on boats and engines over the same period was over 1.3 million US$. By the beginning of the 1970s, fish landings had increased to a level which facilitated, for the first time, the export of more than 455 t of fish to Canada, England and other countries. Local investment in the industry was high, with only 20% of total investment contributed by government. Fishers received higher prices for their fish, and efforts focused on development of the inshore fishery. Imports were however, still substantial. For example, approximately 80,000 UK£ were spend on imported salted and smoked fish in 1980. During the 1970s, there was considerable fisheries infrastructural development on both islands (Anon., 1973).

1980s - 2000

Trinidad and Tobago faced new challenges in the 1980s, with the pending restrictions on fishing areas for the offshore fleets and added responsibilities for conservation, assessment and management of its marine resources under the United Nations Convention on the Law of the Sea. Following the loss of access of the local fleet of large trawlers (10) to traditional fishing grounds due to declarations of EEZs, access was negotiated for waters of French Guyana, through an arrangement with the European Community. Vessels were, however, limited to the capture of 76 t within a 600 day period (Anon., 1973).

Fishery development in Tobago

Pre 1950s

Very little is documented on the fishing industry in Tobago prior to the 1950s. The main gear utilized during the 1940s were the beach seine for targeting pelagic species off the north-west coast, and the bank line for targeting deep water snappers off the west and south-east coasts (Brown, 1942; Rajkumar and King-Webster, 1957). Turtles were also captured for meat (green turtle: *Chelonia mydas*) and shell export (hawksbill: *Eretmochelys imbricata*).

1950 - 1980

As in Trinidad, new gear was introduced in Tobago during the 1950s. These included gillnets for catching flyingfish in the local 'drifting' fishery, and 'tight lining' (fishing at night with lights) for the capture of large pelagics (Caesar, 1988). Fishpots were introduced earlier, but the bamboo used for construction was replaced by chicken wire (Caesar, 1988). Foreign fleets from Grenada and St Vincent and the Grenadines also operated from the capital city, Scarborough, during the 1950s and 1960s (Caesar, 1988).

During the 1970s the Tobago Fisheries Division, after a period of experimentation, introduced fish aggregating devices to the drifting fishery. These increased catches considerably, and were rapidly adopted by the fleet. They continue to be used in the drifting fishery. The Tobago Fisheries Division embarked on an awareness campaign in 1973 to increase the local demand for flyingfish, by introducing the processing methodology to the public (Caesar, 1988). The fiber-glass pirogue, introduced in 1977, eventually replaced the wooden boats because of the lower maintenance costs. Following the establishment of the National Fisheries Company Ltd. (NFC) in Trinidad, a Collector Vessel System was implemented towards the end of the 1970s. Industrial vessels from the NFC were stationed off south west Tobago and purchased flyingfish and associated species directly from the fishing boats at sea. This system was successful in increasing catches during 1979 to 1981 (Caesar, 1988). During the late 1970s two other fish processing plants, Pisces Limited and Roy Jacob's Enterprises were set up in Tobago.

1980 to 2002

In the 1980s, through a project funded by the United Nations, demersal longlines were introduced for the capture of sharks and other demersal fish. The existing local longline fishery benefited from the associated change in technology (Caesar, 1988). Other fish processing plants, Tobago Sea Products, Yeates processing and Stewart's processing plants were established in the 1980s. Two other fish processing plants, Terry Swan Ltd and Fresh Fish of Tobago were established in the 1990s. Towards the end of the 1980s, ice-boats were introduced to the flyingfish fishery. The fleet of ice-boats increased to 10 vessels by 2001, and Trinidad and Tobago became a member of the Western Central Atlantic Fisheries Commission *Ad-Hoc* working group on flyingfish. Trinidad and Tobago was also a participant in a regional project aimed at assessment and management related research on the flyingfish fishery in the eastern Caribbean (Oxenford *et al.*, 1993). The project resulted in an improved data collection system for the fishery in Tobago.

Fisheries statistical data collection

Trinidad

Prior to 1941 almost the entire fish supply to Port of Spain was from the north western peninsula. The focus of fisheries statistical data collection programs reflects Government's main objectives at the time. Accounts of fisheries landing statistics prior to the 1940s were limited to reports of individual stakeholders (Vincent, 1910). Subsequent to this, Colonial Fisheries Advisors (Stockdale, 1945; Luke, 1957) reported on development and welfare in the region. Formal collection of fisheries statistics commenced in 1945 (Anon., 1946), some ten years before the establishment of the Fisheries Department (Fiedler *et al.*, 1957). At this time fishing was mainly a subsistence activity, with data collection aimed at assessing self sufficiency in food production, and fish import requirements of what was then a British colony. Documentation of fish landings and distribution from the major wholesale fish market was introduced in 1954 (Kenny, 1955), as the first step in development of an island-wide statistical data collection system. The quantities, species of fish landed, landing site as well as fish prices were recorded (Kenny and Lagois, 1961). By 1958, fisheries statistics were collected at 16 of the 53 landing sites and major markets (Anon. 1958). Additional details pertaining to the fishing trip were also recorded (Anon. 1958). This system, established in the 1950s and modified in the early 1960s, remained unchanged until the early 1990s.

In the early 1990s, analytical procedures of the existing system were refined under an FAO/UNDP Project entitled 'Establishment of Data Collection Systems and Assessment of Marine Fisheries Resources' (McClure, 1991). The program focused on species of major importance nationally and regionally. A standardized procedure for estimation of total landings was conceptualized and enhanced by the zonation of landing sites, based on similarities in fishery types and fishing practices. In the mid-1990s, under the CARICOM Fisheries Resource Assessment and Management Program (CFRAMP), an enhanced supervisory mechanism for field data collectors contributed to improved precision in reporting. To date, the statistical data collection system targets the artisanal fishery operating in areas within 15 miles from shore. Recent improvements have focused on refinement of estimates of shrimp landings by the trawl fleets.

Tobago

No accounts of the collection of fisheries statistics is documented prior to the early 1960s. The Tobago Fishing Co-operative Society, established at Charlotteville in 1959 (Kishore, 1990), kept records of the quantities and species of fish purchased from fishers in the area. Since market availability and competitive pricing affected the selection of species and associated quantities sold to the co-operative, these records reflect, at best, underestimates of the actual quantities caught or landed, and provide an inaccurate estimation of the actual species composition in the catch.

During the 1960s, statistics were recorded daily at four beaches (Vidaeus, 1970) located at Plymouth, Castara, Speyside and Man-of-War Bay. This included information on trip duration, fishing methods or gear used, and landings and prices by major species groups for individual boats. The total number of boats fishing each day was also recorded. To promote fisheries development, and in particular the flyingfish component, the Government instituted a Collector Vessel System (see above) between 1979 and 1982 (Fabres, 1986). Since this provided a guaranteed market for the respective species, recorded transactions detailing the quantities by species purchased are thought a reliable representation of actual catches between 1979 and 1982. By the early 1980s data were collected at five landing sites (Jordan, 1986). However, there were some ten additional landing sites (Jordan, 1986) at which landings were not recorded, and no attempts were made to estimate total overall landings from recorded data.

Under the Eastern Caribbean Flyingfish Project, a data collection system targeting the flyingfish and associated pelagic fishery was implemented at Buccoo Point, Pigeon Point and Mt Irvine. Thereafter, and until the implementation of the CARICOM Fisheries Resource Assessment and Management Program (CFRAMP) in 1995, data collection focused on this fishery. In 1993, the system was expanded to include two additional landing sites, but reverted to the original three sites by the following year (Mohammed, 1998). Under CFRAMP, the data collection system was expanded to include large pelagic and reef species caught by trolling, fishpots and handlines (Alexander, 1998). Due to staff shortages, random stratified data collection was implemented. This resulted in four and eight days of data at each landing site per month. Data on the quantities and associated species of fish sold at the Scarborough fish market were recorded. Additionally, some data exists on fish purchases by the major processing plants. However, the completeness or accuracy of the information cannot be verified at this time.

Fisheries management and policy

The Fisheries Act of 1916 is the legislative basis for management. The authority of the Act extended three miles from the coast, and responsibility was held by the Governor in Council. A 1966 amendment, following Trinidad and Tobago's independence from Britain, included the management of turtles and corals, and conferred authority to the Minister in charge. A further amendment in 1975 specified new offences, increasing penalties and extended jurisdiction of the act to 12 miles from the coast. Jurisdiction was later extended to 200 nautical miles from the archipelagic baselines under the 1986 Archipelagic and Exclusive Economic Zone Act. This act also sought to regulate foreign fishing through specifications of an 'allowable catch', and introduction of a licensing system for associated vessels. From a conservation perspective, the Marine Areas Preservation and Enhancement Act of 1970 is also relevant, although its implementation has so far been limited to the reef areas off Tobago. Management of local fisheries has been limited to the trawl and gillnet fisheries, through regulations under the 1916 Act. Regulations pertain to areas of operation and gear specifications for different trawler types, as well as the exclusion of turtles caught incidentally (Conservation of Marine Turtle Regulations of 1994). To date, the exploitation of fisheries has followed an open access policy. A review of the existing marine fisheries policy in 1998 sought to update fisheries laws and legislation in keeping with international measures to assess, manage and conserve fisheries resources. The transition from open access to limited entry is to be undertaken through a licensing system.

Objective

The objective of this study was to assemble a time series of catch and effort data for Trinidad and Tobago from 1908 to 2002. However, the present study is still in progress, and the current report is thus preliminary in nature.

METHODOLOGY

Catches

Differences in the major species harvested, the development and implementation of statistical data collection programs, and the availability of time series data between Trinidad and Tobago, required that the reconstruction of catch and effort statistics be conducted separately for both islands. The complexity of the fisheries (multi-species and multi-gear) contributed to aggregation of species in reported landings. Also, the tendency to report fish species by local names has resulted in uncertainties in species identification over the time period covered. Often only the most important commercial species were identified to the species level. Ramjohn (1999) was consulted for identification of species reported by local names. However, to address the problem over the entire time series of reconstructed data, it was necessary to confine reporting to the family level. Due to the variety of fleet types exploiting the resources (Figure 2), and the differences in the data collection programs reflecting the differences in fleet operations, the reconstruction was conducted separately for the respective fleets.

Trinidad

Artisanal multi-gear fleet

Prior to 1962, landings data are available for specific years at major markets from the following sources: 1908 (Vincent, 1910), 1933 (Anon., 1935), 1942 (Brown, 1942), 1945 (Stockdale, 1945), 1946 (Anon., 1946), 1954 (Kenny, 1955), and 1955 to 1960 (Kenny and Lagois, 1961). Based on estimates of the proportion of total landings sold at the major markets, estimates of total landings island-wide were derived from market records. These estimates were considered anchor points, around which estimates for missing years were interpolated. Information on species composition was limited to 1954 and 1957, with up to nine species groups being reported. The species composition prior to 1954 was based on inferences from details on the relative commercial importance in the available documents. The Fisheries Statistical Data Collection System contains landings data for Trinidad from 1962 to the present.

Data prior to 1995 are available in hard copy form only. Recorded data from 1995 to 2002 were adjusted based on the methodology in McClure (1991) to represent total landings. The methodology is based on a zoning system which groups landing sites according to similarities in fleet activity. It uses information on fleet distribution and target species by gear, derived from periodic boat censuses, to estimate landings at sites not incorporated in the data collection system. The species composition of estimated data is based on that of recorded data for similar gear types within the respective zone.

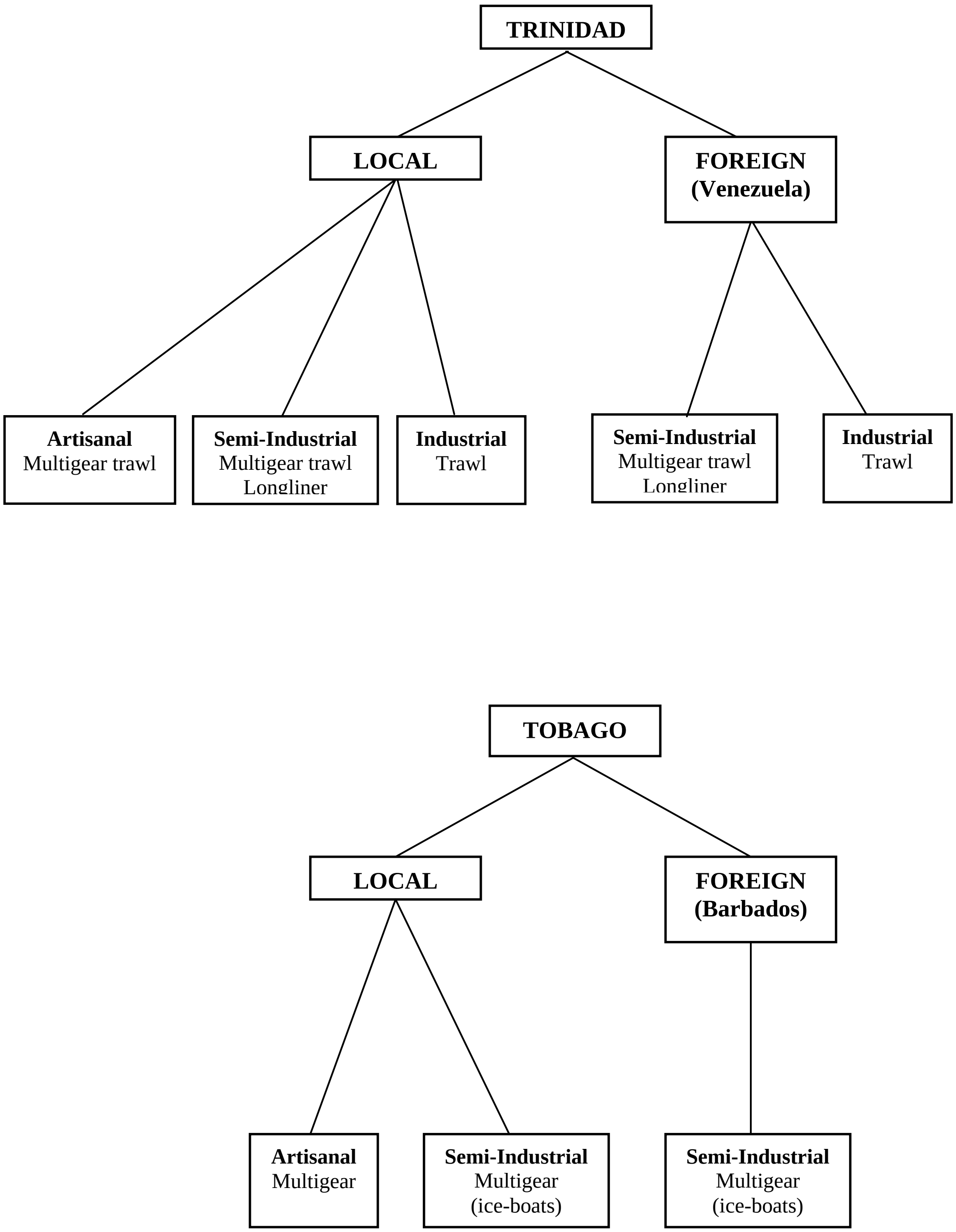

Figure 2: Fleet types operating in the EEZ of Trinidad and Tobago.

As a preliminary exercise, the estimation procedure described above is being applied on recorded data for 1963, 1975, 1985 and 1993, to facilitate estimation of total catches, disaggregated by the species components for the respective years. The selected years will serve as anchor points, around which data for missing years will be estimated by interpolation. Such data will be disaggregated into the respective species components, based on interpolation of the relative species contributions to overall total catch for the years selected as anchor points.

Artisanal trawlers
The otter trawl was introduced in 1953. Over the period examined, artisanal trawlers operated both in the Gulf of Paria off Trinidad's south coast and in the waters off the northeast coast of Venezuela. The target species comprised shrimp, and the by-catch consisted mainly of groundfish species. The traditional fishery in Venezuelan waters, conducted mainly by vessels from the south-western peninsula was legitimized in 1972, and a formal agreement between Trinidad and Tobago and Venezuela signed in 1977 (Kuruvilla *et al.*, 2000). Initially, 60 artisanal vessel were allowed to fish in Venezuelan waters, but by 1990 this was increased to 70. A reciprocal arrangement allowed Venezuelan vessels to fish off the north and east coasts of Trinidad. A new agreement, based on co-operation in exploitation and management of the area south of Trinidad, was negotiated in 1997. This excluded fishing by artisanal trawlers from Trinidad in the area allowed under the previous agreement. Data collection of the associated trawl fleet is incorporated under the national data collection system for the artisanal fleet (which includes also the multi-gear fleet). Total landings are estimated in a similar manner as for the artisanal multi-gear fleet, however, recorded data do not include the associated discarded by-catch. Here, these data are reported separately by fishing area, as the associated catches during the period of the agreement with Venezuela do not represent catches within the EEZ of Trinidad and Tobago. The by-catch (landed and discarded combined) associated with shrimp catches in the EEZ of Trinidad and Tobago will be estimated. The landed component of the by-catch, incorporated in the statistical database, was therefore excluded from this analysis.

Semi-industrial trawlers
Although there is no data collection system targeting this fleet, since landings occur at one major site also utilized by the artisanal fleet, data are incorporated in the national data collection system for the artisanal fleet. The fleet was gradually introduced from the early 1980s, and data are available on the shrimp and landed component of the by-catch since 1987. Shrimp catch estimates from 1987 to 1991 were available from Maharaj *et al.* (1993). Estimated catches for 1993 to 2001 were available from L. Ferreira and S. Soomai (pers. comm.). The landed component of the by-catch, comprising mainly juvenile fish, is incorporated in statistics for the artisanal multi-gear fleet in the associated database. The discarded component is not recorded in the on-going statistical data collection program.

Industrial trawlers
In 1969, an industrial fleet comprising some 33 vessels existed. Nine locally owned vessels exploited the shrimp resources in the Gulf of Paria, while an additional 24 vessels, owned by NFC, exploited the fishing grounds off the Brazil-Guyana shelf. These vessels landed their catch in Trinidad for processing and exporting (Kuruvilla *et al.*, 2000). Amos (1990) indicated 56 and 63 vessels flagged by Trinidad and Tobago, operating on the Brazil-Guyana shelf in 1975 and 1976, respectively. Between 1977 and 1985, however, the uncertainty in securing access to these fishing grounds affected operations of the respective fleets. Amos (1990) reported no vessels operating in the area as of 1977, and by 1985, the NFC had sold its fleet. Some of the vessels were purchased by nationals of Trinidad and Tobago, and operated locally (Gulf of Paria and north coast of Trinidad), and by 1985, 25 industrial trawlers operated in the waters off Trinidad and Tobago. At the Fisheries Division there are no records of the catches of this fleet prior to 1998. Attempts at implementation of a logbook system for data collection in 1991 were unsuccessful. Maharaj *et al.* (1993) estimated a total shrimp catch of 1000 t and associated by-catch of 300 t. Data on shrimp and the landed component of the by-catch have been collected since 1998 under a similar arrangement as for the semi-industrial trawl fleet. Estimation of total landings, available for 1998 to 2001, is based on the estimation procedure outlined for the artisanal multi-gear fleet. Catches between 1991 and 1998 were estimated by interpolation between the respective

estimates. The average annual catch per vessel in 1991 was assumed the same for the period 1987 to 1991. The associated annual estimated catch was taken as the product of the average annual catch per vessel and the number of vessels. The numbers of industrial trawlers in 1987 and 1995 were 25 and 21, respectively, and estimates for years with missing data were derived by interpolation. Although the shrimp to by-catch ratio is comparably less than for the artisanal and semi-industrial fleets, there is nevertheless some discarding which is not accounted for in the data collected.

Semi-industrial multi-gear fleet
Currently there is no data collection system targeting this fleet. The associated vessels were introduced to the fishery in 1986. Based on the number of vessels operating each year, the average number of trips per boats each year, and the fish hold capacity (1.5 t), estimates of maximum annual total catch were derived. The number of vessels was taken from vessel registration records, and the number of active vessels and average number of trips derived from interviews with vessel owners and key informants. This fleet is comprised of vessels targeting pelagic resources using pelagic handlines, and others targeting demersal resources using handlines and fishpots. The species composition of catches from the respective components of this fleet was assumed the same as for artisanal vessels which utilize similar gear, and fish in the same area as the multi-gear fleet.

Semi-industrial longliners
A data collection system, based on reporting of trip details (catch by species, effort, area of fishing) by vessel-captains or owners, was implemented in 2001. However, these vessels were present in the fishery since late 1986. Estimates of landings from 1987 to 1992 were taken from Chan A Shing (1993). The information is based on data obtained from the state-owned National Fisheries Company (NFC), a major trans-shipment port set up in 1972 and operating under Taiwanese management. Both local and foreign vessels land at this port. Data provided in this report pertain to locally flagged vessels which operated within the Exclusive Economic Zone of Trinidad and Tobago and on the high seas. Data were adjusted for the respective species, based on Conversion Factors from the International Commission for the Conservation of Atlantic Tunas (ICCAT) listed in Table 1 (Kebe, 2001). Catches pertain to locally owned and locally flagged, as well as locally owned and foreign flagged vessels. Catches from 2001 were taken from a trip reporting system implemented for the fleet in 2001. In all instances, data were recorded according to the respective species landed.

Table 1: Conversion factors for adjusting dressed weight to whole weight, according to ICCAT.

Species	Conversion Factor
Yellowfin tuna	1.13
Bigeye tuna	1.13
Billfish	1.20
Swordfish	1.33
Sailfish	1.20
Blue marlin	1.20
Wahoo	1.20
White marlin	1.30
Mixed Fish	1.13
Albacore	1.13

Tobago

Artisanal multi-gear fleet
Limited data are available for this fleet, and point estimates of total catches were derived using information from the following documents: 1957 (King-Webster, 1957; King-Webster and Rajkumar, 1958); 1962 to 1968 (Vidaeus, 1970; Horsford, 1975); 1972 to 1976 (Horsford, 1975; Ramsaroop, 1978). Catches for years with missing data were estimated by interpolation between anchor points. Estimates of total catches for the main fishery targeting flyingfish and associated large pelagic species were taken from Pandohee (1993, 1994) and Mohammed (1996, 1998) for the period 1988 to 1997. Total catches from troll lines, fish pots, bank lines and beach seines were estimated for 1988 to 1998 based on recorded catches, and effort statistics were derived from data on the number of boats at respective landing sites (Potts *et al.*, 1988).

Barbados semi-industrial ice-boat fleet
Traditionally, boats from Barbados have fished in the EEZ of Trinidad and Tobago primarily for flyingfish and associated large pelagics. Their catches are not captured in the data collection system in Tobago. A bilateral fishing agreement signed in 1991, allowed simultaneous fishing of up to 13 Barbadian vessels at any given time over a four month period from January 01, to April 30, 1991. However, since the expiration of the agreement, the Barbados fleet has continued to fish in the waters of Trinidad and Tobago. Based on the mean catch rate of 415 kg/day

from a single logbook return during the period of the agreement, the number of vessels which applied for licenses under the agreement, and the allowed fishing period, a crude estimate of 70 t was derived for 1991.

Estimation of by-catch in the local shrimp-trawl fishery

Annual by-catch for the respective fleets of the trawl fishery was estimated based on the ratio of by-catch to shrimp. For the artisanal fleet (Types I and II), Maharaj (1993) estimated a ratio of by-catch to shrimp of 14.7:1 for 1987, and Kuruvilla *et al.* (2000) estimated a ratio of 12.2:1 for 1999. For the semi-industrial fleet (Type III trawlers), Amos (1990) estimated a 1990 by-catch to shrimp ratio of 12.1:1 for the entire Gulf area, while Kuruvilla *et al.* (2000) estimated a ratio of 9.10 for 1999. The annual ratio of by-catch to shrimp for artisanal trawlers (1988 to 1998), and for semi-industrial trawlers (1991 to 1998) was estimated by interpolation between available estimates from the above sources. Estimates of total by-catch were derived as the product of the by-catch to shrimp ratio and the associated total catch of shrimp for the respective fleets.

Maharaj (1993) and S. Soomai (pers. comm.) provided details on the quantity of by-catch by weight for the artisanal fleet from which the corresponding species composition was derived for 1987 and 1999, respectively. Similarly, the species composition of by-catch in the semi-industrial fleet was derived using information from Amos (1990) and Soomai (unpublished data) for 1990 and 1999, respectively. The complete species composition of by-catch of the artisanal and semi-industrial fleets was estimated by interpolation between available estimates from these sources.

Estimation of catches of flyingfish utilized as bait in Tobago

Starting in 1995, estimates of the quantity of flyingfish utilized as bait were recorded. Based on the relative proportions of flyingfish bait to catches of large pelagic species, estimates of the quantity of flyingfish utilized as bait from 1988 to 1997 were derived.

Estimation of catches of marine turtles

Turtle shells were traditionally exported from Trinidad (Anon., 1973). Estimates of the quantities of turtle meat sold at the major markets were available for 1947 (27.27 t), 1969 (5.34 t), 1970 (3.98 t) and 1971 (6.64 t) from Anon. (1973). These figures however, represent minimum estimates as turtles were sold at other beaches that have not been included in the data collection program.

Brown (1942) documented the capture of green turtles (*Chelonia mydas*) and hawksbill turtles (*Eretmochelys imbricata*) off Tobago by a few fishers using turtle nets. Catches ranged between 20 to 40 turtles per fisher per month, with the main season being April to September. King-Webster (1957) noted the capture of turtles with spears from three boats. A catch of two turtles per day was expected. Fishers claimed to target turtles only during the legal season (October-May).

Estimation of catches from fishing tournaments

Data from fishing tournaments were available from the Trinidad and Tobago Game Fishing Association. The data covered landed catches of target species, and by-catch species to a lesser extent, from 1991 to 2001 for the following tournaments conducted in Trinidad over the period: Citibank Kingfish Tournament, the Royal Bank Wahoo Tournament, the Scotia Bank Funfish Tournament, the Teacher's Scotch Whiskey Kingfish Tournament and the Winfield Aloeng Tournament. Data were available from 1981 to 2001 for the Carib International Game Fishing Tournament conducted annually in Tobago.

Fishing effort

Trinidad

Point estimates of the number of boats by type were derived from the following sources: 1942 (Brown, 1942), 1946 (Anon., 1948), 1957 (Anon., 1958), 1959 (Kenny, 1960), 1968 (Vidaeus, 1970), 1980, 1991 and 1998 (Fisheries Division Vessel Census, unpublished data). Except for the most recent data from 1991 to 1998, these statistics represent mainly the artisanal multi-gear fleet and possibly also the artisanal trawl fleet. Additional information was taken from Maharaj (1993) for the trawl fleet, and from coast guard sightings and unpublished notes of briefings for fishing negotiations for the foreign fleet from Venezuela. The number of multi-gear vessels operating in the respective years was derived from interviews with key industry representatives, and the number of semi-industrial longliners was taken from Chan A Shing (1993) and the national report submitted to the ICCAT for 2002 (Anon., 2003).

Tobago

All data sources were as stated above, except those for 1988 and 1998, which were taken from Potts *et al.* (1988, 2002). The estimate for 1957 also considered information in King-Webster and Rajkumar (1958).

Assigning fishing days

It was assumed that unmechanized vessels fished 15 days per month from February to July, and did not fish November to January due to rough seas. The associated total number of fishing days was 90. Vessels switching to the demersal fishery from August to October were assumed to fish 15 days per month, excluding one month for vessel maintenance. Mechanized vessels targeting large pelagics were assumed to fish on average 10 days per month between November and January, and on average 20 days per month otherwise (150 days per year). Vessels primarily targeting the offshore pelagic fishery, and shifting to the demersal fishery during the pelagic off-season, were assumed to fish 15 days per month from August to October, excluding one month for vessel maintenance. For vessels that target large pelagics year round, it was assumed that these fish 20 days per month for 11 months per year. The total number of fishing days was 220. It was assumed that sloops fished at least 20 days per month from July to March, with July to December being the best season for red fish (snapper), and November to March being the best season for grouper. All vessels not specified as targeting large pelagics year round were assumed to focus on this fishery from November to July, and to switch to targeting demersal and reef resources from August to October, with one month of no fishing activity. The total number of fishing days devoted to the pelagic fishery was 150 days, and to the demersal fishery was 30 days. Vessels targeting the beach seine or demersal fishery year round were assumed to fish 15 days per month from January to December. Semi-industrial launches or ice-boats which target large pelagics from November to July were assumed to fish 20 days per month. These were assumed to target demersals form August to October, at 20 days per month, excluding one month for vessel maintenance.

RESULTS

Preliminary estimates of total catches for the respective fleets are shown in Figure 3. Currently, data are missing for the artisanal multi-gear fleet prior to 1995, for the trawl fleets prior to 1987, for the semi-industrial multi-gear fleet post 1999, and for Venezuelan trawlers post 1996. Data from the Venezuelan multi-gear fleet operating in the EEZ of Trinidad and Tobago are lacking also, and efforts are focused on obtaining an estimate. However, despite these data gaps, it is evident that the Venezuelan trawlers obtain catches in excess of the local fleets, and that the artisanal fleet accounts for the major proportion of total catches of local vessels.

As of June 2003 catch statistics for Trinidad and Tobago currently in the FAO FISHSTAT database (Figure 4) were disaggregated into 26 species groups. However, statistics for all categories were not available each year. Prior to 1983, catch data were available for less than ten species groups, beginning with four groups in 1950. Between ten and 17 species groups were represented from 1983 to 1995, and from 1996, an increasing number of species groups were reported. A review of the percentage total catch in the aggregate unidentified category ('marine fish nei') indicates a general improvement in the level of dis-aggregation of reported catches from 1950 to the mid 1990s (Figure 4b). However, from the early 1990s onwards the unidentified category accounts for an increasing proportion of overall catch, when both marine fish nei and demersal percomorphs nei are considered. The proportion of total catches reported only as aggregate, unidentified category decreased from 50% to 30% between 1950 and 1994, but increased to `60% by 2001 (Figure 4b).

The available data for the artisanal multi-gear fleet comprised up to 97 species groups between 1995 and 2002. Estimated catches for this fleet increased from 4,186 t in 1995 to 9,165 t in 2002. Estimates for the pre 1995 period are currently being developed. The percentage of catch in the aggregate fish category for this fleet has declined from 6.98% to 2.24% between 1995 and 2002.

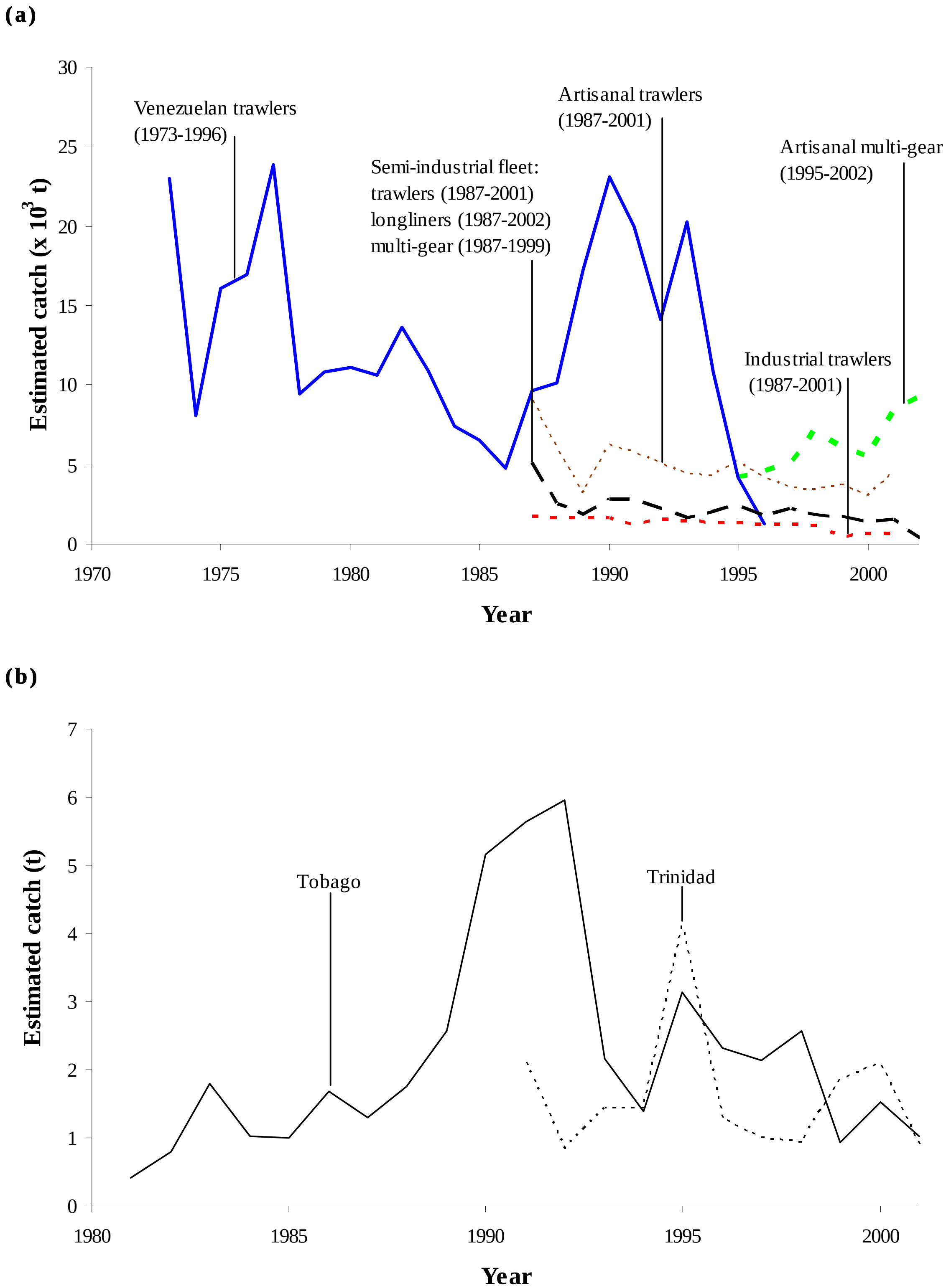

Figure 3: Preliminary estimates of total catch from national sources by gear type (a) and island (b)

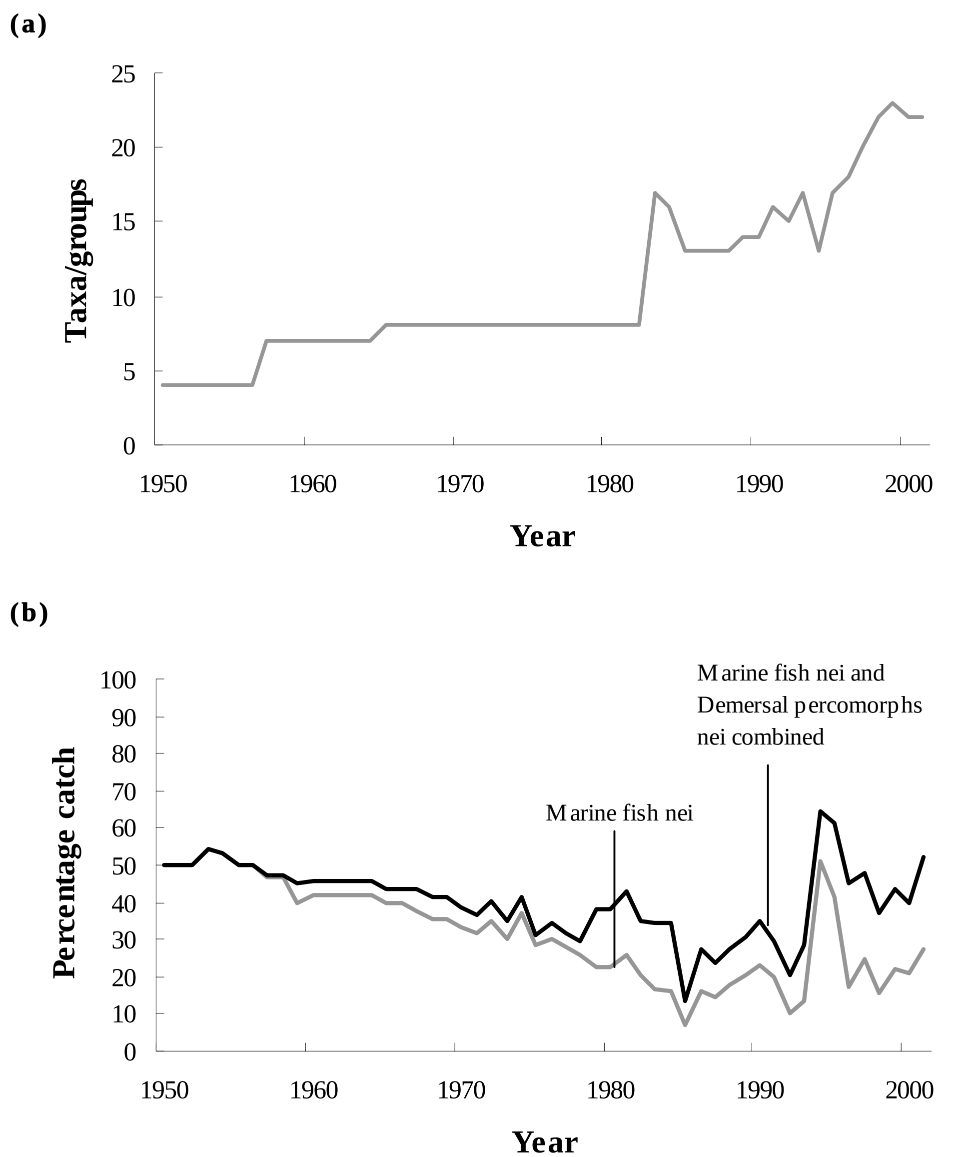

Figure 4: FAO FISHSTAT statistics for Trinidad and Tobago, showing the number of taxa or groups reported by FAO for Trinidad and Tobago (a), and the percentage of catch being reported as aggregate groups (b). The notation 'nei' refers to 'not elsewhere indicated'.

Shrimp catches of the trawl fleets have declined since 1987, from a peak of 2,042 t to the lowest level of 881 t (Figure 5a). This is attributed mainly to declining catches of the industrial fleet. By-catch of the shrimp trawl fleet (Figure 5b) is considerably higher than the targeted shrimp catches, with total by-catch declining from 13,712 t in 1987 to 4,099 t in 2001, with the greatest proportion of the total by-catch taken by the artisanal fleet (ranging from 62% in 1987 to 75% in 1999). The by-catch of the artisanal and semi-industrial trawl fleets comprised 49 and 46 family groups, respectively. The species composition of the by-catch from the industrial fleet has not yet been examined.

Estimated catches from the local semi-industrial longline fleet increased from 0.09 t in 1987 to 351 t in 2002. The main species captured are yellowfin tuna (0.03 t – 222 t) and swordfish (4 t – 180 t). However, several other species are also landed, including bigeye tuna (*Thunnus obesus*), albacore (*T. alalunga*), skipjack tuna (*Katsuwonus pelamis*), dolphinfish (*Coryphaena hippurus*), sailfish (*Istiophorus albicans*), blue marlin (*Makaira nigricans*), white marlin (*Tetrapturus albidus*), Serra Spanish mackerel (*Scomberomorus brasiliensis*), frigate mackerel (*Auxis rochei rochei*), wahoo (*Acanthocybium solandri*) and several species of sharks.

DISCUSSION

Based on the data reconstructed so far, it is difficult to assess the relative importance of catches by local and foreign fleets in the EEZ of Trinidad and Tobago. Particular attention will be placed on the pre-1987 and post 1995 period in the time series. The present assessment has shown that data submitted to the FAO consists of estimates of total catches for the artisanal multi-gear fleet and all trawl fleets in Trinidad. In contrast, catches from the semi-industrial multi-gear and longlining fleets in Trinidad, as well as all fleets in Tobago are not included. Obviously, foreign catches are also not included in reports to FAO, as they are expected to be reported by the flag country of the vessels.

The procedure for adjusting recorded to estimated total catches by fleet, gear and species is continuously being refined. More recent refinements, to eliminate overestimation of catches, pertain to the trawl fleet, and fleets which capture blue marlin and sailfish off Trinidad's north coast (L. Ferreire, Fisheries Officer, pers. comm.). Such refinements are due to improvements in the data collection system, and consideration of species distributions in assessing the likelihood of specific fleets targeting certain species. Unfortunately, this results in some inconsistency in interpretation of current, compared to historic data, since the refinements are applied to the most recent years only.

Bait species used in trolling are sprats, ballahoo and several species of sardines, locally called sardines rouges, anchois, sardines dorees, cha-cha, small coulihou and sardines cailleux. (Vincent, 1910). Pices of mackerel, bonito and mullet may also be used. Mackerel, among others, are used for the 'ligne dormante', and jelly-fish (genus *Physalia*, local name 'galére') are used at specific times to catch a large carangid locally called 'paoua'.

It appears that discarding was a common practice at all beaches where beach seining was practiced, as fishers were reluctant to spend time freeing small fish entangled in the nets. Specifically at Cedros in the late 1940s, where between 45-100 beach seines operated regularly, the quantity of fish discarded was estimated at between 300 – 3000 tonnes.

The field identification of landed species uses either local names or the FAO common names. This leads to discrepancies in the assignment of scientific names, particularly for the artisanal fleet. This situation is also complicated by the variation in local names given to the same species at different landing sites. Some local names correspond to FAO common names, but refer scientifically to different species. A more accurate representation of the breakdown of catches is therefore provided by family groups.

Mendoza and Lárez (1996) examined catches of the artisanal medium range fishery off northeastern Venezuela, through a series of interviews and landing controls. Results of the study indicated considerable declines in catch per unit effort of three important species between 1981 and 1992. Over this period, catch per unit effort (in weight of catch per handline per fishing day) of the red snapper (*Lutjanus purpureus*) off Trinidad's east coast declined by 40%. Declines in CPUE in excess of 50% were also observed for the

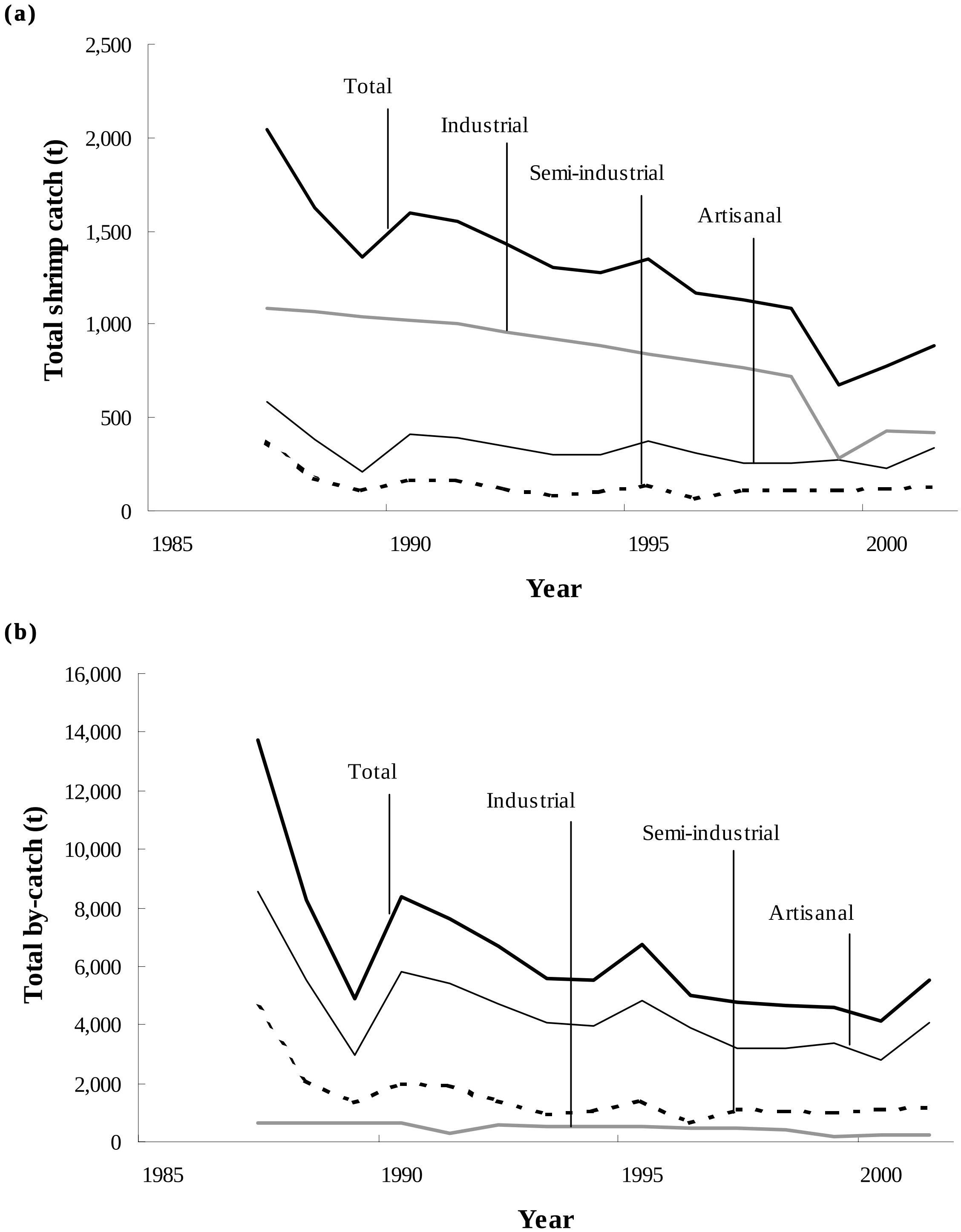

Figure 5: Shrimp catches of the various trawl fleets of Trinidad and Tobago (a), and the associated by-catch (b).

yellowedge grouper (*Epinephelus flavolimbatus*) and vermillion snapper (*Rhomboplites aurorubens*) off the north coast of Trinidad. Confirmation of illegal fishing activity of Venezuelan vessels was obtained from a reliable but confidential source as a regional meeting in 2000. During the period 1997 to 1999, thirty-six Venezuelan boats fished between 120 and 160 miles off the east coast of Trinidad. They targeted the red snapper (*Lutjanus purpureus*) using handlines and landed the catch at night in Port of Spain for subsequent export. The operation was coordinated by a national of Martinique and there are no records of the catch. In 2000, there were also 120 Venezuelan vessels fishing within the 200 nm zone, using live bait fishing to catch carite (*Scomberomorus brasiliensis*) and surface longlines and hook and line to catch dolphin fish (*Coryphaena hippurus*) and billfishes (Istiophoridae). An unknown number of Venezuelan boats targeting billfishes also operate off Trinidad's north coast.

There is some uncertainty regarding interpretation of historic data of catches. Amos (1990) provided estimates of shrimp landings in Trinidad and Tobago from 1962 to 1989. In the absence of a system for estimating total catches from recorded data at the time, it was assumed that the statistics represent recorded data, and therefore are likely an under-estimate of total catches. Prior to 1978, a bilateral agreement between Trinidad/Tobago and Brazil allowed for shrimp fishing in the waters of the Guyana-Brazil shelf by trawlers from Trinidad. Statistics on shrimp catches between 1962 and 1978 may therefore reflect catches taken from both the waters of Trinidad and Tobago, and the Guyana-Brazil Shelf.

By-catch estimated by the present study concurs with Kuruvilla *et al.* (2000), who estimated annual discards of 8,800 t of by-catch. Certainly, it appears that this applies to the late 1980s, early 1990s period, as more recent estimates indicate about 5,500 tonnes as total by-catch (discarded and landed) for 2001. Several assumptions were made with respect to the point estimates of by-catch to shrimp ratio, as well as the species composition of the by-catch for the artisanal and semi-industrial fleets. This involved some measure of duplication, particularly for the landed component of the by-catch. Based on the ratio of by-catch to shrimp, and the ratio of landed by-catch to shrimp for the respective fleets in Kuruvilla *et al.* (2000), the percentage of total by-catch landed is 10%, 29% and 33% for the artisanal, semi-industrial and industrial fleets, respectively, assuming of course that all shrimp are landed. Presently, data on the landed component of the by-catch is adjusted based on the procedure applied to data on the artisanal multi-gear fleet for estimating total landings. However, the species composition of the landed component of the by-catch is dictated by the size of fish, species composition, fish prices and market demands. Therefore, these data cannot readily be utilized for estimating the species composition of the discarded component of the by-catch. This provides the rationale for utilizing quantities, and species composition, of the entire by-catch sampled, to arrive at total estimates of by-catch for the respective fleets. Limited data are available on the species composition of the by-catch. The 1990 estimate for the semi-industrial fleet is based on a one month study, however, the species composition of the by-catch is known to vary temporally and spatially. This could not be considered in the present study.

ACKNOWLEDGEMENTS

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Cuban fisheries catches within FAO area 31 (Western Central Atlantic): 1950 - 1999

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ABSTRACT

Two sources of fisheries catches by Cuba were compared: National records pertaining to national waters (EEZ/shelf) obtained from local scientists, and FAO FISHSTAT for the entire FAO area 31 (Western Central Atlantic). This permitted the spatial separation of catches into 'inshore' (EEZ/shelf) and 'offshore' components (area 31 outside of Cuban EEZ/shelf). Through consideration of additional information on by-catch composition, we were able to allocate significant portions of the reported by-catch, previously recorded as 'miscellaneous marine fishes' (MMF), to individual taxa, thus reducing the MMF component in the reported landings by up to 41%. Overall, Cuban reported catches peaked at 76,000 t in 1987, and have been declining since, to just under 55,000 t by 1999. Catches are dominated by Caribbean spiny lobster (*Panulirus argus*), shrimp (*Penaeus* spp.), and in earlier periods also red grouper (*Epinephelus morio*) and grunts (Haemulidae), with Lane snapper (*Lutjanus synagris*), sharks & rays, and mangrove oysters (*Crassostrea rhizophorae*) also contribute significantly to reported catches.

INTRODUCTION

Reviews of Cuban fisheries are presented in Adams *et al.* (2000) and Claro *et al.* (2001), and will only be briefly summarized here. Cuba is increasingly becoming a significant global supplier of high-valued seafood (Adams *et al.*, 2000). Until the 1960s, most Cuban fisheries were artisanal in nature, focusing on resources of the continental shelf (Claro *et al.*, 2001). A small number of larger vessels (20-25 m length) targeted tuna and shrimp, or high priced demersal species on the continental shelves near Florida and the Bahamas, and on the offshore Campeche bank (Figure 1). Catches were relatively low at an estimated < 30,000 t annually (Claro *et al.*, 2001). During the 1960-70s, assistance from the Soviet Union permitted the development of significant long-distance fleets fishing international waters in the Atlantic and Pacific, mainly providing low-value seafood for the domestic market (Joyce, 1997; Adams *et al.*, 2000). The declaration of 200 nm EEZs by many countries starting in the late 1970s, together with increasing costs of fuel, began to curtail offshore fishing efforts considerably in the early 1980s (Joyce, 1999). The breakup of the Soviet Union in the early 1990s resulted in further price pressure coming to bear on fuel intensive offshore fisheries, essentially shutting down the long-distance fleets, leading to a major restructuring of the fishing industry in Cuba in the 1990s (Adams *et al.*, 2000). In general, emphasis shifted from high-volume, but low-value pelagic fisheries to high-value, coastal fin- and shell-fish species caught primarily in near-shore waters (Adams *et al.*, 2000).

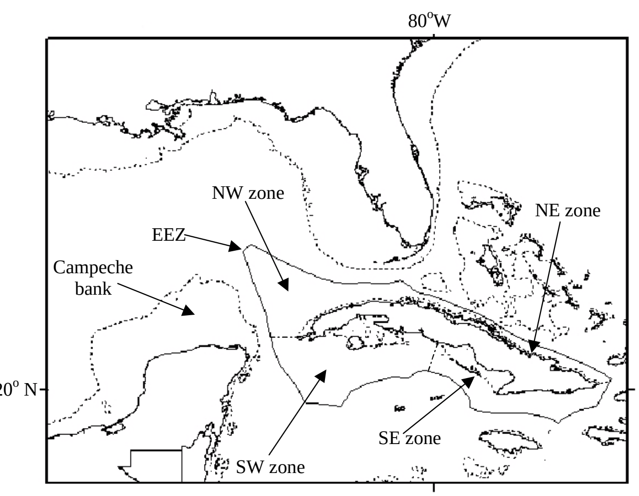


Figure 1: Map of Cuba, also showing the southern tip of Florida, the Bahamas, the 200 m shelf depth contour, Campeche Bank, and the EEZ of Cuba.

Fisheries

The majority of fisheries resources in Cuban waters are considered fully- or over-exploited (Claro *et al.*, 2001), and a wide variety of species (typical for tropical multi-species fisheries) are being targeted by a wide range of gears. The most valuable target species is the Caribbean spiny lobster (*Panulirus* *argus*), which accounts for approximately 15% of total near-shore catches (Claro *et al.*, 2001). By the early 1990s, this fishery consisted of about 290 simply equipped vessels of modest size operated by approximately 1,300 fishers, and generated US$100-125 million export revenues annually, accounting for over 60% of the country's annual income from fisheries (Baisre and Cruz, 1994; Joyce, 1997; Adams *et al.*, 2000). The lobster fishery is predominantly an export industry, with the major markets for Cuban lobster being Japan (28%), France (24%), Spain (19%), Italy (15%), and Canada (10%) (Adams *et al.*, 2000). Part of the annual export revenue is utilized for importing lower-valued fish products for local consumption. The lobster fishery is executed essentially in four distinct areas of the Cuban shelf waters shallower than 200 m (Figure 1): the Northeast Shelf (with ~15% of total catch) stretching from Cárdenas in the west to Nuevitas in the east (the Saban-Camagüey Archipelago); the Southeast Shelf (~ 18%) stretching from Casilda in the west to Niquero in the east (Gulfs of Anna Maria and Guacanayabo); the Northwest Shelf (~4%) stretching from the western tip of Cuba (Cape San Antonio, Gulf of Guanahacabibes) to Punta Hicacos in the east; and the Southwest Shelf (~63%), encompassing the Gulf of Batabanó and La Broa Bay (Joyce, 1997; Claro *et al.*, 2001). Strict management, including enforcement of regulations, limited entry into the fishery, regulation of gear, assignment of exclusive fishing zones and reliable data gathering systems have been proposed as reasons to consider the Cuban fishery one of the best managed lobster fisheries in the world (Baisre and Cruz, 1994).

The shrimp fishery, being the second most valuable fishery within Cuban waters, is based mainly on two species: the nocturnally active pink shrimp (*Penaeus notialis*) and the diurnal white shrimp (*P. schmitti*). Approximately 85% of commercial catches are from the former species (Joyce, 1999). Overfishing of this resource lead to declining catches from the late 1970s, exacerbated by degraded estuarine nursery habitats due to reduced river outflow caused by extensive damn construction during the 1970s and 1980s (Claro *et al.*, 2001).

The finfish fishery targets a large number of fish species (about 120 species of fishes are listed on the official government price list). The main families targeted are the Lujanidae, Serranidae, Mugillidae, Gerreidae and Pomadasidae representing demersal species, while the Clupeidae, Scombridae (mainly mackerels) and Carangidae dominate the near-shore pelagic fisheries. The Scombridae (mainly larger tuna), sharks (various families) and Istiophoridae and Xiphiidae (marlin and swordfishes) are primarily targeted in oceanic environs (Joyce, 1996). The fishery for mullets (Mugillidae) is among the most ancient in Cuba, pre-dating Spanish colonization; more recently, however, the dominant species were high value lutjanids and serranids, as well as pelagics (Joyce, 1996). The finfish fisheries are widespread on the Cuban shelf, occurring on all four shelf areas indicated above, with the highest catches coming from the eastern part of the Cuban archipelago. Historically, drastic increases in effort, combined with the widespread and rapid introduction of more efficient gears (net based rather than the traditional hook-and-line or traps) led to overfishing and a drastic decline in catches in the late 1970s. While some improvements were observed after the introduction of stronger management measures, overall, most species continue to be fully or over-exploited (Joyce, 1996; Claro *et al.*, 2001).

Fisheries management

Management of Cuban fisheries differs from that of most other countries in that a fairly high amount of centralized control has historically been exerted through the Ministry of Fishing Industries (Ministerio de la Industria Pesquera, MIP), which traditionally held responsibility for all aspects of management of marine resource use (Joyce, 1999; Claro *et al.*, 2001). An improved fishery administration policy was implemented in 1981, and licensing of commercial and recreational fisheries, as well as quota, size, seasonal closure and inspection regulations have been introduced in the 1990s, and are thought to improve control and monitoring of management activities. The major development related to increased de-centralization of the day-to-day operations. Thus, MIP is directly responsible for legal and administrative functions, while production activities, control and services was delegated to newly created Provincial Fishing Associations (Adams *et al.*, 2000). One major concern related to management is the fact that both production by the industry as well as conservation of the resource is being controlled by the same entity, raising the spectre of overemphasis of production at the expense of sustainability (Claro *et al.*, 2001). Furthermore, while historically, fishing was the primary economic activity in Cuban marine waters, tourism is increasingly placing different demands on the marine ecosystems. This development is calling for integrated management approaches, with some trial projects being in place, and coordinated by the Ministry of Science, Technology and the Environment (Claro *et al.*, 2001).

The aims of this study were to:

1. Compare the official FAO FISHSTAT statistics for Cuba (FAO area 31) from 1950 to 1999 with the national data as obtained directly from Cuban Ministry of Fishing Industries (MIP);
2. Use the above comparison to separate Cuban catches into those taken within national waters (EEZ/shelf) and from waters outside EEZ but still within FAO area 31 (historically mainly on Campeche Bank and shelf- or near-shelf-waters of Florida and the Bahamas); and
3. Account for the substantial component of 'miscellaneous marine fishes' in the FAO data through species allocation of the reported by-catch component.

RESULTS

Total reported landings from Cuban fisheries in FAO area 31, as reflected in the official FAO FISHSTAT database (Figure 2a), show the typical development for many fisheries, with an increase in reported landings from < 10,000 t year^{-1} in the 1950s to its peak of 76,000 t year^{-1} in the late 1980s, and have been declining ever since. Catches are reported by 34 taxonomic groups, and are dominated by lobster (*Panulirus argus*), shrimp (*Penaeus* spp.), and in earlier periods, also red grouper (*Epinephelus morio*, Serranidae) and grunts (Haemulidae), but by far the largest single component is 'miscellaneous marine fishes' (MMF, Figure 2a). This large MMF component masks a peak in reported landings for taxonomically accounted entities in the late 1960s – early 1970s (Figure 2a). The peaks of catches for red grouper, grunts and (slightly later) shrimp in the late 1960s – early 1970s, followed by declines in reported landings for these taxa indicate overfishing of these resources (especially in light of habitat destruction for the inshore shrimp resources), as well as the reported decline of the offshore fisheries discussed earlier. Comparison of the FAO dataset (for entire FAO area 31) with the national data for Cuban catches in Cuban waters (Cuban EEZ/shelf) obtained from the Cuban Ministry of Fisheries (MIP), indicated similar patterns, although lower catches are reported for national waters before 1976 (Figure 2b). Good correspondence since the mid 1970s reflects good transfer mechanisms of landings statistics from the national source institutions to FAO FISHSTAT. The provision of national catches covering Cuban waters (EEZ/shelf) only, permitted differentiation of reported landings into 'inshore' (EEZ/shelf, based on national data) and 'offshore' (non-national FAO area 31) waters (see below). Furthermore, the availability of national data on by-catch, combined with Cuban studies on shrimp fisheries by-catch (Claro *et al.*, 2001), permitted re-allocation of by-catch from the indiscriminate MMF category to taxonomic entities in the adjusted catch (see below). Thus, accounting for by-catch components of catches, and inshore versus offshore catches, enabled us to generate a 'new' adjusted catch database for Cuban fisheries in FAO area 31 containing data for 57 taxonomic groups from 1950-1999 (Figure 2c).

Shrimp fisheries by-catch

Studies summarized in Claro *et al.* (2001) provide information on species composition and percentage contribution of by-catch (Table 1). The shrimp fisheries accounts for approximately 80% of total reported by-catch (Table 2). The component not accounted for by the shrimp fisheries consists of unspecified finfish fisheries (Claro *et al.*, 2001). As all by-catch is landed and utilized for animal feed (Claro *et al.*, 2001), Cuba also reports these by-catches to FAO, which incorporates these catches as MMF (L. Garibaldi, FAO, pers. comm.). Utilizing the data on composition of by-catch we were able to reassign a significant proportion of FAO MMF (Figure 2a) to individual taxa within the adjusted database, thus reducing MMF by up to 41% (Figure 2c).

Inshore-offshore distribution

The availability of EEZ/shelf based catches by a national source enabled us, by way of comparison with FAO area 31 data, to separate Cuba's reported landings by area, resulting in catches from inshore areas (EEZ/shelf waters) and offshore areas (waters outside Cuban EEZ, but within area 31). The results indicate that offshore catches peaked in the late 1960s- early 1970s, and were minimal by the early 1990s (Figure 3a).

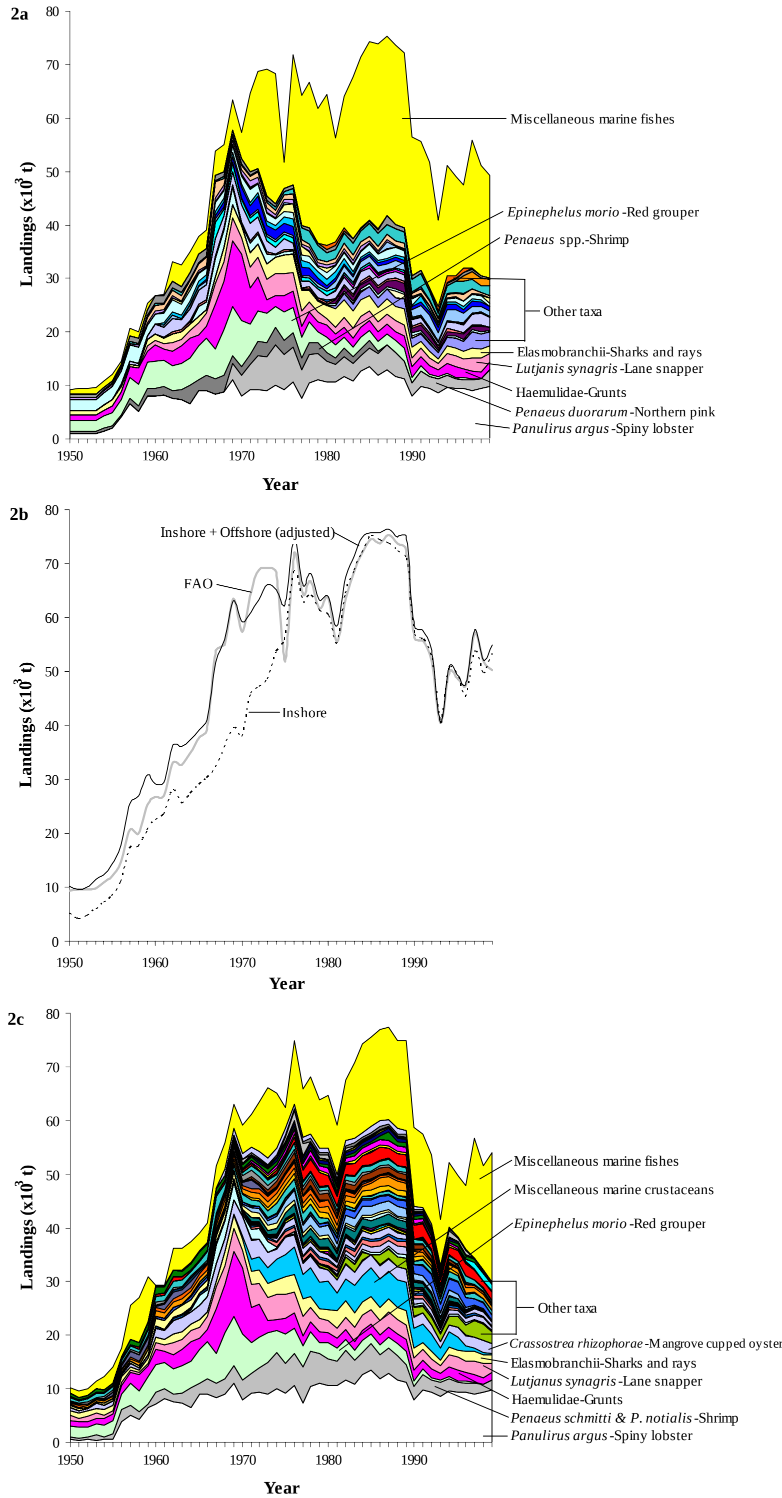


Figure 2: Time series of fisheries catches for Cuba, (a) FAO FISHSTAT data for FAO area 31 (Western Central Atlantic), (b) total catches from FAO (area 31), inshore (Cuban EEZ/shelf), and 'new' adjusted catch time series, and (c) 'new' adjusted catch time series by taxonomic entity, accounting for Cuban catches taken in national waters and offshore.

Table 1: Taxonomic composition and percentage contribution of by-catch, based on studies in the shrimp fisheries (Claro *et al.*, 2001). The 'other marine fishes' category also contains by-catch reported by the general finfish fisheries.

Taxon	Percentage	Taxon	Percentage
Chondricthyes	1.90	*Lepophidium brevibarbe*	4.59
Clupeidae	1.18	*Acanthurus* spp.	0.53
Synodontidae	2.30	*Scomberomorus* spp.	0.03
Congridae	1.11	*Prionotus* spp.	4.41
Hippocampus spp.	0.27	Pleuronectiformes[a]	2.26
Centropomidae	0.23	Balistidae	0.45
Serranidae	2.87	Sphoeroides	0.32
Carangidae	4.02	Diodontidae	0.05
Lutjanus synagris	3.45	Ostraciidae	0.12
Diapterus rhombus	6.93	*Ogcocephalus* spp.	0.83
Eucinostomus spp.	7.92	Crustaceans	24.04
Haemulon spp.	0.91	Molluscs	5.29
Sparidae	1.30	Other marine fishes	22.29
Micropogonias furnieri	0.45	------	---

[a] Originally reported as Bothidae and Cynoglossidae.

Table 2: Total by-catch reported by Cuba, based on shrimp and general finfish fisheries, for the time period 1969-1999.

Year	Tonnes	Year	Tonnes
1969	1,061	1985	21,540
1970	2,407	1986	22,182
1971	9,577	1987	21,253
1972	10,149	1988	21,665
1973	11,974	1989	22,298
1974	15,753	1990	15,464
1975	17,269	1991	13,844
1976	21,167	1992	14,183
1977	18,521	1993	9,830
1978	22,064	1994	12,082
1979	20,430	1995	9,783
1980	22,228	1996	4,547
1981	13,752	1997	2,190
1982	16,695	1998	1,532
1983	21,243	1999	1,058
1984	19,986	---	---

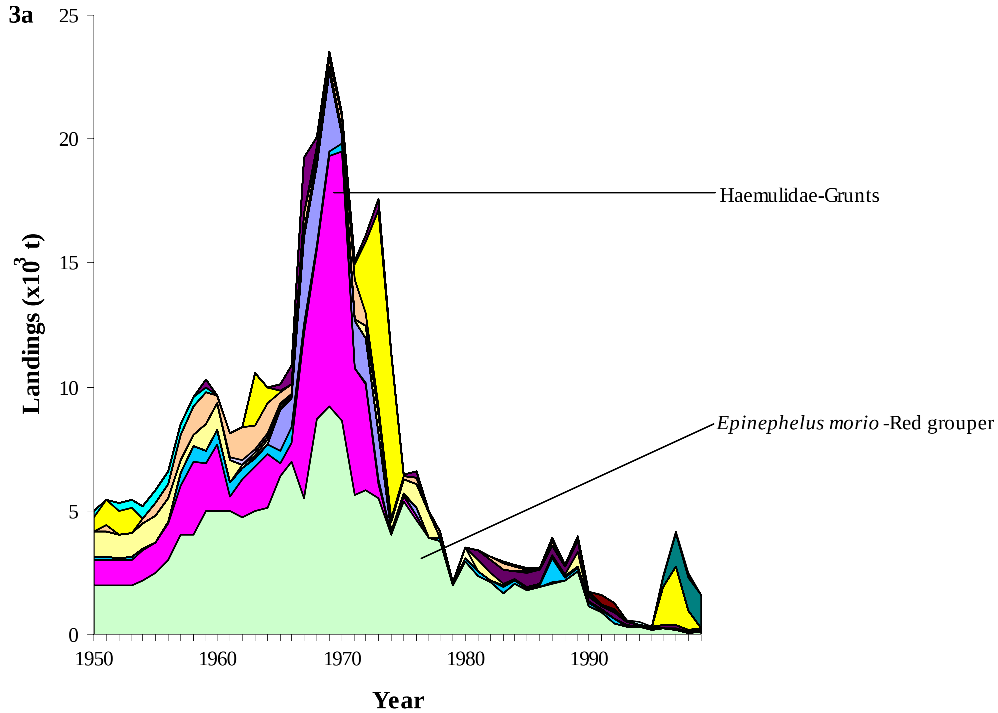
Catches were dominated by red grouper (*Epinephelus morio*, Serranidae) and grunts (Haemulidae). Inshore catches, on the other hand increased significantly until the mid 1980s, after which they started declining (Figure 3b). The inshore catches consisted of a higher diversity of taxa, dominated by lobster (*Panulirus argus*), shrimp (*Penaeus* spp.) and MMF, with lane snapper (*Lutjanus synagris*), oyster (*Crassostrea rhizophorae*), sharks and rays, and marine crustaceans also contributing significant amounts.

Adjusted catches by Cuba in area 31

The 'new', adjusted catch statistics (Figure 2c) indicate only minor overall changes from the original FAO dataset (Figure 2a). However, the availability of by-catch information permitted a distinct improvement of species allocations with concomitant reduction in the MMF component.

DISCUSSION

Overall, the data comparison between national source data and FAO FISHSTAT indicated a good data transfer mechanism between Cuba and the global database maintained by FAO, something rare in this region (see other contributions in this volume). The general decline in catches illustrated by these data are in line with many other countries, and reflect a global fisheries crisis (Watson and Pauly, 2001; Pauly *et al.*, 2002). The history of Cuban fisheries (Claro *et al.*, 2001), at least for FAO area 31, is reflected in the spatio-temporal distribution of reported landings. The overall decline of catches since the early 1990s should be considered of great concern for Cuba, both with regards to internal supply of food, as well as revenue generation. Worrisome in this regards is the concentration of production management and resource conservation under the auspices of one industry-associated organization (Claro *et al.*, 2001), a situation not conducive to sustainability.



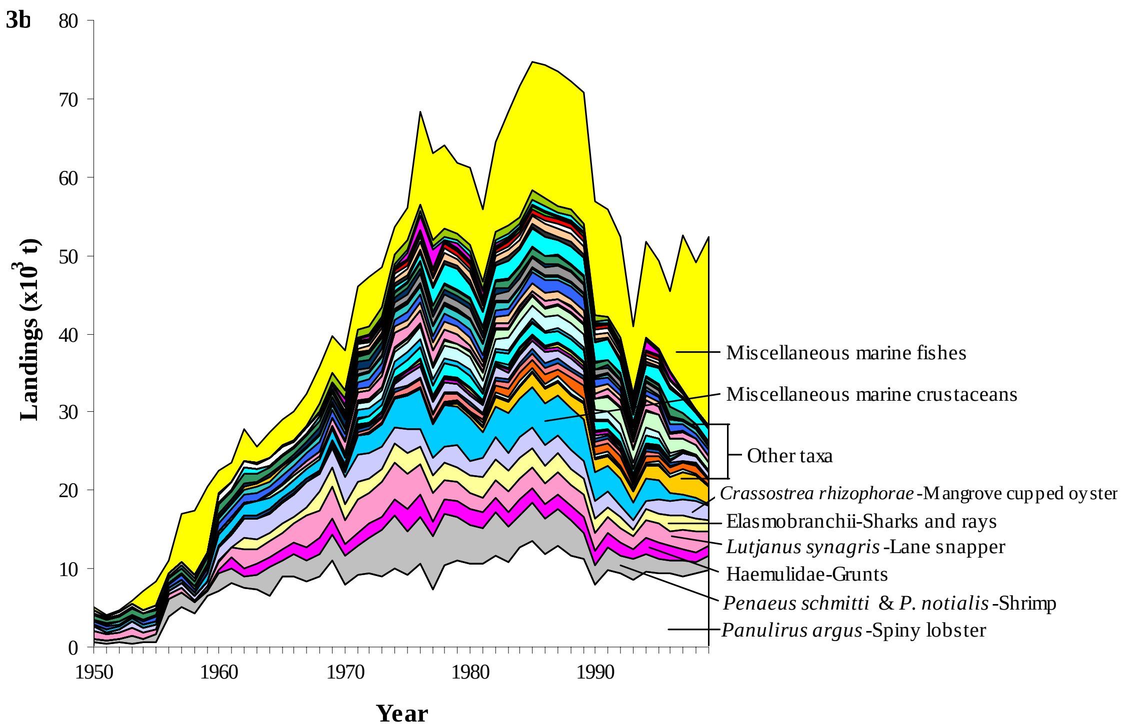


Figure 3: Cuban fisheries catches, separated into (a) 'offshore' and spatially non-assignable component, and (b) 'inshore' catches from EEZ/shelf waters, for the period 1950-1999.

Thus we were able to incorporate information of by-catch composition into species allocation of reported catches, and thereby reduce the indiscriminate MMF component, is of considerable importance for ecosystem-based management considerations in Cuba. This will allow better accounting of extractions in an ecological context, and enables fisheries catches to be mapped onto ecosystems.

The improved spatial assignment and taxonomic composition of catches of Cuban fisheries will be incorporated into the *Sea Around Us Project* database (see www.seaaroundus.org), which forms the foundation for large-scale, spatial catch maps (Watson *et al.*, 2001; Watson and Pauly, 2001; Pauly *et al.*, 2002). Such data are also useful for assessment of spatial trends in fish biomass over time (Christensen *et al.*, 2003).

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The Fisheries of Belize

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ABSTRACT

Belize relies heavily on fishing for subsistence and primary income for a significant section of the population. Furthermore, marine based tourism is a rapidly growing and nationally important industry, and both tourism and fishing depend on healthy and productive marine environments. The export oriented, commercial component of fisheries has been dominated by lobster (*Panulirus argus*) and conch (*Strombus gigas*), with shrimp (*Penaeus* spp.) increasing from the late 1980s. Reported landings reached a peak just below 2,000 t in the early 1970s (driven by conch) and again in the early 1990s (due to shrimp), but generally have been declining since the mid 1980s. However, the substantial catches of subsistence and artisanal fisheries, and tourist-based recreational catches, remain unaccounted for. Despite extensive legislative tools for management, Belize has not been successful in management of their resources, nor been able to guarantee the health of the ecosystems. Historically, management has largely been top-down and not sufficiently participatory. The need to rationalize government management of its fisheries and coastal resources has been met by some innovative partnerships, e.g., between fishers cooperatives and conservation NGOs. Thus, a concept of resource 'governance' has emerged where government recognizes that various non user groups have legitimate rights and negotiate for their share of the resource. The role of government is therefore limited to that of setting the rules of engagement and ensuring that rules are obeyed.

INTRODUCTION

Belize, with a population of ~230,000, is the second smallest country on the American continent, covering an area of ~23,000 km^2. Mexico lies to the north, Guatemala to the west and south, and the Caribbean to the east. Belize has responsibility for an EEZ of ~170,000 km^2, over 7 times its land area (see www.seaaroundus.org). The Belize coast harbours complex ecosystems that include mangrove forests, river deltas, estuaries, sea grass beds and coastal lagoons which support many important species including crocodiles, manatees, turtles and seabirds (McField *et al.*, 1996). At least 594 genera and 1,040 species occur in coastal regions, while at least 634 genera and 1,304 species occur in marine areas (Gillett, 1999). Nineteen rivers from the interior empty into the coastal system. Until recently, these rivers were the most important avenues of communication and transport in the country (Gordon, 1981).

Included in Belize's national jurisdiction is the Belize Barrier Reef complex (the largest barrier reef in the Atlantic), which lies about 20-25 km off the coast, running in a north-south direction, from the southern tip of the Yucatan Peninsula to the Gulf of Honduras. The 250 km long reef complex contains over 1,060 mangrove and sand cays, and 113 coral species have been reported as endemic (Jacobs, 1998). Three offshore atolls lie to the east of the reef in deeper oceanic waters.

Agriculture is the leading industy, accounting for ~22% of GDP, ~70% of export earnings, and ~29% of the total labour force in the late 1990s, with sugar cane and bananas being the primary export items (www.caricom.org; www.belize.gov.bz). However, besides their role as a vital domestic food source, marine products have increasingly become an important source of foreign exchange, with the fisheries sector (and aquaculture) now third largest foreign exchange earner (B.Z.$[1] 71.8 million in 2000), and is dominated by exports of lobster and shrimp (Belize Government Cabinet Briefing - May 8th, 2001; www.belize.gov.bz). Already during the mid-1990s, marine products represented 2.6% of national GDP and 5.3% of the countries total exports (Anon., 1996; Sorensen and Aschan, 1997). In real terms, the marine products industry has expanded by almost 25% during the 1990s, largely as a result of high market prices and increased production, especially from the aquaculture sector for shrimp (Huntington and Dixon, 1997).
As in other countries, high population growth including immigration and refugees from neighbouring countries (Plaisier, 1996) has

[1] B.Z.$ 1.0 = U.S.$ 0.50

lead to increased pressure on coastal resources, this being added to the 'normal' growth of the fisheries (Wells *et al.*, 1992). Thus, overfishing of conch and lobster was already evident by the mid 1990s, though price increases have tended to mask the effects of declining catches in weight.

Also, the number of tourist arrivals increased, e.g., from 142,000 in 1988 to 329,000 in 1994, and by 1995 generated income of about US$ 75 million (McField *et al.*, 1996). Seventy-two percent of all tourists spend time snorkelling, and over 50% will participate in a dive. Thus, tourists compete for healthy and diverse reef and fish resources.

The Belize fishing industry

The Belize Barrier Reef and coastal waters have supported subsistence fishing by the indigenous population for millennia. Fishing and trading activities that took place along the coast by Mayan people some 2,500 years ago are still evident at several Mayan archaeological sites (Craig, 1966; Gordon 1981; Vail, 1988), and evidence of pre-historic effects of fishing on marine ecosystems in the Caribbean have been documented (Jackson, 1997; Jackson *et al.*, 2001). Fishing as a commercial activity did not develop until the mid 19th century (Price, 1984), and records of fishing activity have been kept by coastal communities since the early 1840s. Between 1920 and 1960, the Belize fishing industry changed from a small scale domestic fishery, with periodic incursions into the Mexican market, to whole sale marketing of lobster (*Panulirus argus*), conch (*Strombus gigas*) and fin-fish to the more lucrative U.S. and Caribbean markets. The commercial fishery did in fact evolve from foreign dominated purchasing and marketing companies, to locally owned 'cooperative' bodies which gained prominence during the 1950s and 1960s (Snyder, 1976; Gibson, 1977; Vega, 1979; Gordon, 1981; Espeut, 1994). This form of economic organization has come to dominate the sector, with 13 registered fishing cooperatives being owned, operated, and managed by the fishers themselves. It is these cooperatives that are dominating the export market for lobster, conch and fin-fish products. There are believed to be between 3,000-4,000 fishers operating with a fleet of approximately 900 licensed vessels (Richards, 1995), of which ~60% belong to cooperatives (www.caricom.org).

The Belize fishery may be divided into the following categories:

Lobster and conch fishery: Both of these species are taken along the reef and within the atolls. Traps are set for lobsters, while conch (as well as lobster) are taken by free diving. The trend observed for lobster suggests that the fishery is operating at or just above its sustainable level. Conch show a declining trend;

Inshore artisanal fishery: This includes reef fish and estuarine fishes and crabs:

- *(i)* Reef fish are primarily snapper (Lutjanidae) and to a lesser extent grunts (Haemulidae), porgy (Sparidae) and hog fish (Gerreidae). They are taken largely by line fishing, spears, gill nets, traps and weirs;
- *(ii)* The estuarine fishery consists of mullet (Mugilidae), stone bass (Serranidae), and mojarras (Gerreidae), caught using nets and weirs. This is a seasonal, small scale fishery;
- *(iii)* Two species of crabs are exploited. They are the stone crab. *Menippe mercenaria*, and the blue crab, *Callinectes sapidus.* Both are caught in specially baited traps and are destined for export;

Deep slope and bank fishery: These fisheries are composed largely of snappers (Lutjanidae) and groupers (Serranidae). They are the traditional base of the fin fish export industry. The fish are usually caught using hand lines, primarily during spawning aggregation events. Overexploitation is an acknowledged threat;

Inshore pelagic and shark fishery: The scombrids (mackerel, tunas and barracuda) and sharks are targeted. The fishery is seasonal and largely for the Mexican, Honduran, or Guatemalan market;

Inshore commercial trawl fishery: Established in 1984, this fishery peaked in 1988 with a fleet size of 11 standard Mexican/Gulf trawlers. Declining catch and uncertainty haunt the industry; and

Marine aquarium fishery: This fishery targets the fish hobbyist in the U.S. and Europe. The value of the catch continues to increase.

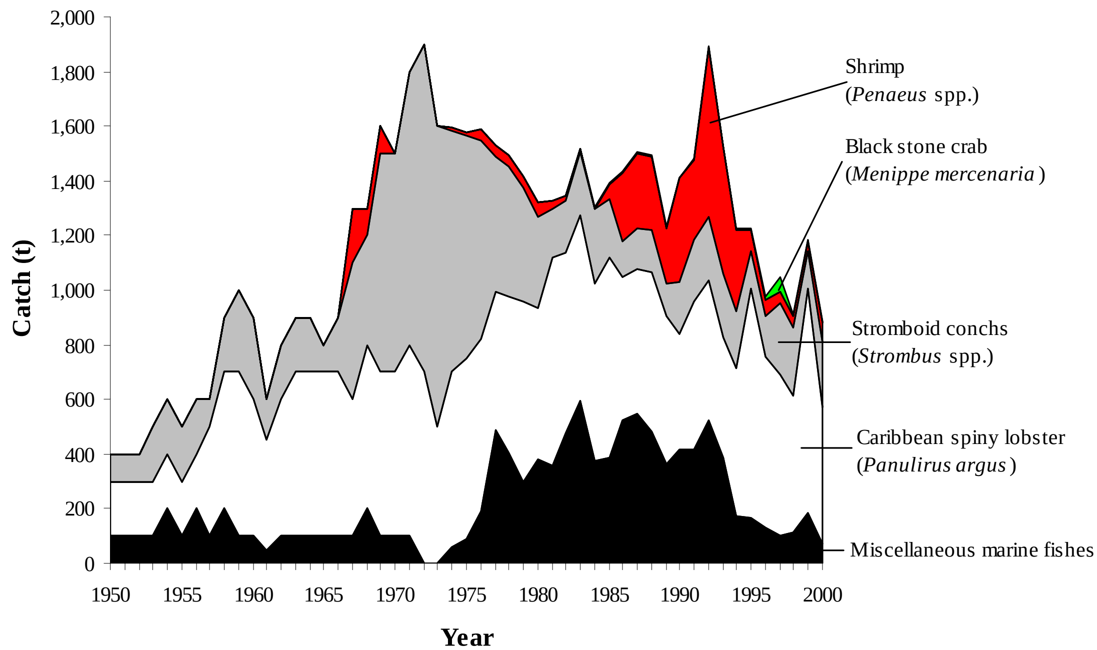

Figure 1: Reported landings of Belize in FAO area 31 (Western Central Atlantic), based on FAO-FISHSTAT.

Fishery catches

Historically, Belize fishers have only been active in FAO area 31 (Western Central Atlantic), indicating the predominantly subsistence and artisanal nature of fisheries operations, and the reliance of Belize on their own coastal and reef resources (Figure 1). Reported landings have traditionally been dominated by lobster and conch, with shrimp becoming important in the late 1980s to mid 1990s (Figure 1). Overall, reported landings peaked just below 2,000 t in the early 1970s (driven by conch) and again in the early 1990s (driven by shrimp), and, with the exception of the brief peak in shrimp catches in the early 1990s, have shown a distinct decline since the mid-1980s (Figure 1). However, given the high levels of subsistence and artisanal fishing activities throughout the country, one has to assume that substantial catches remain unreported. This would especially apply to finfish, here only reported as 'miscellaneous marine fishes'. Note also that the reported landings from national waters do not include the increasing recreational catches due to the expanding tourism industry. Hence, one would suspect that the overall extractions of marine resources by Belize are considerably higher than represented by the data supplied to FAO by the Government of Belize.

The lobster fishery has historically been the most valuable fishery in Belize. In 1995, the lobster catch was valued at over USD 7.7 million, and is representative of a continuing increase in weight and value of lobster. However, the fishery is of concern as signs of overexploitation are evident (Glaholt, 1986). Another major marine income earner, the conch fishery also shows signs of overexploitation (Gibson *et al.*, 1982), with harvesting driven solely by demand and high prices for the product. The fishery for shrimp is also in decline, and it has been recommended that the shrimp fleet be disbanded or drastically reduced (RDA, 1989). The fishery is under pressure from the public due to destructive practices and high discards. Furthermore, the fisheries department is of the view that the fishery has outlasted its usefulness, and shrimp catches have been overtaken by aquaculture production. The fin-fish or scale-fish fishery appears the only fisheries sector with any future potential, and appears to have expanded during the 1990s. However, certain key species, such as groupers were already viewed as in danger of overexploitation in the early 1990s, due to over-harvesting of spawning aggregations (Carter *et al.*, 1994).

Starting in the early 1990s, Belize reported increasing catches from waters in the Eastern Central Atlantic (FAO area 34), which by the year 2000 had grown to nearly 40,000 t (Figure 2). These catches are dominated by large and small pelagics, as well as cephalopods and some other schooling species such as hake. These landings exceed those from national waters (Figure 1) by nearly 40 times for the year 2000 (Figure 2). For the last two years of available data (1999 and 2000), Belize also reported catches from the southwest Atlantic and the eastern Pacific (Figure 2), which are dominated by squid and large tuna, respectively. These catches were made by vessels with Belize flags, but are not of concern here, as we consider only catches from Belize waters.

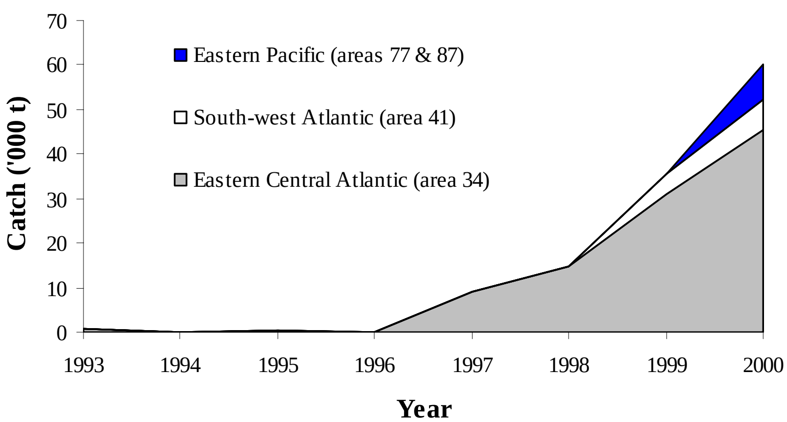

Figure 2: Reported landings of Belize from Atlantic and Pacific FAO areas, based on FAO FISHSTAT data.

Fishery management

The Ministry of Agriculture and Fisheries is the Government agency responsible for fisheries management, and it carries out this duty through the Fisheries Department. The Fisheries Department is slated to be replaced by a semi-autonomous agency, the Belize Fisheries Development Authority (Belize Government Cabinet Briefing - May 8th, 2001; www.belize.gov.bz). The Belize Fisheries Department and the other Government departments tasked with managing the fisheries and other users of the marine resources, lack the human and material resources to do the job, notwithstanding extensive arrays of legislative acts and formal institutions (Gillett, 1999). Thus, in Belize, there are 94 Acts pertaining to marine resource conservation, administered by 18 Permitting Agencies and 10 Ministries (McField *et al.*, 1996). Belize is a member of 24 international conventions and treaties concerning marine life and coastal protection, including the CITES Convention, the World Heritage Convention, the Convention on Biological Diversity and MARPOL (McCalla, 1995; Jacobs, 1998). Issues related to mangroves have been described by Zisman (1992), and Cirelli (1993) and McCalla (1995) covered fisheries. McCalla (1995), for example, identified 27 legal tools which have some bearing on fisheries or marine related activity.

Despite this extensive legislative accounting for resources, however, the Government has not been successful in sustainable management of fisheries and their resources, nor guarantee the health of the ecosystems upon which the fisheries and the resource depend. The primary legislative tool is the Fisheries Act (1980), which was revised in 1993, and focuses on new formulae for fishing licensing and regulation of the aquaculture sector (Cirelli, 1993). However, historically management has largely been top-down and not sufficiently participatory. Indeed, the present management of the Belize fishery which aims to maximize yield, to provide foreign currency, and to provide jobs for the disadvantaged cannot achieve the tasks of sustainability. The inability of governments to successfully manage marine resources is not unusual (Dubbink and van Vliet, 1996), and afflicts governments even when they invest considerable time and energy in fisheries management. Indeed, some of the legislation enacted by Belize reflects advanced thinking on natural resource conservation. But the existence of a legislative framework does not always reflect or guarantee a coordinated view of agencies responsibilities and power, leading to jurisdictional and enforcement problems (Freestone, 1995). For example, while the concept of the participatory principle has been embraced by legislation, its practice lags far behind. Several problems exist:

Firstly, although regulated by the Fisheries Act through prescribed closed seasons, size limits, closed areas, etc., the fisheries are largely open access. Anyone who wishes to do so can buy a license; thus licensing is not used as an effort control mechanism (Sorensen and Aschan, 1997). Secondly, there is a lack of good analytical information which can be meaningfully accepted and adopted. Thirdly, there is a deliberate policy to diversify the industry, targeting new species for which little or no biological information exist. Fourthly, there is the perceived threat of declining environmental health. The area devoted to aquaculture development continues to increase: For example, over 400 hectares of ponds were developed in 1995. Seagrass beds are being impacted by dredging operations, siltation due to land clearing, and nutrient enrichment due to agricultural runoff. Sea grass beds are an important habitat link between the mangrove and coral reef ecosystem. It is also an important breeding and feeding ground for many marine species including lobster, conch and many fish. While the ecological integrity of Belize's mangroves is thought to be good, the rate of clearance, especially on the cays, is troubling. Only 2% of mangrove cays are protected compared to 25% along the mainland coast. Scientific opinion recognizes that losses in mangrove habitat will reduce biodiversity and threaten the natural wealth of the ocean, both near and far from shore (Ruetzler and Feller, 1996).

The expansion of residential development, throughout the mainland coast and on the cays highlights the issues associated with development, including contamination and disposal of sewage into the marine environment. The issues of solid waste disposal, habitat destruction and degradation, and socio-economic and cultural problems, are prominent. The tendency to overlook these problems and 'grow first, clean up later' should be challenged as it also alienates Belize nationals whose accessibility to credit for investment in the fisheries sector has been eroded. For example, Ambergris Cay was, prior to 1957, owned largely by nationals, who mostly fished for a living. By 1995, most of the available land, except for 14 hectares, was acquired by foreign interests.

Furthermore, with the decline of lobster on the fishing grounds adjacent to the island, most of the fishers have shifted to tourism, largely to work as tour guides. Membership in the fishing cooperative has declined from 148 active members in 1985 to 86 in 1991. The importance of tourism is not being denied. It generates considerable foreign earnings and employment, as indicated by a 52% increase in tourist arrivals between 1991 and 1994. It is, however, impacting the fishery sector as visitors compete for snorkeling, diving, and fishing space. Sport and recreational fishing is also heavily promoted by the industry but the status of the underlying resources is largely unknown.

Thus, fisheries *per se* are not managed for conservation or sustainability, nor for optimal utilization. Historically, developments occur mainly though state intervention in the form of legislation and development plans crafted by the Ministry of Agriculture and Fisheries or the Ministry of Economic Development. Indeed there is increasing capital investment in open access fish capture through utilization of faster, more efficient vessels (Auil, 1993). Furthermore, the number of fishers is also increasing (Gillett, 1995), despite the lack of adequate knowledge of the potential yield, structure or stability of stocks. Concern is now growing for the future viability of the fishery which is compounded by the destruction of critical habitats for fish stocks, such as mangrove habitats (McField *et al.*, 1996), and the depletion of stocks as illustrated through declining catches at known fish spawning aggregation sites.

Trend towards decentralization

The need to rationalize government management of its fisheries and coastal resources has been met by some innovative inputs, particularly by the cooperatives and the conservation NGO communities, often in innovative partnerships. This latter group has been remarkable in the extent to which it has taken on the responsibility of funding and managing activities in the conservation sector. This has led to a *de facto* acceptance, by the Government of Belize, of governance arrangements wherein power is shared between stakeholders. These efforts have led to the acceptance by government of the concept of establishing protected areas to sustain the country's biological diversity and, by extension, its economic viability. Thus, e.g., the Advisory Committee of the Bacalar Chico Reserve is composed of representatives of the following institutions:

- Fisheries Department;
- Forestry Department;
- Coastal Zone Management Project;
- San Pedro Town Board;
- North Ambergris Cay Land-owners Association;
- Caribena Fishermen Co-operative;

Table 1: Some NGOs active in protected area management in Belize (Gillett 1999)

Organization	Inputs	Area Protected	Support
Belize Audubon Society	Education, funding, management	Half Moon Caye Natural Monument; Laughing Bird Caye reserve	Broad community support
Belize Center for Environment Studies	Technical, Education	Port Honduras; Ambergris Caye	Limited community support
Belize Enterprise for Sustainable Technology	Training, education, management	Manatee Special Development Area	Rural community support
Belize Tourism and Industry Association	Educational, promotional	Country-wide	Special interest
University College of Belize	Technical, education, training	Turneffe Island, Belize City	Special interest
Coral Caye Conservation	Technical, research, funding	Bacalar Chico, Caye Caulker, South Water Caye	Special interest
International Tropical Conservation Foundation	Technical, research, funding	Bacalar Chico	Special interest
Wildlife Conservation Society	Consultancies, funding	Hol Chan, Pedro Glovers Reef	Special interest

- Sartaneja Village Council;
- Hol Chan Marine Reserve;
- Coral Cay Conservation;
- International Tropical Conservation Foundation;
- San Pedro Tour Guide Association; and
- University College of Belize.

Such wide representation also occurs in the Boards or Advisory Committees of various marine protected areas, and Table 1 gives a non-exhaustive list of groups involved.

It is ironical that some of the theoretical advances (Kooiman *et al.*, 1999) concerning the manner in which natural resource management systems ought to operate should be tested first in developing countries such as Belize. Upon reflection, however, we can see that this only duplicates the experience with marine protected areas, where developing countries have a lead (Roberts, 1999).

Management options

It has been recognized that for fisheries management to be successful, it must look beyond fisheries *per se*. Management concepts cannot be simply imposed upon those intended to benefit from it. A buy-in process has to be developed within which all stake holders participate in developing, implementing, and monitoring the performance of policies. Three alternative approaches have been proposed to the archaic 'top-down' regulatory approach to fisheries management (Pauly, 1999):
(i) Market-based approaches;
(ii) Community-based approaches; and
(iii) Ecology-based approaches.

The first is meant to deal with the race-to-fish, based on open access resource, which results in overcapitalization of the industry and the transfer of public assets to co-operate ownership (Pauly, 1999).The second alternative, although popular and seemingly supportive of participatory processes, is often exclusive as it generally excludes non-user groups. The third approach essentially promotes management incorporating ecosystem considerations and processes, including Marine Protected Areas (MPA's), as the best opportunity to apply precautionary approaches in the light of high natural uncertainty (Pauly *et al.*, 2002).

A new concept, that of 'modern governance' has emerged where government recognizes that various non-user groups have legitimate rights. Therefore, a forum is provided within which all the stake holders (extractive and non-extractive) justify their claim, in a transparent way, and further negotiate for their share of the resource. The role of government is therefore limited to that of setting the rules of engagement and ensuring that the rules are obeyed (Pauly, 1999). It remains to be seen which path Belize takes in the management of its marine resources.

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Fisheries Landings and Trade of the Turks and Caicos Islands

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ABSTRACT

The Turks and Caicos Islands is a sparsely populated island country located at the southern end of the Bahamian Archipelago. The Caicos Bank has supported an export-oriented queen conch fishery for over 100 years. More recently, an export-oriented spiny lobster fishery developed and a burgeoning domestic market for reef fishes is currently developing as local tourism grows. This paper provides an overview of fisheries landings and trade in the Turks and Caicos over the past century.

BACKGROUND

The Turks and Caicos Islands (TCI) are located at the southern end of the Bahamian Archipelago (Figure 1) and are comprised of three platforms: the Caicos, Turks and Mouchoir Banks. Caicos Bank is a shallow, oolitic limestone platform covering an area of about 6,140 km^2 (Olsen, 1986) and is comprised of sand (64%), mixed coral and algae (18%), coral reefs (7%), and other habitats (11%), typically at depths of 1-5 m. Extensive coral reefs fringe the shelf edge and are characterized by steep drop-offs. The smaller Turks Bank (about 324 km^2) is comprised mainly of sand (43%), mixed coral and algae (29%), coral reefs (26%), and other habitats (3%) (Olsen, 1986). Mouchoir Bank (20.6^o N, 70.4^o W; 1,109 km^2) is located east of Turks Bank and consists largely of coral and sand.

The Caicos Bank supports export-oriented fisheries for queen conch (*Strombus gigas*) and spiny lobster (*Panulirus argus*), and a domestic fishery for 'scale-fish' (primarily reef fish, including groupers, snappers, grunts and hogfish), which are most often landed as by-catch by lobster fishers.

Virtually all commercial fishing takes place on the Caicos Bank. South Caicos is the traditional home of the artisanal fleet, but landings of conch and reef fishes on the island of Providenciales ('Provo') have increased over the last two decades as Provo has been developed for tourism. Limited subsistence fishing occurs on the Turks Bank, where fishers seek reef fishes and lobsters for local use. TCI fishers seldom visit Mouchoir Bank, although there are anecdotal reports of illegal fishing for lobsters and reef fish in the 1980s and 1990s by boats from the Dominican Republic and Haiti.

There are currently about 60 commercial licenses operating from South Caicos, 75 from Provo, and 14 from Grand Turk (Halls *et al.*, 1999). Almost all lobster is landed in South Caicos, while the conch total allowable catch (TAC) is split evenly between processors (currently three in South Caicos and two in Provo). Small 14-ft fiberglass runabouts equipped with 70 to 110 hp outboards are popular for fishing as they handle waves well, are maneuverable, and can be used to reach fishing grounds up to 40 km from home port.

The Department of Environment and Coastal Resources (DECR) manages the conch and lobster fisheries using traditional tools. As an Overseas Dependency of the United Kingdom, the TCI has received technical support for fisheries management and has extensive (albeit imperfect) landings data. Resource assessments have been undertaken for conch and lobster (Medley and Ninnes, 1997, 1999). A combination of TACs, seasonal closures, gear restrictions (a prohibition on SCUBA being the most important), minimum size limits for conch and lobster, and other restrictions are used to manage export-oriented conch and lobster fisheries. Despite the regulations, compliance with rules has been poor since the 1960s (Olsen, 1986; Raven, 1994; Rudd *et al.*, 2001). Rampant drug smuggling starting in the 1980s also encouraged a culture of distrust and

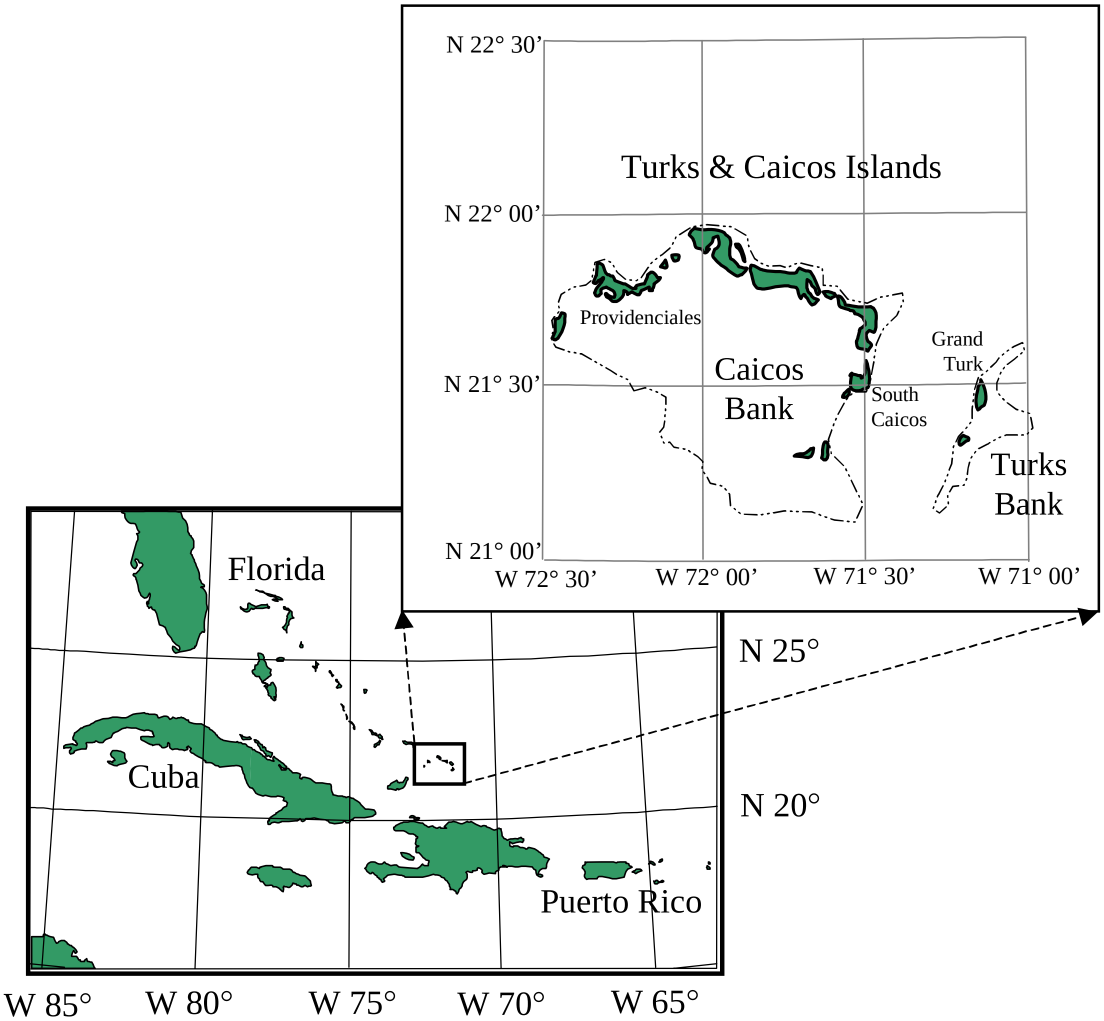

Figure 1: Location of the Turks and Caicos Islands, showing approximate 100-m depth contour for Caicos and Turk Banks

disregard for authority in the TCI[1] Besides DECR data and reports (Homer, 2000a, 2000b, 2000c; Clerveaux and Danylchuk, 2003; Clerveaux and Vaughan, 2003), a number of reports and articles have been completed relating to fisheries and fisheries habitat in the TCI, including work sponsored by the British government (Medley and Ninnes, 1994, 1997, 1999; Ninnes, 1994; Raven, 1994; Ninnes and Medley, 1995; Medley, 1998; Halls *et al.*, 1999; Bennett *et al.*, 2001; Bennett and Clerveaux, 2003), by faculty at one time associated with the Center for Marine Resource Studies, South Caicos (Green *et al.*, 1996, 1997, 1998a, 1998b; Steiner, 1999; Tewfik and Béné, 1999; Béné and Tewfik, 2001; Rudd, 2001, in press a, b; Rudd *et al.*, 2001, 2003; Rudd and Tupper, 2002; Tupper, 2002; Tupper and Rudd, 2002; Danylchuk *et al.*, 2003), and other miscellaneous books, reports and theses (Doran, 1958; Hesse, 1976, 1979; Nardi, 1982; Simon, 1983; Olsen, 1986; Sadler, 1997).

[1] According to the President's Commission on Organized Crime (Anon., 1986): "Drug-related corruption has reached the highest offices of government in the British-held Turks and Caicos Islands, where in March 1985, that country's Chief Minister, Norman Saunders, was convicted of conspiracy to travel in furtherance of a drug plot and on five counts of traveling in furtherance of in illicit drug transaction. Saunders, the first foreign head of state to be convicted on drug charges, was found not guilty of more serious charges of conspiracy to smuggle marijuana and cocaine. Trial witnesses testified that Saunders accepted a total of $50,000 to allow drugs to move freely through his island chain. He planned to use the islands as a "safe-haven" for traffickers smuggling illicit drugs from Colombia to the United States." Britain temporarily dissolved the TCI government in 1986 as a result of the scandal. After serving prison time in Miami, Saunders returned to the TCI and now serves as an elected representative of the Legislative Council (the TCI Government) from South Caicos.

Driving Forces in TCI Fisheries

The introduction of snorkeling gear and freezing technology led to the development of the modern lobster fishery in the TCI in the 1950s and 1960s. The renewal of the conch fishery in the 1970s was driven by demand-side factors, as new export markets opened in Florida. More recently, tourist arrivals in the TCI have increased sharply (Figure 2). This has led, in turn, to an influx of permanent residents (Figure 3), as expatriate business owners and retirees settle in the islands. In addition, tourism development has spurred immigration from poorer neighboring countries (primarily Haiti and the Dominican Republic) as people seek service and construction jobs.

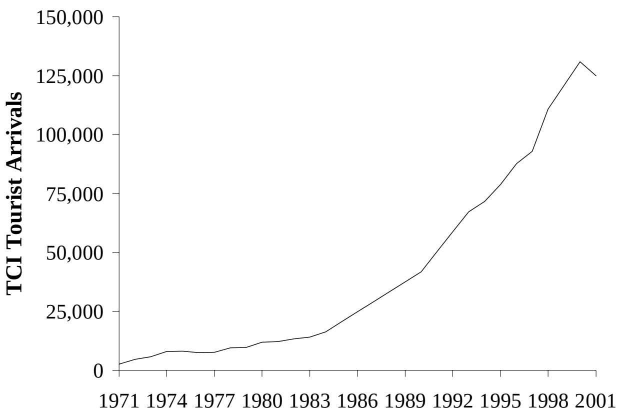

Figure 2: Turks and Caicos Islands tourist arrivals, 1971-2001 (source: TCI Tourism Board, 2001 estimated)

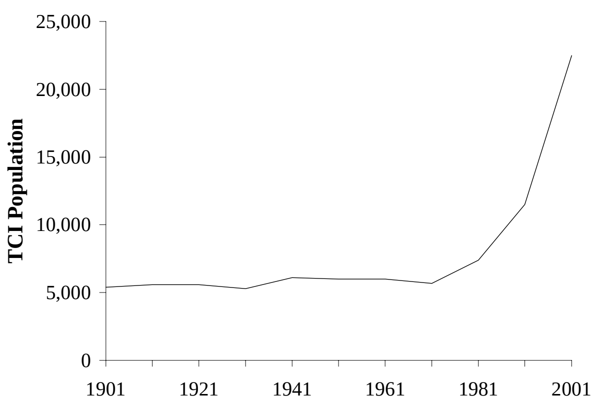

Figure 3: Estimated population of the Turks and Caicos Islands, 1901-2001.

Fisheries Landings

Queen Conch

In the TCI, dried conch have been traded with Haitians since the mid-1800s, when conch were bartered for fruit, sugar cane, vegetables and rum, as there is very little farm production on the dry, barren limestone islands of the TCI (Sadler, 1997). Doran (1958) documented trading records going back to 1904, and other records have been found going back to 1888 (Raven, 1994).

Wooden sailing sloops would act as collecting platforms for 2-man teams in 3 or 4 small wooden tenders (Doran, 1958). Conch were taken using waterglasses and a long conch rake. After cleaning ('knocking'), conch meat was dried for several days. Weekly expeditions took 75,000 to 125,000 conch per sloop, and each sloop made two or three such trips a year. As late as 1960, there were 60 sloops in operation, fishing from South Caicos to the outer conch grounds near Ambergris Cay (Raven, 1994). Conch hooks remained in use until the mid-1970s, but by the 1980s most conch fishing was conducted by free divers operating from fiberglass boats equipped with outboard engines (Nardi, 1982). The traditional East Harbor (Cockburn Harbor) grounds on South Caicos were closed to commercial fishing in 1993. The East Harbor Lobster and Conch Reserve was implemented in 1993 and currently provides protection for an important conch juvenile nursery ground (Danylchuk *et al.*, 2003).

Figure 4 shows total estimated conch production in the TCI for the period 1905-2001. Domestic consumption of conch (round weight in kg) was estimated using TCI population statistics and per capita consumption rates. Olsen (1986) estimated a per capita consumption rate of 35 $kg \cdot person^{-1} \cdot year^{-1}$ in the early 1980s, based in part, on the fact that there is virtually no agriculture in the TCI. In Figure 4, I assume that historical per capita conch consumption is lower, at 20 $kg\ person^{-1}\ year^{-1}$, peaking at 30 $kg \cdot person^{-1} \cdot year^{-1}$ during war years, because salt cod was readily available most of the first half of the 20^{th} century[2]. I assume consumption stayed at 20 $kg \cdot person^{-1} \cdot year^{-1}$ in the 1950s and 1960s, fell to 10 $kg \cdot person^{-1} \cdot year^{-1}$ from the 1970s to 1990s, and has since fallen further to

[2] Salt production for the Maritime/New England fisheries was the major industry in the TCI for two centuries (see Sadler, 1997). Ships from Canada and the USA brought salt cod to TCI and Bahamas when they came to load salt. During the war years, market demand for salt fell dramatically, putting many islanders out of work. Without employment, there was a surge in artisanal commercial fishing and, hence, spikes in conch catch. I assumed that subsistence consumption rose as well as exports to other Caribbean nations.

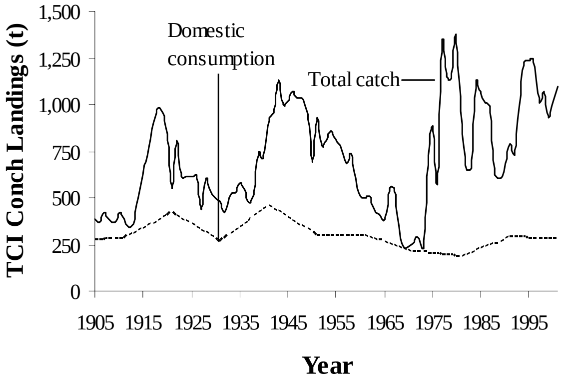

Figure 4: Total conch landings of the Turks and Caicos Islands, 1905-2001.

5 kg·person^{-1}·year^{-1}. This decline is due to an influx of immigrants who do not eat much conch, the number of alternative imported foods available, and the demand (and cash payment) for export conch by the processing plants. A restaurant survey (Rudd, in press a; Table 1) estimated total TCI restaurant consumption to be about 160 t; total domestic consumption is estimated at 280 t.

Commercial conch landing data were derived from a number of sources (Olsen, 1986; Medley and Ninnes, 1994, 1997, 1999; Raven, 1994; DECR unpublished data). Raven (1994) found that annual landing data from a variety of sources often conflicted. Landing slips are often not properly filled out in the TCI, and commercial landing data are suspect, especially prior to the 1980s.

CPUE data for the conch fishery are available from 1975 (Figure 5), but early data are of questionable quality. There have been no discernable trends in landing size. Conch abundance has declined substantially close to the South Caicos harbor over time: Doran (1958) reported that a crew of two could land 1,000 conch per day in areas near South Caicos in the 1950s.

The USA is the main market for TCI conch. One way to verify the accuracy of TCI landing data is to compare them with USA imports, as USA Census Bureau data are usually quite accurate (www.st.nmfs.gov.st1). Figure 6 compares TCI conch landings and USA imports for the years 1977 to 2001.

TCI reported landings were consistently lower than USA imports for the 1983-1989 period, indicating that TCI records underestimated the volume of conch caught in the TCI. Since 1993, TCI landings and USA imports have corresponded quite closely: USA imports are therefore a useful proxy for current TCI landings. Note that queen conch is listed as a CITES Appendix 2 species. Under current management, a round weight TAC of 725 t (1.6 x 10^6 lbs round = 600,000 lbs meat) is set based on MSY (Ninnes and Medley, 1995) but does not take account of domestic landings.

TCI is a major conch producer and accounts for a substantial proportion of USA imports in recent years (Figure 7). The price difference between TCI conch (traditionally sold at a premium) and other producers has narrowed recently (Figure 8). Monthly USA imports show that imports from the TCI are highly seasonal (Figure 9), with peaks between April and July, the off-season for the TCI lobster fishery (see also Béné and Tewfik, 2001). Figure 10 shows that there has been substantial monthly price volatility. Nominal conch import prices have increased little since the late-1980s; when accounting for inflation, real prices over the past 20 years have fallen.

Spiny Lobster

Spiny lobster was harvested early in the 20th century by women during nocturnal 'torch walks' to attract lobster in shallow, accessible waters (Raven, 1994). Lobsters were canned starting in the early 1930s and were rapidly depleted in accessible areas as fishers began using boats, waterglasses, and barbed poles or nets on poles ('bullying').

Free diving became more prevalent in the 1950s after the introduction of masks, snorkels and fins (Raven, 1994). Lobsters were captured by hooking (hook on a flexible pole) or using the 'toss', a flexible spring noose on a stick. By the late 1960s, two man crews were landing up to 1,000 lobster per day using the toss.

In 1958, lobster traps were introduced by Jamaicans (Raven, 1994). Lobster fishing remained an uncommon occupation in South Caicos during the 1950s and early 1960s as the salt industry still employed most local workers; only six lobster divers were operating as late as 1966, as salt production ended. Larger trap boats entered the fishery in 1972. Due to low capital costs (divers initially worked from canoes), free diving became the most prevalent method and trapping has usually only accounted for 5-10% of lobster landings (Medley and Ninnes, 1997).

Table 1: Estimated annual restaurant consumption of locally landed seafood in the Turks and Caicos Islands. Processing yield of 40% for conch and 34% for lobster. Local reef fishes are sold whole to restaurants. 'Tourist' restaurant consumption is based on weekly consumption and an estimated 90% survey coverage for tourist restaurants in the TCI. 'Native' restaurant consumption is approximately equal in volume to tourist restaurant consumption. Note that 30.3 tonnes of native restaurant consumption of other fish is locally landed 'small fish' and was estimated as equaling tourist restaurant consumption of pelagics.

Species	Restaurant purchases (kg week^{-1})	Locally landed (%)	Consumption (t·year^{-1}) Tourist restaurant	Native restaurant	Total dressed weight	Meat yield (%)	Total round weight consumption (tonnes year^{-1})
Grouper (Nassau)	725	60	25.0	25.1	50.3	100	50.3
Lobster	650	90	33.8	33.8	67.6	34	187.8
Conch	550	100	31.8	31.8	63.6	40	158.9
Snapper	440	50	12.7	12.7	25.4	100	25.4
Mahi Mahi	400	100	23.1	-	23.1	100	23.1
Wahoo	125	100	7.2	-	7.2	100	7.2
Others	265	0	-	30.3	30.3	100	30.3
Total	**3,155**	**-**	**133.8**	**133.8**	**267.5**	**-**	**483.0**

Fiberglass boats and outboard engines (2.5 to 6 hp) were first used for lobster fishing in 1952. As engine horsepower increased over time (for fishing and/or smuggling in the 1980s), distant parts of the Caicos Bank were opened for fishing. By 1983 all areas of the Bank had been exploited by fiberglass runabouts with 55 to 70 hp outboards. As late as the 1960s, productive grounds close to South Caicos (The Bank, Six Hills, South Caicos) still yielded large lobster (Raven, 1994). By the mid 1970s, fishers complained that these areas had only barely legal and sublegal lobster. Deeper water grounds (The Lake, South of Ambergris Cay, Seal Cays, Bush Cay, White Cay, East Side, North Side of East Caicos, Phillips Reef – see Rudd *et al.*, 2001) were progressively depleted as lobster fishers ventured farther afield and into deeper waters.

Despite a hook ban until the late 1970s, it was – and remains, despite periodic bans – the lobster fishing tool of choice. The use of bleach and detergent (to flush lobsters out of dens) has also become widespread despite the damage it causes to coral habitats, possibly leading to increases in macroalgal coverage on coral reefs in heavily fished areas (Tupper and Rudd, 2002).

Divers from Provo have always fished conservatively in relatively shallow waters compared to fishers from South Caicos (Raven, 1994). When lobster inhabiting shallow water (<13 m) became scarce, Provo divers tend to switch to conch (or more recently, finfish) while South Caicos lobster divers have tended to go farther afield and dive deeper for lobster.

The lobster fishery is regulated using minimum size limits (3.25 inches carapace), a closed season (April 1 to July 31) and prohibitions on the use of scuba (high compliance) and noxious chemicals (low compliance). Capture of mature females is prohibited, but compliance is relatively low and there has been a major problem with minimum size limit compliance in the TCI. The beginning of the lobster season is known locally as the 'Big Grab'. As many as 95% of lobsters landed from some accessible fishing grounds fall below the legal minimum size (Rudd *et al.*, 2001).

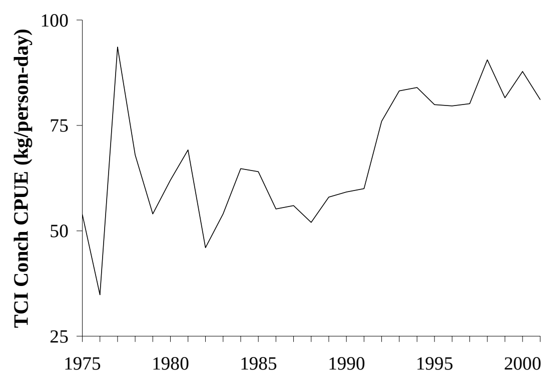

Figure 5: Relative abundance of Queen conch 1975-2001.

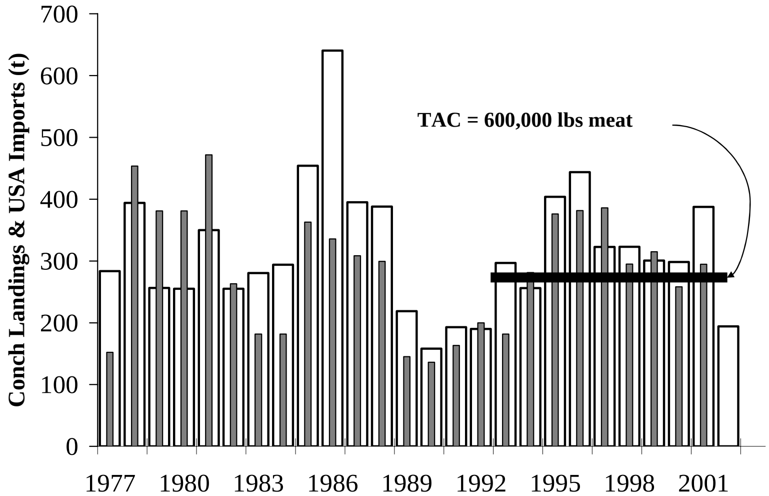

Figure 6: USA conch imports (open columns) versus TCI conch landings (grey columns) 1977-2001 (fishing year, 01 August to 31 July). TCI landings converted to meat equivalent using 40% meat yield.

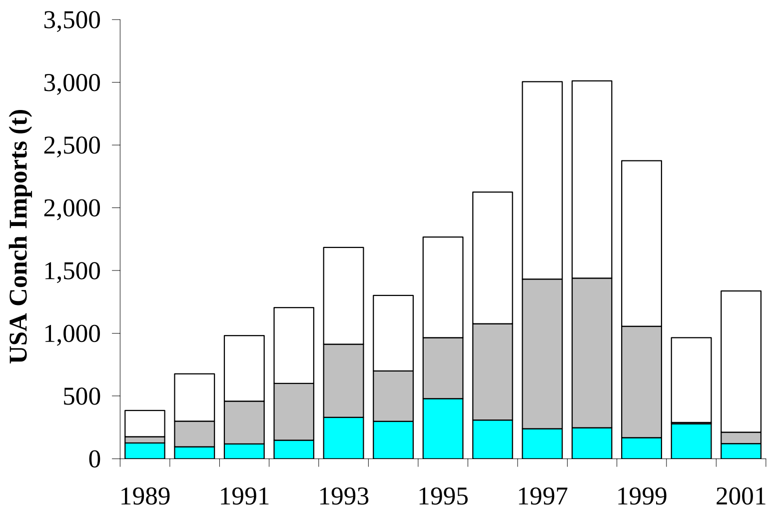

Figure 7: USA conch imports by origin (TCI, bottom; Jamaica, middle; other, top), 1989-2001 (calendar year)

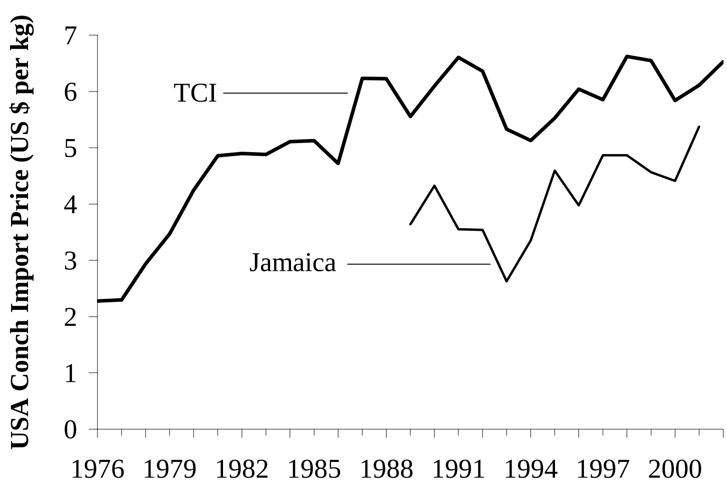

Figure 8: USA mean annual conch import prices by origin, 1976-2001.

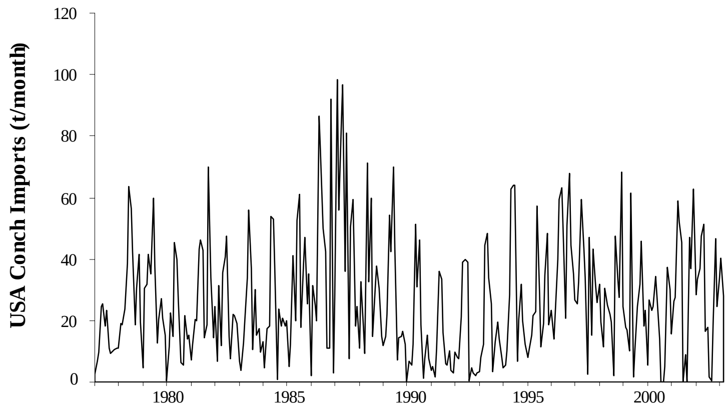

Figure 9: USA monthly TCI conch import volume, 1976-2001.

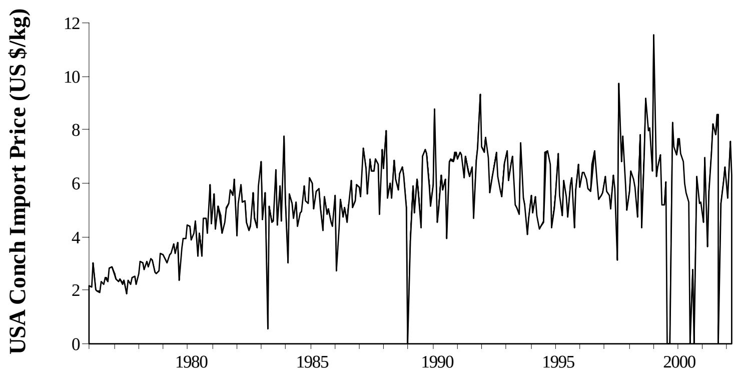

Figure 10: USA monthly TCI conch import prices, 1976-2001

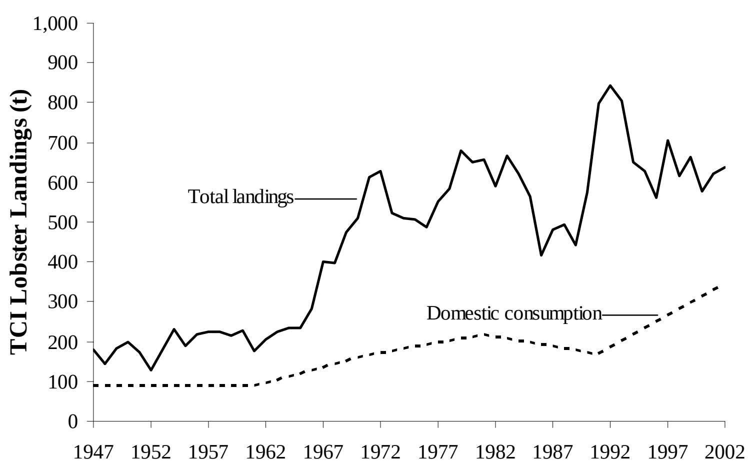

Figure 11: Total spiny lobster landings and domestic consumption in the Turks and Caicos Islands, 1947-2002 (based on fishing season, 01 August to 31 July).

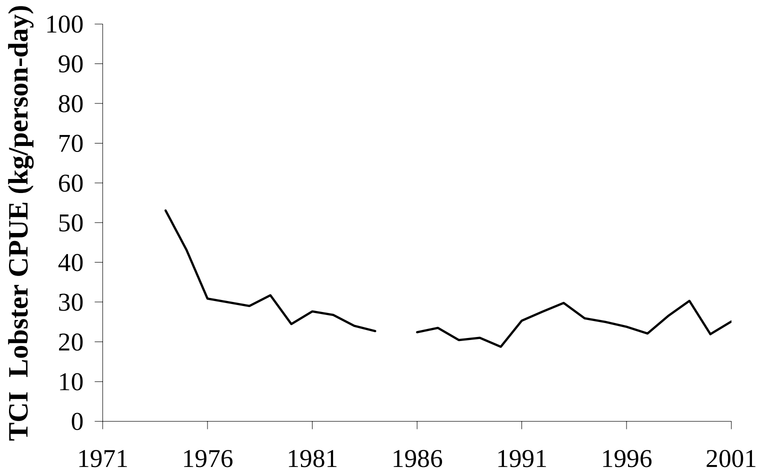

Figure 12: Spiny lobster CPUE (kg per person-day), 1971-2001.

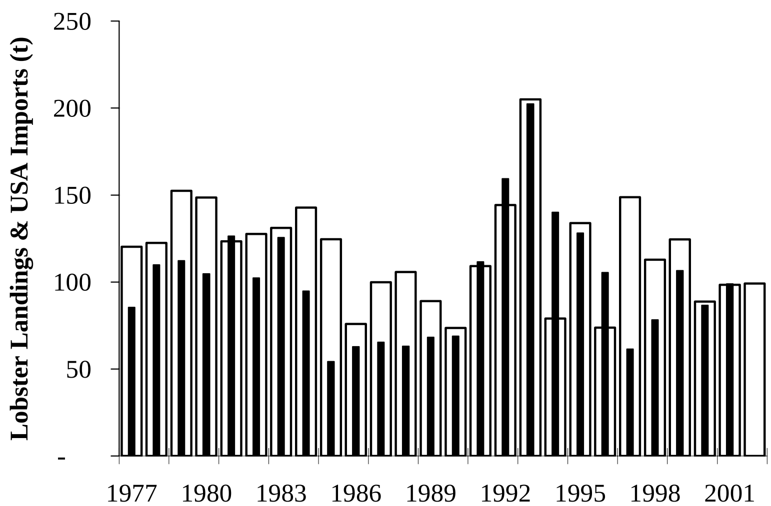

Figure 13: USA imports (open columns) versus TCI landings (black columns, converted from round weight to dressed weight at 34% recovery). Imports and landings are for 01 August to 31 July fishing year.

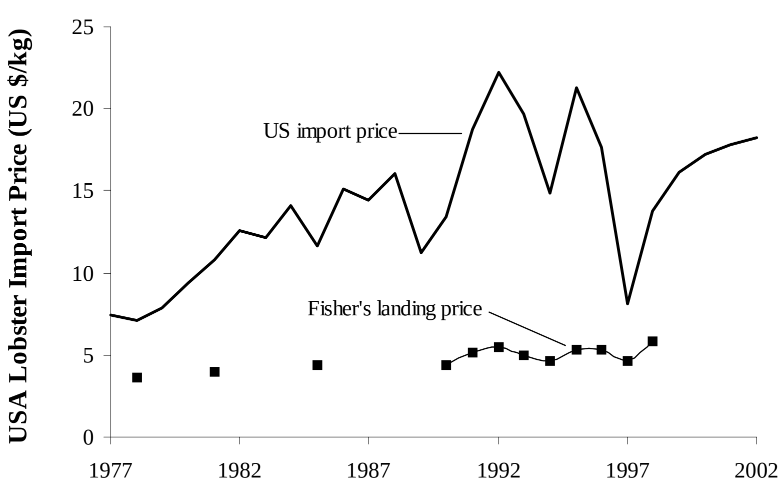

Figure 14: USA mean annual import price and TCI fisher landing price (US $ kg^{-1}) for TCI spiny lobster, 1977-2001.

Production statistics from DECR were available until the 2000-2001 fishing season (01 August 2000 to 31 July 2001). USA import data are available since 1977 and appear to be a reasonable proxy for TCI landings in recent years (see below). Lobster landings were therefore calculated as the maximum of DECR production figures or USA imports, converted to round weight equivalent at 34% recovery. Domestic consumption was estimated using per capita consumption of 5 $kg \cdot person^{-1} \cdot year^{-1}$ for the periods 1948 to 1971, and 1991 to 2002. Per capita consumption of 10 $kg \cdot person^{-1} \cdot year^{-1}$ was used for the period 1971 to 1991 as reliance on local food products was likely higher at that time than earlier (when local fishing activity was minimal) or later (when more imported food was available).

The restaurant survey conducted in 2000 (Rudd, in press a; Table 1) estimated restaurant consumption of 188 tonnes $year^{-1}$ in the TCI. Total domestic consumption for 2000 is estimated at 331 tonnes based on per capita consumption. This seems to be reasonable, as many people in the TCI buy lobster directly from fishers and store them in home freezers for consumption throughout the year. Total estimated spiny lobster production is shown in Figure 11.

Raven (1994) reported anecdotal information that mean lobster size in the range of 3 kg had been reported by the early trap fishers. Since the 1970s, average sizes remained quite constant around 0.7 kg. After starting at high levels in the early 1970s, CPUE has fallen and leveled off in the 20 to 30 $kg \cdot person^{-1} \cdot day^{-1}$ range (Figure 12). Early CPUE data is likely not very reliable.

Figure 13 compares USA spiny lobster imports from the TCI (converted to round weight using 34% meat recovery rate) with TCI production. Between 1974 and 1980, some whole cooked and live lobster was exported to other eastern Caribbean nations (Raven, 1994). While some carry-over of frozen inventory is possible from year to year, it appears that DECR figures have under-estimated landings in the mid 1980s and again from 1997 to 1999 (Figure 13). Presumably this discrepancy resulted from lack of processing plant monitoring and/or plant misreporting.

TCI is only a minor lobster supplier in the USA and, unlike the situation for conch, is certainly a price taker in a world market. Figure 14 shows average USA import prices for TCI lobster and, where available, landing prices for TCI fishers (Raven, 1994; Béné and Tewfik, 2001). Lobster landings are highly seasonal, with most effort and landings occurring during the first month of the season (August). For the period 1989-1998, almost 40% of annual production was landed during the August 'Big Grab' (Béné and Tewfik, 2001). Effort and landings decrease rapidly during the autumn. This production trend is mirrored by USA imports (Figure 15).

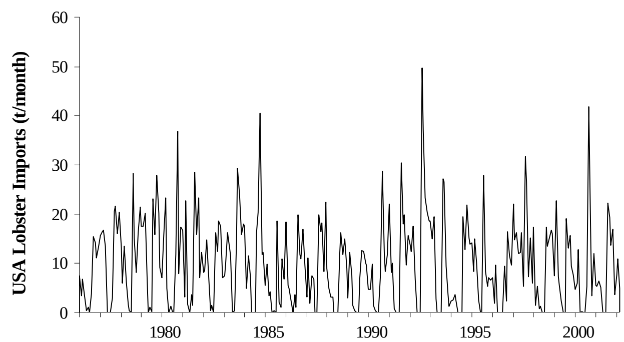

Figure 15: Monthly TCI lobster imports into USA, 1976-2001.

The Big Grab is a phenomenon driven by visiting 'Belonger' (a term referring to native islanders) fishers (Rudd *et al.*, 2001). Many Belongers take leave from other employment to travel to South Caicos for several weeks in August. All Belongers have a right to fish lobster and, although they are supposed to abide by regular fisheries rules, there are widespread violations. Visiting fishers tend to be less skilled than resident fishers (many cannot free dive more than 10 m). As a result, they tend to target shallow areas, intercepting young lobsters migrating from the shallow Caicos Bank to deeper fringing reefs. The result is severe growth overfishing as well as indirect effects on the conch fishery (i.e., causing fulltime fishers to shift effort to conch sooner than would be normal) (Béné and Tewfik, 2001). Processing plants are complicit in the illegal harvest, as they regularly receive and process undersize lobster tails as 'head meat' (pers. obs.). Other undersize lobster is used locally in native restaurants or sold to individuals.

Lobster prices in the USA have been quite volatile over the past 25-years (Figure 16). In general, price volatility in the USA market is related to international supply and demand

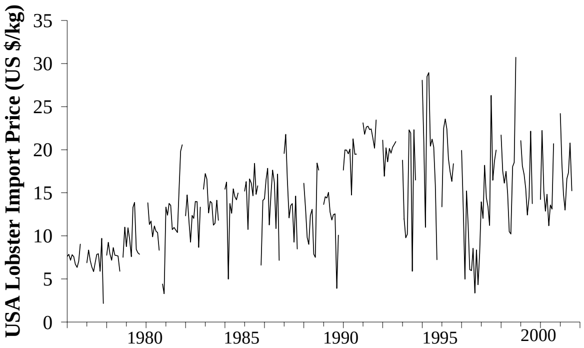

Figure 16: Monthly TCI lobster import prices into USA, 1976-2001

factors. Low prices for TCI lobster in August and September probably relate, at least in part, to strategic pricing by USA importers, who realize that TCI processing plants have limited cold storage and must sell lobster quickly. No formal price determination research has been conducted for TCI lobster to date. Recent research (Rudd, 2001) has shown that spiny lobster has non-extractive economic value, increasing divers' willingness to pay for dive charters in which lobster are observed.

Finfish

The production and use of finfish in the TCI is poorly documented. It is likely, however, that some species of fish have been important for subsistence purposes back through the 20th century and before. There are three types of finfish resource that have been exploited in the TCI at different times: demersal reef fishes (e.g., groupers, snappers, grunts, hogfish), pelagics (e.g., mahi mahi, tuna, wahoo, swordfish) and bonefish.

Bonefish (*Albula vulpes*) and Nassau grouper (*Ephinephelus striatus*) are the historically favored species for local consumption (Olsen, 1986). Bonefish are shallow-water bottom feeders that school on the Caicos Bank. They were historically important for subsistence, but consumption has fallen in recent decades as old-time 'haulers' retire. Bonefish is also regarded as a 'poor man's' food to some extent and is not as popular with islanders as it was historically. Bonefish is a highly regarded sport fish and several companies now offer catch-and-release fishing charters on the flats of the Caicos Bank.

Reef fishes are primarily caught as bycatch of commercial lobster fishing. Nassau grouper is the preferred species, due to size and flesh quality, but a number of other fishes are taken opportunistically. Nassau groupers are often speared by lobster fishers as they follow close to free divers, waiting for opportunities to snatch lobsters (Tony Morris, personal communication, South Caicos, 2000). Sometimes, lobster boats will take a day to target reef fishes exclusively. In dockside samples, Tupper and Rudd (2002) found CPUE for reef fish was 3.2 $kg \cdot hour^{-1}$ for the 456 hours fishing effort (i.e., lobster was primary target) in regularly fished grounds. In lightly fished lobster grounds, reef fish CPUE rose to 17.8 $kg \cdot hour^{-1}$.

Anecdotal evidence suggests that a large multi-species spawning event occurs annually off East Caicos (location details withheld). Dive charter operators have also reported seeing spawning aggregations (Rudd and Tupper, 2002). The aggregations do not appear to be regularly targeted by artisanal fishers, although some have been targeted specifically in the past.

Reef fish fishing is essentially open access in the TCI. There is a prohibition on the use of scuba gear, but there are no size limits, seasonal closures or TAC. A small marine reserve near South Caicos provides some protection for smaller hogfish (*Lachnolaimus maximus*) and white margate (*Haemulon album*), but there are no differences in density inside and outside the reserve for the larger Nassau grouper (Tupper and Rudd, 2002). While finfish densities are high in the TCI relative to other countries in the region, the historic focus on Nassau grouper has almost certainly reduced their abundance substantially from pristine conditions. Nassau grouper is a high-profile species in the dive tourism industry and divers in the TCI are willing to pay more for dive packages on which they observe more and/or larger fish (Rudd and Tupper, 2002). Lack of effective management of fisheries may thus impose significant economic externalities on the dive tourism industry.

Pelagic fishes (e.g., tuna, wahoo, swordfish, mahi mahi, marlin) have rarely been targeted in the TCI. A Japanese company leased 24 Taiwanese vessels and was granted licenses to fish in the TCI from 1980 to 1992 (Halls *et al.*, 1999). The vessels used longlines, targeting swordfish and tuna (and some red snapper) near the Gentry Banks. The licenses were not renewed after 1992 due to fears that fishing would adversely impact the sport fishery. Small amounts of pelagics are landed by sport charter boats from Provo and sold to local restaurants (Rudd, in press a). It is estimated that about 30 tonnes·year^{-1} are consumed locally, all in tourist-oriented restaurants. The mortality rates for catch-and-release fish in the sport fishery are unknown.

Total finfish production is shown in Figure 17. I assume the domestic per capita finfish consumption was 20 kg·person^{-1}·year^{-1} from the 1951 to 1981 and then decreased to 15 kg·person^{-1}·year^{-1}. This is substantially below the estimate of 35 kg·person^{-1}·year^{-1} by Olsen (1986). Total restaurant consumption of all finfish in 2000 was about 135 tonnes. Using per capita consumption of 15 kg, this translates to landings of about 360 t. The difference between these figures is substantial, indicating the per capita estimate may be somewhat high or, alternatively, suggesting that native restaurant consumption may be under-estimated.

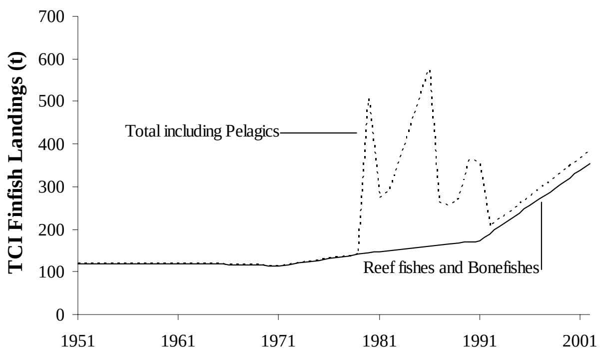

Figure 17: Finfish landings for Turks and Caicos Islands from 1951-2001.

Other Species

Sponges were exported starting in 1841 when Bahamian operations spread to the Caicos Bank. Sponge exports peaked at 9,277 pounds sterling in 1901 (Raven, 1994). At its peak in the early 1900s, three bases were operating on South Caicos, Dellis Cay and Five Cays (Sadler, 1997), and employed about one third of the local work force. Sponges were harvested using waterglasses and iron hooks by up to 50 sailing sloops that had crews of 3-9 men each working out of dinghies. 'Wool' sponges were initially targeted, but were depleted rapidly as operations grew on South Caicos. Culture experiments were initiated in the early 1900s, but sponge blight and a move to plastic sponges in the market killed the industry by 1940. Occasionally, small-scale exports do take place these days.

Turtle shell was exported to England from 1887 to the early 1900s with a peak export value of 1,706 pounds sterling in 1906 (Raven, 1994). Poaching by foreigners became such a problem that the government of the TCI implemented a Turtle Protection Ordinance. By 1909, the Caicos Development Company leased Chalk Sound on Providenciales for raising and canning turtles. After the person exporting turtles died in 1915, trade slowed greatly. Sea turtle is still consumed locally, although there is no information about catch levels. However, it is likely in the hundreds per year.

Between 1845 and 1859 there was a brief, but important, sperm whale fishery based on Salt Cay (Sadler, 1997). Whales were taken from Silver Bank (Dominican Republic), so presumably some whales would have also been taken on nearby Mouchoir Bank.

CONCLUSIONS

Based on current estimates, total seafood landings in the TCI is just reaching the 1,000 tonne·year^{-1} mark (Figure 18). While conch landings have remained relatively steady, there have been increases in lobster and finfish landings to satisfy growing local demand by hotels and restaurants that cater to tourists.

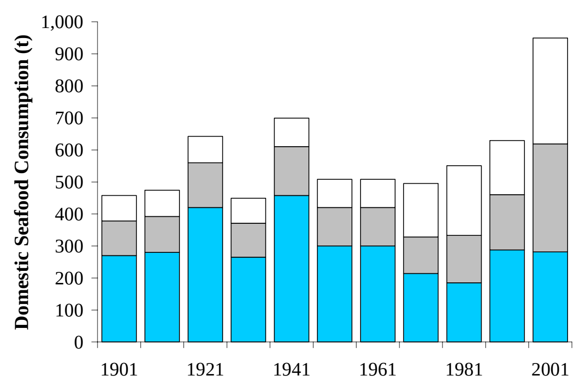

Figure 18: Total seafood production from TCI (excl. pelagic fishes).

Although data for the TCI goes back in time farther than most other countries in the region, data quality is poor, especially prior to the late 1970s. Estimates of current consumption should be viewed with caution. There are many landing sites in the TCI (Halls *et al.*, 1999), and a comprehensive seafood consumption survey would be the only way to accurately assess domestic seafood consumption.

The recent congruence between USA import and TCI production figures is promising. The USA statistics are available online from the U.S. National Marine Fisheries Service with a delay of only about three months. This should allow accurate monitoring of TCI conch and lobster landings. When products are misclassified, it is relatively easy to sort out proper classifications in USA imports because TCI ships such a limited variety of products.

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Brief History of Bermudian Fisheries, and Catch Comparison between National Sources and FAO Records

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Abstract

The purpose of this report is to present a brief overview of the Bermuda fisheries and to adjust the *Sea Around Us* Poject (SAUP) catch database to recognize differences between more detailed national datasets and the aggregated data reported to FAO-FISHSTAT. These changes modify the species composition of Bermuda's fisheries catches starting in the mid-1970s, by disaggregating larger categories such as 'miscellaneous reef fish' into smaller taxonomic groupings. Catch records between 1950 and 1970 were adjusted for total catch.

Introduction

Bermuda, located in the western part of the central North Atlantic (32°17'N, 64°46'W, Figure 1), consists of more than 100 islands (total land area ~ 50 km^2), forming the emergent top of a seamount. The remainder of this broad seamount consists of a geological platform of several hundred square kilometers of coral reefs with a lagoon-like area on the central platform. Bermuda is the most northerly location of reef building corals and coral-algal reefs in the western Atlantic Ocean. Bermuda, and offshore banks less than 200 m in depth, including Argus and the Challenger Banks, provide a total fisheries area of approximately 1,000 km^2 (Butler *et al.* 1993).

Fisheries

The fisheries of Bermuda are primarily for local consumption and may be classed as artisanal, although technologically advanced. Historically, fishers have accessed shallow inshore waters and have targeted mainly reef fishes, with serranids (groupers) dominating the catch. Traditionally, groupers were marketed to hotels and restaurants. As serranids became depleted in the late 1970s, and in line with correspondingly tightened regulations, efforts shifted first to deeper waters, primarily targeting two species of lutjanids, *Etelis oculatus* and *Pristipomoides macrophthalmus* (Luckhurst, 1996). As this fishery was rapidly depleted, fishing effort shifted more to pelagic species.

Throughout its history Bermuda has used various mechanisms to attempt to limit fishing effort, including gear restrictions, size and weight limits, temporal closures, restricted access to spawning sites and implementation of no-take zones. The earliest conservation measure to limit the effects of fishing pressure was for the protection of juvenile green turtles. This measure, introduced in 1620, is believed to be the first marine conservation/fisheries legislation in the New World. The most recent significant management measures were implemented in 1990 (Table 1) and there are new licensing and management measures pending. Thus, fisheries in Bermuda have been under some form of control for nearly 400 years, yet these restrictions seem to have had only limited success in protecting the resources. More effective enforcement in the past five years has helped to stabilize the fishery and consequent landings.

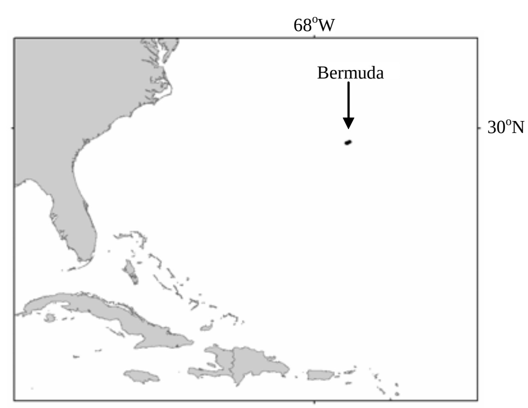


Figure 1: Location of Bermuda in the central North Atlantic Ocean.

Table 1: Time sequence for limiting fishing effort on particular stocks in Bermuda from 1620-1996 (Source: Smith-Vaniz *et al*. 1999).

Year	Regulation
1620	Restrictions on turtles (shell size limit >18 inches, approximately 46 cm), and on using pilchards and fry for use in oil production (to ensure a supply of bait fishes).
1627	Limit on net length (18 m) for the taking of small fishes.
1677	Restriction against the taking of porgy (*Calamus calamus*) during spawning in April or May except for personal consumption.
1687	Legislation set limits on certain types of fishing gear.
1703	Further limiting of net length for hauling of fish to 5.5 m.
1791	Ban on setting fish pots.
1891	Mesh size limits, preventing the harvesting of oysters and scallops during summer months, new turtle size limit by weight (4.5 kg), minimum weight restrictions for rockfish (Serranidae or *Mycteroperca* spp.), hogfish (*Lachnolaimus maximus*), Nassau grouper (*Epinephelus striatus*) and porgies (*Calamus* spp., Sparidae) as well as size limits on mullets (Mugil spp.), yellow grunts (*Haemulon flavolineatum*), breams (*Diplodus bermudensis* (Sparidae) and chubs (Kyphosidae).
1911	Fish preserve in Harrington Sound (banned fish pots and nets except casting nets by special permit).
1912	Fisheries Act made provisions to enable: the restriction or prohibition of the taking of any species of fish, closing specified areas to fishing, designating minimum sizes, restricting the use of fish pots and nets, and prescribing the duties of the fisheries warden as well as provisions made for a fish hatchery to stock Harrington Sound.
1972	Fisheries Act and Regulations. Restrictions on fish pot use for commercial fishing only, while non-commercial fishers were allowed a maximum of two pots with an application, vessels and fishers to be licensed annually.
1973	Turtle fishery closed after 360 years of operation in local waters.
1974	Spawning sites of red-hind (*Epinephelus guttatus*) designated as seasonally protected areas.
1980	Moratorium on any new fish pots being licensed.
1982	Moratorium on issuance of new fishing vessel licenses (only transference).
1984	Fish pots limited to full-time fishers only (minimum of 100 days at sea).
1987-1990	Planned reduction in the number of fish pots (3200 to 1600).
1990	Fish pot fishery closed.
1995	Six species of grouper fully protected - no take, no possession
1996	Minimum sizes introduced for 3 grouper species and 2 snapper species, recreational bag limit - lane snapper, minimum sizes - bluefin tuna and swordfish

In 1962, the Government sponsored a freezing facility to store surplus fish caught in summer in order to market them in the winter when landings decreased (Smith-Vaniz *et al*. 1999). In order to meet the growing demand in a period with declining landings of groupers, fishers began to target other 'white meat' species such as snappers and other reef fishes including parrotfish (Scaridae). In the 1950s groupers comprised up to 90% by number of all reef fish caught in fish pots (Bardach 1958 in Smith-Vaniz *et al*. 1999), whereas by 1989 groupers accounted for only 19% of food fish catch (Luckhurst and Ward, 1996).

In response to the changing state of the reef fish communities, the Government initiated a marine protected areas (MPA) strategy beginning in the 1970s. Initially, two seasonally protected areas were declared based on the spawning aggregation sites of red hinds (Luckhurst, in press). Over the past 15 years, a total of 29 no-take MPAs have been created around the reef platform, based primarily on popular dive sites. A moratorium was placed on the introduction of new fish pot licenses (the primary fishing gear at the time) in 1980, followed by a 1982 moratorium on the issuance of new fishing vessel licenses, although the transferring of licenses was allowed (Smith-Vaniz *et al*. 1999, Table 1).

A limited entry fish post fishery was established in 1986 but despite these regulations, reef fish populations continued to decline. The Government introduced a three-year plan (1987-1990) to reduce the number of fish pots by half, from 3,200 to 1,600. However in 1990, prior to the completion of the program, it was decided to ban the use of fish pots altogether. The fish pot ban was meant to help restore populations of reef fishes for non-consumptive uses (big and colorful reef fish are major tourist attractions). Interestingly, the first ban on fish pots was introduced in 1791, but did not meet with popular approval (Smith-Vaniz *et al*. 1999). The fish pot ban in 1990 displaced fishers who in turn targeted other fishes including deep-water snappers

(Lutjanidae, *Etelis oculatus* and *Pristopomoides macrophthalmus*) and pelagic species, such as wahoo (*Acanthocybium solandri*) and tunas (Scombridae). The deep-water snapper stocks were depleted rapidly within two years (Luckhurst, 1996). However, the two deep-water snapper species appear periodically in catches, primarily as a result of pulse fishing (Figure 2).

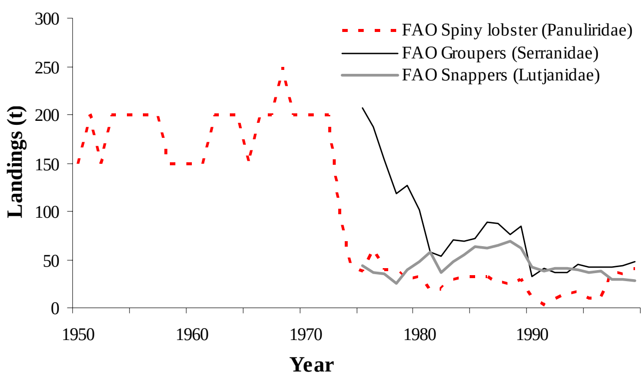


Figure 2: Landings of Spiny lobsters (1950-1999), Groupers and Snappers (1975-1999). Source: FAO-FISHSTAT.

Available records of fishing effort concentrated on the number of fishers estimated to be employed, the size of vessels and the h.p. of motors for the time period 1950-1962. For the time period 1963-1970 the records of the fleet concentrated on the number of registered fish pot fishers and on the number of fish pots used (Table 2). With the advent of the Fisheries Act, 1972, a statistical monitoring system was established to collect more detailed information on the catch and effort from the commercial fishery. Mandatory reporting by licensed fishers provided more detailed information on the species taken as well as fishing effort. The principal measure of fishing effort for the Bermuda commercial fishing fleet starting in 1975 is hours at sea. The effort measure for fixed gear is number of trap hauls. Since the fish pot ban in 1990, this measure continues to be collected for the spiny lobster fishery where licensed fishers use a Government standard trap (Luckhurst, 2001).

Tourism and Resident Population

Bermuda, a British Crown colony, was claimed and permanently colonized in 1612. In 1700 the population for the island was estimated to be 4,000 inhabitants (Smith-Vaniz *et al.* 1999) and by 2000 the population had grown to 63,022 (www.os-connect.com/pop, Figure 3).

The major factor driving local fisheries is the number of tourists who visit the island, as the growth in the tourism industry significantly increased demand for local fish. Tourism started to expand rapidly after 1950, as reflected by the growth in visitor days per year. Visitor days per year was over 440,000 in 1950, peaked in 1980 at over 3,175,000 and then started to decline so that by 1995 visitor days per year were 1,675,000 (Figure 3). After 1970, these numbers reflect only visitors who arrived by air and not by cruise ship. It is assumed that cruise passengers would have a lower impact on Bermudian fishery resources since a large proportion of cruise passengers would be eating aboard and most cruise ships would not take on provisions in Bermuda. From the 1950s to the 1970s the average stay by visitors was 6 days and 7 nights (Anon. 1950-1970), and it was here assumed that this average stay for visitors was also applicable in later years for those arriving by air. The percentage of visitors who arrived by air in 1995 (i.e., 67%, Archer 1995) was also assumed to be the same percentage as that in 1993.

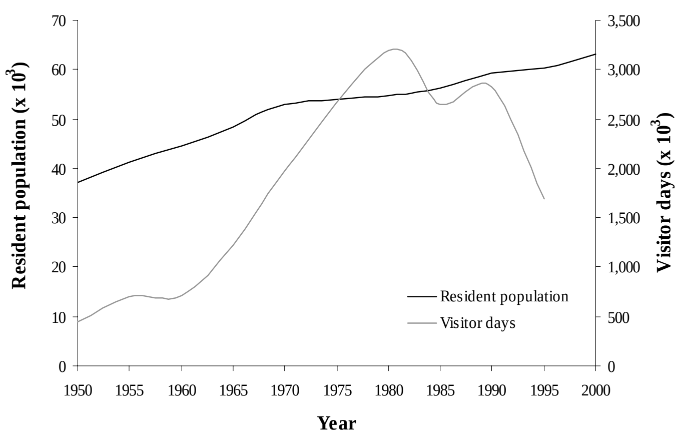
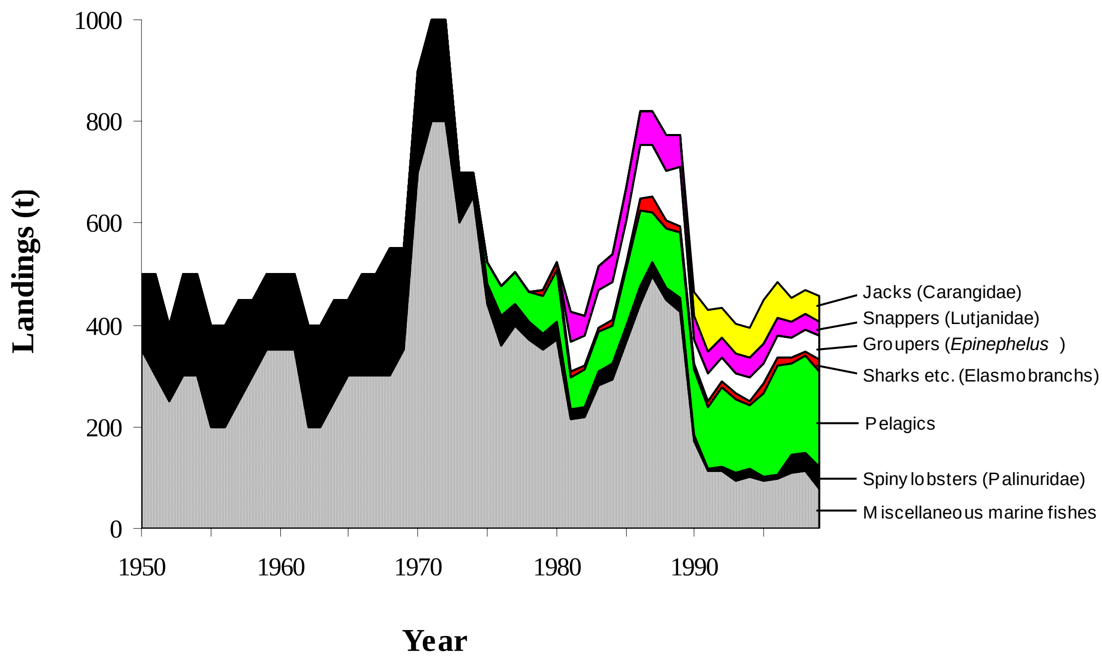


Figure 3: Resident population of Bermuda and the number of visitor days year^{-1} for the time period 1950-2000. Visitor days year^{-1} are included until 1995 only as more recent data was not available. Visitor days were calculated using an average of 6 days and 7 nights (6.5 days) per visitor for the 1950-1970 period, the same average was used in later years for passengers arriving by air only.

Table 2: Historical data on fishing fleet 1950-1970. (Source: Bermuda Reports for relevant years; n/a = not available).

Year	Number of fishers	Number/Size of boats	Registered fishers	Number of fish pots	Estimated Total Catch (tonnes)	
					Fish	Lobster
1950	100 full-time	50-60 boats/16 ft rowboat to 45 foot power boat	n/a	n/a	404	64
1951/52	100 full-time	n/a	n/a	n/a	399/ 386	64/64
1953/54	100 full-time	60 boats/16 ft rowboat to 50 ft power boat	n/a	n/a	431/454	68/64
1955/56	130 full-time	52/n/a	n/a	n/a	544/567	64/64
1957/58	130 full-time	53 boats/only 3 over 30 ft in length	n/a	n/a	572/637	64/61
1959/60	130 full-time	58 boats/average length of 28 ft	n/a	n/a	624 (1960)	n/a
1961/62	170 full-time and part-time	90 boats/ between 12 and 60 ft (50% between 20-29 ft with inboard motor average of 43 h.p.; 25% between 30-50 ft with motor average of 109h.p.)	n/a	n/a	612 (1962)	64 (1962)
1964	n/a	n/a	480 (100 of which are amateurs)	5400	n/a	n/a
1966	n/a	393	572 (58 of which are amateurs)	n/a	n/a	n/a
1967	100 full-time	n/a	530 (91 of which don’t use fish pots)	6750	658	n/a
1968	100 full-time	n/a	535 (90 of which don’t use fish pots)	6850	658	n/a
1969	100 full-time	n/a	556 (87 of which don’t use fish pots)	7000	658	64
1970	100 full-time	n/a	556 (87 of which don’t use fish pots)	7000	658	64

(a)



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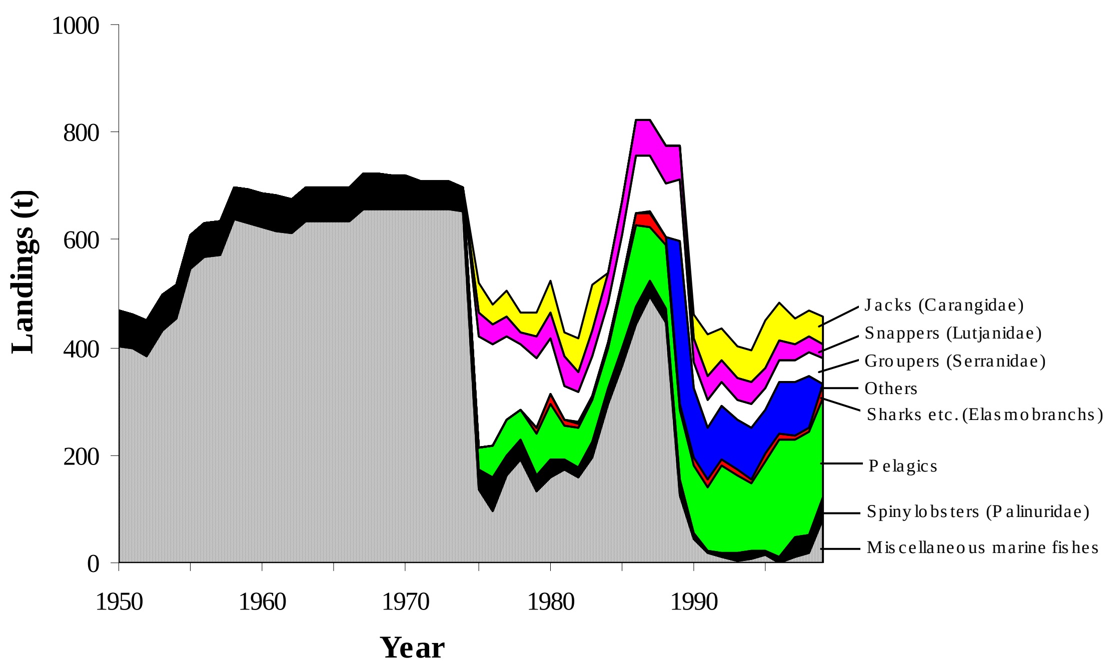

Figure 4: Bermudian landings as based on (a) the FAO FISHSTAT database and (b) the SAUP database (adjusted FAO data).

Fisheries Catches and Database Adjustments

The average annual landings (+/- SE) as reported by FAO for the time period 1950-1999 were 537 tonnes (+/- 22). Two peaks in landings of 1,000 tonnes and approximately 800 tonnes are reported for the early 1970s and late 1980s, respectively (Figure 4a). While some groups, such as the lutjanids (other than the two deep-water snappers previously mentioned), display little sign of decline in catches in the FAO database, others, such as groupers (Serranidae) and spiny lobsters (*Panulirus argus*), have had landings decline drastically from historical levels (Figure 2).

Prior to 1975, FAO-FISHSTAT landings for Bermuda were reported in only two groups, 'marine fishes nei' (miscellaneous marine fishes) and Caribbean spiny lobster (*Panulirus argus*, Figure 4a). In 1975, FAO landings started to include 'large pelagics' (tunas, wahoo & marlins) and in 1979 'Elasmobranchs' were added. Since 1981, both Groupers (reported as *Epinephelus* only) and Snappers (reported as Lutjanidae) became listed, and Carangidae were first reported in 1990 (Figure 4a).

Landings in the *Sea Around Us* Project database were modified from the FAO-FISHSTAT landings data to reflect adjustments and changes in taxonomic groupings reported by the British Colonial Office's Bermuda Reports published between 1950 and 1970 (Anon. 1950-1970), the Western Central Atlantic Fishery Commission (WECAFC 1985), Luckhurst (1996) and Anon. (1999). Landings were updated for the period 1950 to 1998.

Data from Luckhurst (1996) and WECAFC (1985) overlapped for both the reporting period and taxonomic breakdowns. The former source reports on landings from 1975-1992 and the latter reports on periods from 1975-1983. Additional data supplied by Anon. (1999) was for the period 1989-1998. Data taken from the Bermuda Reports adjusts the landings reported for the time period 1950-1970 (Anon. 1950-1970). The estimated landings in the Bermuda Reports differ from those reported by FAO, as the estimated landings for spiny lobsters are considerably lower while those for miscellaneous marine fishes are considerably higher. These reported values change the trajectory of these two groups. The landings for spiny lobsters do not show the significant decline in catches, and the miscellaneous marine fishes make up a larger proportion of total catches (Figure 5).

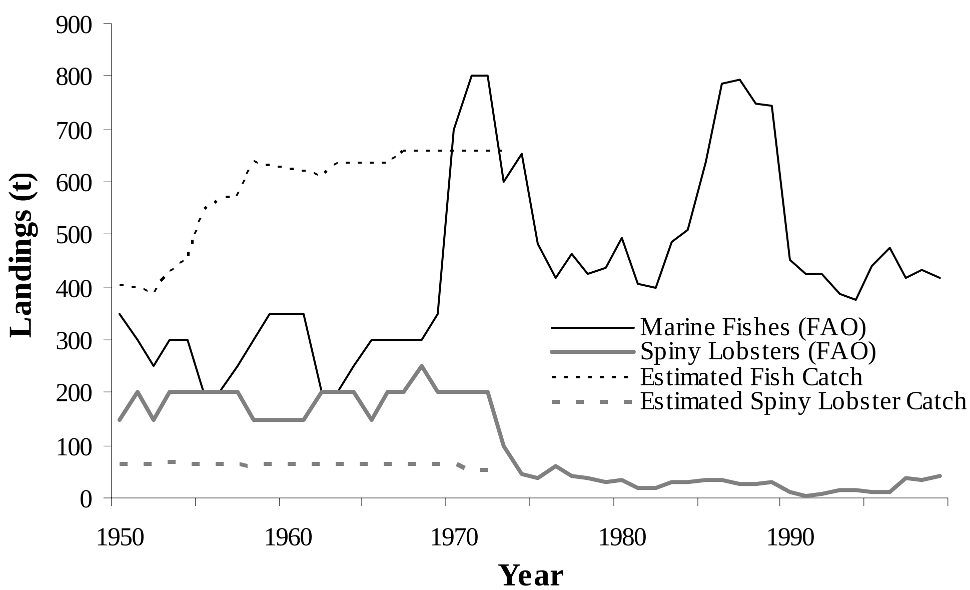

Figure 5: Landings of spiny lobsters and marine fishes for the period 1950-1998. Dashed lines represent the estimated catches as per the Bermuda Reports (Anon. 1950-1970).

For the period 1984-1998 the new data improve the species breakdown within the Lutjanidae and *Epinephelus* groups, by assigning landings, where possible, to the species level. For other years the data decrease the component of 'miscellaneous marine fishes' by reassigning these landings into lower taxonomic groupings at the family, genus or species level. In the case of the Lutjanidae, the FAO landings were separated into genus and species levels with a remaining component at the family level (Lutjanidae). FAO-FISHSTAT landings for groupers (Serranidae) were adjusted to reflect genus and species groups. However, for 1990-1992 the remaining amounts were assigned to the family level (Serranidae) to reflect proper taxonomic groupings (Figure 4b).

In summary, adjusted fisheries catches for Bermudian waters have shown a decline from the 1970s and 1985 peaks in landings. However, more recent years show an increase in landings mainly driven by increasing landings of pelagics (Figure 4b). A marked shift in target species composition driven by management action in response to observed depletions has occurred throughout the 1980s and 1990s. The present study has contributed to improved taxonomic accounting of catches and some corrections of historic catches by Bermudian fishers.

ACKNOWLEDGEMENTS

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Venezuelan marine fisheries catches in space and time: 1950-1999

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ABSTRACT

The FAO FISHSTAT landings for Venezuela were compared to data obtained independently directly from the primary collection authority. The major fisheries target small pelagics, snappers and groupers, ark shell, shrimp, and large pelagics. Total landings corresponded well, reflecting a good transfer of landings data from national sources to FAO's database. However, taxonomic breakdown of landings did not transfer as effectively as their tonnage, with FAO listing 62 taxa compared to 120 reported by the national source. Thus, FAO data reflect a higher degree of data pooling than original national source data, resulting in a loss of biodiversity information. In the present report, the spatial allocation of Venezuelan landings, based on state-boundary specific landings record for the period 1984-1999 have been improved. Given the often small coastal extent of some states, we pooled data from several states, resulting in eight spatial zones for landing records. Thus, we created an updated dataset for incorporation into the *Sea Around Us* project global database, combining better taxonomic breakdown as well as improved spatial landings allocation.

INTRODUCTION

Venezuelan fisheries are characterized by a very large small-scale, artisanal sector servicing local consumption as well as supplying some processing and export industries. Species caught include small and medium pelagics, primarily sardine (mainly *Sardinella aurita*), as well as snappers (Lutjanidae) and groupers (Serranidae), other demersal fish and invertebrates. Most components (over 60%) of the small-scale fisheries sector operate close to home ports and in relatively shallow waters within the EEZ (Anon., 2000a). For example, the large sardine fishery generally uses small boats deploying seine nets, with operations usually restricted to waters < 50 m deep in a narrow belt rarely exceeding 5 nm from the coastline (Fréon, *et al.*, 1997). Some components, however, such as the snapper and grouper fishery, operate also over extensive areas of the continental shelf and slope of Venezuela, Trinidad and Tobago, Suriname and French Guiana (Figure 1). Commercial fisheries consist primarily of shrimp trawl fisheries and large tuna/billfish fisheries.

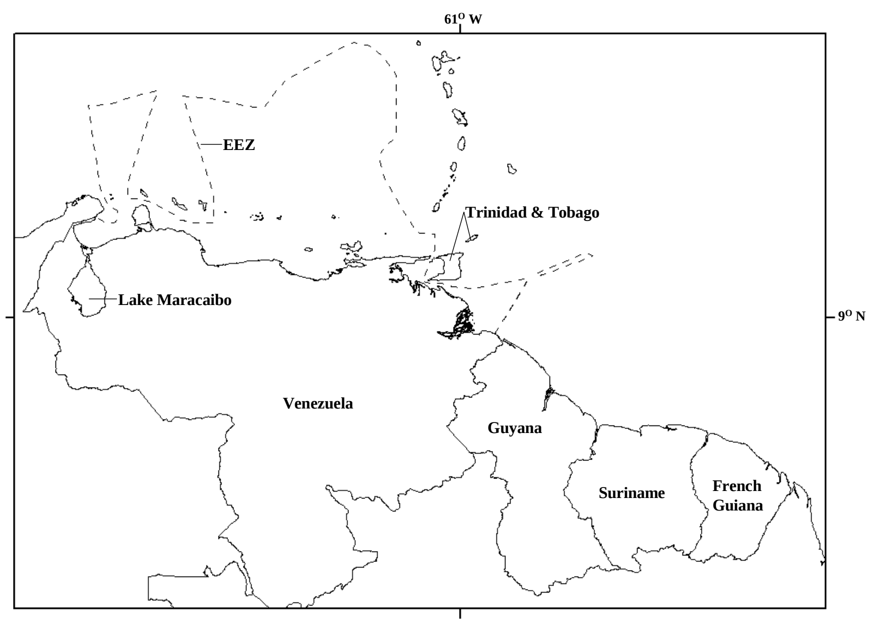
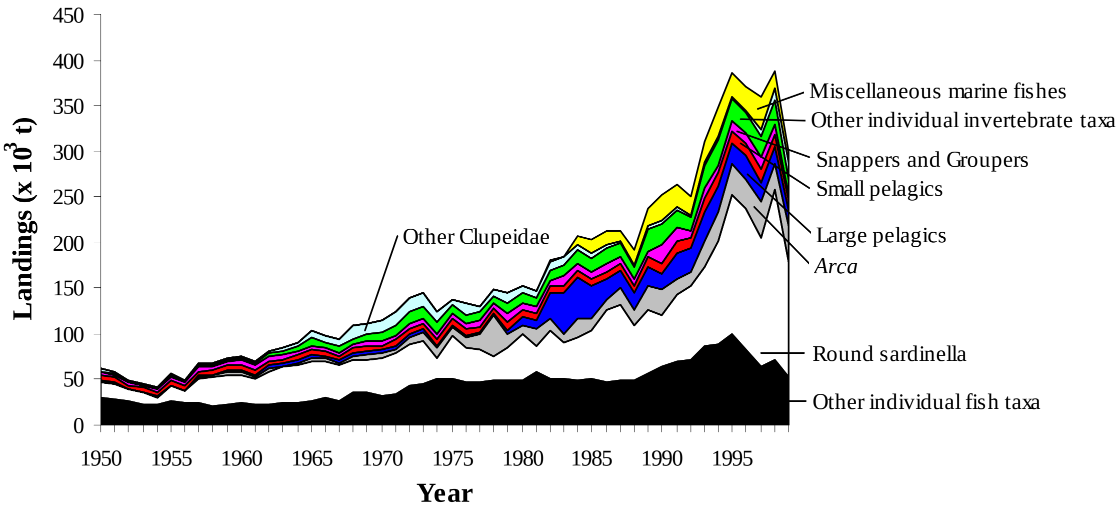


Figure 1: Map of Venezuela, showing EEZ, Orinoco delta, Lake Maracaibo, Trinidad and Tobago, Guyana, Suriname and French Guyana.

In terms of landings (Figure 2a), the artisanal sardine fishery forms the bulk of Venezuelan catches (reported mainly as 'round sardinella', *Sardinella aurita*,) followed by large pelagics (mainly yellowfin tuna, *Thunnus albacares*) and ark shell (*Arca zebra*).

(a)



(b)

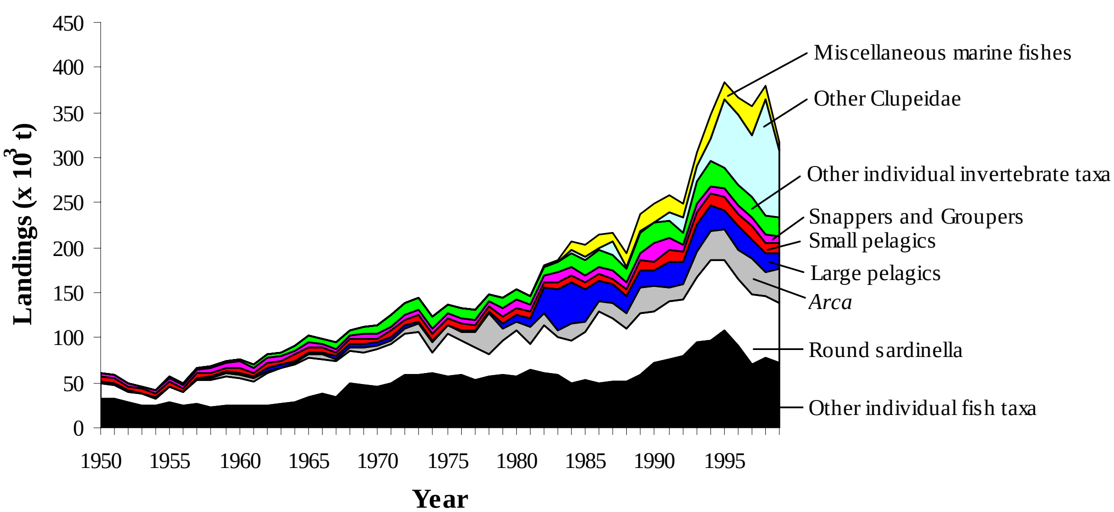


Figure 2: General catch time trend (1950-1999); a) Original FAO data (n = 62 taxa, source: FAO FISHSTAT), and b) FAO data (1950-1983) and Venezuelan national data (1984-19999, n = 112 taxa) showing general trend through time. Taxonomic breakdown was simplified through pooling for visual clarity.

The eastern Venezuelan shelf areas (Figure 1) are more productive due to the upwellings in the dry season (January to larger shelf area, as well as seasonal nutrient inputs due to localized wind-induced June) and river discharge from the Orinoco in the rainy season (Fréon, *et al.*, 1997). The central region of Venezuela is characterized by a narrower shelf area, and contains only sparse resources (Strømme and Saetersdal, 1989), resulting in low fishery yields. The most productive waters in western Venezuela are the Gulf of Venezuela and Lake Maracaibo (a large, shallow estuary) with the latter supporting a significant shrimp and crab fishery. In terms of landed value, yellowfin tuna and shrimp are the leading products, followed by crab and sardine fisheries.

Historically, until the middle of the 20th century Venezuelan fisheries were exclusively artisanal, with hook and line, and trap and gillnets being the dominant gears, along with a few large beach seine operations known locally as 'trenes de chinchorro', operated by as many as 200 fishers (Suarez and Bethencourt, 1994). In 1940, total catches reached 32,500 t of mainly demersal and medium-sized pelagic fish. With the construction of the first canneries during this period, an artisanal fishery for sardines developed, and became the largest in the country. By 1960, its catches had reached over 80,000 t, of which approximately 40% was sardine for human consumption and other small pelagic species such as *Cetengraulis edentulus* and *Opisthonema oglinum*, used for fish meal (Novoa, 2000). The introduction of the outboard engine during the 1950s with public assistance for the small-scale fisheries represented a revolutionary change at the time, allowing many fishers to become independent producers, and leading to the configuration of the fishing fleets that is known today.

The Venezuelan industrial fisheries started their development in the early 1950s with the introduction by European immigrants of trawling for penaeid shrimps in the Gulf of Venezuela and longlining for tuna and related species in the Caribbean and western Atlantic. The shrimp trawl fisheries expanded their activities during the 1960s and 1970s to the eastern Venezuelan shelf and Orinoco delta area. During this period, public investment in port and landing facilities and financial assistance led to a rapid development of this fishery, which peaked in the 1980s. During the late 1970s and early 1980s, government policies and a favorable international context permitted the development of the tuna purse seine fisheries, allowing the country to become one of the major producers in the eastern tropical Pacific, representing around 15% of the total catch in this area (Novoa, 2000). From 1983 onwards, Venezuela's economic crisis led to increasing unemployment with a resultant shift towards increased natural resource exploitation, with indications of unsustainable catches (Rodríguez, 2000).

Fishing fleets

The artisanal fleet consists of approximately 20,000 small vessels (<10 m, open deck, outboard engines) and approximately 1,000 medium- and long-range vessels. The medium and long-range artisanal fleet targets snappers and groupers inside and outside the EEZ using handline and demersal longline gear, as well as medium pelagics mainly within the Venezuelan EEZ using pelagic longline. The commercial fleet consists of approximately 400 shrimp trawlers operating essentially within the continental shelf area, and about 30 long-distance, large pelagic purse seine vessels (average fishing capacity 900 t) targeting large tuna. Only 5-6 of these vessels operate within Atlantic waters (mainly FAO area 31), the rest fish in the eastern Pacific (Anon., 2000a).

Research/Management authority

According to Prado and Drew (1999), the Government agency assigned responsibility for oversight and support of scientific research is the Fondo Nacional de Ciencia, Tecnología e Innovación, FONACIT (National Fund for Science, Technology and Innovation). In 1982 the fisheries research section of the National Fisheries Office of Venezuela, as it was then called, was moved to the National Fund for Agriculture and Husbandry Research (FONAIAP), which has recently become the National Institute of Agricultural Research (INIA). These days, the two institutions responsible for fisheries are the National Institute for Fisheries and Aquaculture (INAPESCA) and the National Institute of Agricultural Research (INIA). INAPESCA is responsible for overall catch data collection and fisheries management, while INIA provides more detailed catch and effort data for some fisheries (e.g., sardine, shrimp, tuna) and management advice.

Aims

The aims of this report were to:

Improve on the Venezuelan national catch data series documented in "El Atlas Pesquero Marítimo de Venezuela" of Novoa et al. (1998), both by extending the time series it contains, as well as improving the data quality and species composition, using national data sources;

Improve the spatial allocation of catches, currently assigned to FAO area 31 (Western Central Atlantic), through allocation to eight national zones based on landing records from the 13 coastal states of Venezuela; and

Use this modified national database to suggest adjustments to the FAO catch database, thus contributing to the SAUP database.

RESULTS

We have been able to obtain the complete Venezuelan landing records (National Dataset) from 1984-1999, directly from the government agencies collecting the data (INAPESCA and INIA). For most artisanal fisheries earlier data are not available in electronic form, and the location of much of

Table 1: Taxonomic entities used for Venezuelan fisheries landings in FAO FISHSTAT (n=62) and Venezuelan national data (n=112)

FAO	Venezuela	FAO	Venezuela
Acanthocybium solandri	*Acanthocybium solandri*	*Istiophorus albicans* (continued)	Istiophoridae*
Ariidae	Ariidae	Jacks, mullets, sauries	Miscellaneous pelagics
	Cathorops spixii	*Katsuwonis pelamis*	*Katsuwonis pelamis**
Arca	*Arca zebra*	*Loligo*	*Loligo* spp.
Auxis	*Auxis thazard*	Lutjanidae	*Lutjanus* spp.
Auxis thazard			*Lutjanus analis*
Brachyura	Brachyura		*Lutjanus griseus*
Carangidae	*Chloroscombrus chrysurus*		*Lutjanus purpureus*
	Decapterus punctatus		*Lutjanus synagris*
	Decapterus tabl		*Pristipomoides* spp.
	Elagatis bipinnulata		*Rhomboplites aurorubens*
	Oligoplites sp.	*Makaira nigricans*	*Makaira nigricans**
	Trachurus spp.	*Micropogonias furnieri*	*Micropogonias furnieri*
Caranx	*Caranx*	Miscellaneous marine fishes	*Albula vulpes*
	Caranx hipppos		*Elops saurus*
	Caranx latus		*Hemirhamphus spp.*
Carcharhinidae	Carcharhinidae		*Holocentrus* sp.
	Galeocerdo cuvier		*Lepophidium profundorum*
	Mustellus spp.		*Megalops atlanticus*
	Various sharks		*Merluccius albidus*
Centropomus undecimalis	*Centropomus* spp.		Miscellaneous pelagic fishes
Cetengraulis edentulus	*Cetengraulis edentulus*		Various fishes
Coryphaena hippurus	*Coryphaena hippurus*	Miscellaneous marine molluscs	Miscellaneous marine molluscs
Crassostrea rhizophorae	*Crassostrea rhizophorae*		*Citarium I*
	Pinctada imbricata		*Donax* spp.
Cynoscion	*Cynoscion* spp.		Scallops
	Cynoscion jamaicensis	*Mugil cephalus*	*Mugil curema*
		Mugil liza	*Mugil liza*
Epinephelus	*Epinephelus* spp.	Octopodidae	*Octopus* spp.
	Epinephelus itajara	*Ocyurus chrysurus*	*Ocyurus chrysurus*
	Epinephelus guttatus	*Opisthonema oglinum*	*Opisthonema oglinum*
	Epinephelus niveata	*Panulrus argus*	*Panulirus argus*
Euthynnus alleteratus	*Euthynnus alleteratus*	*Penaeus*	*Penaeus brasiliensis*
Gerreidae	Gerreidae		*Penaeus schmitti*
	Eugerres spp.		*Penaeus subtilis*
Haemulidae	*Haemulon aurolineatum*		Penaeidae
	Haemulon chrysargyreum	*Peprilus*	*Oligoplites palometa*
	Haemulon steindachneri	Perciformes	*Acanthurus spp.*
	Orthopristis ruber		*Calamus* sp.
Istiophorus albicans	*Istiophorus albicans**		*Erythrocles monodi*

*These taxa were not compared in this report due to uncertainty of reported values and location of catches.

Table 1: (cont'd)

FAO	Venezuela	FAO	Venezuela
Perciformes (continued)	*Halichoeres* spp.	*Tetrapturus albidus* (continued)	Various swordfish or billfish*
	Larimus breviceps	*Thunnus alalunga*	*Thunnus alalunga**
	Lobotes surinamensis	*Thunnus albacares*	*Thunnus albacares**
	Macrodon ancylodon	*Thunnus atlanticus*	Not reported
	Miscellaneous demersal fishes	*Thunnus obesus*	*Thunnus obesus*
	Pomacanthus sp.	*Trachinotus*	*Trachinotus* spp.
	Priacanthus arenatus	*Trichiurus lepturus*	*Trichiurus lepturus*
	Rachycentron canadum	Veneridae	Veneridae
	Sciaenidae		*Tivella mactroides*
	Sparisoma spp.	*Xiphias gladius*	*Xiphias gladius**
Perna perna	*Perna perna*		
Pleuronectiformes	Pleuronectiformes		
Pomatomus saltator	*Pomatomus saltatrix*		
Portunus spp.	*Callinectes* spp.		
Rajiformes	*Aetobatus* or *Myliobatis* spp.		
	Various rays		
Sarda sarda	*Sarda sarda*		
Sardinella aurita	*Sardinella aurita*		
	Clupeidae		
Scomber japonicus	*Scomber japonicus*		
Scomberomorus brasiliensis	*Scomberomorus brasiliensis*		
Scomberomorus cavalla	*Scomberomorus cavalla*		
Scombridae	Scombridae*		
Selar crumenophthalmus	*Selar crumenophthalmus*		
Selene setapinnis	*Selene setapinnis*		
Seriola	*Seriola zonata*		
	Seriola rivoliana		
Serranidae	*Mycteroperca rubra*		
	Mycteroperca spp.		
	Serranus dewegeri		
Sphyraena	*Sphyraena* spp.		
Strombus	*Strombus gigas*		
Tetrapturus albidus	*Tetrapturus albidus**		

*These taxa were not compared in this report due to uncertainty of reported values and location of catches.

Table 2: The zones delineated from 13 Venezuelan states used for the spatial allocation of catches.

Zone Number	Zone Name	Venezuelan States pooled in this Zone (remarks)
1	Lake Maracaibo	Merida, Trujillo, Zulia (crab, shrimp and weakfish)
2	Gulf of Venezuela	Merida, Trujillo, Zulia (all other taxa)
3	Western Venezuela	Falcon (landings split between Area 2 & Area 3)
4	West-central Venezuela	Carabobo
5	East-central Venezuela	Aragua, Anzoategui, Vargas (formerly: Districto Federal) , Miranda
6	Eastern Venezuela	Sucre and Nueva Esparta
7	Gulf of Paria	Monagas and Sucre
8	Delta Amacuro	Delta Amacuro

this earlier data is currently unknown. Thus, the updated catch time series reported here contains original FAO data from 1950-1983, while catches from 1984-1999 are based on the national dataset (Figure 2b). Total catches peaked at over 350,000 t year^{-1} in the late 1990s. Quantitative differences between the two data sources were minimal, reflecting good data transfer mechanisms between Venezuela and FAO. The same did not apply to the taxonomic breakdown of reported catches.

Taxonomic differences in reporting

One of the greatest challenges that emerged was the 'taxonomy' of the catch, as all national data are recorded using non-standardized local names, which varied through time. This use of highly localized names may also explain some of the allocation uncertainties and irregularities found in the FAO data for Venezuela. It appears that national catch statistics are reported to FAO by their local names, likely resulting in taxonomic uncertainties and the observed pooling of numerous taxa, such as several distinct species to their family level or 'Miscellaneous Marine Fishes' in the FAO data. The National Dataset obtained here, with 120 taxonomic entities has enabled us to improve the species breakdown of the existing FAO database records which contains 62 taxa for Venezuela (Table 1).

The most obvious change in the updated catch time series from the original FAO dataset was the re-allocation of considerable tonnage from round sardinella (Figure 2a) to the group 'other clupeids' (Figure 2b). This reflects more correctly the diverse species composition of catches in the small pelagic fisheries.

Spatial catch allocation

With respect to spatial allocation, the national dataset is broken down by the 13 coastal states of Venezuela that report marine landings (Table 2). However, given the sometimes small coastal extent of some states, several were amalgamated for the purpose of spatial catch allocations, resulting in eight spatial zones (Table 2, Figure 3). Based on total landings, the Eastern Venezuelan zone dominates due to its large shelf area, accounting for approximately 75% of the total Venezuelan catches in the late 1990s (Figure 4, Table 2). This spatial

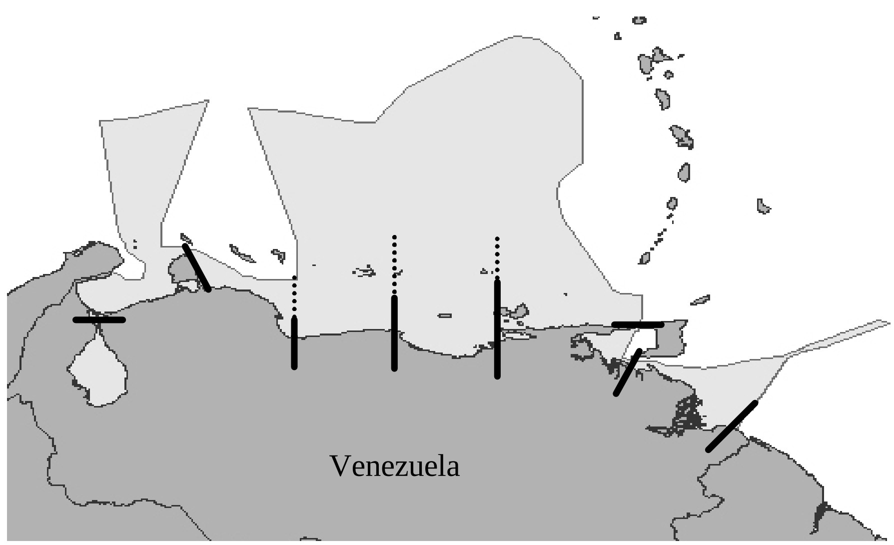


Figure 3: Map of eight reporting zones used for spatial allocation of reported landings, derived through partial amalgamation of the 13 reporting states for national statistics. Venezuelan EEZ is shown also.

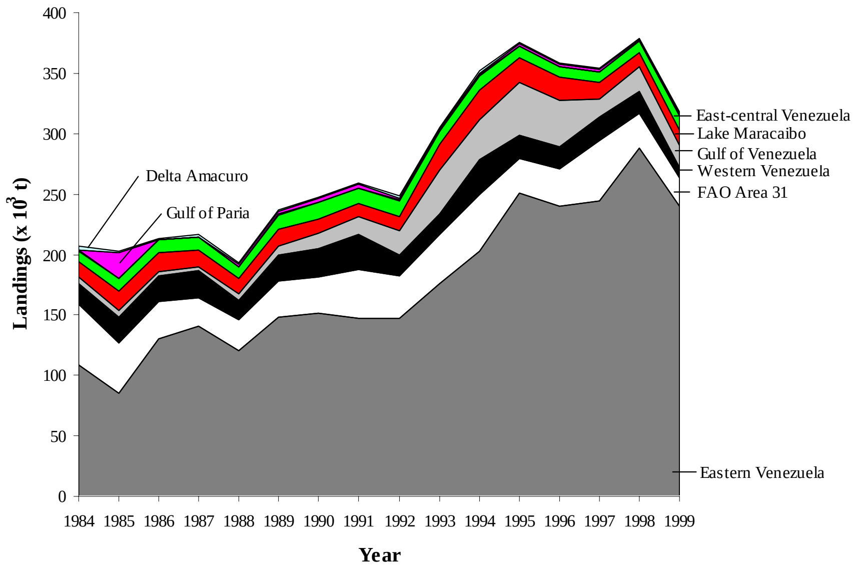


Figure 4: Total national catches allocated to the eight reporting zones indicated in Figure 3 and Table 2, depicting the predominance of the large eastern shelf area (Eastern Venezuela) in total catches.

catch allocation has significantly improved the spatial breakdown of landings over the three zone approach (east, central and west) utilized in previous data descriptions (Novoa *et al.*, 1998), and the broad assignment to FAO area 31 (Western Central Atlantic) in FAO FISHSTAT. To what extent this breakdown of landing locations reflects true spatial location of catches is uncertain, but likely to be high for most species (due to the large, localized artisanal sector). An exception is the snapper/grouper fishery, which has a considerable component outside of Venezuelan waters, our next topic.

Snapper and Grouper fishery

The major taxonomic target for this handline and bottom longline fishery are the Lutjanidae, especially the Southern Red Snapper (*Lutjanus purpureus*), while the Serranidae, (e.g., *Epinephelus* spp.), form a minor component of the reported landings (Mendoza and Lárez, 1996; Figure 5a). Although a significant portion of fish are caught in foreign waters (data only available since 1988), the major part of the landings are still taken in national waters (Figure 5b). The major part of foreign landings appear to be made in French Guiana, followed by Suriname and Trinidad & Tobago (Figure 5c). This historic geographic range of the fishery is in part maintained through existing agreements, mainly with Suriname and French Guiana. Under existing license agreements, 75% of catches made in the waters of French Guiana have to be landed there, while the rest may be landed in Venezuelan home ports (Charuau and Die, 2000). Similarly, 50% of catches taken in Suriname are to be landed in that country. The national dataset reports these catches as landings in 'foreign ports' ('Puerto Extranjeros'), which are assigned spatially according to local expert advice.

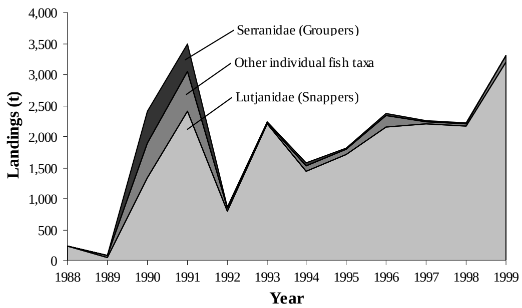
Invertebrate fishery

Fisheries for invertebrates are dominated by ark shell (*Arca zebra*), which accounts for over 50% of the total reported invertebrate landings of just under 60,000 t year^{-1} in the late 1990s (Figure 6a). The remaining invertebrate catches are dominated by shrimp, crab and other bivalve catches (Figure 6b). The white shrimp (*Litopenaeus schmitti*) is one of the economically most significant fisheries resources of Venezuela, and accounts for ~90% of the total shrimp catch in Lake Maracaibo (Andrade de Pasquir, 1998). Interestingly, the white shrimp stock in Lake Maracaibo is the largest known population within the range of this species. Overall, the Venezuelan commercial shrimp trawl fisheries began in the 1950s, and the fleet reached a peak of 450 vessels in the 1980s, before dropping to approximately 370 vessels in the mid 1990s (Anon., 1996b; Marcano and Alio, 1996). The traditional fishing grounds are thought to be intensively exploited, although the overall effort seemed to have declined in the mid 1990s (Marcano *et al.*, 1996). However, effort in most places is still considered well beyond levels leading to MSY (Marcano *et al.*, 1996). Approximately 40% of the catch is exported, mainly to North American and European markets, while small shrimp are sold nationally. Bycatch is significant in this fishery, accounting for 93% of the total catch in the nets in 1998, of which 33% is kept for sale in local markets (utilized bycatch), while 60% is discarded at sea (Anon., 2000b).

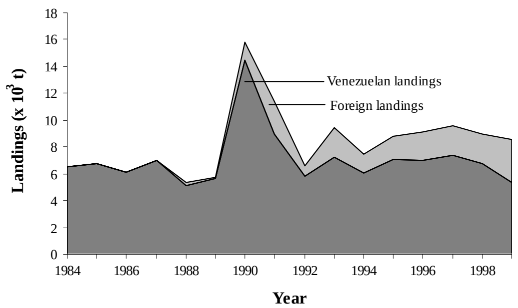
Underreporting

It is generally thought that parts of the artisanal fisheries sectors are not well covered with regards to catch data collection.

(a)



(b)



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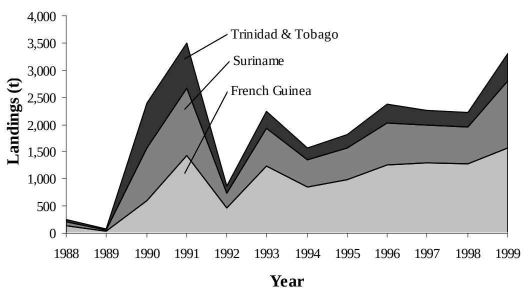


Figure 5: Reported landings for the snapper and grouper fisheries operating in waters of Venezuela and neighboring countries: a) Taxonomic breakdown of reported landings, illustrating dominance by Lutjanidae; b) Separation of catches in those taken in national waters and those taken in neighboring countries; and c) Breakdown of catches taken and landed in the three respective countries.

Official catches for some species might, in some areas or for some time-periods under-represent true catches by as much as 200-500% (Salaya *et al.*, 1985a, 1985c, 1985d, 1985b; Mendoza and Freón, 1991). While the general problem is known, currently there seems to be no reliable way to correct for this, due to massive spatial and temporal variation and uncertainty. However, this problem does not apply to the substantial sardine fishery, nor the catches for ark shell, both of which are thought to be recorded reliably.

International agreements

Information was also obtained on international agreements to which Venezuela is party (Anon., 1996a). Venezuela is member of FAO, the International Commission for the Conservation of Atlantic Tunas (ICCAT) and the Inter-American Tropical Tuna Commission (IATTC). A bilateral agreement exists since 1985 with Trinidad & Tobago, designed to permit a limited number of Venezuelan vessels to fish for snappers and groupers in their waters. In return, vessels from Trinidad & Tobago are allowed to continue their traditional fishing for shrimp off the Orinoco delta in Venezuelan waters. There is also an agreement with Suriname which allows around 100 Venezuelan snapper-grouper vessels, through a license system, to fish in Surinamese waters as long as 50% of the catch is landed in that country. There is no written agreement between the French and Venezuelan governments, but administrative permits are given to snapper-grouper vessels to fish in French Guiana, as long as 75% of the catch is landed in this overseas French department.

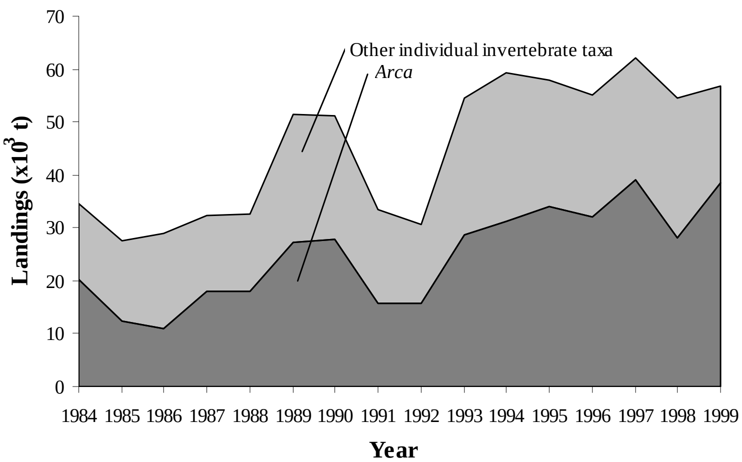
DISCUSSION

Overall, the temporal trend in total catches as reported by Venezuela indicated a dramatic increase in reported landings throughout the 1980s and 1990s from levels around 150,000 $t \cdot year^{-1}$ to over 350,000 $t \cdot year^{-1}$. The latest year of the dataset examined here (1999) indicated a distinct decline in reported landings. Whether this is a true representation of trends in landings or a reflection of data anomalies for the last year of the dataset utilized here is uncertain, and has to await future work to verify. Thus, this decline has to be treated with caution until 2000 and 2001 data are incorporated.

Concurrence with the global landings database maintained by FAO was good in terms of tonnage, but taxonomic information was transferred less reliably from national sources to FAO, with a ~50% loss of taxonomic diversity. The work reported here corrects for some taxonomic over-aggregating, and improves the spatial allocations through use of eight landings zones.

It is hoped that investigations such as the present will encourage FAO to refine their excellent global dataset on fisheries landings both in-house, as well as through feedback

(a)



(b)

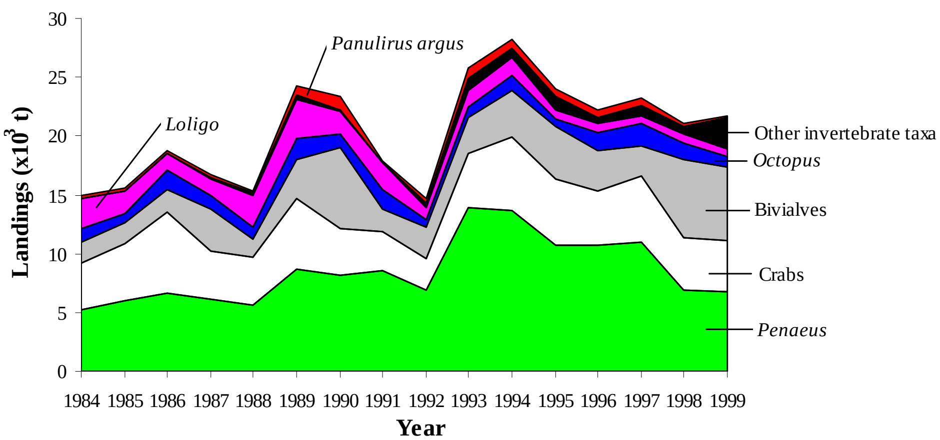


Figure 6: Venezuelan national reported landings for invertebrates: a) Illustrating the predominance of ark shell (*Arca zebra*); and b) Breakdown of the 'other individual invertebrate taxa' pooled in (a) and illustrating the importance of shrimp, crab and bivalve components.

requests to their member countries, i.e., to encourage better taxonomic and spatial allocation of landings. Such efforts will improve the utility of FAO's global database for investigations and evaluations of effects of fishing at the ecosystem levels (Pauly *et al.*, 2002; Christensen, *et al.*, 2003) as mandated by the precautionary and sustainability principles.

Acknowledgements

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A Database of Landings Data on Brazilian Marine Fisheries, 1980-2000

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ABSTRACT

The objective of this study was to compile and document landings data on Brazilian marine fisheries for the period from 1980 to 2000. The Brazilian coastline ranging from above 3ºN to below 30ºS does not form a homogeneous unit. Thus, data by states rather than national landings data should be used as input to Brazilian marine ecosystem models. A description of the suitable data sources is given, along with information on the scientific and common names of the species in the database. Brazilian landings peaked at approximately 756,000 tonnes in 1985 and have been declining since. Sardines, croakers, drums, shrimps, tunas, and tuna-like fishes are the main groups caught. Landings originate mainly from the two southeastern states of Rio de Janeiro and São Paulo, although Santa Catarina, located in the southeast, also has considerable landings. These three states all have an industrial fleet, which contributes to these states dominating national landings.

INTRODUCTION

Fishery management aims to maintain fished stocks at sustainable levels, even if there is no consensus on what population sizes are needed to ensure sustainability of fishery resources or, indeed, on what sustainability is. The stock size and species composition found in fished areas at present have been altered by decades or even centuries of fishing pressure (Jackson *et al.*, 2001). To better understand these changes, it is necessary to have at least some indirect indicators such as catches or landings, for those cases where no direct information on stock abundance and species composition is available. Moreover, time series data for these indicators should be long enough to help overcome such problems as the 'shifting baseline syndrome' (Pauly, 1995). This can lead to increasingly depleted stocks caused by successive cohorts of scientists basing the status of a stock on short-term analysis of abundance rather than historical abundance. This can cause the persistence of low population levels for stocks subjected to high rates of fishing pressure. Thus, instead of maintaining the recent past, fishery management should aim to rebuild stocks and ecosystems to historical levels (Pitcher, 2001). Jackson *et al.* (2001) noted that short time series also fail to detect long-term environmental shifts and subsequent impacts on stocks, and consequently the depletion process of many fishing stocks worldwide are not fully explained.

Long time series of fishery data are not readily available for Brazil and thus the objective of the present study was to compile and document landings data on Brazilian marine fisheries by state for the time period 1980-2000 and to discuss some of the main features of these fisheries on a national and regional basis. The large range of the Brazilian coastline has led many researchers to accept a division of the marine environment into five different regions (north, northeast, east, southeast, and south), based on bathymetry, oceanographic structure, fauna, flora and fishery (Matsuura, 1995). Having data broken down to the state level allows for attributing data to smaller regions, which is not possible using the Food and Agriculture Organization's electronic database (FISHSTAT – www.fao.org).

FISHERIES MANAGEMENT AND LANDING DATA

Fisheries management

The first record of a large-scale fishery in Brazil goes back to 1602 when fishers from the Bay of Biscay were allowed to catch whales in Brazilian waters and build factories to process the oil (Barbosa, 1983). By the end of the 1880s, some fisheries started to decline and restrictive measures were taken: no slaves were allowed onboard fishing boats and only up to one-fifth of the employees in a fishing company could be foreigners. The first documentation related to regulation of fishing activities was prepared in 1846, following the independence of Brazil from Portugal (1822). Several colonies of fishers were established, and they were able to secure some basic rights. In 1897, after the declaration of the Brazilian Republic, the fishing sector was nationalized and all professional fishers were required to register with their respective Port Authority.

From 1933 to 1961, the Division of Hunting and Fishery became responsible for Brazilian fisheries and the Code of Hunting and Fishery was the basis for its activities (Anon., 1973). This division was linked to the National Department of Animal Production, a unit of the Ministry of Agriculture. In 1961, the Council for Fisheries Development (CODEPE) was created and the Division of Hunting and Fishery was transferred to that council. One year later, the division was dissolved and the Superintendence for Fishery Development (SUDEPE) was created, as part of the Ministry of Agriculture (Anon., 1973). The main goal of SUDEPE was to promote a highly organized fishing sector, representing a new industrial phase of fisheries development. The specific objectives of the superintendence were to elaborate the National Plan for Fisheries Development, to give technical and financial assistance to projects related to fishing, to conduct research, and to promote the application of a Fisheries Code.

In 1967, a decree was approved to stimulate the development of fishing industries. Unfortunately, this legal measure also removed rights that fishers had enjoyed earlier (Barbosa, 1983). Simultaneously, SUDEPE and the United Nations established the Fishery Research and Development Program (PDP), and fishery research finally began to develop in a structured context.

The Institute of Research and Development of the Fishing Sector was created in 1980; it was linked to SUDEPE, and was responsible for the continuation of the activities developed by the PDP. In 1989, SUDEPE was dissolved and replaced by the Institute of Environment and Natural Renewable Resources (IBAMA). This institute deals with issues formerly handled by the Secretary of Environment (SEMA), the Superintendence of Rubber (SUDHEVEA), the Brazilian Institute for Forest Issues (IBDF), and SUDEPE. This concentration of responsibilities had a negative impact on the fishing sector, since IBAMA lacks financial and human resources, and therefore cannot meet its responsibilities.

In 1998, a National Plan for Fishery and Aquaculture was proposed (GESPE, 1998), but it never became operational. In the same year, a decree split fishery responsibility between the Ministry of the Environment (MMA/IBAMA) and the Ministry of Agriculture and Supply (Cardoso *et al.*, 1998). This decree established that MMA/IBAMA would be responsible for setting catch limits, gear restrictions, and minimum 'fish' size for all Brazilian fisheries, except those involving migratory species and unexploited or under-exploited stocks. This was hardly practical, and a new bill was proposed where all responsibility related to the fishing sector would be transferred to the Ministry of Agriculture and Supply. However, in 2003, a newly elected Brazilian President created a Secretary of Fisheries directly associated with the Presidential Office. Such a pattern of sequential changes in institutions managing the fishing sector does not allow for the establishment of a good system of data collection, or a sound national fishery policy.

Landing data

Aragão (1997) presents an overview of the evolution of the system of data collection related to the fishing sector. Before 1967, the Production Statistical Service (SEP) of the Ministry of Agriculture was responsible for assembling landing data collected by IBGE (Brazilian Institute of Statistics and Geography), state institutions and the Ministry of the Treasury. In 1967, SUDEPE created the Statistical Advisory Board, which proposed a new plan for data collection. However, it was never put in place. In 1968, the PDP Program (SUDEPE/FAO) began collecting landings data in the southern region and later extended its activities to other regions. In the early 1970s, PDP and SUDENE (Superintendent for the Development of the Northeastern Region) collaborated to collect data from the northeast region. When PDP took sole responsibility of SUDEPE in 1980, the data collection system started to deteriorate. During this period, IBGE continued to collect data, but their quality is considered low.

One year after the demise of SUDEPE and the establishment of IBAMA, the latter developed a system of data collection that began in Ceará (ESTATPESCA), northeastern Brazil. This system was gradually extended to other states of the northeast region, but was not able to encompass all states in this region. Some states did not collect any data during this transitional period due to lack of human and financial resources. At present, data

Table 1: Sources used to compile marine landings data from industrial and artisanal fleets.

PERIOD	PERIODICITY	FORMAT	SOURCES
1980	Annual	Paper	(IBGE, 1980)
1981-89	Semi-annual	Paper	(IBGE, 1981; 1982; 1983; 1984; 1985; 1986; 1987; 1988; 1989)
1990-97	Annual	Paper	(CEPENE, 1995a; b; c; d; e; 1997a; b;1998)
1998	Annual	Electronic	IBAMA, (G.C. dos Santos, pers. comm.)
1999	Annual	Paper	(CEPENE, 2000b)
2000	Annual	Electronic	IBAMA, (S. Bezerra, pers. comm.)

collection is highly heterogeneous, as it is conducted by IBAMA, state institutions, and/or universities. IBAMA is still responsible for gathering data from all these institutions and presenting them in the form of printed bulletins ('Estatística da Pesca'). With recent political changes, the future of data collection from the fishing sector is unclear.

Some argue that the importance of the artisanal fishery in Brazil is one of the factors leading to poor data collection (Paiva, 1997). Another factor is the difficulty in establishing a clear boundary between the artisanal and industrial sectors. Others attribute the difficulty of data collection to problems in communication and in organizational structure (see e.g., Marcílio and Lisanti, 1973), lack of institutional interest in an activity with low contribution (0.25%) to the gross domestic product (FAO Fishery Country Profile: The Federal Republic of Brazil, March 2002, www.fao.org/fi/fcp), the shortage of financial and specialized human resources, and quite rightly, to unstable institutional arrangements.

Compiled Data

Annual landing data for Brazilian commercial marine fisheries were compiled for the period 1980-2000 by state, by fishery type (artisanal and industrial), and by species or group of species (Table 1). Some terms have to be defined in the context of this study:

- Landings data: refers to weight in tonnes of the taxa caught (molluscs, crustaceans, fish, turtles, mammals), but excluding discards or other unreported catches;
- Commercial: includes both artisanal and industrial fisheries, but excludes subsistence and recreational fisheries;
- Artisanal: including manual collection, or using paddled or sailing boats, and small motor boats (usually < 12-15 m and < 20 Registered Gross Tonnage); however, the limits differ among states; and
- Industrial: originated from boats > 12-15 m and > 20 Registered Gross Tonnage; limits differ among states.

Results and Discussion

The landings data for Brazilian commercial marine fisheries compiled in this study from national documents are available in electronic format from www.seaaroundus.org. The sum of the data for the seventeen states that record marine landings reproduces the majority of the data available for Brazil from the FAO database for the period 1980-1988, with a peak of 756,000 tonnes in 1985 (Fig.1). After 1988 there is increased discrepancy between the two sources. However, both databases show a strong decline (about 32%) in catch from 1985 onwards, with the total landings in 2000 of 468,000 tonnes. This national pattern follows the declining trend of global catches discussed in Pauly *et al.* (2002), and will likely lead to a shortage of seafood supply.

The overall decline in Brazilian landings is mainly accounted for by the massive decline in landings of sardine (mainly *Sardinella brasiliensis*), which collapsed by 1990 when landings dropped from 300,000 to 50,000 tonnes (Figs. 2 and 3). The marine mammal fishery (exclusively whales) was completely banned in 1985, although a ban on successive species had taken place since 1981, the last exploited species being the minke whale, *Balaenoptera acutorostrata* (Singarajah, 1997). The turtle fishery is a minor component of the total landings and in 1980 landings were 60 tonnes. A gradual process to ban turtle fisheries also occurred in Brazil from 1967 onwards, until the complete ban in 1986 (Marcovaldi and Marcovaldi, 1999).

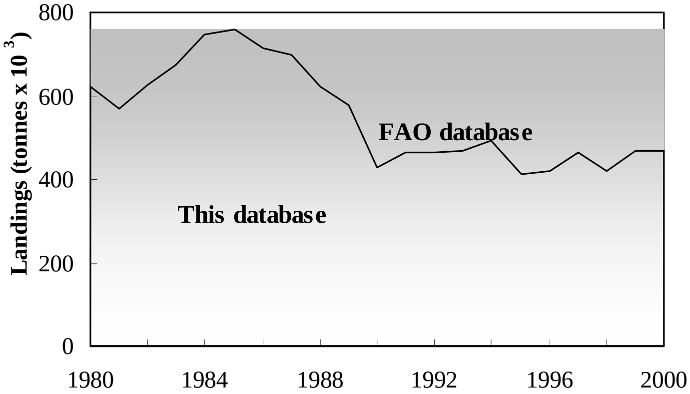

Figure 1: Landings data for Brazilian marine commercial fisheries from FAO FISHSTAT (www.fao.org), covering Brazil as a whole (i.e., without divisions into states) and from the reconstructed, state-specific data based on this study.

However, contrary to the whale fishery, some turtles were still caught in 1987-88 and are recorded in this database (< 5 tonnes). After that year, there are no landings data for turtles, although they are still caught as by-catch in swordfish and other pelagic longline fisheries (Weidner and Arocha, 1999), and for home consumption.

After encoding the database, the common names presented in the original source were assigned to their proper scientific name, using the decision process illustrated in Figure 4. The database of common and scientific names (I) was created only for this study and includes molluscs, crustaceans, fish, turtles and whales. The database of names (II) includes 4,172 common names associated with 725 species of marine and estuarine fish, representing an extension of the database presented in Freire and Pauly (2003), and has now been included in FishBase (www.fishbase.org). After applying the process illustrated in Figure 4, seven species remained unknown: 'bonito barriga lisa', 'ubaroba' and 'miracú' (Rio de Janeiro state), 'papa fina' and 'papuda' (Bahia), 'sagra' (Paraná), and 'tapa pomba' (Santa Catarina)[1].

The majority of Brazilian marine landings come from Rio de Janeiro, São Paulo, and Santa Catarina (Fig.5). The drastic decline in landings from Rio de Janeiro is mainly associated with the collapse of the sardine fishery. These states are located in the southeastern and southeast regions, where most of the landings occur (Fig.6). The decline in landings from the industrial sector is evident in both regions, although it is also noted in the artisanal sector. This reflects the typical development of the fishing sector, where the introduction of a new fishery (in this case, the industrial), leads to initial increases in landings and then to oscillations and collapse (Pauly, 1997). The northeastern and northern regions account for about 200,000 tonnes, with most landings coming from artisanal fisheries. In this case, the introduction of a limited industrial fishery appears to have caused little damage to the artisanal sector, as they have both remained stable for the past 20 years. When this study can be extended to include the period 1950-1979, a more detailed analysis may be done as most of the industrial fleet began to operate in the 1960s, although a new burst had been observed in the mid 1990s.

Future Work

This study will be extended to include, in the first phase, data related to the period 1970-1979. For those cases where landings data are available from sources other than the national database, they will be incorporated in the present database, together with the original information. Furthermore, this database will be gradually corrected for discards and other unreported catches, and incorporated into a global database following the methodology described in Watson *et al.* (2000) and developed by the *Sea Around Us* Project (SAUP; see www.seaaroundus.org).

In the second phase, the database will be expanded to the period 1950-1969. This phase will probably be more problematic as no comprehensive data was found for this period, except for publications by IBGE that present landings data combined in broad groupings such as 'fish', 'crustaceans', 'mammals', and do not distinguish between catches originating from marine and freshwaters.

[1] If any local expert identifies any problems in the match between common and scientific names or knows the scientific names of the species listed, please contact the author.

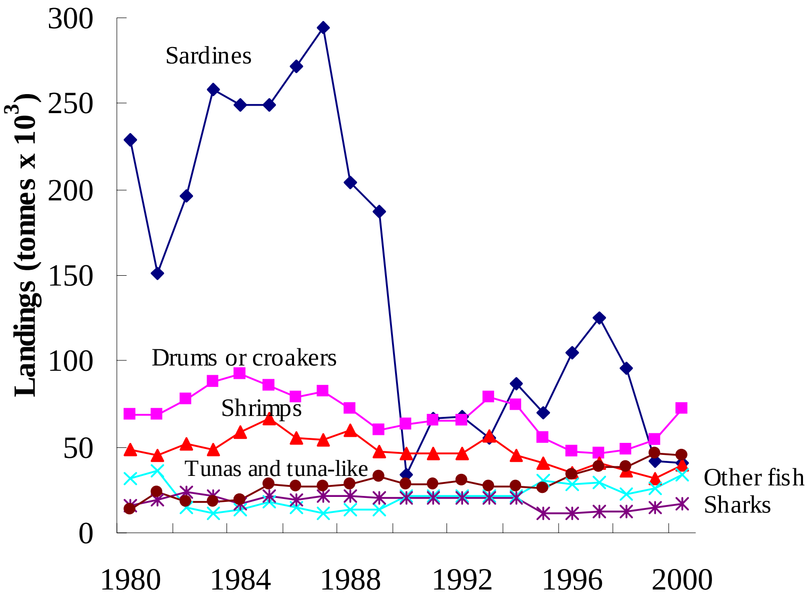

Figure 2: Landings of the main groups represented in Brazilian marine commercial fisheries (1980-2000).

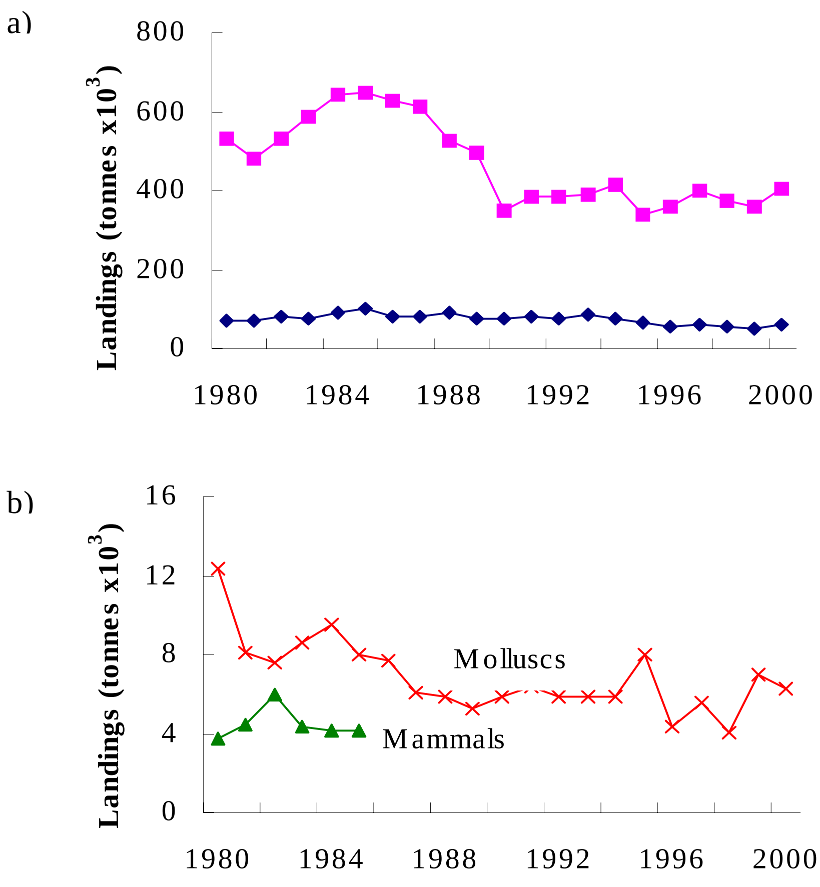

Figure 3: Groups represented in the landings from Brazilian marine commercial fisheries (1980-2000): a) Fish and crustaceans; b) Molluscs and marine mammals.

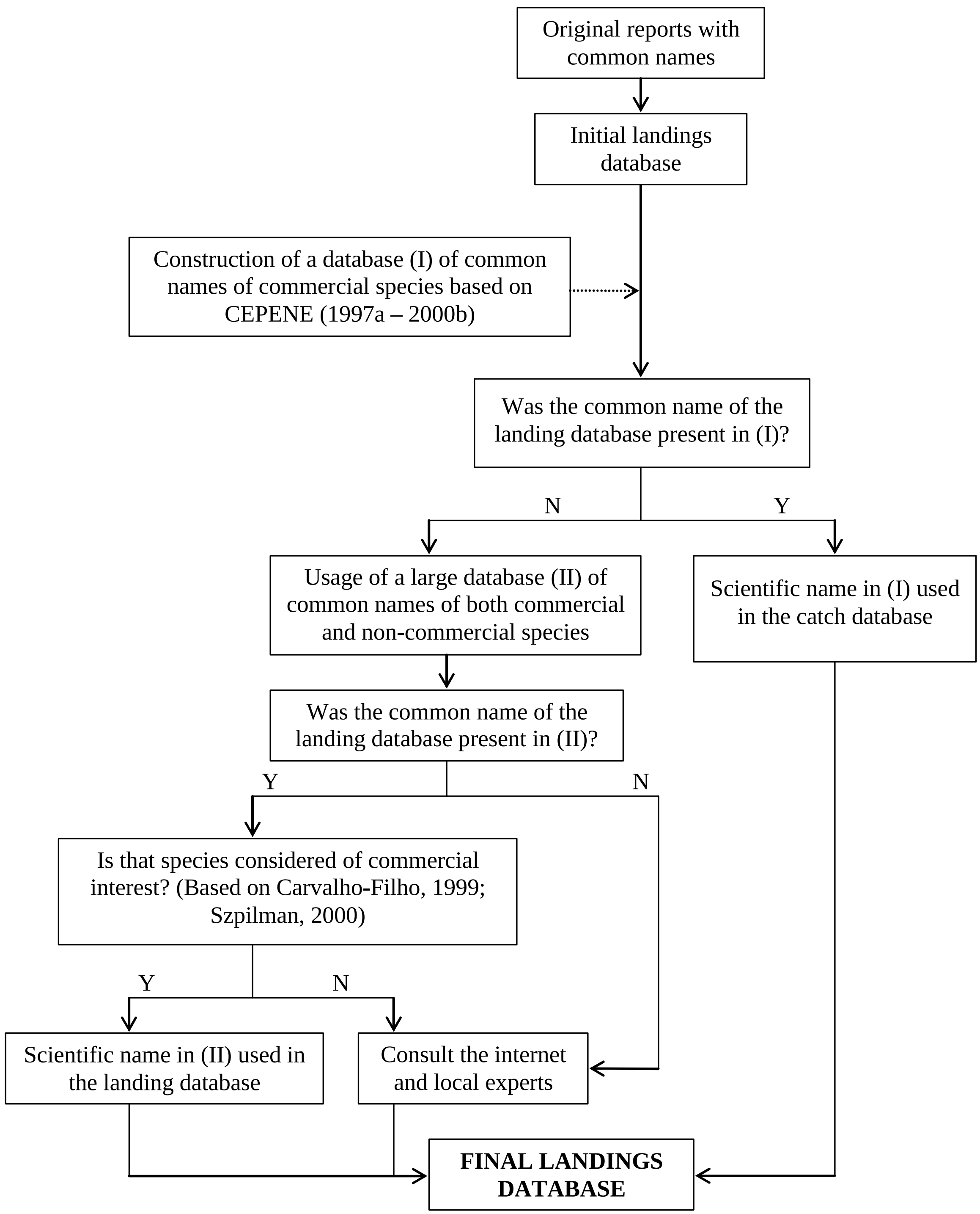

Figure 4: Decision process on the correspondence of common names and scientific names for commercial species to obtain the final landing database. The database of common names (II) is largely available in FishBase (www.fishbase.org).

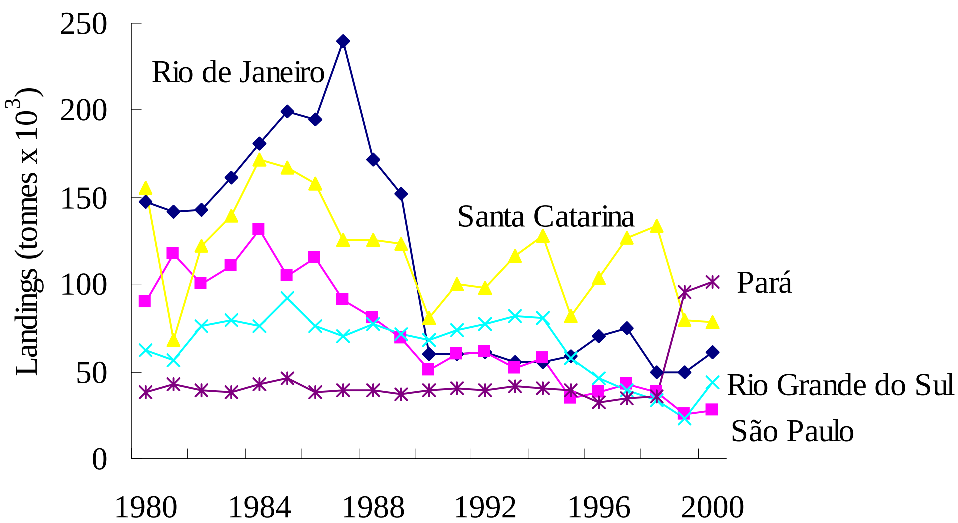

Figure 5: States that record the highest landings in Brazil (industrial and artisanal fisheries combined).

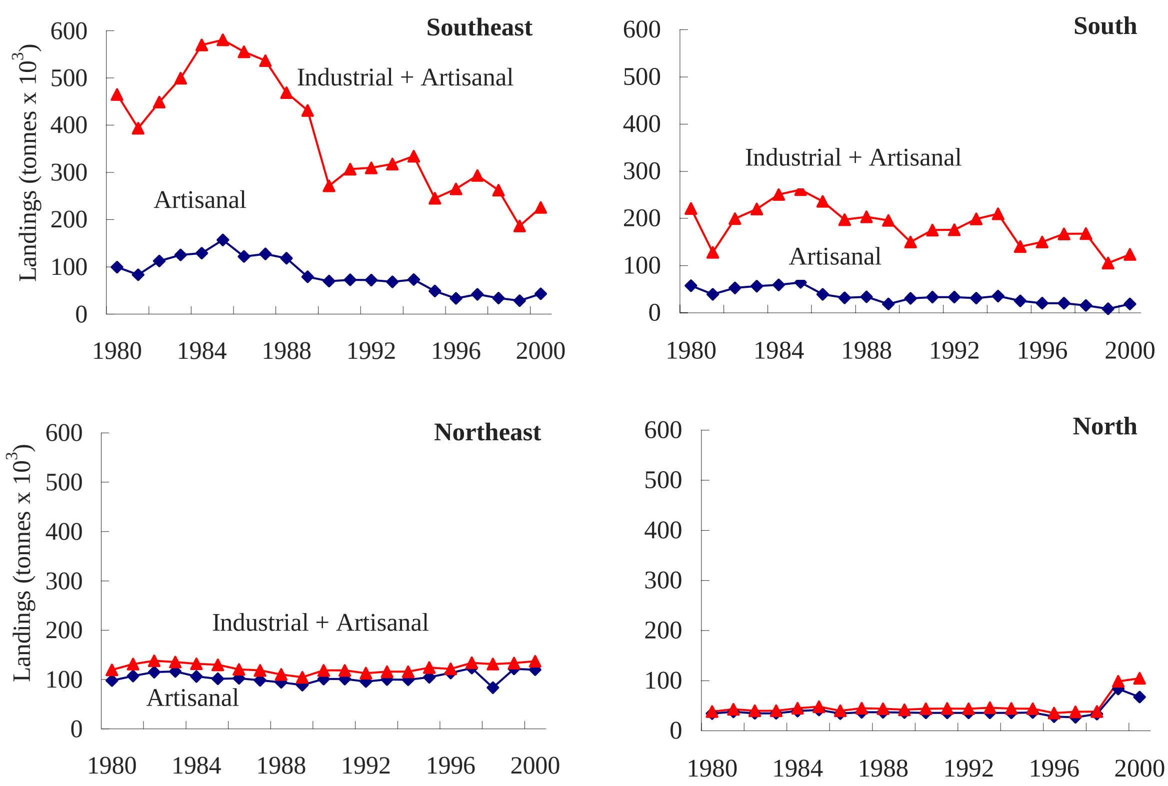

Figure 6: Landings for industrial and artisanal fisheries broken down by region for Brazilian marine ecosystems (1980-2000).

Conclusion

This database represents the landings data for marine commercial fisheries of Brazil recorded in national reports, but several flaws inherited from the original sources could not be overcome. For example, for the period between 1990 and 1994, the entries were calculated based on the mean/average landings for the period 1986-1989, and corrected only for those species that were dealt with in the context of a previous study (CEPENE, 1997a); Maranhão and Bahia states were not included in the ESTATPESCA program developed for the northeast region (CEPENE, 2000a), and data were repeated for some years. Finally, catch data for shrimps and sardines from São Paulo are probably underestimates (Gasalla and Tomas, 1997).

The objective was to assemble basic data needed for assessments, which have been scattered in documents that are not readily available. It also presented an opportunity to collaborate with fellow researchers to create a better national database from specific study groups.

All users should be aware that the state associated with each record does not imply that all the landings came exclusively from the marine environment corresponding to the political division of that state. There is high mobility for some boats with higher power engines and the user should be able to define the extension of these movements to attribute landings to the correct marine area. Finally, some uncertainty exists between the common and scientific names for some reported species and the database is biased towards nomenclature used in the northeastern region as most of the documents were available for analysis from this region.

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PART II: ECOSYSTEM MODELS

A Generic Marine Ecosystem Model for the Southeastern Caribbean in the Late 1990s: Application to Grenada and the Grenadines.

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ABSTRACT

A generic ecosystem model was constructed for the southeastern Caribbean region using the Ecopath with Ecosim software, covering the late 1990s. It integrates available ecological, biological and fisheries related information for the region. The model was adjusted to the Exclusive Economic Zone (EEZ) of Grenada and the Grenadines by inclusion of the respective habitat areas and fisheries catches in 1999. Model parameterization, preliminary results, knowledge gaps and future research are discussed.

INTRODUCTION

The collapse of many fisheries worldwide has prompted scientists to re-examine the methodologies used for assessing and managing fish stocks. Failure to reliably predict stock responses to increasing fishing pressure is often attributed to single-species approaches to assessment. These traditional approaches usually consider individual species in isolation from the surrounding environment, thereby neglecting the important inter-specific interactions (e.g. competition and predation) and environmental impacts on fisheries resources, as well as the impacts of fisheries on the ecosystem. Traditional single-species assessments, however, provide essential biological (e.g., growth) and fishery related (e.g., fishing mortality) information that can be used in models depicting the multi-species nature of the fisheries and resources. The importance of traditional assessments thus remains undisputed. However, a framework is required for integrating these estimates and examining their biological and ecological compatibility, and the overall fishing impacts on both target and non-target species. This has contributed to the development of ecosystem-based management, as called for in the United Nations Convention on the Law of the Sea (United Nations, 1983), the 1992 Convention on Biological Diversity (UNEP, 1992), the 1995 United Nations Fish Stock Agreement (United Nations, 1995), the FAO Code of Conduct for Responsible Fisheries (FAO, 1995) and more recently, the 2001 Reykjavik Conference on Responsible Fisheries in the Marine Ecosystem (Nuengsigkapian, 2002). The inshore reef and shelf resources of the southeastern Caribbean islands are overexploited (Mahon, 1993; Singh-Renton and Neilson, 1994). Rebuilding of these depleted resources can form the basis for an ecosystem-based fisheries management approach. These fisheries remain the main source of income for the majority of fishers without the financial resources to invest in semi-industrial longline vessels for exploiting the offshore pelagic fishery. These resources have also supported ‘buffer fisheries’ ensuring a continued livelihood for fishers during the pelagic ‘off-season’. Until recently, inshore fisheries have been the main fisheries in the Grenadines. While future efforts are directed at increasing exploitation of offshore, highly migratory, large pelagic resources, stock assessments by the International Commission for Conservation of Atlantic Tunas (ICCAT) indicate that many large tunas and billfishes are already over-exploited. Hence the prospects for development are limited. The status of smaller pelagics (e.g., mackerels) is unknown.

The main objective of the present study was to integrate available ecological, biological and fisheries related information for resources in the southeastern Caribbean in a generic, preliminary marine ecosystem model for the region, and present a case example for one country. This may allow estimation of the available resources and flows within the ecosystem, and hence contribute to a better understanding of ecosystem structure and function.

METHODS

The marine ecosystem model was constructed using Ecopath with Ecosim (Christensen *et al.*, 2000, Pauly *et al.*, 2000). The software allows for construction of mass-balance trophic models (Christensen *et al.*, 2000; www.ecopath.org). It was first developed by Polovina (1984) for estimating biomass of species groups on the French Frigate Shoals in the north-west Hawaiian Islands. Subsequently, various routines implementing theoretical approaches in ecology (e.g., Ulanowicz, 1986) were incorporated into Ecopath (Christensen *et al.*, 2000), enabling detailed analysis of flows between groups in the system. The software is comprised of three components: a static mass-balance snap-shot of the system (Ecopath); a time dynamic simulation module for policy exploration (Ecosim, Walters *et al.*, 1997); and a spatial and temporal dynamic module for exploring optimum placement and relative size of protected areas on the resources within the ecosystem (Ecospace, Walters *et al.*, 1999). In the present study, only Ecopath was used.

Habitat area

The Ecopath parameter called 'habitat area' refers to the fraction of the total area covered by a model in which a given functional group occurs (Christensen *et al.*, 2000). The area being modeled for this case study of Grenada and the Grenadines (Figure 1) comprises the EEZ of 25,957 km^2 (Global Maritime Boundaries Database: Veridian MRJ Technology Solution, 2000), containing reef areas of 209 km^2 (Oliver and Noordeloos, 2002; Bacon *et al.*, 1984) and non-reef shelf areas of 1,595 km^2 (Mahon, 1993). Thus, habitat area fractions of 0.931, 0.008 and 0.061 were estimated for pelagic, inshore reef and shelf species, respectively. The distribution of pelagic species, which also feed on reef species, was assumed to cover the reef and outer EEZ (0.939 of total habitat area). A habitat area of 0.069 was estimated for the snapper, grouper, shark, spiny lobster and queen conch groups (see below), which are distributed across both the shelf and reef areas. It was assumed that juveniles of predatory pelagic species and small coastal pelagics were confined to shelf areas. Turtles were assumed confined to reef areas. Cephalopods and phytoplankton are distributed throughout the EEZ and reef areas, microfauna and detritus throughout the shelf and reef areas and zooplankton are present in all three areas.

Functional groups

The model comprises 50 functional groups, plus detritus. Three are mammals, 33 are fish groups (including several groups split into adults and juveniles), eight are invertebrates, three are primary producers, plus zooplankton, seabirds and sea turtles. A complete list of the species assigned to each fuctional group and associated parameters can be obtained from the author.

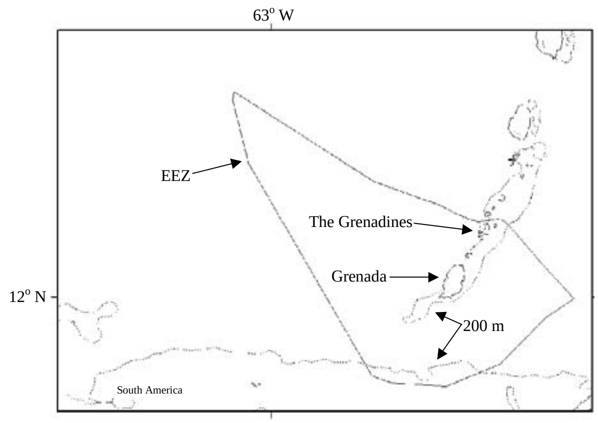

Figure 1. Map of Grenada and the Grenadines, showing the EEZ as well as the 200 depth contour.

Marine mammals

A list of marine mammals present in the Caribbean Province (Longhurst *et al.*, 1995) was assembled from the distributional information of Jefferson *et al.* (1993). This list comprises seven species of baleen whales, 12 species of toothed/beaked whales and 11 species of dolphins. Others (Reeves, 1988; Levenson and Leapley, 1978; Gordon *et al.*, 1998; Mattila *et al.*, 1994; Winn *et al.*, 1975) have listed additional marine mammal species in the southeastern Caribbean region. However, the species incorporated in this model are confined to those for which information is available.

Fish groups

Using a species list generated for the Caribbean from FishBase (Froese and Pauly, 2000; www.fishbase.org), individual species were assigned functional groups based on similarities in habitat, diet type and maximum size of fish species in the ecosystem. Because of data limitations, only 379 of the 1,072 species listed were included in the model. Exploited groups, identified based on catch statistics supplied by the Grenada Department of Fisheries, were explicitly represented to facilitate future examination of the impacts of fishing on the ecosystem. Since catches of reef and demersal shelf species of snappers (Lutjanidae) were all reported under the general heading 'snappers', and similarly for groupers (Serranidae) and sharks, it was not possible to represent these groups separately by habitat in the grouping. Further, since shark landings were not identified to the species level, thereby enabling assignment to the pelagic or demersal habitat, it was assumed that only pelagic sharks are landed as by-catch of the longline fishery.

To reduce instances of cannibalism, the adults and juveniles of top predators with ontogenetic shifts in diet and differences in growth and mortality were represented in separate groups, which also avoids the appearance of spurious cycles in Ecosim simulations (Christensen *et al*., 2000). Here, sharks, mackerels, snappers, groupers and jacks, were split into separate adult and juvenile components.

Functional groups were assigned names reflective of the most important commercial species they included. Non-exploited groups were assigned general names. This generated 33 fish groups, seven of which comprised the juveniles of predatory species, and 22 of which are exploited commercially.

Non-fish consumers and primary producers

Based on diet composition data in FishBase (Froese and Pauly, 2000; www.fishbase.org), for the respective fish groups, 11 non-fish groups, excluding detritus, were identified. The spiny lobster (*Panulirus argus*) and queen conch (*Strombus gigas*) were explicitly represented because of their commercial importance (Mahon, 1993). The other groups were organized according to Opitz (1996), and included cephalopods, benthic crustaceans, molluscs and worms, echinoderms, and zoobenthic sessile animals. Four species of marine turtles are exploited in the region (Rebel, 1974): loggerhead turtle (*Caretta caretta*); green turtle (*Chelonia mydas*); hawksbill turtle (*Eretmochelys imbricata*) and leatherback turtle (*Dermochelys coriacea*). These were all represented in one general group. All seabirds were also pooled into one group. Primary producers consisted of three groups: seagrasses and seaweeds, symbiotic algae, and phytoplankton.

Model parametrization

Two related models were consulted for model parameterization, the coral reef model of the US Virgin Islands constructed by Opitz (1996), and the pelagic ecosystem model for the central Pacific constructed by Kitchell *et al*. (1999). These models were used to assess the suitability of input parameters for similar functional groups in the present model. Input parameters were reviewed for ecological validity according to Christensen *et al*. (2000). These included a specified range for the production/consumption ratio (0.05 to 0.3) and estimates of total mortality which exceed natural mortality for exploited species. For cannibalistic species, the associated proportion of the diet should be less than 20%; for groups feeding at trophic levels higher than themselves the associated component of the diet should be less than 10%. Initial and balanced input values are listed in Table (1).

Biomass

Marine mammals

An estimate of biomass was derived for the entire Caribbean region using data in Trites *et al*. (1997), adjusted for the Caribbean Province (4.48×10^6 km^2) after Longhurst *et al*. (1995). Data were available for seven baleen, 12 toothed/beaked whales and 11 dolphin species occurring in the Province (Table 2).

Fish groups

Large tunas and other pelagics

Singh-Renton and Neilson (1994) presented estimates of maximum sustainable yield (MSY), computed by the International Commission for the Conservation of Atlantic Tunas (ICCAT), for several highly migratory pelagic species in the Atlantic Ocean (Table 3). Using the estimated MSY for yellowfin tuna (*Thunnus albacares*), albacore (*Thunnus alalunga*), bluefin tuna (*Thunnus thynnus thynnus*) and bigeye tuna (*Thunnus obesus*) for the respective distribution ranges, and assuming even distribution, the potential yield per unit area was estimated. Christensen (1996) estimated that approximately 25 per cent of fish production goes to catches or potential yield. Hence B * (P/B) * 0.25 = Potential Yield (where B is the biomass and P/B the production/biomass ratio). Using the estimate of P/B below (1.23 $year^{-1}$), and potential yield per unit area, total biomass of large tunas was estimated at 0.021 $t \cdot km^{-2}$. This is comparable to biomasses estimated for similar species in the central Pacific (Kitchell *et al.*, 1999).

Mackerels

In this model landings were treated synonymous with yield although it is understood that yield also includes catches which are not landed. Hence, biomass estimates based on landings are considered minimum estimates. George *et al.* (2001) estimated fishing mortality rate for *Acanthocybium solandri* at 3.98 year^{-1}, the difference between total mortality (4.612 year^{-1} from catch curve analysis) and natural mortality (0.63 year^{-1}, using Pauly, 1980). The estimated total mortality, however, seems quite high, implying a fishing mortality rate of more than six times natural mortality. Thus, a fishing mortality equivalent to twice the natural mortality rate (1.26 year^{-1}) was assumed representative for the group.

The combined catch of all mackerel species in Grenada and the Grenadines was 50.74 t in 1997 (Grenada Fisheries Department, unpublished data). Assuming that the catches were taken within the EEZ area (24,153 km^2), the estimated biomass is 0.00167 t·km^{-2}.

Small tunas, barracudas and other pelagics

Biomass of small tunas, barracudas and other pelagics was estimated using the method described for large tunas, the estimate of P/B derived below and a catch estimated at 0.0013 t·km^{-2} for skipjack tunas (Table 3), using data from Singh-Renton and Neilson (1994). The resulting biomass estimate is 0.006 t·km^{-2}. Since data for barracudas and other pelagics are not considered, this biomass should be considered a very low estimate.

<u>Coryphaena</u> spp.

Parker *et al.* (2001) estimated fishing mortality (5.27 year^{-1}) for *Coryphaena hippurus* in the eastern Caribbean. This was taken as the difference between the estimated total mortality (5.98 year^{-1}) from catch curve analysis and natural mortality (0.71 year^{-1}) estimated by the authors using Pauly (1980). The overall catch of *Coryphaena* spp. within the EEZ (24,153 km^2) of Grenada and the Grenadines is 132 t. The estimated biomass is 0.001 t·km^{-2}.

Four-winged and other flyingfishes

Oxenford *et al.* (1995) reported on visual surveys to estimate abundance of the four-winged flyingfish (*Hirundichthys affinis)* and other flyingfishes (*Parexocoetus brachypterus* and *Cypselurus cyanopterus*) in the southeastern Caribbean region. The total number of fish of each species sighted was estimated as the product of the mean number of each species sighted per 0.5 nautical mile transect, and the total number of such transects surveyed (Table 4). Using length-weight conversion parameters and maximum length from Samlalsingh and Pandohee (1992), and FishBase (Froese and Pauly, 2000), the corresponding weight of each species sighted over the entire survey area was estimated. Zuyev and Nikol'skiy (1980) estimated that about 20% of flyingfish take to the air within 25m of an approaching vessel. However, Oxenford *et al.* (1995) suggested a lower percentage for *H. affinis* which is distributed deeper than the other species. Therefore, it was assumed that 10% of the number of *H. affinis* took to flight while 20% each of the remaining two species did the same. This assumption was used to adjust the estimated number taking to flight to the total number existing in the survey area. The area surveyed was estimated as the product of transect length (0.5 nm), number of transects surveyed and a total horizontal distance of 10 m surveyed by observers on either side of the research vessel (R. Mahon, pers. comm.). Biomass estimates of 0.0011 t·km^{-2} and 0.0002 t·km^{-2} were computed for the four-winged flyingfish and other flyingfishes, respectively. These estimates, however, seem low, especially since these species are the major prey for *Coryphaena* spp., and are also eaten by tunas.

An alternative estimate was derived using B = Y/F with estimates of annual catch (Y = 433 t) and fishing mortality (F = 3.3 year^{-1}) after Samlalsingh and Pandohee (1992) for *H. affinis* off Tobago. A fishing area of 250 km^2 was assumed based on the fishing area map provided by the authors. The estimated biomass is 0.524 t·km^{-2}. This is comparable to the corresponding group in the Central Pacific (Kitchell *et al.*, 1999). Using a raising factor equivalent to the ratio of biomass estimated for the four-winged flyingfish from Oxenford *et al.* (1995) and Samlalsingh and Pandohee (1992), the biomass estimate for 'other flyingfish' after Oxenford *et al.* (1995) was adjusted to 0.116 t·km^{-2}.

Demersal and reef sharks

Based on information in Saetersdal *et al.* (1999) and a personal communication from Mr Oddgeim Alvheim, who provided data from the NanSis Database (documenting survey results of R/V *Dr Fridtjof Nansen* off the South American shelf in 1988), biomass of demersal and reef sharks was estimated at 0.385 t·km^{-2} for the areas off the north coast of Trinidad. A similar biomass was assumed for the group in Grenada. However, because of the greater shelf area off Trinidad and the higher nutrient inflow from discharges of the Orinocco and Amazon rivers, it can be expected that biomass of demersal species is greater off Trinidad than around the oceanic islands further north.

Reef fishes (reef jacks, groupers, etc.)
Corless *et al.* (1997) estimated densities for several reef species in St Lucia. From these, the corresponding length-weight relationship from various sources in FishBase (Froese and Pauly, 2000), and the mean common length from Humann (1991), estimates of biomass were derived for selected species (Table 5). The estimate for *Caranx ruber* (4.45 t·km^{-2}) was taken as representative for Carangidae, similarly for the other groups listed. However, since other species of the group are not included, this estimate should be considered a minimum. Biomass of triggerfish and similar species was estimated using data for *Mulloidichthys martinicus* (11.9 t·km^{-2}; Table 5) and an estimate of 0.0116 t·km^{-2} for grunts off Trinidad's north coast (NanSis Database, Mr Oddgeim Alvheim, pers. comm.). The combined estimate (11.91 t·km^{-2}) was used as representative of this group.

Other carnivorous demersals
Manickchand-Heileman (1994) examined the distribution and abundance of flatfish on the South American shelf from Colombia to Suriname. Data on density and the associated mean individual weight of demersal species of the families Bothidae, Cynoglossidae, Pleuronectidae and Soleidae were presented for four separate surveys of the same area, with mean biomass of 0.141 t·km^{-2}. This was a minimum estimate, as the group comprises several other species besides those of the families listed.

Croakers, snooks and other carnivorous/omnivorous demersals
A biomass estimate of 2.032 t·km^{-2} for croakers off the north coast of Trinidad, was taken from the NanSis Database (Mr Oddgeim Alvheim, pers. com.) and used as the group representative. It was assumed that the biomass of other omnivorous demersals was the same as for other carnivorous demersals.

Non-Fish Groups
Cephalopods
A mean biomass estimate for squids (0.023 t·km^{-2}) off the north coast of Trinidad, obtained from the NanSis Database, was used as the group representative.

Queen conch
Several estimates of abundance and biomass were available for queen conch (CFMC and CFRAMP, 1999). The biomass estimate of 2.739 t·km^{-2} (Appeldoorn, 1995), for the artisanal zone of the Pedro bank (Jamaica) was used in the model. This estimate was selected because of the similarity of Jamaican to Grenada fisheries, and because the estimate was derived for 1997, closest to the time period (1999) covered in this model.

Echinoderms
A biomass estimate of 3.24 t·km^{-2}, derived under the Caribbean Coastal Marine Productivity Network, for *Diadema* spp. in Barbados was used as the group representative (CARICOMP, 2001).

Seagrasses, seaweeds and other autotrophs
The mean biomass of 3167.15 t·km^{-2} estimated for turtle grass and other autotrophs in Barbados under the CARICOMP programme was used (CARICOMP, 2001).

Phytoplankton
Primary productivity (PP) estimates used are based on SeaWiFS satellite data analyzed by the Institute for Environment and Sustainability of the EC Joint Research Centre (www.me.sai.jrc.it). These relied on chlorophyll, photosynthetically active radiation, and sea surface temperature maps to estimate PP from the model of Behrenfeld and Falkowski (1997). The resulting PP maps are available on a monthly and quarterly basis, but for the present study a one-year production average representing 1999 was used. Using the estimate of primary production (272.58 gC·m^{-2}·year^{-1}) after Behrenfeld and Falkowski (1997), a conversion factor of 9 gww/gC, and a production/biomass ratio of 70 year^{-1} (Opitz, 1996), phytoplankton biomass was estimated at 35.05 t·km^{-2}.

Detritus
Detritus biomass was estimated based on an empirical model in Pauly *et al.* (1993), which

uses primary production (272.58 gC·m^{-2}) and euphotic depth (85 m; from Rajendra *et al.*, 1991) to predict detritus concentration of 37.89 gC·m^{-2}. However, estimates ranged between 23.93 and 51.03 gC·m^{-2} when the range of 50 to 120 m for the euphotic depth (Rajendra *et al.*, 1991) is used in the calculation.

Production/biomass ratio (P/B)

Marine mammals

A P/B ratio of 0.02 per year, half the maximum rate of population increase for cetaceans (Trites and Heise, 1996), was assumed for baleen and toothed whales. A slightly higher estimate (0.03 year^{-1}) was assumed for dolphins.

Fish Groups: Exploited

For exploited fish groups, the production/biomass ratio is considered equivalent to the instantaneous rate of total mortality (Allen, 1971).

Billfishes

Total mortality (1.13 year^{-1}) of billfishes was estimated from mean lengths using Beverton and Holt (1957), using, for billfishes in Grenada, length data provided by Eric Prince of the Billfish Foundation. Parameters for converting pre-pectoral fin length (PFL) to lower jaw forked length (LJFL) were derived (Table 6) and used to estimate missing values of lower jaw forked length. Table (7) presents the input parameters and estimated total mortality for the respective species. The overall total mortality for the group was taken as the mean of the individual species estimates.

Pelagic sharks

A consumption/biomass ratio of 0.069 for adult sharks in the central Pacific (Kitchell *et al.*, 1999) was used to estimate production/biomass ratio via an assumed value of P/Q. However, the resulting P/B ratio (0.16 year^{-1}) was lower than the estimated natural mortality (0.22 year^{-1}) for this exploited group. Therefore a consumption/biomass ratio of 0.11 was assumed, leading to an estimated P/B ratio of 0.255 year^{-1}. For the corresponding juvenile group, production/biomass ratio was computed at 0.58 year^{-1}, assuming a consumption/biomass ratio of 0.125 (similar to juvenile sharks; see Kitchell *et al.*, 1999), and a consumption/biomass ratio twice that of the adults.

Large tunas and other pelagics

Total mortality (3.06 year^{-1}) was estimated for yellowfin tuna (*Thunnus albacares*) using Beverton and Holt (1957), with L_∞ = 169 cm and K = 0.627 year^{-1} (Hennemuth, 1961), and length data provided by the CARICOM Fisheries Large Pelagic and Reef Fish Resource Assessment Unit. A mean and minimum length in the catch of 52.8 cm and 29.0 cm for the fishery in Grenada were used, respectively. The estimate of total mortality obtained is high. Natural mortality was estimated at 0.41 year^{-1} using Pauly (1980). This implies a fishing mortality in excess of six times natural mortality. This high estimate is possibly a result of hook selection resulting in a slope of the descending limb of the catch curve suggesting a higher rate of mortality than exists in the actual population. Therfore, it was assumed that fishing mortality was twice the computed natural mortality; the resulting total mortality (P/B) was assumed to be 1.23 year^{-1}.

Mackerels

As mentioned above, the estimated total mortality after George *et al* (2001) is considered too high for this group. Thus, total mortality was estimated as the sum of assumed fishing mortality (1.26 year^{-1}) and natural mortality (George *et al.*, 2001), leading to 1.89 year^{-1}, which satisfies the consumption/biomass ratio constraint. For the juvenile group, the production/biomass ratio (6.224 year^{-1}) was estimated assuming a production/consumption ratio of 0.2 and a consumption/biomass ratio twice that of the adults.

Small tunas, barracudas and other pelagics

The mean estimate of total mortality (0.886 year^{-1}) for the blackfin tuna, *Thunnus atlanticus* (0.31 year^{-1}) and skipjack tuna, *Katsuwonus pelamis* (1.48 year^{-1}) computed using Beverton and Holt (1957) was assumed representative of small tunas, barracudas and other pelagics. Mean length in the catch of 47.8 cm and 49.5 cm, and minimum length in the catch of 25 cm and 34 cm were used for blackfin and skipjack tuna, respectively, based on length data for the fishery in Grenada, provided by the CARICOM Fisheries Large Pelagic and Reef Fish Resource Assessment Unit. Growth parameters were computed from Garcia-Coll *et al.* (1984) and Claro and Garcia-Arteaga (1994) for blackfin tuna, and Claro and Garcia-Arteaga (1994) and Erzini (1991) for skipjack tuna.

Coryphaena spp.
The estimated total mortality for dolphinfish, *Coryphaena hippurus* (5.98 year^{-1}) in the southeastern Caribbean was used (Parker *et al.*, 2001). This estimate is very similar for the species in the central Pacific (5.0 year^{-1}; Kitchell *et al.*, 1999). However, a review of input parameters for *Coryphaena* spp. prior to model balancing indicated violation of the gross-food conversion efficiency constraint (0.05-0.3) with existing estimates of production/biomass and the below estimated consumption/biomass. Two options for adjustment were possible: accept the estimated total mortality from Parker *et al.* (2001) and adjust the consumption/biomass ratio to achieve a gross food conversion efficiency of 0.25 (Kitchell *et al.*, 1999); or accept the consumption/biomass ratio from Palomares and Pauly (1998) and adjust the production/biomass ratio with the same gross food conversion efficiency constraint. Since the estimate of total mortality (after Parker *et al.*, 2001) was tentative (S. Singh-Renton, pers. comm.; K. Cochrane, pers. comm.), this parameter was selected for adjustment, i.e., total mortality (production/biomass) was reduced from 5.98 year^{-1} to 2.12 year^{-1}.

Pelagic jacks, needlefish
Assuming a production/consumption ratio of 0.1 and 0.2 for the adults and juveniles, respectively, and using the computed consumption/biomass ratio below, production/biomass ratios of reef jacks and similar species were estimated at 0.944 year^{-1} and 3.776 year^{-1} for adults and juveniles, respectively.

Four-winged flyingfish
The estimated total mortality for Hirundicthys affinis (5.8 year^{-1}) off Tobago was used (Samlalsingh and Pandohee, 1992).

Reef jacks, tilefish, barracudas etc.
Initially the production/biomass ratio of reef jacks, tilefish, barracudas etc., was estimated as natural mortality (0.75 year^{-1}) using Pauly (1980), and the estimate for the corresponding juvenile group (2.396 year^{-1}) estimated assuming production/consumption ratio of 0.2.

Groupers
Straker *et al.* (2001) estimated total mortality (2.78 year^{-1}) for red hind, *Epinephelus guttatus,* in the eastern Caribbean. The species was considered representative of all adult groupers. Total mortality of the corresponding juvenile group (2.94 year^{-1}) was estimated assuming a production/consumption ratio of 0.2. However, a review of input parameters for adult groupers prior to model balancing indicated violation of the gross-food conversion efficiency constraint (0.05-0.3) with existing estimates of production/biomass and the below estimated consumption/biomass. Since the estimate of production/biomass after Straker *et al.* (2001) was tentative (based on the nature of estimates for other species derived at the same workshop), the production/biomass ratio was reduced from 2.78 to 0.84 year^{-1}, giving a production/consumption ratio of 0.12, as computed for similar groups by Opitz (1996).

Snappers
Total mortality of snappers was estimated as the mean estimate (1.068 year^{-1}) for *Etelis oculatus* in St Lucia (1.873 year^{-1}; Murray and Moore, 1992), *Lutjanus synagris* in Trinidad (0.76 year^{-1}; Dass, 1983) and *Lutjanus purpureus* in Tobago (0.57 year^{-1}; Manickchand-Heileman and Philip, 1996). Total mortality of the corresponding juvenile group (2.180 year^{-1}) was estimated assuming a production/consumption ratio of 0.2.

Squirrelfish and other small reef carnivores
Initially, the production/biomass ratio of other small reef carnivores was left for estimation by Ecopath, with an assumed ecotrophic efficiency of 0.95. However, following initial balancing of the model, the estimated production/consumption ratio (0.007) was exceedingly low, as was the production/biomass ratio (0.114 year^{-1}) compared to the estimate of natural mortality (1.73 year^{-1}; after Pauly 1980) for this exploited group. As a result, the same production/consumption ratio as 'other carnivorous reef species' (0.125 year-1) was assumed and the resulting production/biomass estimated at 2.013 year^{-1}. Ecotrophic efficiency was therefore left for estimation by Ecopath.

Triggerfish, grunts, porgies, angel fish, butterflyfish and other omnivorous reef species
Initially the production/biomass ratio of other omnivorous reef species was estimated as natural mortality (1.06 year^{-1}) using Pauly (1980). The group however, is exploited, and the P/B ratio was adjusted during balancing (Table 1).

Parrotfish, surgeonfish, triggerfish etc.
Initially the production/biomass ratio of parrotfish etc. was left for estimation by Ecopath, with an assumed ecotrophic efficiency of 0.95. However, the resulting production/biomass ratio of 0.008 year^{-1} was much lower than the natural mortality (1.05 year^{-1}) estimated after Pauly (1980) for this exploited group. As a result a P/Q of 0.23 (Van Rooij *et al.*, 1998) was assumed and P/B estimated at 5.83 year^{-1}.

Croakers, snooks and other carnivorous/omnivorous demersals
Estimates of total mortality were not available for this group. Assuming the same estimate for the production/consumption ratio (0.12) as for similar species in other models (Arreguín-Sanchez *et al.*, 1993 a, 1993 b; Mendoza, 1993; Vega-Cendejas *et al.*, 1993; Manickchand-Heileman *et al.*, 1998 a, 1998 b), the production/biomass ratio was estimated at 1.03 year^{-1}, using the consumption/biomass ratio estimated below. This estimate compares well with the natural mortality (0.98 year^{-1}) estimated using Pauly (1980).

Small coastal pelagics
Total mortality of small coastal pelagics (3.471 year^{-1}) was estimated using the consumption/biomass ratio estimated below and an assumed production/consumption ratio of 0.147, based on the mean for similar species in other models (Arreguín-Sanchez *et al.*, 1993 a, 1993 b; Mendoza, 1993; Vega-Cendejas *et al.*, 1993; Opitz, 1996; Manickchand-Heileman *et al.*, 1998 a, 1998 b).

Total mortality estimates of other exploited groups were left for estimation by Ecopath, assuming ecotrophic efficiency of 0.95.

Fish Groups: Unexploited
The production/biomass ratio of unexploited fish groups was estimated as the natural mortality rate using Pauly (1980), growth parameters from FishBase (Froese and Pauly, 2000), and an estimated mean habitat temperature of 28°C (Opitz, 1996).

Other flyingfishes
A review of input parameters for other flyingfishes prior to model balancing indicated violation of the gross-food conversion efficiency constraint (0.05-0.3) with existing estimates of production/biomass and the below estimated consumption/biomass computed using empirical equations. There was little basis for selecting one parameter over the other for modification. The production/biomass ratio was reduced from 4.00 to 3.80 year^{-1} (P/Q = 0.29).

Demersal and reef sharks
Assuming a consumption/biomass ratio of 0.069 and 0.125 for adult and juvenile sharks, respectively, and using the consumption/biomass estimated below, production/biomass ratio was estimated at 0.320 year^{-1} and 1.188 year^{-1} for the respective groups.

Small herbivorous/detritivorous reef species
The production/biomass ratio of small herbivorous/detritivorous reef species was initially estimated at 2.21 year^{-1} based on estimates for similar groups in other models (Aliño *et al.*, 1993; Vega-Cendejas *et al.*, 1993; Opitz, 1996; Venier and Pauly, 1997; Manickchand-Heileman *et al.*, 1998 a, 1998 b). However, a review of input parameters resulted in modification of the consumption/biomass ratio (to 33.39 year^{-1}) for this group, and an assumed production/consumption ratio of 0.15. Therefore, the production/biomass ratio (5 year^{-1}) was re-estimated as the product of consumption/biomass and production /consumption.

Mullets and other herbivorous/detritivorous coastal pelagics and demersals
A review of input parameters for mullets and other herbivorous/detritivorous coastal pelagics prior to model balancing indicated violation of the gross-food conversion efficiency constraint (0.05-0.3), while the estimated production/consumption ratio was very low (0.057), as perhaps befits detritivorous and herbivorous fish. To overcome the constraint, a production/consumption ratio of 0.15 from other models was assumed and the production/biomass ratio re-estimated at 3.033 year^{-1}.

Non-Fish Groups
Production/biomass ratio for all non-fish groups except lobster, queen conch and seagrasses were taken from Opitz (1996). However, since turtles are exploited in the southeastern Caribbean, the estimate for this group should be considered a minimum, as Opitz (1996) did not consider turtles to be exploited.

Spiny lobster

The estimate of total mortality (1.475 $year^{-1}$) for spiny lobster was based on the average for Pedro Bank, Jamaica (2.5 $year^{-1}$; Haughton and King, 1992) and the reefs of the US Virgin Islands (0.45 $year^{-1}$; Opitz, 1996). However, lobster were not fished in the Opitz model, while exploitation on the Pedro Bank is believed to be higher than in the southeastern Caribbean. Nevertheless, the computed P/B falls within the range specified (0.5-1.5 $year^{-1}$) in Munro (1983) for the species in Jamaica during 1979.

Queen conch

The mean of annual estimates of total mortality for conch between 1994 and 1998 (0.53 $year^{-1}$) in Jamaica (CFMC and CFRAMP, 1999) was taken as representative of P/B for the species in the southeastern Caribbean region.

Seagrasses, seaweeds and other autotrophs

The mean biomass turnover of turtle grass was estimated at 3.28% per day for Barbados and 3.71% per day for Tobago (CARICOMP, 2001). Using the mean turnover rate per day and the biomass estimated previously, production/biomass ratio was calculated as 12.76 $year^{-1}$. This estimate is within the range provided by seagrasses (8.43 $year^{-1}$) and seaweeds (15.34 $year^{-1}$) by Aliño *et al.* (1993), and close to the value for autotrophs (13.25 $year^{-1}$) in Opitz (1996).

Consumption/biomass ratio (Q/B)

Marine Mammals

Consumption was computed using Trites *et al.* (1997), based on daily ration size for individual species after Innes *et al.* (1987), and initial consumption/biomass ratios were computed (Table 8). A comparison of estimates for similar groups in Trites and Heise (1996) indicated tremendous under-estimation of this parameter for baleen whales and over estimation for toothed whales and dolphins. While consumption at higher latitudes is greater for these groups, and in particular large whales which migrate to breeding and calving grounds in the Caribbean, it is here difficult to resolve this problem. As a result, consumption/biomass ratio estimates from Trites and Heise (1996) were used (Table 1).

Fish Groups

The consumption/biomass ratio was estimated using one of two empirical equations depending on the availability of input parameters. In the absence of information on caudal fin aspect ratio, Pauly *et al.* (1990) was used to estimate Q/B; otherwise the model of Palomares and Pauly (1989) was used. A mean habitat temperature of 28°C after Opitz (1996) was used, along with estimates of asymptotic weight and aspect ratios taken from FishBase (Froese and Pauly, 2000). The consumption rate of all juvenile fish groups was assumed to be twice the estimate derived for the corresponding adult group.

For the following groups, the estimated consumption/biomass ratio using the equations after Palomares and Pauly (1989) and Pauly *et al.* (1990) were not comparable to estimates for similar species in other models, and were also considered inappropriate when the activity levels of the respective species were considered:

Billfishes

The initial estimated consumption/biomass ratio of billfishes (2.44 $year^{-1}$) was considered low for this group. The mean estimate for similar species in the central Pacific (Kitchell *et al.*, 1999) was 4.67 $year^{-1}$. However, the Pacific species are not as heavily exploited as in the Atlantic. As a result, a value of 6 $year^{-1}$ was assumed here (Table 1).

Large tunas and other pelagics

The initial estimate of consumption/biomass ratio of large tunas and other pelagics (5.17 $year^{-1}$) was considered too low to support the high activity levels of these fishes. As a result, the consumption/biomass ratio estimate for the same species groups in the central Pacific (15.33 $year^{-1}$; Kitchell *et al.*, 1999) was used.

Small tunas, barracudas and other pelagics

The initial estimate of consumption/biomass ratio for small tunas and related species (4.37 $year^{-1}$) was considered low when compared to estimates for skipjack tuna in the central Pacific (20 $year^{-1}$; Kitchell *et al.*, 1999) and for little tunny (*Euthynnus alletteratus;* 13.4 $year^{-1}$; García and Duarte, 2002). The average consumption/biomass ratio estimate from these two sources (16.7 $year^{-1}$) was used here.

Coryphaena spp.

Initially, a consumption/biomass ratio of 3.05 $year^{-1}$ was estimated for *Coryphaena* spp. using the growth parameters in Oxenford (1985), close to the value of 3.9 $year^{-1}$ estimated by García and Duarte (2002). These estimates differ markedly from the estimates of 20 $year^{-1}$ of Kitchell *et al.* (1999) and even of 8.47 $year^{-1}$ by Palomares and Pauly (1998). The latter estimate was used here since the lower estimates do not adequately explain the fast growth of this species, while the estimate by Kitchell *et al.* (1999) would imply a metabolic rate greater than that of tunas.

Non-Fish Groups
Except for the queen conch, all estimates of consumption/biomass ratio were taken from Opitz (1996). The consumption/biomass ratio of queen conch was left for estimation by Ecopath.

Ecotrophic efficiency
Ecotrophic efficiency is an emergent property of the ecosystem; it cannot be estimated from field studies, and is usually estimated by Ecopath during balancing. For many groups, however, one of the three parameters (B, P/B or Q/B) was not available. As a result, the missing parameter was left for estimation by Ecopath, and assumptions were made on the most likely input estimates of ecotrophic efficiency for the respective groups. In most instances an ecotrophic efficiency of 0.95 was assumed (Christensen *et al.*, 2000), except for seabirds for which an ecotrophic efficiency of 0.2 was assumed. Since ICCAT stock assessments indicate over-exploitation of billfishes, an ecotrophic efficiency of 1.0 was assumed for this group. Generally, sharks are at risk of over-exploitation because of their slow growth rates and late maturity. Pelagic sharks have been recorded as by-catch of longline fleets operating in the Atlantic, prompting international concerns (IUCN, ICCAT). As a result an ecotrophic efficiency of 1.0 was assumed for both adult and juvenile pelagic sharks.

Diet composition
Initial inputs for the diet matrix for this model can be obtained form the author. There was extensive modification to the components and proportions of the diet during balancing, leading to the final diet composition as illustrated in Table (9).

Marine Mammals
The diet composition of marine mammals was taken from Pauly *et al.* (1998), and was adjusted to the present group configuration. Since the marine mammals tend to be migratory and spend only a portion of the year in Caribbean waters, it was assumed that baleen and toothed whales derive only 10% of their diet each year from the study region, the other 90% of the diet was specified as import. The actual species in the diet were extensively adjusted during balancing.

Fish Groups
The main source for diet data of fishes was FishBase (Froese and Pauly, 2000). Some information was available for 87% of the species in the model. Diet compositions were available for 280 species and information on food items for another 46 species. In the latter case, all listed food items were assumed to contribute equally to the diet of the predator.

The invertebrate components of the diet were available in considerable detail, but the fish components were highly aggregated (e.g., nekton, finfish, or unidentified fish). This contributed to high uncertainty in diet composition. When diet was specified as an aggregate category without specific species or family names, diet was apportioned equally to all other functional groups in the system, with reference to the habitat and relative size of the predator. For reef species, Munro (1983) was consulted for identification of associated predator and prey species.

Prey items and contributions to diet were assumed for juvenile pelagic sharks, juvenile reef sharks and juvenile groupers. Diet composition of juvenile mackerels was from Finucane *et al.* (1990) for corresponding species in the Gulf of Mexico and South Atlantic. Diets of juvenile *Caranx hippos* and *Caranx latus* were considered representative of juvenile pelagic jacks and juvenile reef jacks, respectively, while juvenile *Lutjanus apodus*, *L. griseus* and *L. jocu* were considered representative of the juvenile snapper group (Austin and Austin, 1971). Diet composition for billfishes, large tunas and other bathypelagics were taken from Júnior (2000) for the respective species off Brazil, for *Coryphaena* spp. information was from Oxenford and Hunte (1998), while diet composition of the four-winged flyingfish was estimated from food items given in Gillet and Lanelli (1991) for the species in the Pacific.

Non-Fish Groups
The diet matrix from Opitz (1996) was used for the following groups: zooplankton, microfauna, zooobenthic sessile animals, echinoderms, molluscs and worms, benthic crustaceans, spiny lobster, cephalopods, turtles and seabirds. Diet composition of

queen conch was based on Mahon (1987) and Tewfik (1997). Both authors indicated the predominance of benthic and epiphytic macroalgae, occassional ingestion of seagrasses, with juveniles relying more on detritus and as a consequence ingesting small benthic animals as well. Furthermore, queen conch and the spiny lobster were not listed explicitly in the diets of many predators (except for consumption of spiny lobsters by turtles and other crustaceans in Opitz, 1996). A list of predators was derived from Idyll (1971) and Tewfik (1997) for spiny lobster and queen conch, respectively. The proportion in the diets of these predators attributed to crustaceans, molluscs and worms was thought to implicitly include spiny lobsters and queen conch. It was assumed that spiny lobsters and queen conch accounted for 50% of the proportion of diet attributed to the respective broader group.

Rebel (1974) gave details on the food of marine turtles. The hawksbill turtle diet comprises algae, barnacles, other small sessile animals, fish and sea urchins. Green turtles feed on marine grasses, but also feed on algae, yet are not entirely restricted to a vegetarian diet, with small mollusks and crustacea also featuring in their food. Loggerhead turtles sometimes eat marine grasses, but not to the extent of the other two turtle species. Adults eat mainly conchs, shellfish and barnacles but also feed on fish, sponges, jellyfish, crabs and sea urchins. Leatherbacks feed mainly on jellyfish, but the diet is also known to include sea urchins, squids, crustaceans, tunicates, fish, blue-green algae, and floating seaweed (US Fish and Wildlife Service, 1991). Opitz (1996) did not include small fish, queen conch and cephalopods in the diets of turtles. Here, it was assumed that small fish contributed a very small portion (0.0004) to the diet, while queen conch and cephalopods each contributed 0.001 to total diet, and the overall diet was normalized to one.

Cannibalism and feeding at higher trophic levels

Given the uncertainties in diet composition, an automated routine was used to check the proportion of the diet of top predators and reduce cannibalism to 20% of used production for groups with exceedingly high cannibalistic pressure. Though it is possible for a species to feed on organisms that occur at a higher trophic level than itself, usually such organisms do not comprise a large portion of the diet (Daniel Pauly, pers. comm.) An automated routine identified such inconsistencies and reduced this proportion to 10% of the diet, while redistributing the remaining proportion equally among other organisms in the diet.

Fisheries catches

Time series catch data for the period 1942 - 2000 were reconstructed from historical and administrative reports, published papers and information from the Fisheries Department's Fisheries Statistical Database (Mohammed and Rennie, this volume), and are summarized in Table (10).

Uncertainty in input parameters

The 'pedigree' in Ecopath allows consideration of uncertainty in input parameters (Christensen *et al.*, 2000). Specification is based on the data origin and associated default confidence intervals. Pedigree index values range from zero to one, with uncertainty expressed as confidence intervals expressed as percent of central values. An overall index of model quality is computed, with the highest quality being for a model constructed from precise parameter estimates for the system being modeled. Consideration of uncertainty in input parameters in the automated mass balance routine recently incorporated in EwE (Kavanagh *et al.*, 2004) is facilitated through use of the pedigree to specify the sampling/resampling ranges for biomass and diet composition. The lowest confidence interval (Table 11) was used in assigning pedigrees for input parameters estimated from data sources of varying levels of uncertainty.

Model balancing

The model was balanced manually according to Christensen *et al.* (2000). An automated mass-balance routine of Kavanagh *et al.* (2004) was used when ecotrophic efficiencies in excess of one could no longer be reduced manually. This routine changes input diet compositions and biomass until both Ecopath master equations indicate that mass balance has been achieved throughout the system. Conversion to a solution was achieved when a multiplier factor of 1.5 times the input confidence intervals (Table 11) was used.

PRELIMINARY RESULTS

The balanced model parameters and diet matix are presented in Tables (1) and (9), respectively. A comparison of the initial diet estimates with the associated outputs of the balanced model indicates considerbale modification in terms of the food items and relative proportions. Biomass per unit area in the balanced model ranged between 0.001 $t{\cdot}km^{-2}$ (juvenile mackerels, juvenile demersal and reef sharks and other omnivorous demersals) and 0.541 $t{\cdot}km^{-2}$ (other bathypelagics). All production of billfishes, pelagic sharks, large tunas etc., mackerels and *Coryphaena* spp. are utilized in the system (ecotrophic efficiency of 1.00). Small ecotrophic efficiencies were estimated for flyingfishes (0.509), demersal and reef sharks (0.006), squirrelfish and other small reef carnivores (0.197), parrotfish, surgeonfish and triggerfish (0.122) as well as croakers, snooks etc. (0.165).

The percentage change in initial biomass inputs to achieve mass balance varied between –400% and +100% (Table 12). Biomass of *Coryphaena* spp. was reduced by 400% while biomass of snappers, squirrelfish and parrotfish was increased by 100%. Generally predation mortality accounted for the greatest proportion of total mortality (Table 13), ranging from 0.03% (juvenile jacks) to 99.5% (small herbivorous/ detritivorus reef species) for fish groups. Fishing mortality contributed over 30% to total mortality for billfishes, large tunas etc., pelagic sharks, small tunas etc., mackerels, *Coryphaena* spp., the fourwing flyingfish, snappers, groupers and turtles.

Basic summary statistics of the model are provided in Table (14). The mean transfer efficiency is 10.3% and gross efficiency (catch/net primary production) is 2.6×10^{-5}. The total system throughput (the sum of all concumption, exports, respiratory flows and flows to detritus) is 14,332 $t{\cdot}km^{-2}$. Approximately 21.7% of throughput goes to respiration and 35.8% to detritus.

DISCUSSION

This study represents the first attempt at parameterization and construction of an ecosystem model for the southeastern Caribbean. Thus, the model is preliminary in nature. Several other models have been constructed for areas in the Caribbean region (Browder, 1993; Mendoza, 1993; Arregúin-Sanchez *et al.*, 1993 a and b; Aliño *et al.*, 1993; Vega-Cendejas *et al.*, 1993; Opitz, 1996; Venier and Pauly, 1997; and Manickchand-Heileman *et al.*, 1998 a, 1998 b). These focus mainly on continental shelf, coral reef or coastal ecosystems, with little emphasis on the large pelagic component of the systems. In contrast, given the design of the present model, it lends itself well for addressing questions related to large pelagic fisheries.

Output parameters of the balanced model

Compared to corresponding groups in the US Virgin Islands model (Opitz, 1996), the present model for Grenada and the Grenadines indicates exceedingly low fish biomass in the respective habitats, ranging from 0.001 tkm^{-2} to 0.541 tkm^{-2}. Opitz (1996) however, modelled a smaller, more highly productive area and assumed zero fishing. In the present model, all production by billfishes, pelagic sharks, large tunas, mackerels and *Coryphaena* spp. is utilized in the system. This is consistent with reports of overfishing of these groups in the region (Mahon, 1990; Mahon, 1996; Singh-Renton and Mahon, 1996). The low ecotrophic efficiencies of other groups (e.g., EE = 0.509 for flyingfishes), however, require further investigation as they seem not realistic. Small pelagics such as flyingfishes do not die of old age, as most are subject to intense predation mortality (Christensen *et al.*, 2000).

Generally, predation mortality accounted for the major part of total mortality. Top predators, such as large pelagic species, which have few predators, usually are the exceptions. However, predation mortality for pelagic jacks (0.836 $year^{-1}$, Table 13) seems high. This requires further investigation to assess the validity of model estimates. Juveniles of large pelagics are also subjected to high predation mortality. Apart from large pelagic species, turtles were the only species for which fishing mortality exceeded the predation mortality. Fishing mortality for groupers was, however, also quite high.

The model indicates that the fishery catch has a mean trophic level of 4.3. This is reflected in the high proportion of large, migratory pelagic species in the catch. The gross efficiency of the fishery (2.6×10^{-5}) is low, primarily because the fishery is concentrated on apex predators. This parameter has a wide range between different systems, with high values characteristic of fisheries relying on fish low in the food web (e.g., in upwelling systems) and low values characteristic of fisheries concentrating on apex predators (e.g., tunas). The weighted global average is about 0.0002 (Christensen *et al.*, 2000). Mean transfer efficiency (10.3%) is consistent with estimates in the literature (Christensen *et al.*, 2000), while total system throughput (14,332 $t \cdot km^{-2}$) is small compared to the estimate for the US Virgin Islands coral reef model (Opitz, 1996). However, Opitz (1996) considered 6.34 km^2 of highly productive reef area compared to the present model (total area of 25,957 km^2), where only 7% of the total modelled area represented the reef component of the entire ecosystem. The overall system omnivory index, which characterizes the extent of web-like features of the system, is 0.26. The ratio of the total primary production to total respiration is one, indicating that the marine ecosystem (EEZ, reef, shelf and slope areas) off Grenada and the Grenadines is in a mature state. However, this and related model outputs are yet to be validated and other characteristics of the ecosystem indicative of maturity (Christensen, 1995) examined before such a conclusion can be considered as established.

Study limitations

The quality of the present model is affected by the uncertainty in the input estimates. This has resulted in repeated violations of ecological constraints for several groups, and violation of the Ecopath equation for some groups. Modifications to input parameters were necessary to achieve mass balance. Hence this model will benefit considerably from future, area specific research.

Data limitations are discussed in detail in Mohammed (2002). No input estimate in the existing model was specific to Grenada and the Grenadines. A general lack of biomass estimates prompted assumptions about ecotrophic efficiency (actually an emergent property estimated by Ecopath) and the use of estimates from other areas in the southeastern Caribbean. Assumptions for over-exploited groups e.g., pelagic sharks and large tunas, were well justified and supported by the literature. However, for many other groups, 95% of production was assumed utilized in the system (Christensen *et al.*, 2000). It was necessary to use estimates from other areas in the Caribbean though distinct differences in oceanographic conditions, species abundance, primary productivity and exploitation levels exist among these countries. The same concerns relate to the use of estimates of production/biomass ratio derived for similar functional groups in other islands. Estimates of production/biomass ratio were available only for a few species of commercial importance from other islands. Since each functional group comprised several species of similar diet, habitat and activity level, equal susceptibility to fishing gear, predation and mortality were assumed, and total mortality of individual species assumed representative of the group. Consumption of marine mammals within the study region is also not known. The estimate used from Trites and Heise (1996) for the British Columbian shelf is quite likely an over-estimate for the southeastern Caribbean region given the reported reduced feeding during breeding and calving in the area (Whitehead and Moore, 1982). Lack of data also resulted in the use of information for time periods that differ considerably from the model base year (1999). An additional limitation was the underutilization of some studies which did not meet the data requirement standards of Ecopath e.g., abundance surveys for flyingfish (Oxenford *et al.*, 1995), diet composition of flyingfish (Hall, 1955; Lewis *et al.*, 1962) and abundance estimates for marine mammals (Winn *et al.*, 1975; Levenson and Leapley, 1978; Mattila and Clapham, 1989; Matilla *et al.*, 1994).

Catch statistics also did not adequately represent all fisheries types. Catches of specific inshore species groups, e.g., lobster, conch and reef species, have not been adequately covered in the data collection programme (Mohammed *et al.*, 2003). Based on the Fisheries Department's knowledge of local fisheries, a fixed raising factor for adjusting recorded data to total catches has been used since 1978. It has been adjusted to reflect recent developments in the offshore fishery, but does not consider changes in the inshore fishery. Since catch data are aggregated across gear and fishery types (inshore and offshore), the proportion of large pelagics captured in the inshore fishery is unknown. Inshore catches likely include juveniles, and can impact on the offshore fishery targeting adults of the respective species. Foreign and non-commercial catches are also not included in the statistics (Finlay *et al.*, 1988; Murray *et al.*, 1988).

Future analyses and use of the preliminary model

Further examination of the input data, as well as outputs and dynamic behaviour is required to assess the biological and ecological validity of this model. Given the general high uncertainty of input parameters an investigation of the associated model sensitivity is required for consideration in future policy exploration using Ecosim. Additionally, model predictions can be validated by fitting simulation results to time series data on catch per unit effort of the four-wing flyingfish (*Hirundichthys affinis*) and the dolphinfish (*Coryphaena hippurus*), the only two species for which such data are available in the southeastern Caribbean. This preliminary model of the southeastern Caribbean region can be adjusted to increase understanding of functional relationships and ecosystem properties of inshore or offshore systems, and to address specific national and regional management related issues.

Future studies should include application of Ecosim to explore management policy options for the flyingfish and associated large pelagic fishery undertaken by Grenada, Barbados and Trinidad and Tobago. Flyingfish are caught commercially mainly by Barbados and Tobago, but have also increased in importance as bait for the developing longline fleets. Additionally, flyingfish is a natural component in the diet of large pelagic species, especially the dolphinfish. Management recommendations thus far have identified consideration of the predator-prey interactions as high priority in arriving at an appropriate mangement strategy (Oxenford *et al.*, 1993).

Furthermore, several islands in the southeastern Caribbean have embarked on setting up Marine Reserves since the late 1980s. The application of Ecospace can be used to assess the usefulness of these reserves in rebuilding of inshore resources and to test the placement and appropriate size of reserves in achieving this.

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Table 1: Basic parameters of the preliminary ecosystem model for the southeastern Caribbean: Case study Grenada and the Grenadines. Values in brackets were final values for balanced model.

Group No.	Group Name	Trophic Level	Biomass (Habitat)	Biomass		P/B		Q/B		EE		P/Q
				initial	final	initial	final	initial	final	initial	final	
1	Baleen whales	*(3.80)*	*(0.931)*	0.060	*(0.105)*	0.020		14.60			*(0.008)*	*(0.001)*
2	Toothed whales	*(5.06)*	*(0.004)*	0.014	*(0.003)*	0.020		9.80			*(0.502)*	*(0.002)*
3	Dolphins	*(5.07)*	*(0.001)*	0.005	*(0.001)*	0.030		9.80			*(0.784)*	*(0.003)*
4	Billfishes	*(4.91)*	*(0.016)*		*(0.015)*	1.130		6.00		1.000		*(0.188)*
5	Pelagic sharks	*(5.22)*	*(0.004)*		*(0.004)*	0.255		2.32	*(3.70)*	1.000		*(0.069)*
6	Juvenile Pelagic sharks	*(4.64)*	*(0.059)*		*(0.004)*	0.580		4.64	*(7.50)*	1.000	*(0.506)*	*(0.077)*
7	Large tunas and other pelagics	*(4.71)*	*(0.027)*	0.021	*(0.026)*	1.230	*(0.765)*	15.33			*(1.000)*	*(0.050)*
8	Mackerels	*(4.22)*	*(0.004)*	0.002	*(0.003)*	1.890		15.56			*(1.000)*	*(0.121)*
9	Juvenile mackerels	*(4.63)*	*(0.018)*		*(0.001)*	6.224	*(6.220)*	31.12		0.950	*(0.971)*	*(0.200)*
10	Small tunas & other pelagics	*(4.30)*	*(0.013)*	0.006	*(0.012)*	0.885		16.70			*(0.992)*	*(0.053)*
11	Coryphaena spp.	*(4.94)*	*(0.005)*	0.001	*(0.005)*	2.120		8.47		1.000		*(0.250)*
12	Pelagic jacks & other carn pelagics	*(4.53)*	*(0.022)*		*(0.021)*	0.944		9.44		0.950	*(0.961)*	*(0.100)*
13	Juvenile pelagic jacks, needlefish	*(4.18)*	*(0.257)*		*(0.016)*	3.776		18.88		0.950	*(0.953)*	*(0.200)*
14	Four-wing flyingfish	*(3.80)*	*(0.006)*	0.524	*(0.005)*	5.800		25.30			*(0.998)*	*(0.229)*
15	Other flyingfishes	*(3.63)*	*(0.029)*	0.116	*(0.027)*	3.800		12.70			*(0.509)*	*(0.299)*
16	Other bathypelagics	*(3.71)*	*(0.577)*		*(0.541)*	0.830		7.16		0.950	*(0.971)*	*(0.116)*
17	Demersal and reef sharks	*(4.32)*	*(0.096)*	0.385	*(0.007)*	0.320		4.75			*(0.006)*	*(0.067)*
18	Juvenile demersal and reef sharks	*(4.47)*	*(0.013)*		*(0.001)*	1.188		9.50		0.950	*(0.928)*	*(0.125)*
19	Reef jacks, tilefish, barracudas etc.	*(4.07)*	*(3.839)*	4.450	*(0.031)*	0.750	*(1.120)*	5.96		0.950	*(0.987)*	*(0.188)*
20	Juvenile reef jacks etc.	*(3.85)*	*(0.756)*		*(0.006)*	2.396	*(2.390)*	11.98		0.950	*(0.975)*	*(0.199)*
21	Groupers	*(4.33)*	*(0.095)*	0.950	*(0.007)*	0.840		5.61			*(0.989)*	*(0.150)*
22	Juvenile groupers	*(3.83)*	*(0.243)*		*(0.017)*	2.940		14.70		0.950	*(0.992)*	*(0.200)*
23	Snappers	*(4.24)*	*(0.052)*	48.690	*(0.004)*	1.068		5.45			*(0.964)*	*(0.196)*
24	Juvenile snappers	*(3.83)*	*(0.340)*		*(0.024)*	2.180		10.90		0.950	*(0.985)*	*(0.200)*
25	Squirrelfish & small reef carn.	*(4.07)*	*(7.785)*	31.140	*(0.063)*		*(2.013)*	16.10		0.950	*(0.197)*	*(0.125)*
26	Other carnivorous reef species	*(4.08)*	*(10.6610*		*(0.086)*	1.080		8.66		0.950	*(0.955)*	*(0.125)*
27	Triggerfish etc.	*(3.63)*	*(12.144)*	11.910	*(0.098)*	1.590		15.26			*(0.952)*	*(0.104)*
28	Other omnivorous reef species	*(3.53)*	*(6.572)*		*(0.053)*	2.210		23.24		0.950	*(0.971)*	*(0.095)*
29	Parrotfish etc.	*(2.39)*	*(11.845)*	47.380	*(0.096)*	5.830		25.34		0.950	*(0.122)*	*(0.230)*
30	Small herb./detr. reef species	*(3.05)*	*(4.646)*		*(0.038)*	5.000		33.39		0.950	*(0.995)*	*(0.150)*
31	Other carnivorous demersals	*(4.04)*	*(0.131)*	0.141	*(0.008)*	0.610		7.56			*(0.975)*	*(0.081)*
32	Croakers & other demersals	*(3.45)*	*(0.508)*	2.032	*(0.031)*	1.030		8.58			*(0.165)*	*(0.120)*
33	Other omnivorous demersals	*(3.52)*	*(0.017)*	0.141	*(0.001)*	3.340		22.32			*(0.841)*	*(0.150)*
34	Mullets & other herb/det.	*(2.03)*	*(7.094)*		*(0.436)*	3.033		20.22		0.950	*(0.969)*	*(0.150)*
35	Other carnivorous benthopelagics	*(3.80)*	*(1.068)*		*(0.066)*	0.620		2.96		0.950	*(0.974)*	*(0.209)*
36	Small coastal pelagics	*(3.64)*	*(2.915)*		*(0.179)*	3.471	*(3.470)*	23.61		0.950	*(0.970)*	*(0.147)*

Table 1: cont'd.

Group No.	Group Name	Trophic Level	Biomass (Habitat)	Biomass initial	Biomass final	P/B initial	P/B final	Q/B Initial	Q/B final	EE Initial	EE final	P/Q
37	Sea birds	*(4.59)*	*0.002*		*(<0.001)*	5.400		80.00		0.200	(0.161)	*(0.068)*
38	Turtles	*3.11*	*0.527*		*(0.004)*	0.150		3.50		0.950	(0.970)	*(0.043)*
39	Cephalopods	*4.29*	*0.040*	0.023	*(0.038)*	2.340		12.73			(0.992)	*(0.184)*
40	Spiny lobster	*3.74*	*7.423*		*(0.516)*	1.475		7.40		0.950	(0.961)	*(0.199)*
41	Other crustaceans	*2.85*	*108.580*		*(7.546)*	1.840		25.37		0.950	(0.963)	*(0.073)*
42	Queen conch	*2.07*	*0.842*	2.739	*(0.059)*	0.530			(4.42)		(0.997)	*(0.120)*
43	Molluscs and worms	*2.25*	*37.336*		*(2.595)*	4.140		61.60		0.950	(0.996)	*(0.067)*
44	Echinoderms	*2.36*	*0.810*	3.240	*(0.056)*	0.730		6.84			(0.952)	*(0.107)*
45	Zoobenthic sessile animals	*2.29*	*344.394*		*(23.935)*	1.360		12.00		0.950	(0.956)	*(0.113)*
46	Microfauna	*2.00*	*35.386*		*(2.442)*	195.000		2050.00		0.950	(0.931)	*(0.095)*
47	Zooplankton	*2.80*	*2.472*		*(2.472)*	40.000		165.00		0.950	(0.681)	*(0.242)*
48	Seagrasses & other autotrophs	*1.00*	*3483.865*	3167.150	*(27.871)*	12.760					(0.273)	
49	Symbiotic algae	*1.00*	*2800.199*		*(22.402)*	10.200				0.950	(0.398)	
50	Phytoplankton	*1.00*	*38.551*	35.060	*(36.199)*	70.000					(0.080)	
51	Detritus	*1.00*	*37.892*	37.892	*(2.615)*						(0.999)	

Table 2: Estimated biomass of marine mammals in the Caribbean province (area = 4.48 x $10^6 km^2$).

Common Name	Population Numbers[a]		Mean Mass (kg)[b]		Population biomass		Total Biomass (tkm^{-2}) in Caribbean Province[c]
	Female	Male	Female	Male	Female	Male	
Northern right whale	4	4	24960	21805	91	80	0.000038
Blue whale	112	112	110126	95347	12281	10633	0.005115
Fin whale	923	923	59819	51361	55191	47388	0.022897
Sei whale	288	288	17387	16235	5010	4678	0.002162
Bryde's whale	1055	1055	16905	15381	17833	16225	0.007602
Minke whale	6867	6867	7011	6121	48144	42034	0.020129
Humpback whale	176	176	32493	28323	5721	4987	0.002390
Baleen Whales							**0.060334**
Sperm whale	1547	1547	10098	26939	15624	41682	0.012791
Pygmy sperm whale	83	83	177	177	15	15	0.000007
Dwarf sperm whale	83	83	101	101	8	8	0.000004
Cuvier's beaked whale	75	75	886	771	66	57	0.000028
Blainville's beaked whale	8	8	390	508	3	4	0.000002
Gervais' beaked whale	270	270	496	289	134	78	0.000047
True's beaked whale	6	6	473	416	3	2	0.000001
Killer whale	618	618	1974	2587	1219	1598	0.000629
Short-finned pilot whale	842	842	467	819	393	689	0.000242
False killer whale	851	851	464	692	395	588	0.000220
Pygmy killer whale	92	92	78	117	7	11	0.000004
Melon-headed whale	102	102	105	104	11	11	0.000005
Toothed whales							**0.013978**
Tucuxi	1118	1118	39	39	43	43	0.000019
Rough-toothed dolphin	89	89	88	96	8	9	0.000004
Risso's dolphin	773	773	211	236	163	182	0.000077
Bottlenose dolphin	33633	33633	172	203	5781	6835	0.002816
Pantropical spotted dolphin	9678	9678	59	72	572	694	0.000283
Atlantic spotted dolphin	30123	30123	68	65	2034	1970	0.000894
Spinner dolphin	9574	9574	40	43	379	413	0.000177
Clymene dolphin	345	345	47	47	16	16	0.000007
Striped dolphin	8663	8663	115	117	992	1011	0.000447
Common dolphin	8106	8106	68	92	553	746	0.000290
Fraser's dolphin	114	114	95	95	11	11	0.000005
Dolphins							**0.005019**

[a]Fisheries Centre Marine Mammal database; www.fisheries.ubc.ca. [b] Trites and Pauly, 1998. [c] Longhurts *et al*., 1995.

Table 3: Estimated biomass of tuna.

Country	Species (stock)	Area (km²)	MSY (mt)[a]	MSY (t x 10⁻⁴ km⁻²)[b]	Biomass (t x 10⁻⁴ km⁻²)
Antigua	Yellowfin (all)	32,560,045	149,000	45.76	
Barbados	Albacore (north)	35,953,074	24,700	6.87	
Jamaica	Bluefin tuna (west)	23,751,216	2,660	1.12	
St Kitts and Nevis	Bigeye tuna	56,507,011	61,200	10.83	
Sum Large Tunas				64.58	**210.02**
St Vincent and Grenadines	Skipjack (west)	23,555,462	31,300	13.29	
Sum Small Tunas				13.29	**59.99**

[a] Singh-Renton and Neilson (1994); [b] based on Christensen (1996)

Table 4: Estimated biomass of flyingfish. Source: Oxenford *et al.* (1995). Maximum length of *H. affinis* from Samlalsingh and Pandohee (1993), and for *P. brachypterus* and *C. cyanopterus* from FishBase (Froese and Pauly, 2000). Constants of the length-weight relationship for *H. affinis* taken from Samalalsingh and Pandohee (1993) and assumed the same for *P. brachypterus* and *C. cyanopterus*.

Transect Number	Number of 0.5 nautical miles surveyed	Mean number of fish counted per 0.5 nm			Estimated total number of fish counted			Area surveyed
		H. affinis	*P. brachypterus*	*C. cyanopterus*	*H. affinis*	*P. brachypterus*	*C. cyanopterus*	(m²)
9	64	8.67	4.16	0.32	554.88	266.24	20.48	1185280
10	3	13.97	4.89	1.40	41.91	14.67	4.20	55560
11	72	3.85	21.67	0.32	277.20	1560.24	23.04	1333440
12	24	2.21	3.26	0.19	53.04	78.24	4.56	444480
13	73	3.67	2.14	0.10	267.91	156.22	7.30	1351960
14	17	2.91	10.02	2.44	49.47	170.34	41.48	314840
15	66	5.5	2.97	0.45	363.00	196.02	29.70	1222320
16	24	2.53	2.73	0.10	60.72	65.52	2.40	444480
18	60	3.05	3.36	0.30	183.00	201.6	18.00	1111200
19	42	1.6	0.73	0.25	67.20	30.66	10.50	777840
21	84	8.82	5.50	0.10	740.88	462.00	8.40	1555680
22	30	9.7	14.49	0.17	291.00	434.70	5.10	555600
23	79	14.81	8.68	0	1169.99	685.72	0	1463080
24	79	2.06	15.71	0.08	162.74	1241.09	6.32	1463080
25	24	28.47	11.25	0.03	683.28	270.00	0.72	444480
26	26	8.04	4.80	0.06	209.04	124.80	1.56	481520
27	60	24.11	7.03	0.09	1446.60	421.80	5.40	1111200
28	40	0.39	0.85	0.03	15.60	34.00	1.20	740800
29	60	0.83	2.91	0.01	49.80	174.60	0.60	1111200
30	6	0.43	0.57	0	2.58	3.42	0	111120
31	87	1.37	5.29	0.01	119.19	460.23	0.87	1611240
33	80	9.02	21.02	0.24	721.60	1681.60	19.20	1481600
34	36	3.11	3.55	0.29	111.96	127.80	10.44	666720
35	66	1.34	5.69	0.17	88.44	375.54	11.22	1222320
37	93	1.47	0.05	0.03	136.71	4.65	2.79	1722360
38	19	5.36	0	0	101.84	0	0	351880
39	92	3.37	5.18	0	310.04	476.56	0	1703840
Total area surveyed								26039120
Total number of fish counted					8279.62	9718.26	235.48	
Assumed percentage taking to flight					10	20	20	
Estimated number of fish in surveyed area					82796.20	48591.3	1177.4	
Estimated weight (g) (number x Wmax); where Wmax = aLmax[b]					29235	5491	865	
Biomass (gm⁻²)					0.001123	0.000211	0.000033	

Table 5: Biomass estimates for selected reef species.

Group Name	Species	Density 50 m² [a]		Length [b]	Length-Weight parameters			Reference	Common Weight (g)	Biomass (tkm⁻²)
		NRA	NRB	(cm)	*a*	*b*	Locality			
Reef jacks etc.	*Caranx ruber*	0.87	0.24	27.94	0.021	2.954	USVI	Bohnsack & Harper 1988	400.47	4.45
Total biomass										**4.45**
Groupers	*Cephalopholis cruentata*	0.35	0.21	20.32	0.008	3.024	Jamaica	Thompson & Munro 1983b	68.48	0.38
	Cephalopholis fulva	0.22	0.17	20.32	0.017	3.000	USVI	Bohnsack & Harper 1988	145.99	0.57
Total biomass										**0.95**
Snappers	*Ocyurus chrysurus*	2.04	0.84	45.72	0.015	3.032	Jamaica	Thompson & Munro 1983a	1566.07	45.10
	Lutjanus mahogoni	0.74	0.72	24.13	0.043	2.719	S Florida	Bohnsack & Harper 1988	245.82	3.59
Total biomass										**48.69**
Squirrelfish etc.	*Holocentrus rufus*	1.56	2.60	12.70	0.017	3.000	Jamaica	Bohnsack & Harper 1988	34.82	1.45
	Holocentrus marianus [c]	0.18	0.00	22.86	0.017	3.000	Jamaica	Wyatt,1983	203.08	0.37
	Myripristis jacobus	23.10	11.90	11.43	0.111	2.720	Columbia	Duarte *et al.* 1999	83.79	29.33
Total biomass										**31.14**
Triggerfish, grunts etc.	*Mulloidichthys martinicus*	4.99	0.58	22.86	0.009	3.223	Jamaica	Munro,1983	213.64	11.90
Total biomass										**11.90**
Parrotfish, surgeonfish etc.	*Sparisoma aurofrenatum*	1.22	1.36	21.59	0.013	3.110	Jamaica	Reeson 1983a	182.02	4.70
	Sparisoma viride	0.96	1.16	38.10	0.054	2.740	Jamaica	Reeson 1983a	1152.68	24.44
	Scarus taeniopterus	0.43	0.72	22.86	0.018	3.000	USVI	Bohnsack & Harper 1988	211.45	2.43
	Scarus vetula [d]	0.43	0.72	35.56	0.014	3.000	S. Florida	Bohnsack &Harper 1988	607.04	6.98
	Acanthurus bahianus	1.35	0.96	22.86	0.019	3.080	Jamaica	Reeson,1983b	293.08	6.77
	Acanthurus coeruleus	0.18	0.80	19.05	0.031	3.000	USVI	Bohnsack & Harper 1988	210.86	2.07
Total biomass										**47.38**

[a] Data source: Corless *et al.* (1997) with mean density in numbers per 50 m² in non-reserve areas; [b] Mean common length (Human 1991); [c] Data not available, information for *Holocentrus rufus* used; [d] Data for *Scarus taeniopterus*.

Table 6: Conversion parameters for billfishes in Grenada. LJFL: Lower jaw fork length (cm); PPL: Pre-pectoral length (cm); R^2: correlation coefficient; N: Number of fish measured.

Species	Sex	Estimated Equation	R^2	N
Atlantic sailfish	Female	LJFL = 0.9565 PPL + 45.85	0.732	1774
	Male	LJFL = 0.9427 PPL + 46.61	0.702	1203
	Both	LJFL = 0.9684 PPL + 43.91	0.743	2977
Atlantic blue marlin	Femaile	LJFL = 1.3819 PPL - 9.14	0.937	131
	Male	LJFL = 1.1624 PPL + 22.61	0.961	90
	Both	LJFL = 1.2903 PPL + 4.40	0.939	221
Atlantic white marlin	Female	LJFL = 1.0239 PPL + 38.34	0.840	27
	Male	LJFL = 1.3077 PPL + 4.69	1.000	2
	Both	LJFL = 1.0343 PPL + 37.20	0.845	29

Table 7: Growth parameters and lengths used to estimate total mortality for billfishes around Grenada.

Species	L_∞ (cm)	K	Growth Reference	Mean length in population (cm)	Mean length at capture (cm)	Total mortality (year^{-1})
Atlantic sailfish	242	0.6945	Sakagawa and Bell, 1980; Beverton and Holt (1959)	169	77	0.5511
Atlantic blue marlin	210	1.5330	Prince, 1991	189	111	0.4127
Atlantic white marlin	261	0.5800	Pauly, 1978	160	136	2.4408

Table 8: Consumption/biomass estimates for marine mammals. Average estimates for each group in bold. Sources: Inness *et al.* (1987), Trites *et al.* (1997).

Species	Population consumption (kg day^{-1})		Total consumption (kg year^{-1})	Total biomass (kg)	Q/B (year^{-1})
	Female	Male			
Northern right whale	0	0	0	170633	0.00
Blue whale	341	379	262726	22914439	0.01
Fin whale	2683	2615	1933951	102579368	0.02
Sei whale	941	1196	780016	9687823	0.08
Bryde's whale	76992	54776	48095537	34057508	1.41
Minke whale	63812	72334	49693466	90178149	0.55
Humpback whale	271	277	199890	10708130	0.02
Baleen Whales					**0.30**
Sperm whale	1671393	1489406	1153691734	57305326	20.13
Pygmy sperm whale	508	580	397185	29202	13.60
Dwarf sperm whale	32330	32885	23803271	16746	1421.42
Cuvier's beaked whale	112	105	79293	123564	0.64
Blainville's beaked whale	23	23	16509	7548	2.19
Gervais' beaked whale	1035	1035	755361	211788	3.57
True's beaked whale	6	5	4110	5048	0.81
Killer whale	792	913	622467	2816965	0.22
Short-finned pilot whale	2178	2484	1701879	1082392	1.57
False killer whale	3174	3174	2317333	983678	2.36
Pygmy killer whale	543	363	330717	17988	18.39
Melon-headed whale	166	166	121512	21354	5.69
Toothed whales					**124.22**
Tucuxi	11736	9307	7680947	86351	88.95
Rough-toothed dolphin	313	555	316993	16396	19.33
Risso's dolphin	33449	41532	27367880	345640	79.18
Bottlenose dolphin	62929	76868	51025598	12616815	4.04
Pantropical spotted dolphin	149848	112636	95806892	1266318	75.66
Atlantic spotted dolphin	550584	773862	483422986	4004508	120.72
Spinner dolphin	280015	226519	184885041	791471	233.60
Clymene dolphin	0	0	0	32279	0.00
Striped dolphin	78799	71505	54860997	2002979	27.39
Common dolphin	33660	33186	24398883	1298796	18.79
Fraser's dolphin	13560	12165	9389268	21697	432.74
Dolphins					**100.04**

Table 9: Diet matrix for balanced preliminary model of the southeastern Caribbean; case study for Grenada and the Grenadines.

Group No.	Prey/Predator	1	2	3	4	5	6	7	8	9	10	11	12	13
1	Baleen whales	-	-	-	-	.001	-	-	-	-	-	-	-	-
2	Toothed whales	-	-	-	-	-	-	-	-	-	-	-	-	-
3	Dolphins	-	-	-	-	-	-	-	-	-	-	-	-	-
4	Billfishes	-	-	-	.010	.069	-	-	-	-	-	.022	-	-
5	Pelagic sharks	-	-	-	-	-	-	-	-	-	-	-	-	-
6	Juvenile pelagic sharks	-	-	-	-	.076	-	-	-	-	-	-	-	-
7	Large tunas and other pelagics	-	-	-	.003	.021	-	.001	-	-	-	-	-	-
8	Mackerels	-	-	.009	.014	.023	-	.003	-	-	-	.002	-	-
9	Juvenile mackerels	-	.012	.072	.042	.071	.010	-	.010	-	-	-	-	-
10	Small tunas, barracudas and other pelagics	-	.004	.066	.003	.071	-	-	.020	-	.007	.021	-	-
11	Coryphaena (Mahi mahi)	-	.001	.025	.009	.058	-	-	.009	-	.002	.012	-	-
12	Pelagic jacks, needlefish	-	.012	.072	.020	.071	-	-	.017	-	.002	.098	-	-
13	Juvenile pelagic jacks, needlefish	-	.012	.072	.020	.071	-	-	.017	-	-	-	.268	-
14	Four wing flyingfish	-	.012	.072	-	.071	-	-	.024	-	.002	.429	-	-
15	Other flyingfihses	-	.012	.072	.022	-	-	.121	-	-	.002	.023	-	-
16	Other bathypelagics	-	.012	.072	.408	-	-	.610	-	-	.462	.029	-	-
17	Demersal and reef sharks	-	-	-	-	-	-	-	-	-	-	-	-	-
18	Juvenile demersal and reef sharks	-	-	-	-	-	-	-	-	-	-	-	-	-
19	Reef jacks, tilefish, barracudas, etc.	-	-	-	.019	-	-	-	-	-	-	-	-	-
20	Juvenile reef jacks, tilefish	-	-	-	-	-	-	-	-	-	-	-	-	-
21	Groupers	-	-	-	-	-	-	-	-	-	-	-	-	-
22	Juvenile groupers	-	-	-	-	-	-	-	-	-	-	-	-	-
23	Snappers	-	-	-	-	-	-	-	-	-	-	-	-	-
24	Juvenile snappers	-	-	-	-	-	-	-	-	-	-	-	-	-
25	Squirrelfish and other small reef carnivores	-	-	-	.013	-	-	.024	.032	.006	.015	.004	-	-
26	Other carnivorous reef species	-	-	-	.006	-	-		.044	.006	-	-	-	-
27	Triggerfish, grunts, porgies, angelfish	-	-	-	.023	-	-	.037	.006	.011	-	-	-	-
28	Other omnivorous reef species	-	-	-	.026	-	-	.002	.038	.046	.005	.080	-	-
29	Parrotfish, surgeonfish, triggerfish, etc.	-	-	-	.002	-	-	.002	.044	.005	.005	-	-	-
30	Small herb/det reef species	-	-	-	-	-	-	-	.044	-	-	-		-
31	Other carnivorous demersals	-	-	-	-	-	-	-		-	-	.004		-
32	Croakers, snooks, & other carn/omn demersals	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 9: (cont'd)

Group No.	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	-	-	.001	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	.001	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	.002	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	.017	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18	-	-	-	.030	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19	-	-	.002	.024	-	-	-	.051	-	.001	-	-	-	-	-	-	-	-	-
20	-	-	-	-	-	.076	-	-	-	-	-	-	-	-	-	-	-	-	-
21	-	-	-	.023	-	-	-	-	-	-	-	-	-	-	-	-	-	.012	-
22	-	-	-	-	.129	-	-	.051	-	.061	-	-	.060	-	-	-	-	-	-
23	-	-	-	.021	-	-	-	.020	-	-	-	-	-	-	-	-	-	.012	-
24	-	-	-	.048	.129	-	-	.051	-	.061	-	-	.060	-	-	-	-	-	-
25	-	-	.002	.024	-	-	-	.052	-	.016	-	-	-	-	-	-	-	-	-
26	-	-	-	.024	.129	.076	-	.051	-	.061	-	.062	-	.002	-	-	-	.021	-
27	-	-	.026	.035	-	.076	-	.039	-	.008	-	-	-	-	-	-	-	.001	-
28	-	-	-	.048	.129	.076	-	.051	-	.061	-	.067	.015	.002	-	-	-	.021	-
29	-	-	.011	.022	-	.076	-	.051	-	.061	-	-	-	-	-	-	-	-	-
30	-	-	-	.114	.129	.076	-	.051	-	-	-	.067	.119	.002	.003	-	-	-	-
31	-	-	.001	-	.096	-	-	.001	-	-	-	-	-	-	-	-	-	.001	.003
32	-	-	-	.117	-	-	-	.009	-	.002	-	-	-	-	-	-	-	-	-

Table 9: (cont'd)

Group No.	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
28	.001	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
32	-	-	.005	-	-	-	-	-	-	-	-	-	-	-	-

Table 9: (cont'd): Diet matrix for balanced preliminary model of the southeastern Caribbean; case study for Grenada and the Grenadines.

Group No.	Prey/Predator	1	2	3	4	5	6	7	8	9	10	11	12	13
33	Other omnivorous demersals	-	-	-	-	-	-	-	-	-	-	-	-	-
34	Mullets & other herb/det coastal pel & dem	-	-	-	-	-	-	-	.044	-	-	.006		-
35	Other carnivorous benthopelagics	-	-	-	.007	-	-	-	.044	-	-	.004	.188	-
36	Small coastal pelagics	-	.012	.042	.155	-	.990	.037	.382	.911	.040	.004	.194	.420
37	Sea birds	-	-	-	-	.008	-	-	-	-	-	-	-	-
38	Turtles	-	-	-	-	.017	-	-	-	-	-	-	-	-
39	Cephalopods	-	.010	.370	.194	.277	-	.091	.001	.010	.039	-	-	-
40	Spiny lobster	-	-	-	-	-	-	-	-	-	-	-	-	-
41	Other crustaceans	-	-	-	.003	.058	-	.046	.004	.001	.034	-	.211	.580
42	Queen conch	-	-	-	-	-	-	-	-	-	-	-	-	-
43	Molluscs and worms	-	-	.058	-	.002	-	-	.002	.003	.229	-	-	-
44	Echinoderms	-	-	-	-	-	-	-	-	-	-	-	-	-
45	Zoobenthic sessile animals	-	-	-	-	-	-	-	-	-	-	-	.005	-
46	Microfauna	-	-	-	-	-	-	-	-	-	-	-	-	-
47	Zooplankton	.100	-	-	-	.021	-	-	.117	-	.080	-	.134	-
48	Seagrasses, seaweeds and other autotrophs	-	-	-	-	.003	-	.006	-	-	-	-	-	-
49	Symbiotic algae	-	-	-	-	-	-	-	-	-	-	-	-	-
50	Phytoplankton	-	-	-	-	.011	-	-	.100	-	-	-	-	-
51	Detritus	-	-	-	-	-	-	-	-	-	-	-	-	-
Import		.900	.901	-	-	-	-	-	-	-	-	-	-	-
Sum		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 9 (cont'd): Diet matrix for balanced preliminary model of the southeastern Caribbean; case study for Grenada and the Grenadines.

Group No.	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
33	-	-	-	-	.129	-	-	-	-	-	-	-	-	-	-	-	-	.031	-
34	-	-	-	.117	.129	-	-	.051	-	.061	-	-	-	-	-	-	-	.021	.159
35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
36	.005	-	-	-	-	-	-	-	-	-	-	-	-	.001	.040	-	-	.062	-
37	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
38	-	-	-	.002	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
39	-	-	.002	.064	-	.005	-	-	-	-	-	-	-	-	-	-	-	.006	-
40	-	-	-	.127	-	.120	-	.182	-	-	-	.156	.221	-	-	-	-	.251	-
41	-	-	.652	.127	-	.120	1.00	.182	.974	.262	.974	.368	.338	.443	.292	.027	.212	.251	.433
42	-	-	-	.003	-	.074	-	-	-	.001	-	-	.001	.001	-	-	-	.067	.033
43	-	-	.286	.003	-	.074	-	.016	.026	.019	.026	.054	.020	.169	.132	.111	.028	.067	.033
44	-	-	-	-	-	.012	-		-	.003	-	-	.001	.013	.001	-	-	.014	
45	-	.334	-	.014	-	.036	-	.003	-	.017	-	-	-	.241	.216	.056	.439	.038	.082
46	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
47	.995	.666	-	-	-	.094	-	.086	-	.042	-	.221	.109	.081	.238	.073	.028	.093	.162
48	-	-	-	.011	-	.007	-	-	-	-	-	-	-	.013	.048	.733	.293	-	-
49	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
50	-	-	-	-	-	-	-	-	-	-	-	-	-	.017	-	-	-	-	-
51	-	-	-	-	-	-	-	-	-	-	-	.006	.055	.014	.029	-	-	.026	.094
Import	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sum	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 9: (cont'd)

Group No.	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
34	.001	-	.271	.027	-	-	-	-	.006	-	-	-	-	-	-
35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
36	.020	-	.271	.027	.950	-	.175	-	-	-	-	-	-	-	-
37	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
39	-	-	-	-	-	.001	.016	-	-	-	-	-	-	-	-
40	-	-	.001	-	-	.075	.322	-	.001	-	-	-	-	-	-
41	.384	-	.264	.268	-	.159	.320	.945	.015	.013	-	.038	-	-	-
42	.025	-	.001	-	-	.001	.001	-	-	-	-	-	-	-	-
43	.156	.023	.002	.069	-	.001	.001	-	.030	.013	.014	.002	.001	-	-
44	.012	-	-	-	-	.002	-	-	-	.013	-	.028	-	-	-
45	.175	-	.054	.015	-	.466	-	-	.154	.013	-	.070	-	-	-
46	-	-	-	-	-	-	-	-	.286	-	.186	.097	.113	-	.800
47	.158	-	.131	.520	.050	-	.164	-	.159	-	.027	.034	.100	-	-
48	-	.298	-	.001	-	.295	-	.055	.006	.050	.016	.211	-	.018	-
49	-	-	-	-	-	-	-	-	-	-	-	-	.316	-	-
50	-	-	-	.073	-	-	-	-	.097	.798	.382	.074	.146	-	.200
51	.067	.679	-	-	-	-	-	-	.247	.100	.374	.446	.323	.982	-
Import	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sum	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 10: Catches of fishing fleets in Grenada and the Grenadines (1999). Catches of mackerels, reef jacks, and snappers by canoes/dories and seine boats, and catches of pelagic jacks and needlefish by canoes/dories and double-enders were assumed to be juveniles of the respective groups.

Functional Group	Catch (t)				
	Canoe/ Dory	Double Ender	Semi-industrial boats	Pirogue	Seine boat
Billfishes	3.15	5.64	92.49	253.34	0.76
Large pelagic sharks	-	-	24.98	-	-
Large tunas and other pelagics	-	9.51	180.54	288.86	-
Juvenile large tunas and other pelagics	0.48	-	-	-	0.19
Mackerels	-	0.26	3.43	86.73	-
Juvenile mackerels	0.48	-	-	-	2.78
Coryphaena spp.	0.07	0.26	6.91	156.60	0.01
Small tunas, barracudas and other pelagics	-	0.48	4.74	133.47	-
Juvenile small tunas, barracudasa and other pelagics	0.97	-	-	-	0.14
Pelagic jacks, needlefish	-	-	10.70	26.93	-
Juvenile large jacks, needlefish	0.29	0.03	-	-	-
Four wing Flyingfish	-	-	108.00	150.00	-
Reef jacks, tilefish, barracudas, etc.	-	38.07	-	-	-
Juvenile large reef jacks, tilefish	2.53	-	-	-	1.66
Groupers	-	-	2.69	101.29	-
Juvenile groupers	-	-	-	-	-
Snappers	-	-	0.08	39.68	-
Juvenile snappers	1.11	-	-	-	0.08
Squirrelfish and other small reef carnivores	-	-	-	2.33	-
Triggerfish, grunts, porgies, angelfish	-	-	-	3.85	-
Parrotfish, surgeonfish, triggerfish etc	-	-	-	62.24	-
Croakers, snooks and other carn/omn demersals	-	-	-	-	1.01
Small coastal pelagics	-	23.98	9.05	133.47	13.81
Turtles	-	-	-	8.36	-
Cephalopods	-	-	0.18	0.18	-
Spiny lobster	1.78	-	0.13	80.02	-
Queen conch	-	-	-	10.19	-

Table 11: Confidence intervals assigned by author to input parameters based on data sources.

Group No.	Functional Group	Confidence Interval (+/- %)				
		Biomass	P/B	Q/B	Diet[a]	Catch
1	Baleen Whales	50-80	80	50	50	
2	Toothed Whales	50-80	80	50	50	
3	Dolphins	50-80	90	50	50	
4	Billfishes	*	90	80	40	50
5	Pelagic sharks	*	90	50	50	50
6	Juvenile pelagic sharks	*	90	90	80	>80
7	Large tunas and other pelagics	80	90[a]	80	40	50
8	Mackerels	80	90	50	50	50
9	Juvenile mackerels	*	90	90	40	>80
10	Small tunas, barracudas and other pelagics	80	50	80	50	50
11	*Coryphaena* spp.	50-80	90[s]	50	40	50
12	Pelagic jacks, needlefish & other carn. pelagics	*	90	50	50	50
13	Juvenile pelagic jacks, needlefish	*	90	90	40	>80
14	Four wing Flyingfish	50-80	20	50	50	50
15	Other Flyingfishes	50-80	90[a]	50	50	
16	Other bathypelagics	*	80	90	80	
17	Demersal and reef sharks	50-80	80	50	50	
18	Juvenile demersal and reef sharks	*	90	90	80	
19	Reef jacks, tilefish, barracudas, etc.	50-80	90	50	50	50
20	Juvenile reef jacks, tilefish	*	90	90	40	>80
21	Groupers	50-80	90[a]	50	50	50
22	Juvenile groupers	*	90	50	80	>80
23	Snappers	50-80	30	50	50	50
24	Juvenile snappers	*	90	90	80	>80
25	Squirrelfish and other small reef carnivores	50-80	90[a]	50	50	50
26	Other carnivorous reef species	*	50	50	50	
27	Triggerfish, grunts, porgies, angelfish	50-80	90[a]	50	50	50
28	Other omnivorous reef species	*	50	50	50	
29	Parrotfish, surgeonfish, triggerfish etc	50-80	90[a]	50	50	50
30	Small herb/det reef species	*	90[a]	50	50	
31	Other carnivorous demersals	50-80	50	50	50	
32	Croakers, snooks and other carn/omn demersals	50-80	*	50	50	50
33	Other omnivorous demersals	80	50	50	50	
34	Mullets and other herb/det coastal pel and dem	*	90[a]	50	50	
35	Other carnivorous benthopelagics	*	50	50	50	
36	Small coastal pelagics	*	50	50	50	
37	Sea birds	*	80	80	80	
38	Turtles	*	80	80	80	50
39	Cephalopods	50-80	80	80	80	
40	Spiny lobster	*	20	80	80	50
41	Other crustaceans	*	80	80	80	
42	Queen conch	50-80	20	*	80	50
43	Molluscs and worms	*	80	80	80	
44	Echinoderms	50-80	80	80	80	
45	Zoobenthic sessile animals	*	80	80	80	
46	Microfauna	*	80	80	80	
47	Zooplankton	*	80	80	80	
48	Seagrasses, seaweeds and other autos	40	30			
49	Symbiotic algae	*	80			
50	Phytoplankton	40	80			
51	Detritus	40				

* Parameter estimated by Ecopath; [a] Parameter adjusted manually during balancing process.

Table 12: Change in input biomass (%) undertaken to achieve mass balance.

Group Number	Group Name	% biomass change
1	Baleen whales	-75
2	Toothed whales	79
3	Dolphins	80
7	Large tunas and other pelagics	-24
8	Mackerels	-50
10	Small tunas, barracudas and other pelagics	-100
11	*Coryphaena* spp.	-400
14	Four-wing flyingfish	99
15	Other flyingfishes	77
17	Demersal and reef sharks	98
19	Reef jacks, tilefish, barracudas etc.	99
21	Groupers	99
23	Snappers	100
25	Squirrelfish and other small reef carnivores	100
27	Triggerfish, grunts, porgies, angelfish	99
29	Parrotfish, surgeonfish, triggerfish etc.	100
31	Other carnivorous demersals	94
32	Croakers, snooks & other carn/omn. demersals	98
33	Other omnivorous demersals	99
39	Cephalopods	-65
42	Queen conch	98
44	Echinoderms	98
48	Seagrasses, seaweeds and other autotrophs	99
50	Phytoplankton	-3
51	Detritus	93

Table 13: Mortality rates ($year^{-1}$) of functional groups in the preliminary ecosystem model for Grenada and the Grenadines.

Group Number	Group name	Total mortality (Z)	Fishing mortality (F)	Predation mortality (P)
1	Baleen Whales	0.020	0.000	0.000
2	Toothed Whales	0.020	0.000	0.010
3	Dolphins	0.030	0.000	0.024
4	Billfishes	1.130	0.939	0.191
5	Pelagic sharks	0.255	0.254	0.001
6	Juvenile pelagic sharks	0.580	0.000	0.294
7	Large tunas and other pelagics	0.765	0.724	0.041
8	Mackerels	1.890	1.010	0.880
9	Juvenile mackerels	6.220	0.111	5.929
10	Small tunas etc.	0.886	0.436	0.443
11	*Coryphaena* spp.	2.120	1.281	0.839
12	Pelagic jacks, needlefish	0.944	0.071	0.836
13	Juvenile pelagic jacks, needlefish	3.776	0.001	3.599
14	Four wing Flyingfish	5.800	1.815	3.972
15	Other Flyingfishes	3.800	0.000	1.933
16	Other bathypelagics	0.830	0.000	0.806
17	Demersal and reef sharks	0.320	0.000	0.002
18	Juvenile demersal and reef sharks	1.188	0.000	1.102
19	Reef jacks, tilefish, barracudas, etc.	1.120	0.047	1.059
20	Juvenile reef jacks, tilefish	2.390	0.026	2.303
21	Groupers	0.840	0.609	0.222
22	Juvenile groupers	2.940	0.000	2.917
23	Snappers	1.068	0.428	0.602
24	Juvenile snappers	2.180	0.002	2.145
25	Squirrelfish & other small reef carnivores	2.013	0.001	0.394
26	Other carnivorous reef species	1.080	0.000	1.031
27	Triggerfish, grunts, porgies, angelfish	1.590	0.002	1.512
28	Other omnivorous reef species	2.210	0.000	2.146
29	Parrotfish, surgeonfish, triggerfish etc	5.830	0.025	0.688
30	Small herb/det reef species	5.000	0.000	4.975
31	Other carnivorous demersals	0.610	0.000	0.595
32	Croakers and other carn/omn demersals	1.030	0.001	0.168
33	Other omnivorous demersals	3.340	0.000	2.810
34	Mullets & other herb./det. etc.	3.033	0.000	2.939
35	Other carnivorous benthopelagics	0.620	0.000	0.604
36	Small coastal pelagics	3.470	0.039	3.327
37	Sea birds	5.400	0.000	0.868
38	Turtles	0.150	0.075	0.070
39	Cephalopods	2.340	0.000	2.321
40	Spiny lobster	1.475	0.006	1.412
41	Other crustaceans	1.840	0.000	1.772
42	Queen conch	0.530	0.007	0.522
43	Molluscs and worms	4.140	0.000	4.123
44	Echinoderms	0.730	0.000	0.695
45	Zoobenthic sessile animals	1.360	0.000	1.301
46	Microfauna	195	0	181.559
47	Zooplankton	40	0	27.255
48	Seagrasses and other autotrophs	12.76	0	3.485
49	Symbiotic algae	10.2	0	4.056
50	Phytoplankton	70	0	5.63

Table 14: Summary statistics for the balanced preliminary model for Grenada and the Grenadines

Parameter	Value	Units
Sum of all consumption	6086.60	$t \cdot km^{-2}$ $year^{-1}$
Sum of all exports	2.81	$t \cdot km^{-2}$ $year^{-1}$
Sum of all respiratory flows	3116.56	$t \cdot km^{-2}$ $year^{-1}$
Sum of all flows into detritus	5126.14	$t \cdot km^{-2}$ $year^{-1}$
Total system throughput	14332.00	$t \cdot km^{-2}$ $year^{-11}$
Sum of all production	3755.00	$t \cdot km^{-2}$ $year^{-1}$
Mean trophic level of the catch	4.34	
Gross efficiency (catch/net p.p.)	0.000026	
Calculated total net primary production	3118.06	$t \cdot km^{-2}$ $year^{-1}$
Total primary production/total respiration	1.00	
Net system production	1.49	$t \cdot km^{-2}$ $year^{-1}$
Total primary production/total biomass	24.33	
Total biomass/total throughput	0.009	
Total biomass (excluding detritus)	128.17	$t \cdot km^{-2}$
Total catches	0.08	$t \cdot km^{-2}$ $year^{-1}$
Connectance Index	0.18	
System Omnivory Index	0.26	

Trophic Model of a Fringing Coral Reef in the Southern Mexican Caribbean [*Modelo Trófico para un Arrecife de Coral de Tipo Borde-Barrera en el Sur del Caribe Mexicano*]

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ABSTRACT

A mass balance trophic (Ecopath) model of a coral fringing reef in the southern Mexican Caribbean was constructed from published data. The trophic analysis of this reef ecosystem resulted in a model with a P/R ratio of 0.87, a high connectance index of 0.35, a relatively low value for the Finn recycling index of 10.1% of the total throughput, and a low relative internal ascendancy of 26%. Comparisons with other coral reef ecosystems for the southern Mexican Caribbean suggest maturity is high for the system modeled in the present study.

RESUMEN

Se construyó un modelo balanceado de flujos trófico de biomasa para el arrecife mixto de tipo borde-barrera en la porción sur del Caribe Mexicano, mediante el programa Ecopath. El análisis trofico de este ecosistema dio una relación P/R de 0.87, un índice de conectancia alto de 0.35, un índice de reciclaje de Finn relativamente bajo de 10.1% de los flujos totales, y un valor bajo de ascendencia interna de 26%. Comparado con otros 6 modelos para ecosistemas arrecifales, el ecosistema arrecifal mixto de tipo borde-barrera en su porción Sur del Caribe Mexicano, aparece como uno de los sistemas mas maduros.

INTRODUCTION

Coral reefs are ecosystems found in warm, well-lit waters of tropical oceans. They show high spatial heterogeneity with a great variety of plants and animals, comparable in biodiversity with tropical forests (Connell, 1978). These systems are found in extensive zoogeographic areas of the Indo-Pacific and the Caribbean (Stoddart, 1969). The latter includes the coral reefs of Bermuda, Bahamas, Florida, the Gulf of Mexico and the Caribbean Sea.

The Atlantic coast of Mexico includes a large reef system, with an area of 1,500 km², consisting of fringing and barrier island reefs along the littoral coast of the state of Quintana Roo (Jordán, 1993) in the Yucatan Peninsula (Figure 1).

The system exhibits a clear zonation characterized by a lagoon of variable width and mean depth of 5 to 7 m, covered by seagrasses (*Thalassia testudinum*) and algae (*Halimeda* spp., *Udotea* spp., and *Penicillum* spp.), and inhabited by molluscs and fishes (*Gerres* spp., *Abudefduf* spp., *Acanthurus* spp., and *Sparisoma* spp.). Close to the back-reef, there are isolated colonies of alcyonarian and scleractinian corals reflecting a more consolidated substratum (Muñoz, 1992; Alvarez-Hernández, 1994). The back-reef on the shoreline includes the corals *Acropora palmata*, *A. cervicornis*, *Porites porites*, *Agaricia agaricites*, *A. teniufolia*, *Montastrea annularis*, as well as algae, sponges, molluscs, alcyonarians and an abundance of fishes (Muñoz, 1992; Alvarez-Hernández, 1994).

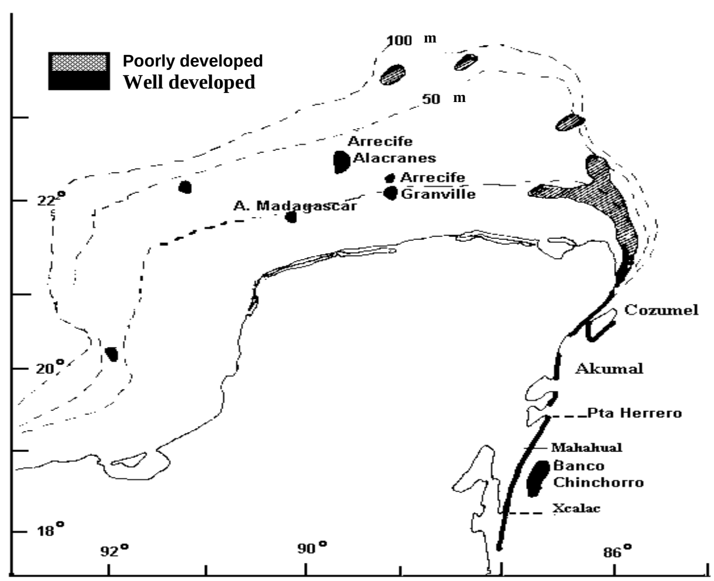

Figure 1: Map of the coral reef systems in the southern Mexican Caribbean (Taken from Chávez, 1994). [*Localización del arrecife de coral de tipo borde-barrera en el sur del Caribe Mexicano (tomado de Chávez, 1994)*].

The exposed fore-reef facing the open sea has a well consolidated substratum, and abundant and diverse coral communities marked by gradients in size, density and diversity. The crest is dominated by alcyonarians (octocorals, particularly plexaurides and gorgonians), together with resistant and fast-growing hermatipic corals such as *Acropora palmata* and *A. cervicornis*. At greater depths, large coral structures of *Montastrea* spp., *Colpophyllia* spp. and *Agaricia* spp., and a great variety of benthic fauna such as sea cucumbers, sponges, molluscs and algae together with larger fishes (*Epinephelus* spp., *Caranx* spp., *Acanthurus* spp., *Chromis* spp. and *Scarus* spp.), are found. Spur and groove systems may be found offshore, at depths of 20 - 25 m (Muñoz, 1992; Alvarez-Hernández, 1994).

The barrier can be divided into northern and southern sectors on the basis of structure, growth and anthropogenic use. The northern sector from Contoy Island to Ascension Bay is characterized by low relief with alcyonarian communities and algae followed by sponges and scleractinian corals (Jordán, 1979). The southern sector, extending from Ascension Bay to Xcalac, is characterized by massive formations of *Montastrea* sp. and *Diploria* sp. in the back-reef while the crest is dominated by hydrocorals and algae, with a well developed fore-reef. Lobster (*Panulirus argus*) and conch (*Strombus gigas*) are fished in both sectors: Tourism was not well-developed at the time of study (early-mid 1990s). Lobster (*Panulirus argus*) and conch (*Strombus gigas*) are fished in both sectors, while tourism is more intense in the north with less development in the south (César-Dáchary and Arnaiz-Burne, 1986).

The objective of this study was to construct a trophic model of a fringing reef typical of the southern sector (Figure 1).

Material and Methods

The southern part of this reef system has a length of about 190 km, with fringing reef, lagoon and barrier island lying on a narrow shelf (Ferre-D'amarre, 1985; Chávez and Hidalgo, 1988). The climate is warm-humid with annual precipitation ranging between 1,100-2,000 mm and mean water temperature of 27.5°C (Ferre-D'amarre, 1985). The oceanic current flows along the coast at speeds often greater than 4 knots. Due to the karstic nature of the Yucatan Peninsula, no rivers exist and fresh-water flows underground (Nolasco-Montero and Carranza-Edwards, 1988).

The Model

The Ecopath program (Christensen and Pauly, 1992; Pauly *et al.*, 2000) was used to construct a mass-balanced trophic model. The basic Ecopath equation is:

$$B_i * PB_i * EE - \sum_{j-1}^{n} B_j * QB_j * DC_{ji} - EX_i = 0$$

where B_i is the biomass of species i; PB_i is the production/biomass ratio for species i, EE is ecotrophic efficiency, QB_j is the consumption/biomass ratio and DC_{ji} the fraction of prey i in the average diet of predator j.

The required input data were obtained from published literature for the Mexican Caribbean and other regions of the Caribbean. Information was standardized to tons per km^2 of fresh weight for biomass ($t \cdot km^{-2}$) and $year^{-1}$ for the fluxes (P/B, Q/B). Different conversion factors were used for this purpose (Crisp, 1971). On the basis of the criteria of Opitz (1993), all species were grouped into 11 non-fish groups and 7 fish groups.

Input data

Primary production was estimated as the average of the total primary production of phytoplankton, microphytobenthos, zooxanthellae, macroalgae and seagrasses after Lewis (1981a) and De Jesús (1994).

Phytoplankton biomass was taken from Margalef (1973); benthic primary producers from Lewis (1981a) and De Jesús (1994); zooplankton from abundance data (Suárez *et al.*, 1991) converted to weight based on the average weight per group (M. Ornelas, Centro de Investigación y de Estudios Avanzados del IPN, Mexico, pers. comm.); sessile organisms including meiobenthos from Alcolado (1990); macrobenthos from coverage data of Jordán (1990), Muñoz (1992) and Tunnell *et al.* (1993) transformed after Lewis (1981b); molluscs from Aguirre (1988); echinoderms from Lewis (1981a); crustaceans from Glynn (1973); and birds and turtles from Polovina (1984). The biomass of cephalopods was left for estimation by Ecopath.

The fishes were divided into seven groups: a) Sharks and rays of the genera *Carcharinus*, *Ginglymostoma*, *Dasyatis*, and *Urolophus*; b) Sharks, scombrids and jacks of the genera *Rhizoprionodon*, *Sphyrna*, *Scomberomorus*, and *Caranx*; c) Groupers of the genera *Epinephelus* and *Serranus*; d) Schooling reef fish of the genera *Harengula*, *Opisthonema* and *Jenkinsia*; e) Carnivorous fishes of the genera *Lutjanus*, *Ocyurus* and *Priacanthus*; f) Herbivorous fishes of the genera *Abudefduf*, *Scarus* and *Acanthurus*; and g) Omnivorous fishes of the genera *Thalassosoma*, *Alutera* and *Stegastes*. Fish biomasses were determined from visual surveys by Garduño (1981, 1989), Tunnell *et al.* (1993), and Alvarez-Hernández (1994). Diet compositions for fish groups were taken from Randall (1967) and Claro (1990).

Production/biomass estimates were obtained from various sources: phytoplankton (Margalef, 1973); zooplankton, birds and turtles (Polovina, 1984); sessile organisms and echinoderms (Lewis, 1981b); and molluscs, crustacean and cephalopods from the equation relating growth to natural mortality (Pauly, 1980). Growth parameters for molluscs came from Díaz-Avalos (1989) and Solís-Ramírez (1994), crustacean (Arreguín-Sánchez and Chávez, 1985; Cabrera *et al.*, 1990), cephalopods (Solís and Chávez, 1986); fishes (Pauly, 1980), sharks and rays (Alvarez, 1988, Alvarez-Hernández and Arreguín-Sánchez, 1990); sharks (Alvarez-Hernández and Arreguín-Sánchez, 1992), scombrid (Cabrera, 1986), jacks (Claro, 1990), groupers (Arreguín-Sánchez *et al.*, 1987), reef fishes (Leonce, 1990; Claro, 1990), carnivores (Mexicano-Cíntora, 1985; Torres and Chávez, 1987), herbivores and omnivores (Claro, 1990).

Consumption/Biomass ratios for zooplankton, sessile organisms, birds and turtles were determined from Polovina (1984), for echinoderms from Optiz (1993), and for molluscs and cephalopods from the relationship of Pauly (1986) and Pauly *et al.* (1990). Sources of asymptotic weight (W_∞) were similar to those for P/B. For fishes, Q/B were estimated from W_∞, mean habitat temperature (T) and caudal fin aspect ratio (Palomares and Pauly, 1989; Pauly *et al.*, 1993). The annual mean temperature was 27°C (Jordán, 1979) and the fin aspect ratios were taken from photos (Randall, 1968) and video films.

Once the model was balanced and the ecosystem parameters estimated, we used the Ecoranger routine (Christensen and Pauly, 1996) to obtain the best fitting model. Ecoranger implements a semi-Bayesian approach in which parameters from the first balanced model are taken as initial values. Triangular distributions and the minimization of residuals as criterion for constraint were selected. It was decided that at least 3000 positives solutions were required to obtain parameter distributions and their modal values, assuming this solution is representative of a stable ecosystem model.

RESULTS AND DISCUSSION

The input parameters for each functional group are given in Table 1 and the diet compositions in Table 2. First attempts with Ecopath resulted in an unbalanced model due to EE values greater than one for some groups. The model was balanced applying small changes in some diets (considering diet composition as the input parameter of highest uncertainty), taking as criterion that values for Ecotrophic Efficiency should be less than unity.

Biomass decreased for echinoderms, sessile organisms, mollusks and crustaceans. This could be due to the sampling technique used (coverage), which overestimates larger organisms and underestimates smaller animals (Anon., 1984). It was necessary to increase the biomass of small and cryptic fishes and reduce the biomass of sharks because the technique used (visual census) tends to overestimate biomass for some groups (Opitz, 1993; Venier and Pauly, 1997).

The estimated fish biomass for the southern reef was 204.6 $t \cdot km^{-2}$, which is higher than the 163 $t \cdot km^{-2}$ and 170 $t \cdot km^{-2}$ reported for reefs in the Virgin Islands (Randall, 1963) and the Gulf of Batabanó, Cuba (Claro, 1990), respectively. However, biomass was similar to the 209 $t \cdot km^{-2}$ reported for the Great Barrier Reef of Australia (Talbot and Goldman, 1972).

In general, excellent descriptive information of the coral reef benthic fauna is available; however, more quantitative information of the trophic ecology of the associated invertebrates is required.

The trophic analysis of this reef ecosystem (Table 1, Figure 2) showed similar results to those found by Polovina (1984), Opitz (1993), Aliño *et al.* (1993), Arias-González (1994) and

Table 1: Parametrization of the model for a coral reef in the southern Mexican Caribbean. Accumulated biomass for detritus was 855.9 t·km^{-2}. Unassimilated food proportion was assumed as 0.2 for all consumers. P/B: production/biomass; Q/B: consumption/biomass; EE: ecotrophic efficiency; TL: trophic level; Omn.: omnivory index; Resp.: respiration; Assim.: assimilation. Values in brackets were estimated by Ecopath. [*Parámetros de entrada usados para la construcción de un arrecife de coral de tipo borde-barrera en el sur del Caribe Mexicano. Biomasa acumulada para detritos fue de 855.9 t·km^{-2}. Se supuso una proporción de 0.2 de alimento no asimilado para todos los consumidores. P/B=Producción/Biomasa, Q/B=Consumo/Biomasa, EE=Eficiencia Ecotrófica*].

Group No.	Group Name	Biomass (t·km^{-2})		P/B (year^{-1})		Q/B (year^{-1})		EE	Catch (t·km^{-2})	TL	Flow to Detritus (t·km^{-2})	Net Efficiency	Omn.	Resp.	Assim.
		initial	final	initial	final	initial	final								
1	Sharks and rays	0.40	0.40	0.12	0.13	7.30	5.70	*(0.87)*	0.030	*(3.634)*	*(0.1)*	*(0.020)*	*(0.189)*	*(0.2)*	*(0.2)*
2	Sharks/scombr./jacks	3.40	3.40	0.55	0.53	9.42	8.49	*(0.70)*	0.030	*(3.495)*	*(0.6)*	*(0.079)*	*(0.267)*	*(2.1)*	*(2.2)*
3	Groupers	2.80	2.80	0.39	0.48	4.00	3.74	*(0.58)*	0.010	*(3.777)*	*(0.2)*	*(0.115)*	*(0.094)*	*(0.7)*	*(0.8)*
4	Schooling reef fishes	36.00	33.00	1.55	1.24	15.50	14.66	*(0.57)*	-	*(3.057)*	*(15.3)*	*(0.124)*	*(0.365)*	*(43.2)*	*(49.4)*
5	Carniverous fish	47.50	50.00	1.20	1.25	9.80	6.63	*(0.66)*	0.600	*(2.983)*	*(12.4)*	*(0.142)*	*(0.354)*	*(31.0)*	*(36.1)*
46	Herbiverous fish	81.90	99.00	1.44	1.69	31.00	31.65	*(0.32)*	-	*(2.003)*	*(52.8)*	*(0.051)*	*(0.004)*	*(181.4)*	*(191.2)*
7	Omniverous fish	8.00	16.00	1.60	1.97	13.70	13.62	*(0.81)*	-	*(2.508)*	*(2.5)*	*(0.152)*	*(0.359)*	*(7.6)*	*(9.0)*
8	Birds	0.02	0.02	5.40	10.68	80.00	73.30	*(0.27)*	-	*(4.017)*	-	*(0.083)*	*(0.027)*	*(0.1)*	*(0.1)*
9	Sea turtles	0.07	0.07	0.20	1.52	3.50	3.57	*(0.22)*	-	*(2.951)*	-	*(0.073)*	*(0.615)*	-	-
10	Cephalopods	10.00	10.00	3.40	2.63	11.40	9.43	*(0.36)*	0.230	*(3.349)*	*(0.2)*	*(0.355)*	*(0.153)*	*(0.5)*	*(0.7)*
11	Echinoderms	605.00	733.00	1.20	0.87	4.00	2.37	*(0.69)*	-	*(2.081)*	*(57.4)*	*(0.403)*	*(0.075)*	*(103.6)*	*(173.4)*
12	Crustaceans	250.00	224.00	2.75	2.18	10.00	9.94	*(0.62)*	0.220	*(2.693)*	*(79.9)*	*(0.343)*	*(0.319)*	*(126.6)*	*(192.7)*
13	Molluscs and worms	510.00	364.00	3.00	3.90	15.00	13.08	*(0.65)*	0.830	*(2.152)*	*(224.0)*	*(0.254)*	*(0.138)*	*(491.0)*	*(658.0)*
14	Sessile animals	907.00	842.00	1.48	1.54	9.00	7.35	*(0.78)*	-	*(2.000)*	*(183.4)*	*(0.217)*	-	*(520.4)*	*(664.8)*
15	Zooplankton	17.50	41.00	45.00	30.90	165.00	158.62	*(0.99)*	-	*(2.098)*	*(68.1)*	*(0.412)*	*(0.098)*	*(118.5)*	*(201.6)*
16	Benthic producers	1641.00	1641.00	13.25	13.25	-	-	*(0.47)*	-	*(1.000)*	*(961.2)*	-	-	-	-
17	Phytoplankton	47.00	47.00	70.00	70.00	-	-	*(0.95)*	-	*(1.000)*	*(59.3)*	-	-	-	-
18	Detritus	600.00	600.00	-	-	-	-	-	-	*(1.000)*	-	-	*(0.372)*	-	-

Table 2: Diet composition for the functional groups of the coral reef ecosystem in the southern Mexican Caribbean showing proportion of each prey (row) comprising average diets of predator (column). [*Matriz presa / predador mostrando la composición de las dietas para los principales grupos en el ecosistema de coral de tipo borde-barrera en el sur del Caribe Mexicano*].

		Predator														
Fct. Group	**Prey**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
1	Phytoplankton	0.597	0.055	0.001	0.157	0.091	-	-	-	0.009	-	0.020	-	0.204	-	-
2	Benthic producers	-	0.426	0.493	0.180	0.695	-	0.377	-	0.983	0.352	-	-	-	-	-
3	Zooplankton	0.089	-	0.002	0.076	0.003	0.197	-	-	0.003	0.105	0.049	-	0.289	0.103	-
4	Sessile Animals	-	-	0.093	0.122	0.074	-	0.111	-	-	0.063	0.042	-	0.044	-	0.023
5	Molluscs worms	-	-	0.045	0.194	0.003	0.542	0.052	-	-	0.141	0.200	-	0.191	0.018	0.258
6	Crustaceans	-	-	-	0.041	-	0.156	0.291	-	-	0.045	0.202	0.421	0.230	-	0.181
7	Echinoderms	-	-	0.005	0.180	-	-	0.030	-	-	0.045	0.170	-	-	0.049	0.008
8	Cephalopods	-	-	-	-	-	0.095	-	-	-	-	-	-	-	0.049	0.018
9	Sea Turtles	-	-	-	-	-	-	0.044	-	-	-	-	-	-	-	-
10	Birds	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	Herbivorous fish	-	-	-	-	-	-	-	0.020	-	0.016	0.077	0.099	-	0.345	0.056
12	Omnivorous fish	-	-	-	-	-	-	0.047	0.019	-	0.015	0.015	-	-	0.099	0.082
13	Carnivorous fish	-	-	-	-	-	0.006	0.049	0.116	-	-	0.014	0.469	-	0.172	0.178
14	Groupers	-	-	-	-	-	0.001	-	-	-	-	0.001	0.012	-	-	0.011
15	Clupeoids	-	-	-	-	-	0.003	-	0.845	-	0.002	-	-	0.042	0.125	0.158
16	Scombridae/Sharks	-	-	-	-	-	-	-	-	-	-	-	-	-	0.040	0.027
17	Sharks	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18	Detritus	0.314	0.519	0.361	0.050	0.134	-	-	-	0.005	0.216	0.211	-	-	-	-

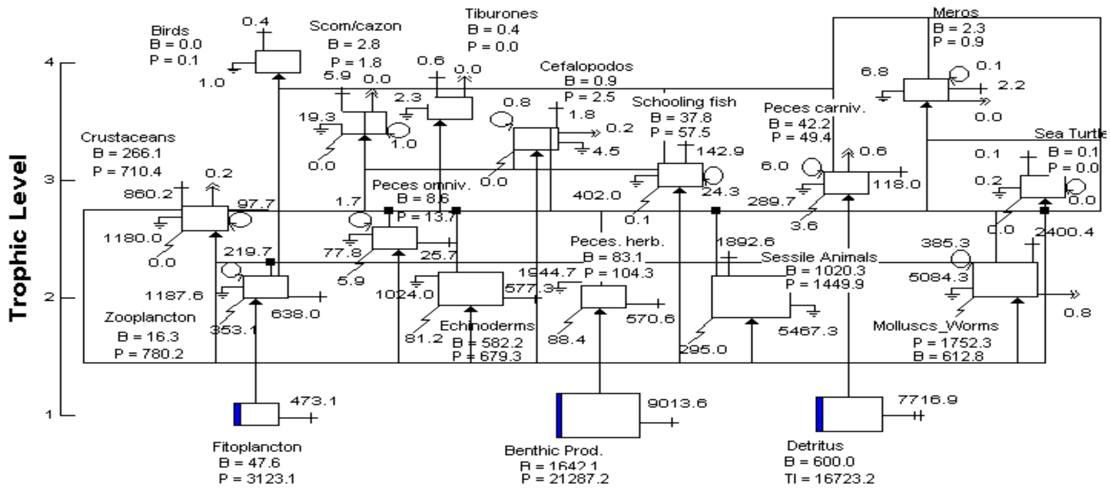

Figure 2: Trophic flow diagram of the ecosystem model for a coral reef in the southern Mexican Caribbean. Flows are in t·km^{-2}·year^{-1}. [*Diagrama de bloques ilustrando los principales flujos de biomasa en un arrecife de coral de tipo borde-barrera en el sur del Caribe Mexicano. Flujos en t·km^{-2}·año^{-1}*].

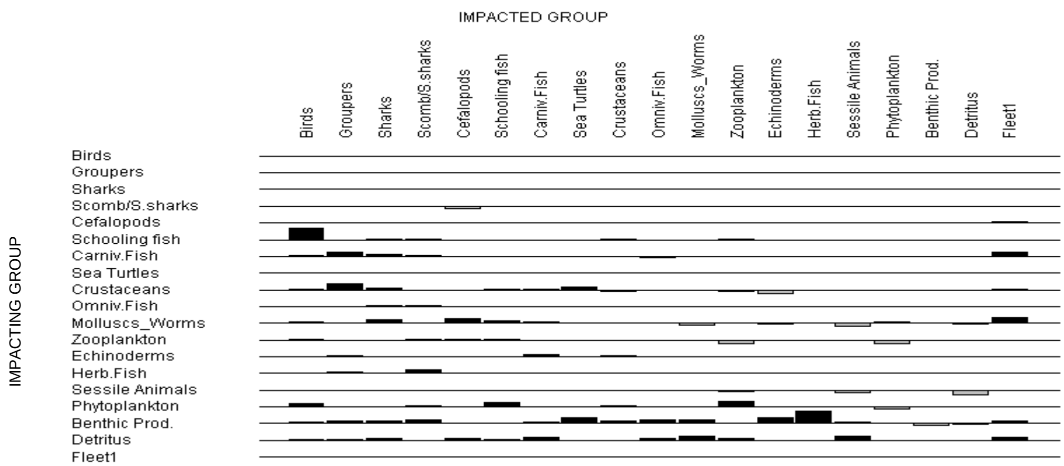

Figure 3: Mixed trophic impacts in the coral reef model of the southern Mexican Caribbean. [*Impactos tróficos relativos entre los principales componentes del ecosistema del arrecife de coral de tipo borde-barrera en el sur del Caribe Mexicano*]

Venier and Pauly (1997), particularly in form of high values of EE, indicating that predation is an important mechanism for biomass regulation. Production is based mainly on detritus and benthic autotrophic organisms. The trophic web is characterized by a number of trophic links with short cycles to obtain an effective recycling of matter and energy.

Figure 3 illustrates mixed impacts (black = positive; gray = negative) of increase in biomass of each group on the others. The results indicate that benthic producers play an important role, interacting with many other groups. The greatest trophic impacts are by groups of the lower trophic levels.

From the overall energetic point of view, the production to respiration ratio (P/R) of the present study compared well with others (Lewis, 1981a; Kinsey, 1985). The ecosystem presented here and that of the Virgin Islands presented values less than one, suggesting a heterotrophic system, with a strong tendency for storage of organic matter. Other ecosystems had values above one, behaving autotrophically (Odum, 1969). Moreover, the overall P/B ratio of the reef studied here had a low value (P/B= 4.7 $year^{-1}$), indicating a low biomass accumulation rate.

The connectance index (number of actual trophic links in relation to the number of potential links) was high (0.35), suggesting a diversity of functional groups (Pimm, 1982). The Finn cycling index (FCI), which expresses the proportion of flows that are recycled (Finn, 1976), was 10.1%, suggesting a relatively low internal stability (Odum, 1969). This may reflect a degree of stress in the system (Ulanowicz, 1986; Baird *et al.*, 1991; Christensen and Pauly, 1996).

From the various global indices for comparison of ecosystem development, the Relative Ascendancy (A/C %) (Ulanowicz, 1986; Kay *et al.*, 1989) excludes the influence of total flows (T) over the Ascendancy (A) and development capacity (C) within the ecosystem (Mann *et al.*, 1989), which is considered a suitable index to evaluate ecosystem stability (Rutledge *et al.*, 1976). Ascendancy presents the same behavior as those reported by other authors (Baird *et al.*, 1991; Christensen, 1994), i.e., it decreases as maturity increases, (Christensen, 1995). The model here shows a low A/C, suggesting a high level of system maturity. The general literature suggests greater maturity for the Caribbean (e.g., Stheli and Wells, 1971), in that this system has a relative age of 50 to 60 million years compared to 25 million for the Pacific.

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Trophic dynamics of a mangrove ecosystem in Celestun Lagoon,Yucatan Peninsula, Mexico [*Dinámica trófica la Laguna de Celestun, un ecosistema de manglar en la Península de Yucatán, México*]

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ABSTRACT

A trophic model of an estuarine mangrove ecosystem in Celestun Lagoon, Yucatan Peninsula, Mexico, was constructed using the Ecopath approach and software. The objective was to evaluate the importance of vascular plant detritus to the heterotrophic community and to determine holistic ecosystem properties, as required to evaluate mangrove production and its ecological role as a nursery and feeding ground. Based on analysis of stomach contents, 32 fish species were grouped into nine trophic groups, omnivores, phytoplankton and zooplankton feeders, piscivorous and five other groups that include microcrustaceans as an important food source. Overall, the model consisted of 19 functional groups, including primary producers and three levels of carnivores. Detritus was important for the benthic producers, which is a major food for many fish groups. Direct fisheries impact is low, but this ecosystem is a critical habitat for the juveniles of commercial fish species that use the lagoon for food and shelter. Biomass export was considered only for piscivores. The food web consists of short trophic chains with production transferred mainly through microcrustaceans and phytoplankton. It is concluded that this model is a potential tool for use in the management of the Celestun Lagoon.

RESUMEN

Este trabajo es un intento por construir un modelo conceptual de la red alimentaria de una comunidad de manglar estuarino de la laguna de Celestun, un ecosistema tropical localizado en la península de Yucatán, usando el modelo Ecopath. El objetivo es evaluar la importancia del detritus de plantas vasculares en la comunidad heterotrófica y determinar algunas propiedades del sistema. Este conocimiento es importante para evaluar la producción del manglar y su papel ecológico como un área de crianza y alimentación. Los contenidos estomacales de 32 especies de peces fueron agrupados por sus similaridades tróficas en nueve categorías: Omnívoros y consumidores de fitoplancton y zooplancton, piscivoros y otros cinco grupos que incluyen microcrustáceos como una importante fuente de alimento. El ecosistema está constituido por 19 grupos funcionales con productores primarios y tres niveles de carnívoros. El detritus es importante para los productores bentónicos, los cuales, junto con la comunidad pelágica es el alimento principal para la mayoría de los grupos de peces que usan el manglar para protección y alimento. En el mismo sentido, la exportación sólo fue considerada para piscivoros. La red trófica del ecosistema sugiere cadenas tróficas cortas donde la producción es transferida a través de los microcrustáceos y fitoplancton. Se concluye que este modelo es una herramienta potencial para el manejo de la laguna de Celestun.

INTRODUCTION

Knowledge of trophic fluxes and the efficiency of energy assimilation, transfer and dissipation is basic to understanding ecosystem structure and functioning (Baird and Ulanowicz, 1993). Studies of trophic fluxes and ecosystem functioning exist for Celestun lagoon (Chavez *et al*., 1993) and the adjacent Campeche Bank (Vega *et al*., 1993). This study elaborates on these, concentrating on energy transfer within the fish community of the mangrove ecosystem of Celestun Lagoon to enable quantification of its ecological value as a nursery area and feeding ground.

MATERIAL AND METHODS

The Celestun Lagoon ecosystem

Located on the Yucatan Peninsula between 20°45' and 20°58' N and 90°15' and 90°25' W, the area of Celestun Lagoon is approximately 28 km^2, with a water volume of about 14 x 10^6 m^3 (Fig. 1). It is connected to the open sea in its southern part (Herrera, 1985, 1988). The climate is tropical (mean annual temperature > 26.2°C), with an average annual precipitation of 790 mm in January (García, 1988). The mean salinity is 24 and ranges from 37 at the lagoon mouth to approximately 6 in its innermost parts.

The coast is lines by a 150 m-wide zone of mangrove, i.e., *Rhizophora mangle*. Within the

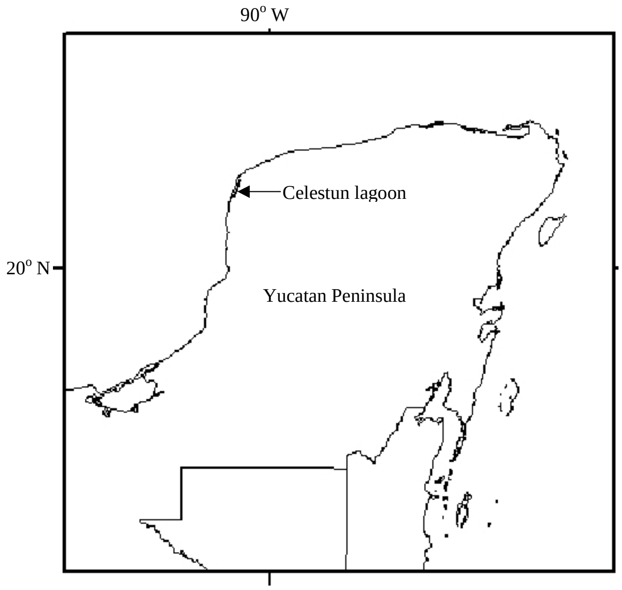

Figure 1: Location of Celestun Lagoon on the Yucatan Peninsula of Mexico. [*Localización de la Laguna de Celestún, Península de Yucatán, México*].

lagoon the dominant mangrove species are *Laguncularia racemosa* at the head; *Rhizophora mangle* and *Avicennia germinans* in the central area and *Avicennia germinans* near the mouth of the lagoon (Sanchez-Argüelles, 1994). The mangrove fish community, dominated by anchovies (Engraulidae) and morrajas (Gerreidae), is composed of 71 species, mostly juveniles using the lagoon for food and shelter.

The Ecopath approach and software

The Ecopath approach and software were first developed by Polovina (1984) to estimate biomass of various species or groups of an aquatic ecosystem, and later improved by D. Pauly and V. Christensen (Christensen and Pauly, 1992; Pauly *et al.*, 1993, 2000) through the inclusion of various routines implementing ecological theory, notably that developed by Ulanowicz (1986) for the analysis of ecosystem fluxes. Detailed description of Ecopath can be found in Christensen and Pauly (1992) and Pauly *et al.* (2000).

In Ecopath, mass-balance between groups is assumed, and their interactions are described by linear equations (Polovina and Ow, 1983; Christensen and Pauly, 1992; Pauly *et al.*, 2000). The basic equation in the system is defined by equation 1:

$$B_i * PB_i * EE - \sum_{j-1}^{n} B_j * QB_j * DC_{ji} - EX_i = 0 \quad ...1)$$

where B_i is biomass for species/group (i), P_i/B_i is production/biomass ratio, EE_i is ecotrophic efficiency, QB_j is consumption/biomass ratio for predator j, DC_{ji} the fraction of prey (i) in the average diet of predator (j), and EX_i is export out of the system (including fisheries catches) for species/group i.

Input data and parametrization

For model construction, 32 fish species occurring in Celestun lagoon were aggregated into nine functional groups based on trophic similarity determined from stomach contents analysis. Other groups such as phytoplankton, zooplankton, molluscs, microcrustaceans, polychaetes, macrophytes and detritus were also incorporated, leading to a total of 19 trophic groups (Table 1), and a diet matrix as described in Table 2.

Input data were biomass (B), standardized as wet weight ($t \cdot km^{-2}$), and production/biomass (P/B) and consumption/biomass (Q/B) rates per year. The ecotrophic efficiency (EE), i.e., the fraction of production that is transferred through the trophic web or exported, was left for the model to estimate.

Phytoplankton primary production was determined using the dark and clear oxygen bottle technique (Strickland and Parsons, 1972). Biomasses of benthos and fish were determined from bimonthly samples taken over two years (1992-1994) in the mangrove zone. Benthic productivity was evaluated with the Robertson empirical equation (Rainer, 1982), and P/B ratios were obtained by averaging the values reported by Chávez, *et al.* (1993) and Vega *et al.* (1993). For benthic producers, the indices reported by Yañez-Arancibia and Day (1988) for adjacent regions were used. Zooplanktonic biomass was obtained from Batllori (1988), while the P/B and Q/B ratios were from Chavez *et al.* (1993) for the same area.

For fishes, consumption rates (Q/B) were computed from the empirical model of Palomares and Pauly (1989) described by equation 2 :

$$\ln Q/B = -0.1775 - 0.2018 \ln W_\infty + 0.6121 \ln T + 0.5156 \ln A + 1.26 f \quad ...2)$$

where W_∞ is the asymptotic weight in grams, T is the mean habitat temperature in °C, A is the aspect ratio of the caudal fin calculated (as $A = h^2/s$) from the fin height (h) and surface area (s), and f is the food type (0 for carnivores and 1 for herbivores).

Production/Biomass ratios were taken as equivalent to total mortality (Z) (Pauly *et al.*, 2000), assuming steady-state of the ecosystem (Allen, 1971). Fisheries catches were not included, but this was, at least in part, compensated for by a fish biomass export of 0.26 $t \cdot km^{-2} \cdot year^{-1}$, a relatively high value because most species are juveniles and use the mangrove ecosystem as nursery area, then leave. The assigned catch value to all the components was zero.

To balance the model, it was necessary to adjust P/B and Q/B of the fish groups due to their excessively high EE values (>1) in the first run of the model. This might have been caused by the fact that initial input for Q/B and P/B applied to the adults, when in reality the mangrove is used by juveniles with growth and mortality rates higher than those of adults. Discrepancies between zooplankton and microcrustaceans biomass were also found, and the values adjusted correspondingly (Table 1).

Once the model was balanced, we used the Ecoranger routine (Pauly *et al.*, 2000) to obtain the 'best-fitting' model. Ecoranger consists of a semi-Bayesian approach in which parameters from the first balanced model provide 'prior' distributions. Triangular distributions were assumed for all parameters and the minimization of residuals was used as criterion. It was decided that at least 3000 positives solutions were required to obtain parameter distributions and their modal values.

RESULTS

Highest values of P/B and Q/B correspond to the groups at the base of the trophic web, e.g., phytoplankton, zooplankton, insects, and micro- and macrocrustaceans (Table 1). The highest values of EE occurred with the microcrustacean (0.945) and phytoplankton (0.951). The groups with the lowest EE values include fishes (Table 1), most likely an effect of the fisheries catches not having been included.

Trophic flows within the system are presented in a three-dimensional pyramid (Figure 2). The highest proportions of the fluxes come from the herbivore level (50%) and first carnivore level (35%). Similarly, the highest transfer efficiency (17.4%) occurred at the first trophic level (herbivore and detritivore).

Impacts of direct and indirect interactions (including competition) among components of the system were evaluated using the mixed trophic impact routine (Ulanowicz, 1990; Christensen and Pauly, 1992; Pauly *et al.*, 2000). Figure (3) shows the positive and negative impacts of an increase in the biomass of each group on the others. The groups with the strongest positive impact on others include detritus, macrophytes, phytoplankton and microcrustaceans. It can be seen that apex predators (piscivorous and 'other fishes') have a negative impact on the other fish groups.

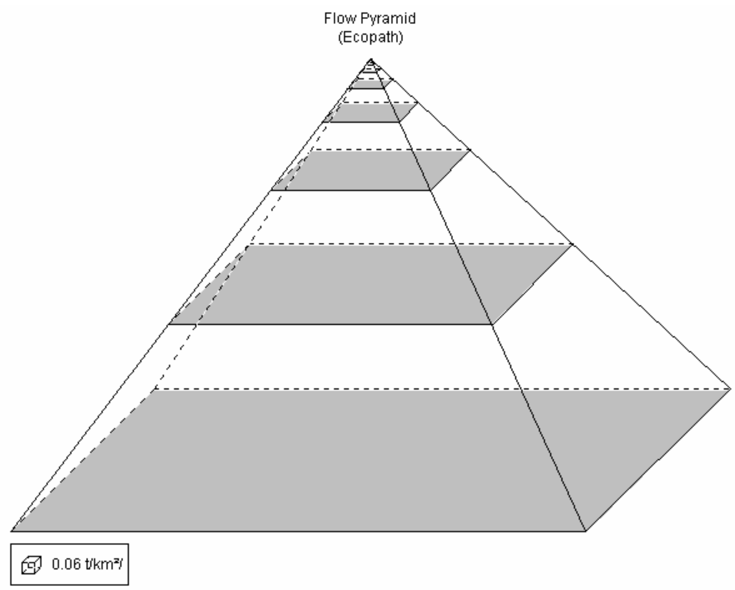

Figure 2: Trophic fluxes represented as a flow pyramid for first order consumers (Trophic Level II) to top predators (Trophic Level V). The volume of each compartment is proportional to the total throughput of that level ($t \cdot km^{-2} \cdot year^{-1}$) and the top angle to the geometric mean of the transfer efficiencies between trophic levels. [*Flujos tróficos representados como una pirámide de flujos, desde consumidores de primer orden (Nivel Trófico II) hasta predadores tope (Nivel Trófico V). El volúmen de cada compartimento es proporcional al total de flujos de cada nivel ($t \cdot km^{-2} \cdot año^{-1}$) y el ángulo en el extremo distal a la media geométrica de las eficiencias de transferencia entre niveles tróficos*].

The flow diagram is presented in Figure (4). The groups are placed on the Y-axis according to their trophic levels as estimated by Ecopath. Here, top predators (piscivores) have a lower trophic level (3.6) than in adjacent systems (Chavez *et al.*, 1993; Vega *et al.*, 1993). Flows to detritus are between 1.4 $t \cdot km^{-2} \cdot year^{-1}$ for omnivores and 199.0 $t \cdot km^{-2} \cdot year^{-1}$ for zooplankton. With regards to cannibalism, flows with a value of 0.3 $t \cdot km^{-2} \cdot year^{-1}$ correspond to insects and 17.2 $t \cdot km^{-2} \cdot year^{-1}$ to fishes.

Table 1: Parameterization of the mass balanced model for a mangrove ecosystem trophic model of Celestun Lagoon, Yucatan Peninsula, Mexico. Values in brackets were estimated by Ecopath. [*Parametrización de un modelo trófico de un ecosistema de la laguna de Celestun, Península de Yucatán, México*].

Group Name	Biomass	P/B	Q/B	EE	Flow to detritus	Net Efficiency	Trophic level	Omnivory index	Respiration	Assimilation
1. Micro-zoo-phyto	0.007	3.12	7.45	*(0.125)*	*(0.030)*	*(0.523)*	*(2.883)*	*(0.183)*	*(19.908)*	*(41.780)*
2. Phyitoplankton-feed	0.001	2.62	5.97	*(0.160)*	*(0.002)*	*(0.549)*	*(2.421)*	*(0.272)*	*(1.272)*	*(2.818)*
3. Microcrust.-phyto	0.22	2.57	8.51	*(0.438)*	*(0.001)*	*(0.377)*	*(2.818)*	*(0.199)*	*(0.932)*	*(1.498)*
4. Microcrust.-mollusc	0.006	2.52	8.37	*(0.077)*	*(0.025)*	*(0.376)*	*(3.008)*	*(0.253)*	*(26.601)*	*(42.654)*
5. Microcrust.-feeding	0.009	3.09	7.09	*(0.262)*	*(0.032)*	*(0.545)*	*(3.049)*	*(0.171)*	*(22.308)*	*(49.006)*
6. Omnivores	0.47	3.06	8.97	*(0.426)*	*(0.001)*	*(0.426)*	*(2.486)*	*(0.266)*	*(1.564)*	*(2.727)*
7. Piscivores	0.004	2.77	6.13	*(0.453)*	*(0.011)*	*(0.565)*	*(3.553)*	*(0.413)*	*(8.621)*	*(19.812)*
8. Other fish	0.012	3.33	8.23	*(0.752)*	*(0.030)*	*(0.506)*	*(3.033)*	*(0.577)*	*(40.057)*	*(81.049)*
9. Zooplankton	0.010	13.75	69.91	*(0.650)*	*(0.195)*	*(0.246)*	*(2.010)*	*(0.010)*	*(438.651)*	*(581.651)*
10. Zooplankton-feeding	0.10	3.76	8.47	-	-	*(0.555)*	*(3.085)*	*(0.068)*	*(0.762)*	*(0.610)*
11. Microcrust-zoo	0.20	3.58	10.97	*(0.707)*	-	*(0.408)*	*(2.998)*	*(0.031)*	*(1.687)*	*(1.755)*
12. Insects	0.001	15.54	51.93	*(0.808)*	*(0.008)*	*(0.374)*	*(2.010)*	*(0.010)*	*(15.862)*	*(25.342)*
13. Microcrustaceans	0.009	15.75	50.51	*(0.945)*	*(0.095)*	*(0.390)*	*(2.040)*	*(0.038)*	*(213.045)*	*(349.125)*
14. Macrocrustaceans	0.004	4.01	14.86	*(0.877)*	*(0.014)*	*(0.337)*	*(2.601)*	*(0.450)*	*(31.906)*	*(48.146)*
15. Molluscs	0.026	1.84	9.58	*(0.845)*	*(0.058)*	*(0.240)*	*(2.222)*	*(0.175)*	*(154.336)*	*(203.096)*
16. Polichaeta	0.010	3.84	13.48	*(0.664)*	*(0.039)*	*(0.356)*	*(2.000)*	-	*(67.704)*	*(105.144*
17. Phytoplankton	0.007	65.55	-	*(0.951)*	*(0.023)*	-	*(1.000)*	-	-	-
18. Benthic producers	0.153	7.45	-	*(0.096)*	*(1.033)*	-	*(1.000)*	-	-	-
19. Detritus	*(2.400)*	-	-	*(0.642)*	-	-	*(1.000)*	*(0.444)*	-	-

Table 2: Diet matrix showing proportional diet composition for a mangrove ecosystem trophic model of the Celestun Lagoon, Yucatan Peninsula, Mexico. [*Matriz presa / predador mostrando la composición de las dietas para un modelo trófico de un ecosistema de la laguna de Celestun, Península de Yucatán, México*].

	Predator															
Prey	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
1. Micro-zoo-phyto.	-	-	-	-	-	-	0.11	-	-	-	-	-	-	-	-	-
2. Phytoplankton-feeding	-	-	-	-	-	-	0.01	-	-	-	-	-	-	-	-	-
3. Microcrust.-phyto.	-	-	-	-	-	-	0.01	-	-	-	-	-	-	-	-	-
4. Microcrust.-mollusc	-	-	-	-	-	-	0.05	-	-	-	-	-	-	-	-	-
5. Microcrust.-feeding	-	-	-	-	-	-	0.16	0.03	-	-	-	-	-	-	-	-
6. Omnivores	-	-	-	-	-	-	0.02	-	-	-	-	-	-	-	-	-
7. Piscivores	-	-	-	-	-	-	0.07	0.03	-	-	-	-	-	-	-	-
8. Other fish	0.02	-	0.01	0.03	0.07	-	0.12	0.17	-	0.07	-	-	-	0.06	-	-
9. Zooplankton	0.24	0.07	0.07	0.01	0.05	0.10	0.02	0.11	0.01	0.82	0.31	-	-	-	0.22	-
10. Zooplankton-feeding	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11. Microcrust.-zoo	-	-	-	-	-	-	-	0.005	-	-	-	-	-	-	-	-
12. Insects	0.01	-	0.02	-	0.02	-	0.02	0.05	-	-	-	0.01	-	-	-	-
13. Microcrustaceans	0.54	0.20	0.68	0.33	0.65	0.37	0.25	0.24	-	0.11	0.63	-	-	0.12	-	-
14. Macrocrustaceans	0.01	0.02	-	0.09	0.05	-	0.07	0.04	-	-	-	-	-	-	-	-
15. Molluscs	0.01	-	-	0.36	-	-	-	0.04	-	-	-	-	-	0.29	-	-
16. Polychaetes	-	0.11	-	0.01	0.08	-	0.02	0.01	-	-	0.03	-	0.04	-	-	-
17. Phytoplankton	0.16	0.56	0.19	-	0.05	0.08	-	0.13	0.28	-	-	0.15	0.28	0.11	0.32	0.05
18. Benthic producers	0.01	0.04	0.03	0.04	0.03	0.45	0.07	0.08	-	-	0.03	0.34	-	-	0.23	0.19
19. Detritus	-	-	-	0.13	-	-	-	0.06	0.71	-	-	0.50	0.68	0.42	0.23	0.76

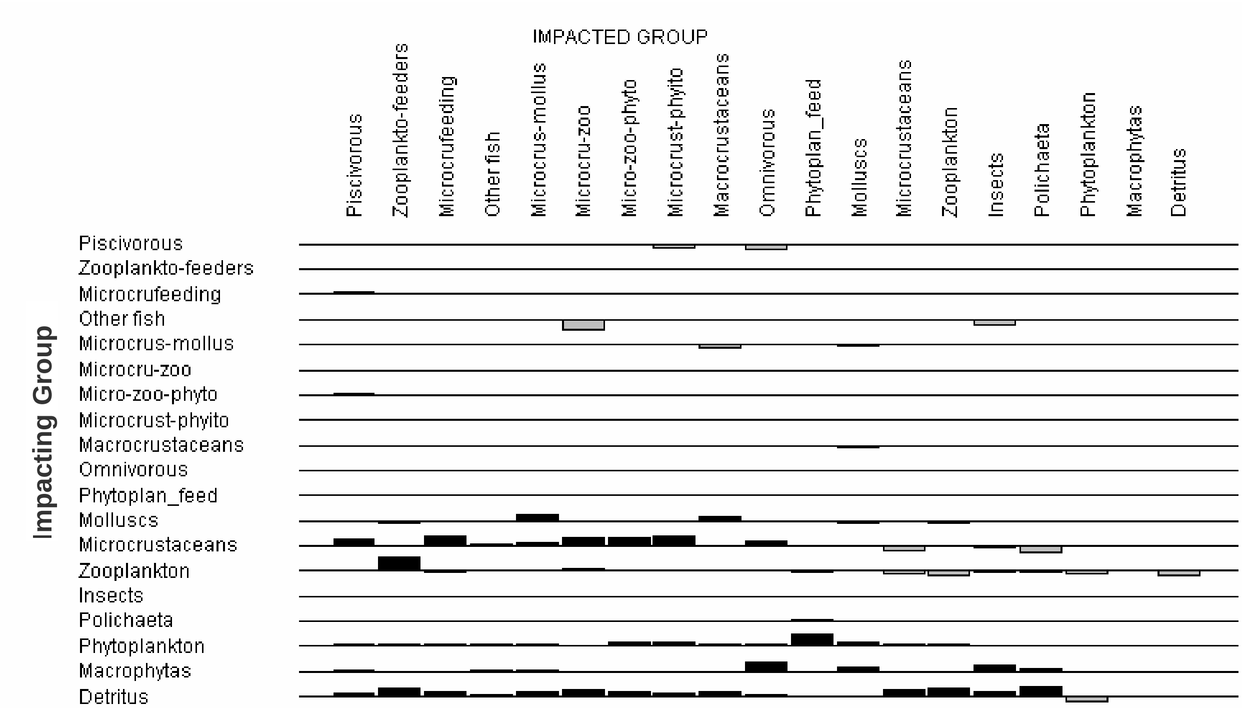

Figure 3: Trophic mixed impacts estimated through the Leontief matrix for the ecosystem of Celestun lagoon, Yucatan Peninsula. Positive impacts are above the line, negative impacts below the line. [*Impactos tróficos estimados a través de la matriz de Leontief para el ecosistema de la laguna de Celestun, Península de Yucatán. Impactos positivos sobre la línea; impactos negativos bajo la línea*].

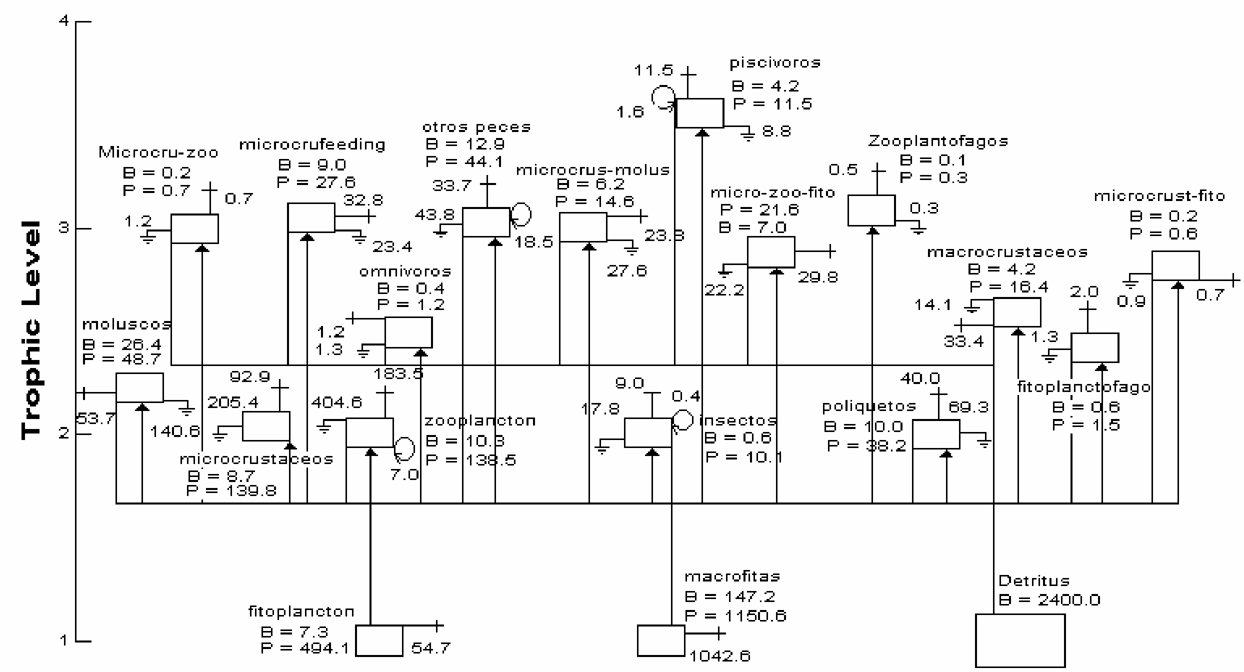

Figure 4: Trophic box model illustrates the main flows of biomass for the ecosystem of Celestún Lagoon, Yucatan Peninsula, Mexico. [*Modelo trófico de bloques ilustrando los principales flujos de biomasa para el ecosistema de la Laguna de Celestún, Península de Yucatán, México*].

DISCUSSION

This study complements an earlier attempt at understanding, in energetic terms, the fundamentals of structure and function of Celestun Lagoon as a fish nursery. Again, Ecopath appears to be a useful tool for understanding trophic interactions, especially because it enables comparisons between different ecosystems using a common currency (Christensen, 1995).

The present study should enable us to focus future research activities on this important area, and improve our understanding of how this system works. The principal advantage of this model presented here, compared to earlier analyses, is that it was derived using trophic information based on stomach content analysis of the fish species actually occurring in Celestun lagoon. The problem in obtaining a balanced model lay in obtaining growth parameters for the juveniles of various fish species, for which fisheries catches were lacking, and whose energy requirements are different from those of the adults. We hope that the next version of this model will have overcome these deficiencies.

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Trophodynamic ecology of two critical habitats (seagrasses and mangroves) in Términos Lagoon, southern Gulf of Mexico. [*Ecología trofodinámica de dos hábitats críticos (pastos marinos y manglares) en la Laguna de Términos, sur del Golfo de México*]

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ABSTRACT

Términos Lagoon is the largest estuarine system in the southern Gulf of Mexico. Its importance as a nursery area for a number of fish and invertebrate species, many of them of commercial interest, is well documented. Particularly, mangrove and seagrasses are considered to be critical habitats. This contribution presents a mass-balanced trophic model of these critical habitats constructed with Ecopath, and which we expect to provide the basis for testing various hypotheses on the functioning of these critical habitats. Total system throughput was 9.47 $t{\cdot}km^{-2}{\cdot}year^{-1}$ (wet weight). Detritus in the form of mangrove leaves amounted to 5,797 $t{\cdot}km^{-2}{\cdot}year^{-1}$, and accounted for 82% of the total flows in the system, and supported nearly 90% of the components of the critical habitats.

RESUMEN

La Laguna de Términos es el sistema estuarino de mayor magnitud al sur del Golfo de México. Su importancia como zona de protección y crianza de una importante cantidad de especies, incluyendo muchas de interés comercial, este bien documentado. De manera particular, las comunidades asociados a manglares y pastos marinos han sido particularmente señaladas como hábitats críticos. En este documento se presenta un modelo de flujos tróficos sobre estas comunidades, construido con el modelo Ecopath, el cual se pretende sirva de elemento base para probar hipótesis relacionadas con la función de estos hábitats críticos. Los flujos totales del sistema fueron estimados en 9.47 $t{\cdot}km^{-2}{\cdot}año^{-1}$. El detritus proveniente del manglar fue considerado como importación al detritus de los sistemas estudiados con un ingreso de 5,797 $t{\cdot}km^{-2}{\cdot}año^{-1}$, donde el 82% de los flujos totales fueron originados. Casi el 90% de los componentes de los hábitats críticos estudiados son dependientes del detritus.

INTRODUCTION

The structural and functional characteristics of aquatic ecosystems modulate the dynamics of their communities. This is well documented for the southern Gulf of Mexico at the ecosystem level (Yáñez-Arancibia and Day, 1988), the community level (Yáñez-Arancibia, 1985), and at the habitat-population level (Yáñez-Arancibia *et al.*, 1993). The different life history stages of a species are thus related to specific environmental characteristics and habitats, *i.e.*, those that are critical for these stages. Herein, critical habitats are those which are essential for the optimal growth in any stage of the life history of the species with certain genetic or commercial importance (Lara-Domínguez *et al.*, 1991). These habitats provide the organisms with abundant food availability and are used as reproduction, shelter, and nursery areas. Thus, from the conceptual point of view, these habitats represent the fundamental functional units of the whole ecosystem. Between different habitats, there are very active functional boundaries whose limits oscillate according to external factors such as climatic variation (Day and Yáñez-Arancibia, 1988).

In Términos Lagoon, located in the state of Campeche, two important critical habitats are seagrass beds (*Thalassia testudinum*), and the submerged roots of the mangrove *Rhizophora mangle*. Considerable efforts have been made toward defining habitats within the tropical estuarine-lagoon ecosystem context (Yáñez-Arancibia and Day, 1988; Twilley *et al.*, 1996). Their detailed evaluation provides a basis for the global interpretation of the tropical estuarine ecosystem, and may lead to ecosystem-based resource management, help in impact mitigation, and in identifying research priorities for coastal area management.

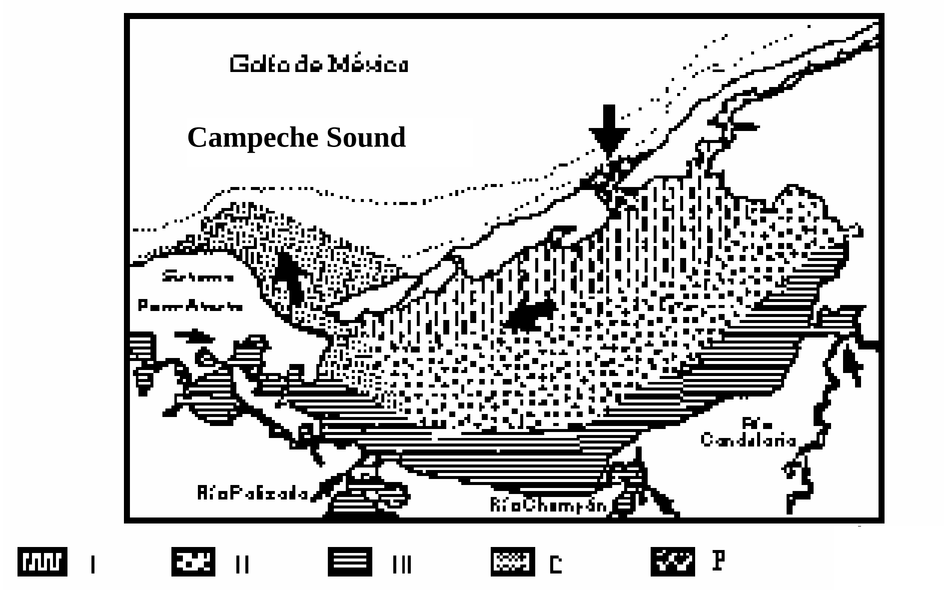

Figure 1: Map of the Términos Lagoon showing the ecological subsystems : I Internal Litoral of El Carmen Island, II Central Basin, III Fluvio-Lagunar System. C = El Carmen Inlet, P = Puerto Real Inlet. Arrows indicate net flows of water (from Yáñez-Arancibia and Day 1982). [*Mapa de la Laguna de Términos mostrando los subsistemas ecológicos : I Litoral interno de Isla de El Carmen, II Cuenca central, III Sistema fluvio-lagunar. C=Boca de El Carmen, P=Boca de Puerto Real. Flechas indican el flujo neto de las masas de agua (Yáñez-Arancibia and Day 1982).*]

The main goal of this paper is to characterize the structure and function of two critical habitats of Términos lagoon: seagrass beds and mangrove roots. As well, this contribution updates the very preliminary Ecopath model of Términos lagoon presented in Pauly *et al.* (1994).

MATERIAL AND METHODS

Study Area

Términos Lagoon is a tropical lagoon-estuarine ecosystem in the southern Gulf of Mexico (18° 20' to 19° 00' N, 91° 10' and 92° 00' W; Fig. 1). The lagoon region, including the associated fluvio-lagunar systems, has a total surface area of 3,670 km² (Yáñez-Arancibia and Day, 1982). The main rivers are the Palizada in the southwest part of the lagoon, the Chumpan in the south, and the Candelaria in the southeast. The lagoon has a sand barrier, El Carmen Island, and two inlets with permanent connection to Campeche Sound: the Puerto Real inlet and El Carmen inlet (Yáñez-Arancibia *et al.*, 1988) (Fig. 1). The former is 3.25 km wide with a strong marine influence, transparent waters and extensive seagrass beds, while the latter is 3.7 km wide, with a strong estuarine influence due mainly to the Palizada river discharge, with abundant fine sediments in suspension and high turbidity (Yáñez-Arancibia *et al.*, 1994a).

There are three climatic seasons: rainy (June-September), winter storms (October-March), and dry (February-May), with a mean annual precipitation of 1680 mm, and a water temperature of 27-33°C (Yáñez-Arancibia and Day, 1982). Yáñez-Arancibia *et al.* (1983) established, that due to the dominant winds from the east, littoral flux, and river discharge, there is a strong estuarine influence towards the western part of the lagoon, and identified five ecological subsystems: 1. fluvio-lagunar systems, 2. central basin, 3. internal littoral of El Carmen inlet, 4. Puerto Real inlet, and 5. El Carmen inlet (Fig. 1).

The specific study area is located in the internal littoral of del Carmen inlet, with two sampling sites: 1) Los Cocoyoles (mangroves roots), and 2) in front of El Cayo (seagrasses) (Fig. 2). The internal littoral of El Carmen island presents a persistent marine influence with a salinity of 14.9 - 34.7. The clear waters promote elevated primary productivity, and the temperature ranges from 28.1° - 30.8° C. The sediments are sandy clay-mud with 30 to 70% of $CaCO_3$ (Yáñez-Arancibia *et al.*, 1994a).

The Ecopath approach

Traditionally, ecosystem models were difficult to construct, resulting in lack of appreciation of ecosystem processes. The Ecopath software now

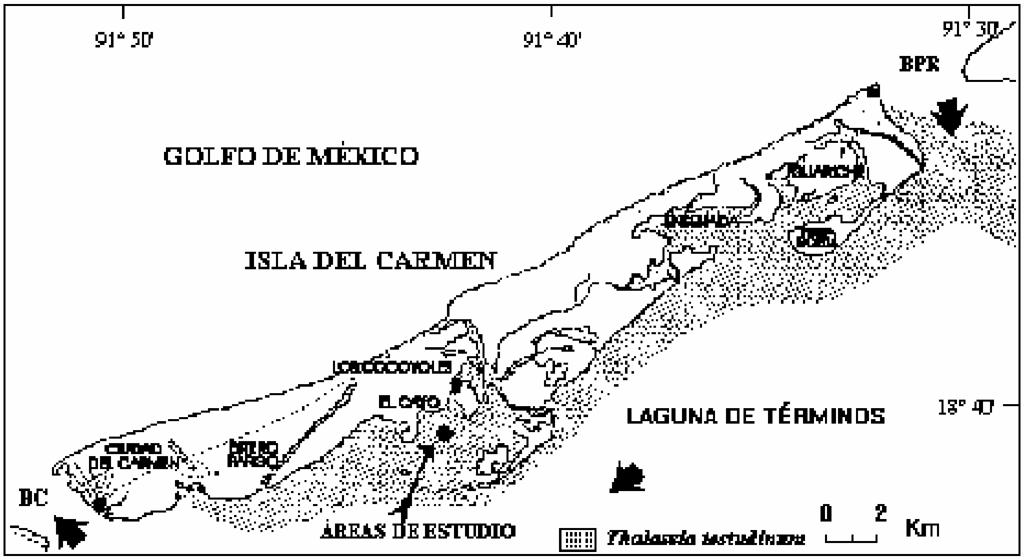

Figure 2: Sampling sites BC = El Carmen Inlet, BPR = Puerto Real Inlet. (taken from Yáñez-Arancibia *et al.*, 1994a). [*Sitios de muestreo. BC= boca de El Carmen, BPR=boca de Puerto Real (tomado de Yáñez-Arancibia et al., 1994a).*]

available for construction and analysis of mass-balanced trophic models, and evaluation of interactions/nutrient flows in ecosystems has contributed in overcoming this problem (Polovina, 1984; Christensen and Pauly, 1992, 1996; Pauly *et al.*, 1994, 2000).

The master equation of Ecopath is:

$$B_i * PB_i * EE - \sum_{j-1}^{n} B_j * QB_j * DC_{ji} - EX_i = 0$$

wherein B_i = biomass of group (*i*); *P/B* = production/biomass ratio of group (*i*); EE_i = ecotrophic efficiency of group (*i*); Q_j/B_j = consumption/biomass ratio of group (*j*); DC_{ji} = fraction of the prey (*i*) in the average diet of predator (*j*); EX_i = exports out of the system (including fisheries catches) of group (*i*); the summation corresponds to total biomass of species (*i*) consumed by predators (*j*).

At least three of the four required input parameters (B, P/B, Q/B, EE) must be known for each functional group (in addition to the DC's), the missing parameter (usually EE) being estimated by the model

All inputs used in this model were standardised to wet weight ($t \cdot km^{-2}$) and $year^{-1}$. Where required, conversions were made from carbon ($gC \cdot m^{-2}$) to wet weight, and from O_2 to kcal and wet weight. Estimates of P/B and Q/B were derived from the abundant literature on Términos Lagoon (see below).

Functional groups

The distribution of the different functional groups along the physical gradients in Términos Lagoon allows the identification of three main regions with characteristic habitats:

1. Tidal freshwater delta areas with riverine mangrove swamps, submerged freshwater aquatic vegetation, and fresh marshes;
2. The central basin with a salinity range from 10 to 25 and where phytoplankton is the major source of primary production;
3. Shallow intertidal and subtidal zones with high marine influence (salinity higher than 25) dominated by fringing mangroves and submerged seagrass beds.

The fish species were grouped into nine categories: Ariidae (*Ariopsis felis*), Cichlidae (*Cichlasoma urophthalmus*); Clupeidae (*Harengula jaguana*); Gerreidae (*Diapterus plumieri*, *Eucinostomus gula*, *E. argenteus*); Lutjanidae (*Lutjanus griseus*); Poeciliidae (*Poecilia mexicana*); Sparidae (*Archosargus rhomboidalis*); Tetraodontidae (*Sphoeroides testudineus*); and other fishes (*Menidia beryllina*, *Anchoa hepsetus*, *Haemulon plumieri* and *Opsanus beta*).

The biomass (Table 1) and diet composition data (Table 2) were taken from Yáñez-Arancibia *et al.* (1994a), complemented with data from FishBase (www.fishbase.org), or from the vast published literature about Términos Lagoon (Day *et al.*,

Table 1: Input values for the critical habitats (mangrove and seagrass bed) ecosystem model in Términos Lagoon, Southern Gulf of Mexico.- P/B production/biomass, Q/B is consumption/biomass. EXP is the export and includes commercial catch. Values in brackets were estimated by Ecopath. [*Parámetros de entrada usados para la construcción de un modelo trófico para los hábitats críticos (raices de manglar y parches de pastos marinos) de la Laguna de Términos, al sur del Golfo de México. P/B=Producción/Biomasa, Q/B=Consumo/Biomasa, EXP=Exportación e incluye capturas comerciales)*]

Group Name	Biomass ($t \cdot km^{-2}$)	P/B ($year^{-1}$)	Q/B ($year^{-1}$)	EE	EXP ($t \cdot km^{-2}$)	Flow to detritus ($t \cdot km^{-2} \cdot year^{-1}$)	Net efficiency	Trophic level	Omnivory index	Resp.	Assim.
Phytoplankton	0.606	66.846	-	(*0.029*)	-	(*39.350*)	-	(*1.000*)	-	-	-
Seagrass	3.081	11.909	-	(*0.001*)	-	(*36.645*)	-	(*1.000*)	-	-	-
Shrimp	0.001	4.292	21.391	(*0.753*)	0.001	(*0.005*)	(*0.251*)	(*2.294*)	(*0.244*)	(*0.013*)	(*0.017*)
Other fish	0.001	4.049	22.298	(*0.008*)	-	(*0.008*)	(*0.227*)	(*3.014*)	(*0.184*)	(*0.014*)	(*0.018*)
Clupeoidae	0.026	1.506	7.101	(*0.022*)	-	(*0.075*)	(*0.265*)	(*2.127*)	(*0.127*)	(*0.109*)	(*0.148*)
Poecilidae	0.001	10.859	38.100	(*0.028*)	-	(*0.018*)	(*0.356*)	(*2.110*)	(*0.112*)	(*0.020*)	(*0.030*)
Tetraodontidae	0.002	0.408	1.678	(*0.297*)	-	(*0.001*)	(*0.304*)	(*3.122*)	(*0.260*)	(*0.002*)	(*0.003*)
Gerreidae	0.002	0.857	2.671	(*0.732*)	0.001	(*0.002*)	(*0.401*)	(*3.082*)	(*0.284*)	(*0.003*)	(*0.004*)
Lutjanidae	0.001	0.691	1.921	(*0.028*)	-	(*0.001*)	(*0.450*)	(*3.386*)	(*0.092*)	(*0.001*)	(*0.002*)
Sparidae	0.005	0.444	2.957	(*0.652*)	0.001	(*0.004*)	(*0.188*)	(*2.368*)	(*0.381*)	(*0.010*)	(*0.012*)
Zooplankton	0.009	42.216	149.310	(*0.600*)	-	(*0.421*)	(*0.353*)	(*2.123*)	(*0.123*)	(*0.695*)	(*1.075*)
Benthos	0.009	9.249	27.343	(*0.605*)	-	(*0.082*)	(*0.423*)	(*2.361*)	(*0.324*)	(*0.114*)	(*0.197*)
Other crustaceans	0.001	2.759	9.052	(*0.865*)	-	(*0.002*)	(*0.381*)	(*2.421*)	(*0.353*)	(*0.004*)	(*0.007*)
Ariidae	0.001	0.285	2.075	(*0.061*)	-	(*0.001*)	(*0.172*)	(*2.901*)	(*0.441*)	(*0.001*)	(*0.002*)
Cichlidae	0.001	0.339	2.372	(*0.899*)	-	(*0.001*)	(*0.178*)	(*2.570*)	(*0.446*)	(*0.002*)	(*0.002*)
Detritus	0.049	-	-	-	-	-	-	(*1.000*)	(*0.013*)	-	-

Table 2: Diet matrix showing proportional diet composition for the mangrove root and seagrass bed community in Términos Lagoon, Southern Gulf of Mexico. [*Matriz presa / predador mostrando la composición de las dietas para el modelo trófico de las comunidades de raíces de manglar y parches de pastos marinos de la Laguna de Términos, sur del Golfo de México*].

	Predator												
Prey	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1. Phytoplankton	0.044	-	0.290	-	-	-	-	-	0.792	0.158	0.146	-	-
2. Seagrass	-	-	0.021	-	-	-	-	0.390	-	0.143	0.146	-	0.342
3. Shrimp	-	-	-	-	-	0.150	0.423	-	-	-	0.049	0.084	-
4. Other fish	-	-	-	-	-	-	0.010	-	-	-	-	-	0.005
5. Clupeoidae	-	-	-	-	-	-	0.102	0.037	-	-	-	0.025	0.027
6. Poecilidae	-	-	-	-	-	-	0.051	-	-	-	-	0.042	0.050
7. Tetraodontidae	-	-	-	-	-	-	0.049	0.010	-	-	-	-	-
8. Gerreidae	-	-	-	-	-	-	0.056	0.010	-	-	-	-	-
9. Lutjanidae	-	-	-	-	-	-	0.010	-	-	-	-	-	-
10. Sparidae	-	-	-	-	-	-	0.055	0.009	-	-	-	0.101	-
11. Zooplankton	0.262	0.631	0.113	0.098	0.060	0.031	0.086	0.044	0.109	0.141	0.144	0.009	0.044
12. Benthos	-	0.224	-	-	0.700	0.608	0.082	0.094	-	0.149	0.144	0.074	0.048
13. Other crustaceans	-	-	-	-	0.071	0.017	0.021	0.066	-	-	-	0.213	0.253
14. Ariidae	-	-	-	-	-	-	0.009	-	-	-	-	-	-
15. Cichlidae	-	-	-	-	-	-	0.045	-	-	-	-	0.105	-
16. Detritus	0.694	0.145	0.576	0.902	0.170	0.195	-	0.341	0.100	0.409	0.371	0.348	0.231

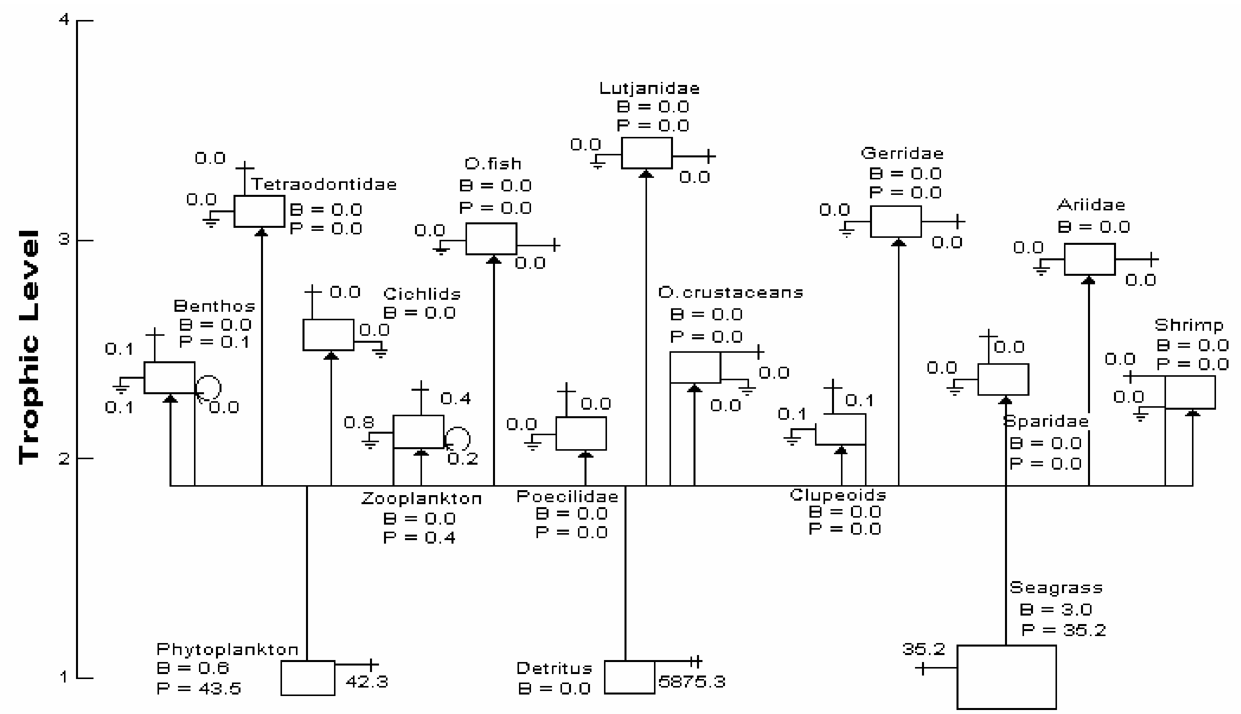

Figure 3: Diagram showing main flows of biomass for the critical habitats (mangrove and seagrasses) system in Términos Lagoon, Southern Gulf of Mexico (t·km^{-2}·year^{-1}). [*Diagrama que muestra los principales flujos de biomasa para las comunidades de hábitats críticos (manglar y pastos marinos) de la Laguna de Términos, sur del Golfo de México (t·km^{-2}·año^{-1}).*]

1982; Román-Contreras, 1986; Gracia and Soto, 1986; Soberón-Chávez, 1987; Yáñez-Arancibia and Day, 1988; Day *et al*., 1988a, 1988b; Reyes, 1992; Rojas-Galaviz *et al*., 1992; Vega-Cendejas *et al*., 1993; Chávez *et al*., 1993). The prey/predator matrix was constructed considering the adult fishes as piscivores, that is, as top predators (there was no harvest of any species in these subsystems at the time this model was constructed). We considered that the larvae and juveniles of those top predators could also be eaten by other species and their own adults, with cannibalism never exceeding 10%.

Model balancing

Once the model was balanced and the ecosystem parameters estimated, the Ecoranger routine (Christensen and Pauly, 1996) was used to obtain a better solution. Ecoranger consists of a semi-Bayesian approach in which parameters from the first balanced model provided the prior distributions. Triangular distributions were selected for all distributions. A minimum of 3000 positives solutions was set to set to derive the posterior distribution of parameters.

Results

A general scheme describing the trophic structure of the communities associated with seagrass meadows and submerged mangrove roots in the inner littoral of El Carmen Island in Términos Lagoon was produced. The model had a total system throughput of 9.47 t·km^{-2}·year^{-1}, with 18.7% due to respiration. Within the model, the detritus originating from the mangroves constituted 5,797.7 t·km^{-2}·year^{-1}, accounting for 82% of the total flows in the system. A diagram illustrating the trophic flows within Términos Lagoon is presented in Figure (3). There were 4 trophic levels in the system, with nearly 90% of the species corresponding to the second and third levels, with a wide trophic spectrum (Fig. 4). The total primary production/total respiration was 19,715 t·km^{-2}, and the sum of all respiratory flows was 1,689 t·km^{-2}.

The niche overlap index calculated in this model is that suggested by Pianka (1973), which is derived from the competition coefficients of the Lotka-Volterra equations. The results indicate that Clupeidae-Poecillidae (0.91-0.96), and Tetraodontidae-Gerreidae (1.0-1.0) have a complete overlap (Table 3).

Discussion

Most of the inputs used to construct the model were taken from the field, or from data collected in the study area. However, some refer to

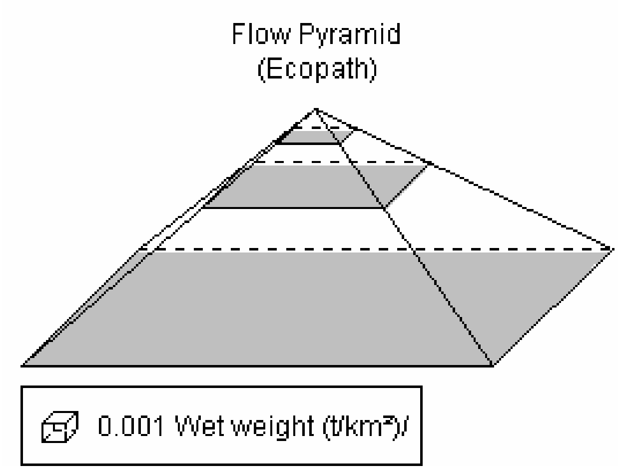

Figure 4: Flow pyramid representing trophic fluxes from first order consumers to top predators. The volume of each compartment is proportional to the total throughput of that level ($t \cdot km^{-2} \cdot year^{-1}$) and the top angle to the geometric mean of the transfer efficiencies between trophic levels. [*Pirámide de flujos que representa los flujos tróficos desde consumidores de primer orden hasta predadores tope. El volúmen de cada compartimento es proporcional al total de flujos de cada nivel ($t \cdot km^{-2} \cdot año^{-1}$) y el ángulo en el extremo distal a la media geométrica de las eficiencias de transferencia entre niveles tróficos.*]

different time periods, which is problematic if changes have occurred over time. In addition, the system was assumed to be closed, apart from import and export of detritus. The different kinds of vegetation in the internal littoral of Del Carmen Island, such as mangroves and seagrasses, are critical habitats for several aquatic and terrestrial species (Weber *et* al., 1992; Yáñez-Arancibia *et al*., 1994a, 1994b). Mangroves systems and extensive seagrass beds within Términos Lagoon generate a large quantity of detritus and export detritus to other critical habitats inside and outside the lagoon towards the Campeche Sound, performing the import-export processes needed for maintenance of the food webs. This source of energy is one of the starting points of the energy transfer process in Términos Lagoon (Yáñez-Arancibia and Day, 1988).

Since the pioneering work of W.E. Odum and E.J. Heald in southern Florida (Odum and Heald, 1975), the importance of mangrove forests in supporting nearshore secondary production via detritus-based food chains is well established. Although the original concept has been subsequently modified to include alternative energy and carbon sources for consumers in mangrove ecosystems, much of the argument for the preservation of mangrove forests rests on the belief that carbon and energy fixed by mangrove vegetation is the most important nutritive source for animal communities in and near mangrove wetlands (Robertson *et al*., 1992).

Day *et al*. (1982) established that in large lagoons, such as Términos Lagoon, with fringing mangrove forests, phytoplankton, benthic algal or other macrophyte production, are a major source of organic carbon. According to Day *et al*. (1996), the net primary production in the fringe mangrove zone is 793 $t \cdot km^{-2} \cdot year^{-1}$ of littercrop. In Términos Lagoon, mangrove coexists with seagrass meadows, and food chains are likely to be more complex in such systems, given the number of carbon sources. Direct grazing on mangrove leaves, and leaf area loss to grazers by some organisms, such as insects and crabs, is highly variable among species, sites and individual trees (Robertson *et al*., 1992). Specific grazing on litterfall by fishes has only recently been shown by analysis of carbon isotopes. This has also shown that the number of consumer organisms in tropical coastal regions adjacent to mangrove forests that are dependent on mangrove carbon is less than that originally suggested (Rodelli *et al*., 1984; Zieman *et al*., 1984).

Retention and rapid processing of litter within forests influences trophodynamic processes in forest sediments. The very high bacterial productivities in the sediments of Australian mangrove forests, with a mean of about 1 $gC \cdot m^{-2} \cdot d^{-1}$ (Alongi, 1988), are probably facilitated by rapid litter processing. For instance, Robertson and Daniel (1989) have calculated that in Bruguiera forests, sesarmid crabs void about 260 $gC \cdot m^{-2} \cdot year^{-1}$ of litter-derived faeces, equivalent to 70 % of bacterial production. Nevertheless, the degree to which litter decomposition by microbes is important in determining carbon turnover within mangrove forests depends on the degree of flushing by tidal waters or floods and the presence or absence of a leaf consuming fauna (Twilley *et al*., 1986).

Robertson *et al*. (1992) reviewed the information available on trophic processes that are believed to be important in wetlands, such as mangrove ecosystems. It is often suggested that most bacterial production in benthic, detritus-based food webs is grazed mainly by meiofauna. These authors found that in tropical Australia, the low field densities and inability of nematodes to influence bacterial abundance indicate that the

Table 3: Niche overlap for predators (top) and preys (bottom) in the mangrove ecosysem in Términos Lagoon, Mexico. [*Superposición de nicho para predadores (arriba) y presas (abajo) en el ecosistema de manglar deLaguna de Términos, México*].

Group Name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
3. Shrimp	-	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
4. Other fish	-	0.01	0.54	-	-	-	-	-	-	-	-	-	-	-	-
5. Clupeoidae	-	0.15	0.23	0.34	-	-	-	-	-	-	-	-	-	-	-
6. Poecilidae	-	0.01	0.43	0.80	0.30	-	-	-	-	-	-	-	-	-	-
7. Tetraodontidae	-	0.14	0.34	0.46	0.96	0.29	-	-	-	-	-	-	-	-	-
8. Gerridae	-	0.13	0.37	0.50	0.95	0.32	1.00	-	-	-	-	-	-	-	-
9. Lutjanidae	-	-	0.56	0.81	0.31	0.48	0.51	0.56	-	-	-	-	-	-	-
10. Sparidae	-	0.08	0.37	0.33	0.65	0.60	0.62	0.62	0.35	-	-	-	-	-	-
11. Zooplankton	0.93	0.24	-	-	-	-	-	-	-	-	-	-	-	-	-
12. Benthos	0.04	0.97	0.07	0.01	0.04	0.01	0.03	0.03	0	0.02	0.24	-	-	-	-
13. O.crustaceans	-	0.13	0.12	0.26	0.79	0.51	0.64	0.62	0.03	0.66	0	0.05	-	-	-
14. Ariidae	-	-	0.56	0.81	0.31	0.48	0.51	0.56	1.00	0.35	0	0	0.03	-	-
15. Cichlidae	-	-	0.35	0.31	0.20	0.64	0.20	0.22	0.36	0.84	-	0.01	0.32	0.36	-

Group Name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
3. Shrimp	-	-	0.64	-	-	-	-	-	-	-	-	-	-	-	-
4. Other fish	-	-	0.29	0.47	-	-	-	-	-	-	-	-	-	-	-
5. Clupeoidae	-	-	0.50	0.16	0.48	-	-	-	-	-	-	-	-	-	-
6. Poecilidae	-	-	0.64	0.18	0.52	0.71	-	-	-	-	-	-	-	-	-
7. Tetraodontidae	-	-	0.14	0.21	0.11	0.14	0.50	-	-	-	-	-	-	-	-
8. Gerridae	-	-	0.16	0.19	0.13	0.17	0.46	0.46	-	-	-	-	-	-	-
9. Lutjanidae	-	-	0.02	0.07	0.01	0.01	0.06	0.11	0.18	-	-	-	-	-	-
10. Sparidae	-	-	0.33	0.12	0.27	0.34	0.15	0.16	0.02	0.44	-	-	-	-	-
11. Zooplankton	-	-	0.14	0.08	0.30	0.09	0.02	0.02	0.01	0.04	0.59	-	-	-	-
12. Benthos	-	-	0.39	0.20	0.35	0.39	0.20	0.20	0.02	0.30	0.19	0.32	-	-	-
13. O.crustaceans	-	-	0.44	0.24	0.39	0.42	0.22	0.24	0.05	0.35	0.21	0.36	0.45	-	-
14. Ariidae	-	-	0.24	0.07	0.19	0.27	0.11	0.12	0.05	0.15	0.03	0.15	0.17	0.17	-
15. Cichlidae	-	-	0.20	0.08	0.17	0.21	0.10	0.09	0.02	0.32	0.03	0.19	0.22	0.14	0.29

meiofauna may not play a major role in the cycling of organic matter in tropical mangrove forest sediments. With respect to the diets of benthic macrofauna, the authors described the trophic interactions between bacteria, meiofauna and species of crabs and gastropods, which inhabit mudflats adjacent to *Rhizophora* and *Avicennia* forests in tropical Australia, Malaysia and Japan. It was revealed that crabs and gastropods often consume large quantities of benthic microalgae, and in some cases, shifted their diets from mangrove to microalgal carbon.

Penaeid prawns are abundant and an important commercial component of mangrove ecosystems in most tropical regions around the world. Based on the analysis of gut contents of several species of *Penaeus*, Robertson *et al.* (1992) concluded that mangrove detritus (and/or their associated microfauan) was the major constituent of the diet of juveniles inhabiting mangrove roots and channels. Indeed, mangroves and seagrasses constitute not only trophic items themselves, but also the associated microfauna and the epiphytic and the microbial community growing on the leaves and roots.

Day *et al.* (1982) showed that on a per area basis, the primary productivity of seagrasses in Términos Lagoon is almost twice as much as that of mangrove and phytoplankton jointly. Seagrass density is also very high, with a peak value of 28.9 $g \cdot m^{-2} \cdot month^{-1}$ from May to June (Soberón-Chávez, *et al.*, 1988). Nevertheless, seagrasses contribute only 7% of the total primary productivity of the whole lagoon, due to their restricted distribution within the lagoon, where they cover a surface area of approximately 100 km^2. This area, in addition to the very high primary production, receives a large import of detritus directly from the mangroves.

The present study indicates that most organisms in this ecosystem has a strong linkage with detritus, generally through short paths of the food web. The fluxes departing from detritus can be divided into two components (Soberón-Chávez *et al.*, 1988). The first component of the detritus flux exports matter to neighbouring ecosystems. This flux is around 78% of the total in the lagoon. The second component of the flux is matter consumed by nekton and benthos. The consumption of detritus in the basin of the lagoon is very reduced compared with the exportation flux. This consumption is around 1% in the lagoon.

Results show that almost 90 % of the components of these critical habitats are detritus-dependent, with detritus coming from seagrasses and mangroves. It is important to underline that many species with economical importance, such as penaeid shrimps, are dependent on these critical habitats during at least one stage of their life cycle. The fishery importance of these two critical habitats is enormous, as nearly 70 % of the estuarine-dependent species are occurring there as juveniles of commercial importance, and are exploited on the shelf areas, after they leave the lagoon (Yáñez-Arancibia and Aguirre-León, 1988).

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A Preliminary Trophic Model of Bahía de la Ascensión, Quintana Roo, Mexico [*Modelo trófico preliminar de Bahía Ascención, Quintana Roo, México*]

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ABSTRACT

Bahía de la Ascension is a bay with an area of 260 km², located along the coast of the state of Quintana Roo, Yucatan Peninsula, Mexico. This paper provides a preliminary description of the marine ecosystem and its mass balance fluxes using the Ecopath with Ecosim software. Bahía de la Ascension is heavily influenced by mangrove and coral reef areas, and functions as a nursery area for important fishery resources (lobster, sharks, other fishes). A flow diagram, summary statistics and mixed trophic impacts of the groups in the ecosystem is provided. Results suggest that 22% of the total system throughput consists of flows to detritus. The key resource in the ecosystem, due to the value of its catch, is lobster (*Panulirus argus*). The most abundant consumer group is benthic invertebrates. Better data for primary production, detritus biomass and detailed benthic invertebrate groups, as well as explicit consideration of seasonality would help to improve the model.

RESUMEN

Este trabajo presenta una descripción preliminar del balance de flujos de biomasa de la comunidad de Bahía Ascención. Esta Bahía tiene un área se 260 km² y está localizada en el estado de Quintana Roo, en la Península de Yucatán. Esta fuertemente influenciada por áreas de manglar y arrecifes de coral, y ha sido considerada como un área de crianza de importantes recursos pesqueros (langosta, tiburones y otros peces). Se presenta el diagrama de flujo, un resúmen de estadísticas del ecosistema y los impactos tróficos entre grupos de especies. Los resultados indican que el 22% del flujo total del ecosistema es expresado como flujo a detritus. El recurso pesquero de mayor importancia económica es la langosta. El grupo consumidor de mayor abundancia son los invertebrados bentónicos. Se considera, para futuros trabajos, involucrar en mayor medida las variaciones estacionales, debido a los períodos climáticos claramente definidos en la región. Asimismo, dada la carencia de datos mas específicos para la Bahía, se considera de suma importancia obtener mayor detalle en los datos de entrada, particularmente los relativos a producción primaria, biomasa de detritus, y mayor detalle en el grupo de invertebrados bentónicos. Esto mejoraría sustancialmente la calidad del presente modelo.

INTRODUCTION

Bahía de la Ascensión represents an important area for artisanal fishing activities in Quintana Roo, on the Yucatan Peninsula of Mexico (Figure 1). It also functions as a nursery area for some of the most important commercially exploited resources along the Mexican Caribbean coast, such as lobster (*Panulirus argus*), sharks and a large number of other fish species (Vásquez-Yeomans, 1990; Lozano-Alvarez and Briones-Fourzan, 1991; Zárate, 1996).

Bahía de la Ascensión is a shallow bay, covering approximately 260 km², with an average depth of 2.5 m, and which is located in the northeast of the Yucatan Peninsula, Mexico between 19° 45’ N and 87° 30’ W in the tropical western Atlantic (López-Ornat, 1983). It is connected to the Caribbean Sea through a coral reef of 12 km width (Espejel, 1983) and is surrounded by well-developed mangroves (Olmsted *et al.*, 1983). Salinity varies between 22 to 31. Water exchange with the sea is low and driven by tides, which have a maximum amplitude of 25 cm (Lankford, 1976). The substratum shows a well-marked zonation: the inner part is covered by calcareous sand interspersed with green and red algae (*Dasycladus* spp. and *Laurencia* spp.) and scattered seagrass (*Thalassia testudinum*). The outer part, which is influenced by the open sea, has mainly hard bottom with coral-reef, coral limestone, calcareous algae and rocks with some patches

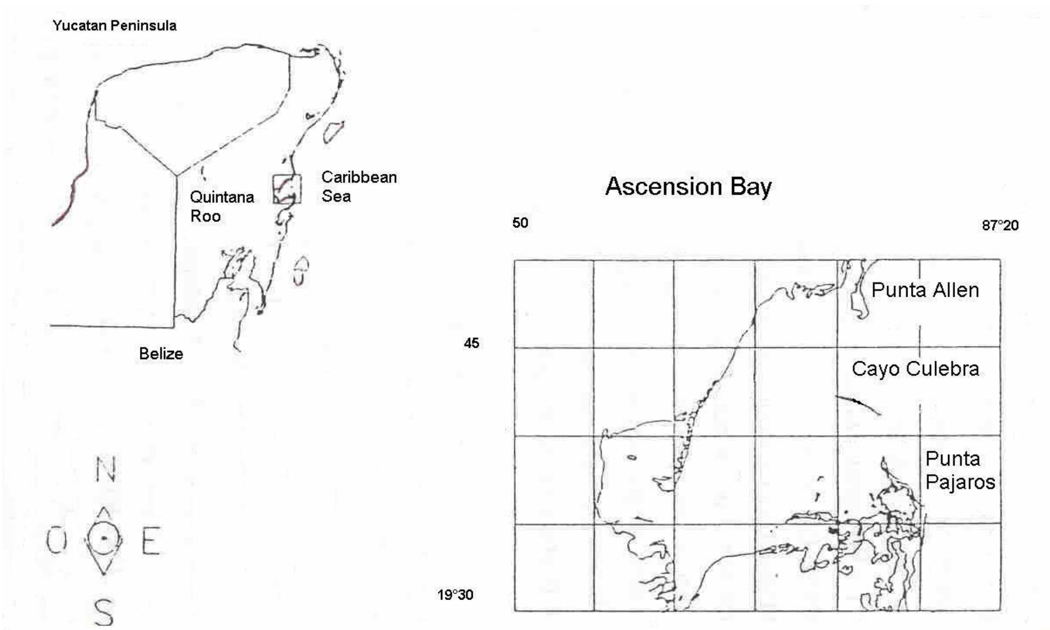

Figure 1: Location of Bahía de la Ascención Bay, on the Yucatan peninsula, Mexico. Shadow region indicates study area. [*Localización de Bahía Ascención en la Península de Yucatán, México. Región sombreada representa el área de studio.*]

of seagrass (Espejel, 1983; Eggleston *et al.*, 1990; Lozano-Alvarez, 1992). In this area, algae richness is high with Rhodophyta being the dominant group (Quijano-Fernández, 1988). The bay is characterized by a high concentration of nutrients, some of which is exported to adjacent areas. Mangroves around the bay contribute detritus, which is associated with high densities of meiofauna. Spiny lobsters attain a high biomass within the bay, and jointly with small sharks, mojarras, juvenile macabi (*Elops saurus*) and jacks (Carangidae), are the most important exploited resources.

Given the ecological and economic importance of Bahía de la Ascensión, it is useful to understand the ecosystem dynamics and its responses to exploitation. This would contribute to and improve the management strategies applied in the area (Beddington, 1984). This document provides a preliminary description of the marine community in Bahía de la Ascensión and its mass balance fluxes using the Ecopath approach (Christensen and Pauly, 1992; Pauly *et al.*, 2000).

MATERIAL AND METHODS

The general model details and the required parameters are described in Polovina and Ow (1983), Polovina (1984), Christensen and Pauly (1992) and Pauly *et al.* (2000).

The trophic relationship between each functional group and the other ecosystem components is represented as follows

$$B_i * PB_i * EE - \sum_{j-1}^{n} B_j * QB_j * DC_{ji} - EX_i = 0$$

where B_i = biomass of group (i); P/B = production/biomass ratio of group (i); EE_i = ecotrophic efficiency of group (i); Q_j/B_j = consumption/biomass ratio of group (j); DC_{ji} = fraction of the prey (i) in the average diet of predator (j); EX_i = exports out of the system (including fisheries catches) of group (i); the summation corresponds to total biomass of species (i) consumed by predators (j).

The present model was constructed with 18 functional groups as follows:

Benthic producers: This group consists of seagrass *Thalassia testudinum*, benthic algae, represented (because of their relative abundance) by *Penicillus capitatus*, *Bathofora oerstedii*, *Halimeda incressata* and *Laurencia intricata* (Aguilar-Rosas *et al.*, 1989), and microalgae.

Phytoplankton: Information on phytoplankton was based on Steidinger (1973) for estuarine waters of the Gulf of Mexico. Steidinger reported numerical abundance of microflagellates and nanoplankton, with diatoms, dinoflagellates and Cyanophyceae being the principal components along the Gulf coast. The most common diatom group was the genus *Chaetoceros*.

Two zooplankton groups: To maintain appropriate trophic differentiation, zooplankton were grouped into herbivorous and carnivorous groups. The dominant groups of zooplankton are copepods, particularly *Acartia* spp. and *Labidocera* spp. (Campos-Hernandez and Suarez-Morales, 1993).

Benthic invertebrates: These include polychaete annelids of the families Cirratulidae, Capitellidae and Nereidae, with *Ceratonereis singularis* being very abundant (Jiménez-Perez, 1992). Amphipoda is also an abundant group, represented by the families Aoridae, Melitidae, Leocothoidae and Lysianassidae; with species such as *Amphilochus neapolitanis*, *Colomastrix pusilla*, *Cymadusa filosa* and *Stenothoe gallensi* being most abundant (Jiménez-Perez, 1992).

Lobster: The lobster, *Panulirus argus*, is important because of its abundance and commercial value. Bahía de la Ascensión is a recruitment area for postlarvae, which remain and grow within the bay for two years, after which the juveniles emigrate to deeper waters, and tend to settle on coral reefs (Lozano-Alvarez, 1992).

Stone crab: *Mennipe mercenaria* is the key species, but other crabs are also included in this group.

Bonefish (macabi): *Albula vulpes* is an important species for sportfishing, but large specimens are not found in the study area, as this species lives in the open sea during the adult part of its life cycle (Basurto and Villanueva, 1996).

Jacks: These are here represented by *Caranx hippos, C. latus* and *C. chrysos*. Jacks are abundant along the coast, but infrequently found in the bay.

Snappers: Here, snappers are represented by *Lutjanus griseus, L. analis, L, synagris* and *Ocyurus chrysurus*.

Mojarra: Represented by *Eugerres plumieri, Gerres cinereus, Calamus bajonado* and *Archosargus rhomboidalis*.

Barracuda: Represented within the bay mainly by juveniles of *Sphryraena barracuda* (Basurto and Villanueva, 1996).

Permit: *Trachinotus falcatus*, an important species for commercial and sport fishing.

Cazones (small sharks): Represented by *Rizoprionodon terraenovae*, and juveniles (less than 110 cm) of *Carcharhinus limbatus* and *Negaprion brevirostris*.

Two shark groups: Adults of *Carcharhinus limbatus*, *C. leucas* and *Negaprion brevirostris* were treated as 'sharks', while the nurse shark *Ginglymostoma cirratum* was retained as a separate group (Zárate, 1996). Separation was based on dietary differences.

Dolphins: Represented by *Tursiops truncatus* (Zacarías, 1992).

Birds: The region presents a high diversity of aquatic birds, the most important species being: *Phalacrocorax auritus*, *Ajaia ajaja*, *Egretta* spp, and *Casmerodius albus* (Rangel-Salazar *et al.*, 1993).

The inputs units are $t \cdot km^{-2} \cdot year^{-1}$. The biomass for benthic producers was estimated by Ecopath, assuming an Ecotrophic Efficiency (EE) of 0.95, and EE values for the rest of the groups were estimated by Ecopath. The biomass for exploited groups was estimated either from surplus yield models using catch and effort data for the period 1989 to 1995, of from the annual average catch. For phytoplankton and zooplankton groups, biomass and other parameters were taken from other estuarine Gulf of Mexico Models (Abarca-Arenas and Valero-Pacheco, 1993; De la Cruz-Aguero, 1993; Rosado-Solórzano and Guzmán del Próo, 1998). The inputs biomass, P/B and Q/B ratios, catches and EE values are shown in Table 1, and the diet matrix in Table 2.

Arreguín-Sánchez *et al.* (1993) provided data on P/B and Q/B ratios for benthic producers, mojarras, plankton, benthic invertebrates and sharks; and Opitz (1993) for marine birds. Values for the other groups were modified from models of Monterey Bay (Olivieri *et al.*, 1993) and of the Yucatan continental shelf ecosystem (Arreguín-Sánchez *et al.*, 1993).

The original stomach contents data for the diet matrix of benthic invertebrates were taken from Olivieri *et al.* (1993); bonefish from Fisher (1978) and García (1992); for lobster from Peacock (1974), Kanciruck (1980) and Colinas-Sanchez and Briones-Fourzan (1990); for crabs from Chávez and Fernández (1976); for jacks from Fisher (1978), De la Cruz and Franco (1981), Sierra and Popova (1982), Popova and Sierra (1985), Barba-Torres and Gaspar-Dillones (1987), Chávez *et al.* (1987) and García (1992); for snappers from Moe (1969), Fisher (1978), Claro (1981, 1983), Munro (1983), Yañez-Arancibia and Sánchez-Gil (1986) and Polovina and Ralston (1987); for mojarra

Table 1: Parametrization of the mass balance model for Bahía Ascención, Mexican Caribbean. P/B: production/biomass; Q/B: consumption/biomass; EE: ecotrophic efficiency; TL: trophic level; Omn.: omnivory index; Resp.: respiration; and Assim.: assimilation. [*Parametrización del modelo balanceado para el ecosistema de Bahía Ascención, Caribe Mexicano. P/B=Producción/Biomasa, Q/B=Consumo/Biomasa, EE=Eficiencia Ecotrófica, ww = peso húmedo.*]

Group No.	Group Name	Biomass ($t \cdot km^{-2}$)	P/B ($year^{-1}$)	Q/B ($year^{-1}$)	EE	Catch ($t \cdot km^{-2}$)	TL	Net Efficiency	Omn.	Resp.	Assim.
1	Phytoplankton	*26.97*	*112.98*	-	*(0.391)*	-	*(1.00)*	-	-	-	-
2	Herbivorous zooplankton	*13.70*	*13.82*	*94.67*	*(0.982)*	-	*(2.00)*	*0.182*	-	*848.249*	*1037.583*
3	Carnivorous zooplankton	*2.00*	*15.00*	*90.00*	*(0.724)*	-	*(3.00)*	*0.208*	*0.06*	*114*	*144*
4	Benthic primary producers	*26.40*	*14.00*	-	*(0.455)*	-	*(1.00)*	-	-	-	-
5	Benthic invertebrates	*19.21*	*2.50*	*8.20*	*(0.687)*	-	*(2.30)*	*(0.381)*	*(0.41)*	*(77.993)*	*(126.018)*
6	Bonefish	*0.40*	*1.13*	*9.80*	*(0.819)*	0.003	*(2.78)*	*(0.144)*	*(0.405)*	*(2.684)*	*(3.136)*
7	Lobster	*2.40*	*0.62*	*8.20*	*(0.818)*	0.006	*(2.98)*	*(0.095)*	*(0.325)*	*(14.256)*	*(15.744)*
8	Crabs	*0.05*	*3.00*	*12.50*	*(0.918)*	0.002	*(2.96)*	*(0.300)*	*(0.454)*	*(0.385)*	*(0.550)*
9	Jacks	*(0.96)*	*0.40*	*4.50*	*0.900*	0.001	*(3.12)*	*(0.111)*	*(0.440)*	*(3.087)*	*(3.473)*
10	Snappers	*0.63*	*0.49*	*5.60*	*(0.960)*	0.003	*(3.31)*	*(0.109)*	*(0.203)*	*(2.514)*	*(2.822)*
11	Mojarras	*0.76*	*1.09*	*15.30*	*(0.950)*	0.001	*(2.81)*	*(0.119)*	*(0.392)*	*(6.148)*	*(6.977)*
12	Barracuda	*0.15*	*0.57*	*5.90*	*(0.869)*	0.001	*(3.28)*	*(0.121)*	*(0.552)*	*(0.623)*	*(0.708)*
13	Permit	*(0.58)*	*0.45*	*7.60*	*0.900*	0.001	*(2.93)*	*(0.074)*	*(0.450)*	*(3.283)*	*(3.545)*
14	Cazones	*0.25*	*0.40*	*4.50*	*(0.948)*	0.003	*(3.44)*	*(0.111)*	*(0.433)*	*(0.800)*	*(0.900)*
15	Sharks	*0.03*	*0.32*	*9.70*	*(0.313)*	0.003	*(3.68)*	*(0.041)*	*(0.649)*	*(0.223)*	*(0.223)*
16	Nurse shark	*0.03*	*0.32*	*3.60*	*(0.815)*	0.002	*(3.86)*	*(0.111)*	*(0.134)*	*(0.077)*	*(0.086)*
17	Dolphin	*0.04*	*0.10*	*25.00*	*(0.708)*	-	*(3.78)*	*(0.005)*	*(0.098)*	*(0.796)*	*(0.800)*
18	Marine birds	*0.01*	*5.40*	*70.00*	*(0.955)*	-	*(3.51)*	*(0.096)*	*(0.337)*	*(0.506)*	*(0.560)*
19	Detritus	*13.00*	-	-	-	-	*(1.00)*	-	*(0.583)*	-	-

Table 2: Diet matrix showing proportional diet composition for the functional groups in the trophic model for Bahía Ascención, Mexican Caribbean.

		Predator															
Group No.	**Prey**	**2**	**3**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
1	Phytoplankton	0.900	0.030	0.100	-	-	-	0.133	0.043	0.051	0.066	0.065	-	-	-	-	-
2	Herbivorous zooplankton	-	0.940	0.100	-	-	0.030	-	0.034	0.050	-	0.060	-	-	-	-	-
3	Carnivorous zooplankton	-	0.030	0.100	-	-	0.030	0.012	0.035	0.002	0.025	0.023	0.103	-	-	0.123	-
4	Benthic primary producers	0.100	-	0.200	-	0.250	0.300	0.054	0.005	0.131	-	0.005	0.108	0.148	-	-	0.015
5	Benthic invertebrates	-	-	-	0.601	0.740	0.603	0.590	0.733	0.576	0.386	0.535	0.420	0.104	0.281	0.258	0.452
6	Macabí	-	-	-	-	-	-	0.015	-	-	0.042	0.007	0.048	0.074	-	0.150	0.012
7	Lobster	-	-	-	-	0.003	-	0.106	0.075	-	0.048	0.010	0.028	0.012	0.282	0.121	0.220
8	Crabs	-	-	-	-	-	0.010	0.005	0.004	-	0.005	0.005	0.017	0.055	0.135	0.020	0.015
9	Jacks	-	-	-	-	0.001	-	-	0.001	-	0.060	0.030	0.038	0.106	0.152	0.040	0.010
10	Snappers	-	-	-	-	0.001	-	0.006	0.009	0.003	0.038	-	0.028	0.121	0.150	0.033	0.045
11	Mojarras	-	-	-	-	0.005	-	0.021	0.027	-	0.130	-	0.114	0.100	-	0.150	0.112
12	Barracuda	-	-	-	-	-	-	0.003	-	-	0.010	-	0.015	0.050	-	0.020	-
13	Permit	-	-	-	-	-	-	0.007	0.006	-	0.009	0.010	0.028	0.052	-	0.070	0.021
14	Cazones	-	-	-	-	-	-	0.003	0.004	-	0.012	-	0.008	0.048	-	0.015	0.023
15	Sharks	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	Nurse shark	-	-	-	-	-	-	-	-	-	-	-	-	0.020	-	-	-
17	Dolphin	-	-	-	-	-	-	-	-	-	-	-	0.002	0.002	-	-	-
18	Marine Birds	-	-	-	-	-	0.027	-	-	-	-	-	0.019	0.028	-	-	0.005
19	Detritus	-	-	0.500	0.399	-	-	0.045	0.024	0.187	0.149	0.250	0.022	-	-	-	0.070
	Import	-	-	-	-	-	-	-	-	-	0.020	-	0.002	0.080	-	-	-

from Randall (1967), Yañez-Arancibia (1978), Abarca-Arenas *et al.* (1982), González and Rodríguez (1983), Salas (1984, 1986) and Abarca-Arenas (1987); for barracuda from Mendoza (1993); for permit from Fisher (1978) and Munro (1983); for cazones (small sharks) from Russo (1975), Gómez and Bashirulah (1984) and Cortés and Gruber (1990); for sharks from Castro (1983), Compagno (1984), Alvarez (1988), Dudley and Cliff (1993) and Olivieri *et al.* (1993); for nurse shark from Compagno (1984), for dolphins from Barros and Odell (1990) and Zacarías (1992); for marine birds from Dumas and Witman (1993) and Olivieri *et al.* (1993). Some of the original input parameters were subsequently modified in order to balance the model.

Following model balancing, the Ecoranger routine (Christensen and Pauly, 1996) was used to obtain a better fit of the model. Ecoranger consists of a semi-Bayesian approach in which the distribution of the parameters from the first balanced model provided the prior distributions. Triangular prior distributions were selected, together with minimization of residuals, as criterion for constraint. It was decided that at least 3000 positive solutions were required to obtain posterior parameter distributions.

RESULTS AND DISCUSSION

The most problematic groups in terms of balancing the model were snappers, crabs, cazones (small sharks) and mojarra, for which original input biomass had to be reduced. The highest biomass among consumer levels was that of lobsters, followed by mojarras. This is consistent with the knowledge of the area as the most important nursery area for lobster in the Mexican Caribbean region (Lozano-Alvarez and Briones-Fourzan, 1991) and some fish larvae of several oceanic and coastal species (Vasquez-Yeomans, 1990). Benthic invertebrates constitute a very important link between primary producers and the higher trophic levels (TL). The average TL in the ecosystem is approximately 2.7. TL for lobster was 2.98 and 3.86 for top predators such as nurse shark. These values are similar to those reported by Opitz (1993) for a Caribbean coral reef ecosystem.

Table 3 shows that of a total system throughput of 4,815 t·km^{-2}·year^{-1}, 35% (1,686 t·km^{-2}·year^{-1}) corresponds to flows to consumption, while flows to detritus were 22% of the total. This is consistent with previous reports that the bay exports detritus to adjacent areas.

Table 3: Summary statistics for the ecosystem of Bahía de la Ascención, Mexican Caribbean.

Attribute	Magnitude	units
Sum of all consumption	1,686,826	t·km^{-2}·year^{-1}
Sum of all exports	984,122	t·km^{-2}·year^{-1}
Sum of all respiratory flows	1,075,623	t·km^{-2}·year^{-1}
Sum of all flows into detritus	1,068,189	t·km^{-2}·year^{-1}
Total system throughput	4,815,000	t·km^{-2}·year^{-1}
Sum of all production	3,686,000	t·km^{-2}·year^{-1}
Mean trophic level of catches	3.2	
Gross efficiency (catch/net pp)	0.000008	
Calculated total net primary production	3,416,671	t·km^{-2}·year^{-1}
Total primary production/total respiration	3,176	
Net system production	2,341,047	t·km^{-2}·year^{-1}
Total primary production/total biomass	36,124	
Total biomass/total throughput	0.020	
Total biomass (excl. detritus)	94,583	t·km^{-2}
Total catches	0.026	t·km^{-2}·year^{-1}
Connectance Index	0.426	
System Omnivory Index	0.283	

The direct and indirect impacts of predation and competition were explored using the Leontif matrix of Ecopath (Figure 2). For economically important species some impacts are relevant, lobsters show positive impact on nurse sharks and birds, and negative impacts on benthic invertebrates, snappers and mojarras. Snappers show positive impacts on sharks, dolphins and marine birds, and negative impacts on lobsters, crabs and cazones (small sharks). On the other hand, lobsters are impacted negatively when the biomass of jacks and snapper increase; macabi are impacted negatively when jackas and dolphins biomass increase; biomass of permits affect jacks biomass and, snapper are impacted negative when mojarras biomass increases.

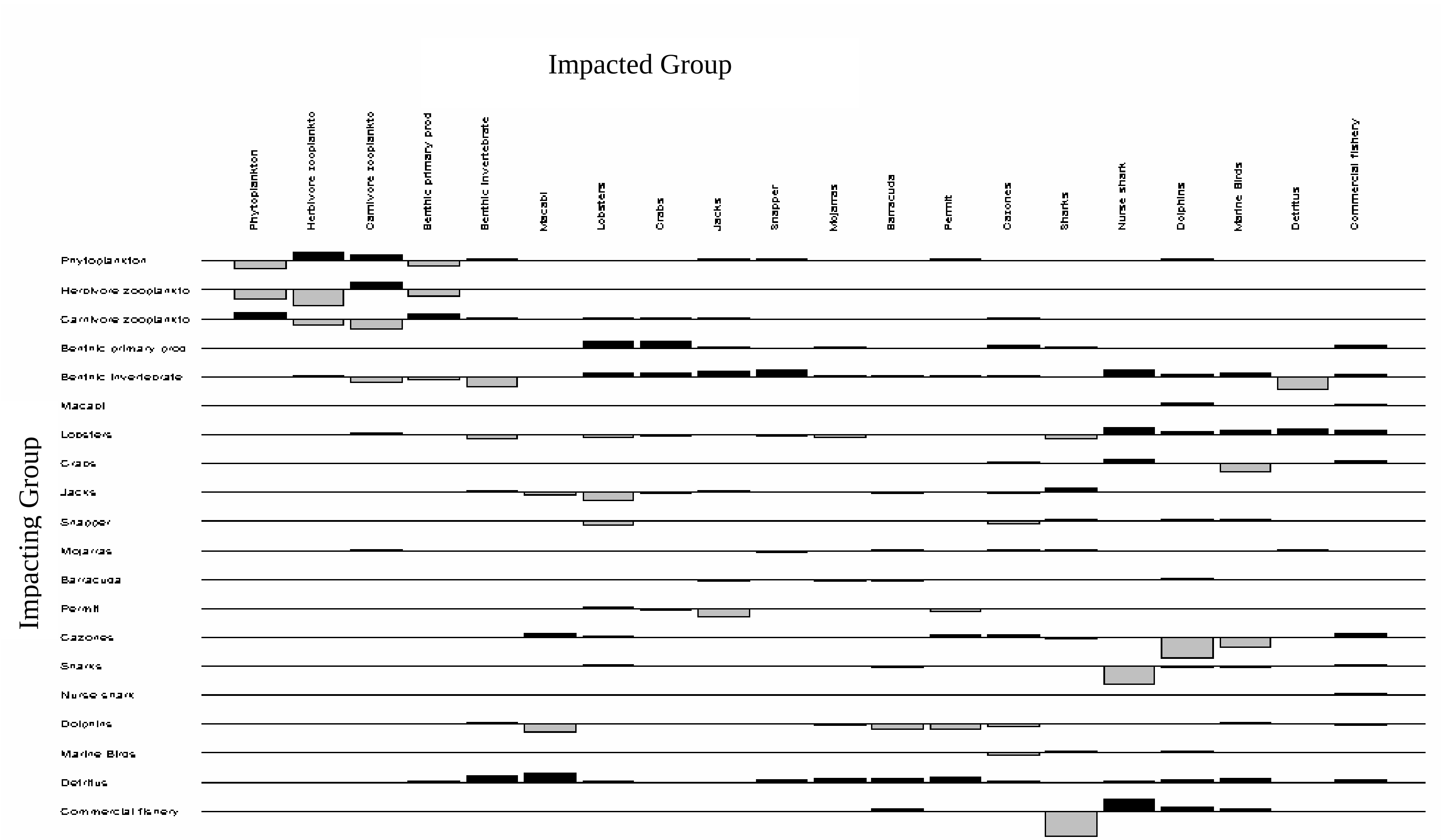

Figure 2: Mixed trophic impacts in Bahía de la Ascensión, Yucatan Peninsula, as analyzed by the Leontief matrix. Positive impacts are shown above the line and negative below each group line. [*Impactos tróficos mezclados en Bahía de la Ascención, Peninsula de Yucatán, analizados por la matriza de Leontief. Impactos positivos se muestran arriba de la línea y los negativos hacia abajo.*]

To balance the model, it was required to assume food imports from adjacent areas, such as reefs, and mangrove. Groups that required these inputs in their diet were barracudas, cazones and sharks, species that are known to move within the coastal region. To improve this model, some considerations should be given to splitting several groups, e.g., benthic invertebrates could be split into several groups, such as molluscs, microcrustaceans and annelids. Given the high complexity of invertebrate groups in this area, such separate treatment should improve any comparison of results with other similar systems.

With lobster being the most abundant group, and a secondary consumer in the system, it is important to note that the population is not homogeneously distributed by size. Small lobsters usually occur in the inner part of the bay, and larger animals occupy zones closer to the reef (Lozano-Alvarez and Briones-Fourzan, 1991). Thus, diet composition could vary significantly from one area to another. Another important factor related to lobsters could be the strong seasonal variation in catches, mainly due to a closed season. We assume that changes in biomass of lobsters due to fishing could introduce important seasonal differences in the trophic dynamics of the ecosystem, given that lobster are the most abundant group.

Furthermore, three very distinct seasonal periods can be distinguished in Bahía de la Ascensión: dry, rainy and winter storms (Merino and Otero, 1991). As a consequence, general species composition, distribution and abundance of the community present seasonal variations. Because the input values used in this Ecopath model were on an annual basis, it is recommended to explore a model involving seasonal variations.

The present study presents a preliminary model, providing basic insights into the structure and dynamics of this ecosystem. Some aspects could not be addressed in this study, and should be considered in future work. For example, information related to migration should be evaluated, particularly since Bahía de la Ascensión is a nursery area for lobsters and commercial fish species, where individuals gain biomass, and then emigrate as adults to adjacent ecosystems.

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