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ASSESSMENT AND MITIGATION OF FISHERIES IMPACTS ON MARINE ECOSYSTEMS: A MULTIDISCIPLINARY APPROACH FOR BASIN-SCALE INFERENCES, APPLIED TO THE NORTH ATLANTIC[1]

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ABSTRACT

The aim of the *Sea Around Us Project* is to quantify, in ecological and economic terms, the impact of fisheries on the marine ecosystems of the North Atlantic, and to evaluate the costs and benefits of various scenarios of mitigation, such as *status quo*, rebuilding of depleted resources and implementation of closed areas. Dealing with these issues requires a methodological package related to, but different from, that typically used in fisheries management, notably because of its ecosystem focus and the much larger temporal and spatial scales, relative to standard fisheries assessments. This paper summarizes the methodology deployed by the project by introducing a suite of papers in which its rationale and operational details are provided.

First, we review the relationships between scale and methodology choices in marine science. Then, the principle modules of the *Sea Around Us Project* methodology are described as follows:

1) The North Atlantic as study area, where we report a new ecosystem classification scheme that is compatible hierarchically with previous work and with all statistical divisions;
2) North Atlantic fisheries catches in time and space, where we present the project's catch and effort database, discuss the problems in estimating total extractions, and outline methods used to overcome them;
3) Fish distribution transects, where the biology and migrations of key commercial North Atlantic species are used to link catches by shallow-water and offshore fisheries;
4) Bio-economic analyses of fisheries sectors, where the effect of competition between small and large –scale fisheries is quantified using a multi-species, multi-gear yield per recruit model and the combination of effort producing a Nash equilibrium is identified;
5) Ecosystem modeling, discussing the use of ECOPATH with ECOSIM and ECOSPACE to represent present and past North Atlantic ecosystems with their embedded fisheries, to evaluate ecosystem status, and to simulate likely response to change;
6) Evaluating alternative ecosystem-based management regimes to quantify the benefits of different ecosystem-based management scenarios;
7) Energy consumption and the ecological footprint of North Atlantic fisheries, to contrast the energy incorporated in landed fishes to that required to catch them;
8) Rapid interdisciplinary appraisal of fisheries status and compliance analyses using RAPFISH, to compare and characterize North Atlantic fisheries in terms of their sustainability (in ecological economic technological and social fields), analysis of their ethical status, and to score their compliance with the FAO Code of Conduct for Responsible Fisheries, together with the compliance of North Atlantic countries vis-à-vis their internationally agreed commitments.
9) Mapping the fate of fisheries landings from the North Atlantic, to identify possible pressure points for intervention by fish product consumers;

We present a diagram expressing the articulation of the various methodological components listed above. The synthesis to emerge from integrating the results of these modules may contain many surprises, both in terms of the ecological damage and economic waste presently generated by the North Atlantic fisheries, and in clarifying the foregone benefits that could be regained, were these economic and ecological issues to be addressed.

INTRODUCTION

The task of the *Sea Around Us Project*, funded by the Pew Charitable Trusts, Philadelphia, and executed at the Fisheries Centre, University of British Columbia, Vancouver, is to provide a synthesis of the impacts of fisheries on marine ecosystems of the North Atlantic. More precisely, the questions to be answered are:

1. What are the total fishery catches from the ecosystems? Total fishery catches includes both reported and unreported landings and discards at sea.
2. What are the biological impacts of these withdrawals of biomass for the remaining living components of the ecosystem?
3. What would be the likely biological and economic impacts of a continuation of current fishing trends (i.e., a maintenance of the status quo)?
4. What were former states of this ecosystem like before the expansion of large-scale commercial fisheries?
5. How does the present-day ecosystem evaluate on a scale from 'healthy' to 'unhealthy'?
6. What specific policy changes and management measures should be implemented:

   (a) to avoid continued worsening of the present situation?
   (b) to improve ecosystem 'health', as defined in (5)?

Each of these questions, though straightforward-looking at first, leads to further questions, many seemingly without answers. Nevertheless, the project staff has developed a 'methodology package' for providing the best possible answers to these questions. This package differs from that normally used to assess local fish populations and local fisheries in that our methods are scalable to the entire North Atlantic basin, and indeed, eventually, to the world ocean. This package therefore, emphasizes aspects of fisheries and other marine science that are usually given short thrift in local studies. Conversely, we do not attempt to assess the exploitations status of exploited single-species fish populations. As we shall attempt to demonstrate, methods concerned with local or single-species studies and those in our methodology package support and complement each other.

Before we present the various elements of this methodology package, we shall briefly contrast two views of (marine) sciences, and provide reason why, given the present, much depleted state of North Atlantic fish populations, and the ruinous state of the fisheries depending thereon, we have chosen to identify with one of these views.

Two views of (marine) sciences

Our reading of the history of science in general, and marine science in particular suggests two basic way that advances are made:

1. Through what, for lack of a better term, we shall call Smart New Tricks (SNT), or
2. Through assimilation of large sets of pre-existing data, and, based thereon, through the creation of New Mental Maps (NMM).

Examples of SNT in fisheries were the invention of Virtual Population Analysis (usually attributed to Gulland, 1965), or of Bayesian risk analysis (reviewed by Punt and Hilborn 1997). SNT usually resolve one problem (often one that was not even perceived as such), and do this in a new way that is often regarded as 'neat' or 'elegant'. On the negative side, we should add that SNT can also be seen as 'techno-fixes', resolving the technological aspect of a problem but usually leaving wide open the underlying process that generated the problem. In the case of the two examples above, the problems were how to estimate fishing mortality, and how to present management options to politicians, respectively. Their downside as techno-fixes was that the former quickly bred a misplaced confidence in its outputs (see Walters and Maguire 1996, Pitcher and Hart 1982), whilst the latter, even though labelling them as such, provided ultra-risky options to industry and politicians (Mace 2000), decision-takers who, by the nature of their professions, tend to prefer risky options to safer ones.

The alternative to the SNT, the NMM can sometimes build on one or several small SNT. The important feature of the NMM, however, is that it involves the assimilation (or meta-analysis) of large (sometimes enormous) data sets. Our best example is the realization by U.S. Navy Commander Mathew F. Maury, in the mid-1800s, that mariners collectively held in their head enough information on currents and winds (e.g., in the North Atlantic), to generate maps which would improve navigation, i.e., shorten the route between Europe and the Americas (Maury 1963).

Maury thus promised cooperating mariners copies of his planned maps, should they agree to contribute their individual knowledge on most favorable routes. These data (and depth soundings he also gathered) enabled him not only to produce, after lots of painstaking work, the best navigation maps then in existence ('applied' science), but also to be the first to perceive the existence of mid-Atlantic ridge ('basic' science). Moreover, single-handedly created the mode of interactions between mariners and naval offices that still prevails, and which has enabled the emergence of modern physical oceanography as a discipline wherein data are *shared*. Hence the existence and collaboration, even during the coldest years of the Cold War, of Data Center A (in Washington, D.C.) and B (in Moscow). This, incidentally, is also the reason why oceanographic data can be used to verify the occurrence of global changes: the data are available since the late 19th Century.

Which brings us to marine biology and fisheries. Here, like Maury since the end of the 19th Century, we inherit a mountain of data on the various organisms, from phyto-plankton (net samples, C_{14} measurements, satellite oceanography) and zooplankton (Hensen nets samples, Hardy samplers time series), trawl and benthic surveys, catch time series, landing and price data, etc. – an enormous, ever-growing data set. Yet we are very often told by fisheries scientists and others that there are "no data" upon which to make inferences about the state of North Atlantic ecosystems, and on remedial actions regarding their depletion, and on the future of the commercial species therein. We are told that what we need is 'new, better data', or indeed that we should hope for a SNT to somehow resolve the problem(s) that led to the mountain of data being accumulated in the first place.

Yet major NMM are based on assimilation of existing data, even in areas with which all are familiar. Thus, for example, it is relatively well known that the report which convinced the US authorities, and the US public, and later others in other parts of the world, that cigarettes are bad for smokers did not present a SNT. Rather, it was meta-analysis of a large number of small studies, each perhaps not very convincing by itself, but jointly providing incontrovertible evidence. Further, more recent meta-analyses added the effects of second-hand smoke, now leading to widespread restraints on smoking in enclosed spaces, both public and private. What changed here is the position of cigarettes in peoples' mental maps.

In a similar way, Rachel Carson's *Silent Spring* assimilated into a coherent whole a large number of previously unconnected observations, and this created a NMM wherein the location of DDT and other pesticides was radically different from it previous position (Lear 1997).

The Convention of Biological Diversity (CBD) requires that all the countries of the world make inventories of their biodiversity, and take measures to protect it. Where does small country X get a global reference list of the plants and animals that have so far been described (and of which the species in country X must be a subset)? Such a list still does not exist, despite the straightforward nature of the science that would be required (just as for Maury's maps).

In the late 1980s, work on a large database intended to provide a rigorous nomenclature and classification for all the fishes in the world, and key facts for each of these 25,000 species. Ten years later, the job is largely done (see www.fishbase.org): the countries of the developing world now thus have a tool that enables them to get started on meeting their obligations vis-à-vis the CBD, at least concerning the fishes (presently, the Internet version of FishBase gets over half a million visits per month, several orders of magnitude more than for any comparable product). Moreover, the database thus created, in a collaborative mode resembling Maury's, has many elements serving as model for Species 2000, which aims at producing a list of all organisms so far described (see www.species2000.org).

An excellent example of a meta-analysis is the series of contributions by R.A. Myers and collaborators on the stock-recruitment relationships of fishes, based on their vast compilation of time series of published stock and recruitment time series. This work recently culminated in Myers et al. (1999) and has the potential to produce massive changes in the mental maps of fisheries biologists. Myers' study shows conclusively that the common feature of stock-recruitment relationships across species (a narrow range of slopes near the origin, indicative of a narrow range of reproductive potentials of individual female fish) was not seen previously because nobody bothered to standardize, over a large number of cases, the scales of plots of recruitment versus parent stocks. Rather, earlier authors emphasized the 'uncertain', even 'chaotic' nature of stock-recruitment relationships, entirely missing what turns out to be highly predictable relationships. It is as if Maury had complained about the 'complex' nature of mariners' knowledge, rather than assemble his maps.

These items are examples of NMM, major pieces of work that make available to practitioners tools that assimilate much of the work previously done in a given area. In each case data was already available in principle, but was not assimilated within a rigorous framework. So we can ask: why are there not more of these collaborative exercises in marine biology and fisheries, given their potential impact?

One reason might be that, in the context of government-funded research, such work can be done only after a consensus has emerged about the research to be conducted, the idea being that such NMM should emerge *from the bottom up*. The problem here is the tendency for collective and committee-led research to reduce new sets of ideas, 'visions' as it were, to a least common denominator: voluminously documented research proposals favoring safe science over risky new approaches.

The methodology package we have assembled to answer the questions above, related to the impacts of fisheries on the ecosystems of the North Atlantic, thus reflect our vision, not yet widely shared, that such questions can be tackled at basin-wide scales. The methodology is devoted to assimilating, in rigorous, quantitative terms, a large amount of previous work and to involving multiple collaborative arrangements. However, we shall maintain standards such that coherent products emerge.

Such approach, from *the top down* is, we believe, the only way products can emerge which are useful at scales above that at which marine and fisheries biologists typically operate, usually that defined by the boat of a university research station, or by the commercial vessels used in a fishery under study.

The North Atlantic as Study Area

As defined by the *Sea Around Us Project*, the North Atlantic includes all marine waters North of Miami, Florida in the West and North of Cape Bojador, Morocco in the East. This area is identified in Fig. 1, which also identifies the Biogeochemical Provinces (BGCP), which are compatible with the Large Marine Ecosystems (Sherman and Duda 1999) of the North Atlantic (see below). These articulate, at different levels, the ecosystem classification adopted by the project (see Pauly et al. 2000). Note that this definition excludes the Mediterranean from the scope of the project. Moreover, for various pragmatic reasons, we also exclude the Baltic proper, though not its connections with the North Sea, the Kattegat and Skagerrak. Except for a Southern border a bit further south, and the omission of the Baltic, our definition of the North Atlantic thus overlaps with the area jointly covered by FAO areas 21 (Eastern North Atlantic) and 27 (Western North Atlantic), themselves largely overlapping with the area for which ICES, and NAFO, respectively, are responsible.

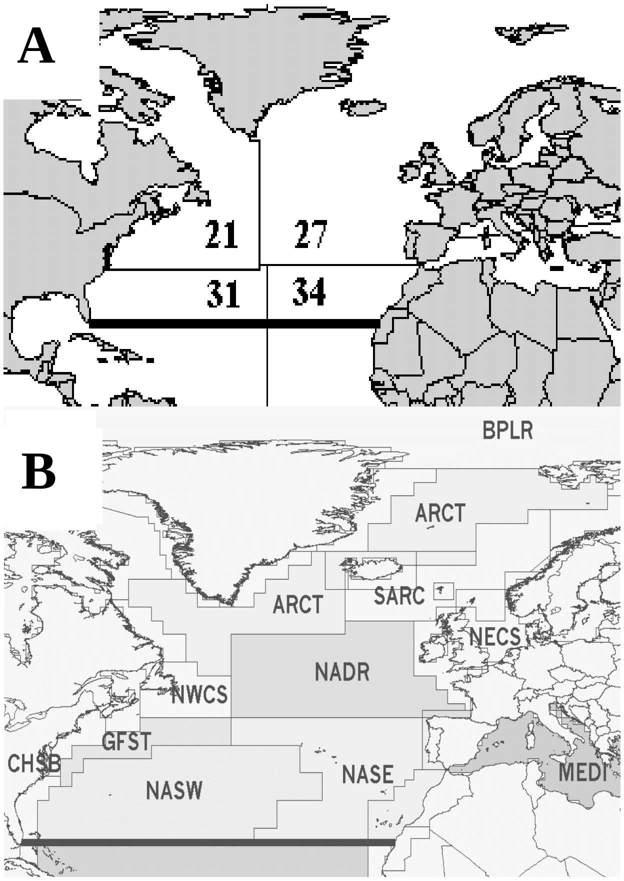

Figure 1. (A) (top) Map of North Atlantic showing that *Sea Around Us Project* area (southern boundary is thick horizontal line) overlaps four major FAO statistical areas. (B) (bottom) The nine major biogeochemical provinces in the *Sea Around Us Project* area. ARCT=Atlantic Arctic Province (in two regions); NECS = Northeast Atlantic Shelves Province; SARC = Atlantic Subarctic Province; NADR = North Atlantic Drift Province; NASE = North Atlantic Subtropical Gyral Province (East); NASW = North Atlantic Subtropical Gyral Province (West); GFST = Gulf Stream Province; CHSB = Chesapeake Bay Province; MEDI = Mediterranean. For further details of how these zones are conflated with Sherman's Large Marine Ecosystems, ICES and NAFO management areas, and USA and Canadian statistical zones, using a half-degree square *Sea Around Us* database, see Pauly et al. (2000).

The questions posed of the *Sea Around Us Project*, referring to the ecosystem impact of fisheries, require that we identify the ecosystems of the North Atlantic. In the spirit of the foregoing, which emphasizes the need to assimilate large amount of pre-existing data, we have adopted, for the *Sea Around Us Project*, the large Marine Ecosystem (LME) concept and definitions developed in the last 15 years by K. Sherman and co-workers, and recently summarized in Sherman and Duda (1999).

This decision was facilitated by the discovery that the LMEs so far defined can be easily mapped onto, and re-expressed as components of coastal Biogeochemical Provinces (BCGP), the larger ecosystem units proposed by Longhurst (1995, 1998) to provide a stratification of the world ocean.

Indeed, this redefinition of LME provides the lower rungs of a hierarchy ranging from 'biomes', i.e., large, circum-terrestrial entities with similar climate (Polar; Westerlies; Trades; and Coastal Boundary) to 56 BGCP and about 80 LME (see Pauly et al. 2000). Moreover, the LME themselves can be further subdivided, especially for modeling purposes (see Pauly et al. 2000 and Christensen and Walters 2000).

This structure for ecosystem classification, proposed as a consensus of several research groups working on this type of issue (Pauly et al. 2000), appears well suited for the stratification required for basin-level estimates of various states and rates and to address the issue of variability of scales emphasized by Levin (1990). Moreover, using this scheme, fisheries may be mapped onto the ecological entities, the ecosystems, that generate the fish caught, and not the artificial boundaries of countries, EEZs, and jurisdictions, our next topic.

NORTH ATLANTIC FISHERIES CATCHES IN TIME AND SPACE

Accurate time series of fisheries catches, here understood as *all* animals killed by fishing gears, and not only those that are *landed*, are at the heart of the *Sea Around Us Project*. However, contrary to what may be believed, assembling such time series for the North Atlantic is not a matter of setting up a new program for sampling primary data in the countries bordering the North Atlantic. Rather, it is largely a matter of identifying, for each of these countries, those elements (if any) that prevent their official catch statistics from reflecting the true effects of fishing gears.

In many cases, even landings are incomplete because the data collecting entity is not mandated to collect data from certain types of gear (often small-scale gear, or sport fishers), notwithstanding the potential impacts of a large number of such gear.

In other cases, obvious sources of biases, notably massive discarding of by-catch are not considered in compiling catch statistics. This also applies to illegal catches, even when, as occur in some fisheries, all those involved – including government scientists - know of their existence, and even their magnitude.

Watson et al. (2000) review these and related issues, and thereby present the database structure and methodology we shall use to obtain, for the North Atlantic, figures that will better reflect true catches (i.e., all withdrawals) than those presently available, illustrated by an example of cooperation with a government agency. Moreover, Pitcher and Watson (2000) explore this issue further, by estimating percentage in each category of unreported catches, following in time the changes in legal instruments, including the Law of the Sea, that provide disincentives to accurate reporting. The analysis is presented such that it can be easily refined by further work.

However, even the first round of estimates resulting from these considerations should contribute to making our catch figures more realistic. This contrasts with the assumption of zero in those categories, the common default position of public agencies, and one that is neither useful nor acceptable to the public itself.

We are well aware that the data set thus assembled will remain fragmentary and incomplete, and that far better data sets will exist on local scales. At the LME and basin-wide scale, however, we expect that our data set will be the most accurate, in that all sources of fishing mortality will be accounted for.

Pauly et al. (2000) present the method by which the global FAO fisheries catch data set will be re-expressed on a global LME map. The key component of the method proposed therein is that it will proceed 'by subtraction', i.e., by first assigning fishes with clear affinities to depth ranges, habitat types and/or certain LME, e.g. the anchoveta *Engraulis ringens* to the inshore part of the Humboldt Current LME, or the neritic fishes reported for Bangladesh to the shelf component of the Bay of Bengal LME, etc., each time subtracting the assigned fish groups from the database. Several rounds of subtraction will lead to small amounts of unallocated landings, pertaining mainly to fish landed in countries with distant water fleets (or providing flags of convenience to such fleets). Assigning the residual landings to the LME where these fleets are known to occur (see Bonfil et al. 1999 and references therein), in proportion to the catches per half-degree square previously allocated, will be sufficient for a first-pass allocation, especially since misallocations should generate visible patterns in the maps thus generated.

For the North Atlantic, this crude approach can be replaced by one in which the catch reported by species, from distinct ICES or NAFO sub areas is assigned to the half-degree squares in each area as a function of the mean depth of each square, and the observed depth distributions in the species in question, as plotted on the 'depth transects' presented below (see also Zeller and Pauly 2000). Here again, misallocations should generate visible patterns in the maps thus generated, and thus lead to improvements of the allocation rules.

FISH DISTRIBUTION TRANSECTS

As mentioned above, the *Sea Around Us Project* will not attempt to perform assessments of single-species fisheries, and not generally question such assessments as performed by various colleagues.

However, we do require connecting our work with key aspect of the distribution of major commercial species, for two reasons:

1) These distributions can help assign catches to areas (see above); and
2) The depth and distance from the coast of major population components determines their relative vulnerability to coastal (often small-scale) and offshore (often large-scale) gear and hence the existence and intensity of interactions and (potential) conflicts between these different fisheries.

The format we have developed for these transect fulfils these requirements by integrating the key information on the distribution and migration of fish in a single graph (see Zeller and Pauly 2000). Using such a graph, catches of both small- and large- scale fisheries, both inshore and offshore, can be partitioned and their impacts evaluated.

Bio-economic analyses of fisheries: small vs. large

Few, if any studies have quantified the economic rent lost from competition between the large- and small-scale sectors of a fishery. Here we have chosen an approach with three important key features:

1) Easily scalable from local fisheries to the entire North Atlantic;
2) Provides management alternatives by emphasizing, where possible, the substitutability of large by small scale fisheries (and vice versa);
3) Should lead to a reliable estimate of economic losses (waste) due to excess capacity and non-cooperative behavior between different elements of the fisheries sector (see Nash 1951, 1953).

This approach uses a multispecies, multifleet yield-per-recruit analysis to estimate, based on the present, calculated recruitment (= influx of young fishes and invertebrates to the fishing grounds), the features of a 'small scale' and a 'large-scale' fleet which maximize the gross value of the catches of both fleets. These features are the level of effort relative to present, and the selection curves of each gear relative to each species. Then, under the assumptions that the present fisheries are at or near their bioeconomic equilibrium point (where total costs equal gross total returns; Gordon 1954), and that fishing mortality scales linearly to fishing cost, we identify the equilibrium point at which maximum net returns can be obtained if the fleets adjusted their fishing mortality such that their joint net benefit is maximized (Munro 1979; Sumaila 1997).

The difference from between these optional returns and the Nash Frontier to the present position of the fleet allows the loss (=economic waste) due to non-cooperation and mismanagement. Finally, we partition benefits by sector and identify the Nash bargaining solution (Nash (1953) associated with the equilibrium point (Binmore 1982). This procedure can be applied successively to a large sample of representative North Atlantic fisheries, thus yielding, by addition, an overall estimate of economic losses, and, more importantly of the economic gains that would result from improved management (Ruttan et al. 2000). We expect these numbers to be very large, especially when scaled up to our reference area, through the ratio of the sum of all catches in the sample fisheries to the total North Atlantic catches.

The Achilles' heel of this approach is, of course, the assumption that for each fishery, relative recruitment, as obtained by dividing yield per recruit into average catches, will remain constant while fishing mortality varies. We note, however, that the approach we propose will tend to associate the Nash equilibrium with levels of fishing mortality lower than those commonly presently occurring in real fisheries (which tend to suffer from growth overfishing). This implies that recruitment would be assumed to remain constant over a small range of F-values only.

Moreover, the proposed method will treat each fishery independently from the others, using distinct mixes of species, each with their own sets of relative recruitment, and growth and selection parameters. Thus, given the Central Limit Theorem, our global estimate of economic loss will tend to be accurate, even if the estimates for certain fisheries are not.

Another aspect of our comparative bioeconomic studies of small-scale vs. large-scale fisheries is that they should provide a framework for evaluating government policies which purport to benefit employment, or other social goods: small-scale and large-scale fisheries often sharply differ in the employment opportunities or other social benefits they provide (see section below on RAPFISH; and Alder et al. 2000).

ECOSYSTEM MODELLING

Embedding the fisheries that generate the catches and economic returns discussed above into ecosystems will be achieved by constructing at least one ECOPATH model for each of the LME in the North Atlantic. The rationale for ECOPATH as modeling tool is that it is the only approach so far demonstrated to be widely applicable for modeling marine ecosystems, notwithstanding a common misunderstanding as to the ready availability of alternative approaches. Christensen and Walters (2000) review ECOPATH as used in the context of the *Sea Around Us Project*, with emphasis on this and other misunderstandings regarding the capabilities and limits of the approach it embodies.

Presently, ECOPATH models exist for numerous parts of the world (see Pauly et al., 2000). However, only 20 of these represent ecosystems of the North Atlantic basin, hence precluding simple raising of biomass flows from ecosystem to basin scales. Thus, a stratification scheme is required, based on the geographic structure outlined above, which can be used to scale models from the sampling area of the field data used to parameterize the models to the wider area that is assumed represented by these same models.

LMEs are seen here as providing the key level for ecosystem model construction. For each LME, an ECOPATH model will be constructed to describe the ecosystem resources and their utilization, and to ensure that the total fisheries catch of each LME is used as output constraint (just as their primary production will be used as input constraint). In addition, the stratification scheme used must be such that it can straightforwardly accommodate any number of additional ECOPATH models for each LME. This can be done so as to simultaneously address the issue of parameter uncertainty, as described in Pauly et al. (2000).

The LME ECOPATH models require information on abundance, production and consumption rates and diets for all ecosystem groupings. Such information can be obtained from the following sources:

- Abundance, production and consumption rates, and diets of marine mammals are available from the *Sea Around Us Project* database for all (117) species of marine mammals and on a seasonal basis;
- Fishery catches: available from the spatially structured catch database generated as described above (see also Watson et al. 2000), and covering all species groups;
- Occurrence, biology and ecology of marine fishes: available from FishBase (www.fishbase.org) at LME level for the North Atlantic, as a result of cooperation between the *Sea Around Us Project* and FishBase projects.
- For marine invertebrates: only limited information (beyond the catches in the FAO database) is available from electronic databases, but a variety of publications provide extensive information. Production rates can be estimated from the well-founded empirical relationships of Brey (1999), now included in ECOPATH;
- Primary production estimates: establishment of a global database aimed at supplying fine grid level satellite based estimates of primary production is presently underway through a cooperation between the Space Applications Institute, EC Joint Research Centre, Ispra, Italy, and several members of the *Sea Around Us Project*.

The LME-level ECOPATH models will serve as the backbone for addressing issues related to fisheries impacts, to derive indices related to ecosystem health (Rapport et al. 1998a; 1998b; Costanza and Mageau. 1999), to evaluate, using ECOSIM and ECOSPACE (Walters et al. 1997, 1999; Walters and Christensen 2000), the likely effects of changes in fishing patterns, including setting up of marine protected areas, and to estimate the expected economic benefits of such interventions.

Moreover, these LME-level ECOPATH models, representing the present states of the systems in question, will also serve as templates for models of selected areas (notably the Gulf of Maine, Newfoundland and the North Sea) for reconstructions representing these systems prior to the onset of large scale mechanized fisheries, and the ensuing resource depletion. Thus, LME-level ECOPATH models of past ecosystems will provide the basis for estimating the benefits that would obtain from rebuilding strategies, as required to address Question 6 in the Introduction (see also Figure 5). The next section provides more details on this issue.

Evaluating alternative ecosystem-based management regimes

To complement the analysis of small- and large-scale fisheries as outlined above, leading to an estimate of potential economic gains from improved management, we will simulate the results of various management regimes, and evaluate their results in the framework of fisheries economics, extended to make it applicable to ecosystem analysis.

The extended theory is then applied to explore a number of questions including (i) to what extent is it worth society's while to restore current ecosystems to their past states? (ii) What is the optimal approach path to the past ecosystem? Is it optimal to invest (disinvest) rapidly in restoring the ecosystem, or should investment (disinvestment) proceed more slowly?

ECOPATH and ECOSIM models will form the ecological basis for our analysis, while ecological economics valuation techniques will help determine the economically feasible restoration plans and paths (see Munro and Sumaila 2000).

Mapping the fate of fisheries landings from the North Atlantic

The validity of the analyses described above depends on the markets presently existing for fish products, and their likely evolution. We propose therefore, that a spreadsheet-based framework can help track the flow of fish landings within the North Atlantic region (details in Sumaila et al. 2000).

Starting with the total fish landings from the waters of each major fishing nation within the North Atlantic region, a map can be developed showing how these landings flow into the major product forms under which they are marketed, i.e., fresh, frozen, salted and smoked. In addition, the portion of the product forms are consumed in the domestic versus the export market can be determined. Finally, the results derived can be used to identify the sectors or product forms which capture most of the economic benefits from the fishes of the North Atlantic.

Energy consumption and ecological footprint of the North Atlantic fisheries

One way to express the overcapitalization of North Atlantic fisheries (i.e., the excess of catching capacity) is to relate the energy dissipated in generating present landings to the energy contained in the landings. This appears more straightforward than estimating fleet 'capacity', which is not only hard to measure, but even hard to define. Energy expenditures, on the other hand are easily defined, and can be estimated reasonably well from the size of the vessels, which relates strongly to that of their engines, and hence to their fuel consumption.

Hence our choice of Horsepower·days as measure of effort, a choice having the further advantage of allowing comparisons between otherwise widely different boat/fishing gear combination (see Watson et al. 2000).

The estimation of energy consumption by the fishing fleets of the North Atlantic, and the related estimation of their ecological footprint (Wackernagel and Rees 1996), are presented by Tydmer (2000), who provides details, as well, on the required distinction between variable energy costs (associated with running vessels) and fixed costs, associated with the construction and eventual retirements of the vessels comprising a fleet.

We anticipate that the aggregate energy costs of fishing, in the North Atlantic, will be very high, relative to the energy (and commercial value) of the landings, the difference being met by various subsides.

RAPFISH and compliance analyses

Evaluations in the *Sea Around Us Project* employ a new multi-disciplinary, rapid appraisal technique, called RAPFISH, that focuses on the comparative sustainability of fisheries (Pitcher and Preikshot 1998; Pitcher et al. 1998a; Pitcher et al. 1998b; Preikshot and Pauly 1998; Preikshot et al. 1998; Pitcher and Preikshot, in press). RAPFISH can be performed even when the rigorous survey data that enables conventional stock assessment are not available, as is the case for many North Atlantic fisheries.

As such, RAPFISH is a typical SNT, a smart new trick as defined above. It is however, suitable for the *Sea Around Us Project* because it allows us to quantify aspects of fisheries thought before to be unquantifiable, and thus allows for comparisons. Moreover, the method can be applied at all scales relevant to the *Sea Around Us Project*, from the fisheries of a small bay of gulf, to those of countries, or of the entire North Atlantic. As well, RAPFISH can be used to compare gears, and thus to contribute its unique perspective to the comparisons between small- and large-scale fisheries mentioned above.

In Rapfish analyses, sets of attributes, chosen to reflect sustainability within each discipline, are scored on a ranked or binary scale. Where data are sparse or uncertain, scores may be refined when better information becomes available. Ordinations of sets of attributes are performed using multi-dimensional scaling followed by scaling and rotation. The leverage of each attribute on the results can be estimated with a step-wise procedure. The ordinations are anchored by fixed reference points that simulate the best (= 'good') and worst ('bad') possible fisheries using extremes of the attribute scores, while other anchors secure the ordination in a second axis normal to the first. Significant differences are defined by Monte Carlo simulation of errors attached to the original scores. Raw plots of the results show fisheries status in relation to 'bad' and 'good'.

Separate Rapfish ordinations are performed in evaluation fields (disciplines) that express status in terms of ecological, economic, social, technological and ethical (Pitcher and Power 2000) sustainability: a further field evaluates compliance with the FAO Code of Conduct for Responsible Fisheries (Pitcher 1999). Status results may be combined in a hierarchical way in 'kite diagrams' (see Figure 2) to facilitate comparison of fisheries by gear type, country, ecosystem or size category, and data may be constructed to represent the outcomes of alternative policies (Alder et al. 2000).

At this stage in the SAU project, we present a paper reporting preliminary Rapfish analyses of fisheries in two major North Atlantic areas, the Gulf of Maine and the North Sea (Alder et al. 2000). By the end of the SAU project all major fisheries will be covered by Rapfish evaluations. This will allow examination, for each country, of fisheries compliance with the FAO Code of Conduct for Responsible Fisheries. Compliance scored in this way will be also be evaluated using a matrix expressing international fisheries conventions to which each country in the North Atlantic is signatory.

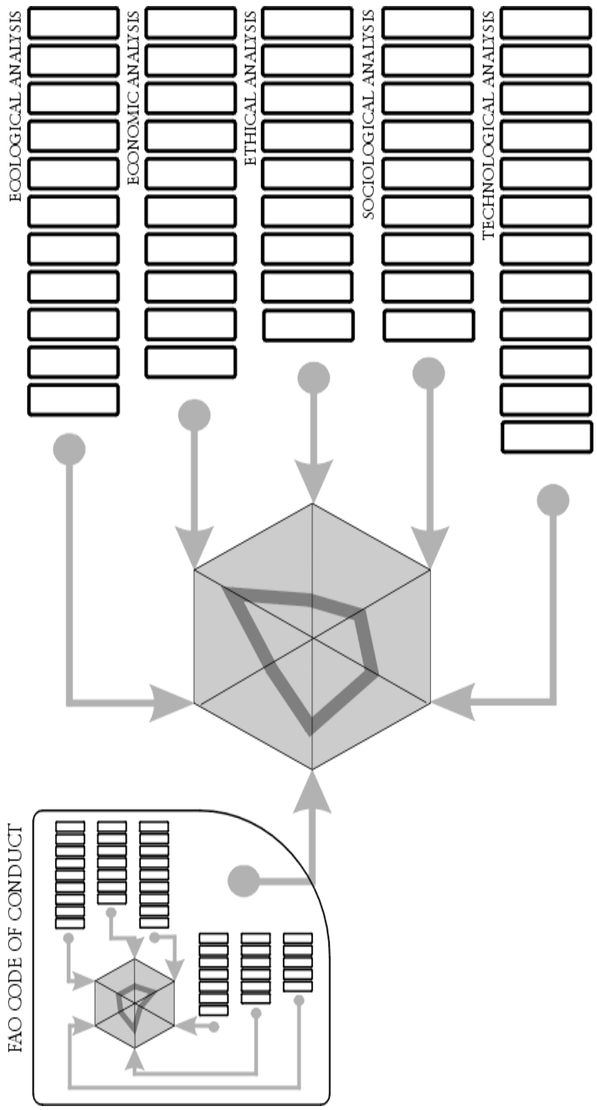

Figure 2. Diagram illustrating how Rapfish evaluation fields for different modalities of sustainability can be considered together as scores on the axes of a kite diagram. Boxes represent the attributes used to ordinate fisheries within each evaluation field. Connections, arrows and kite apices represent a score between 0% and 10% from each field. The outer rim of the kite is equivalent to 100% scores (= 'good') in each field, while the centre of the kite represents scores of 0% (= 'bad'). Six evaluation fields are illustrated here, one of which, for the Code of Conduct, is comprised hierarchically of a five-field Rapfish.

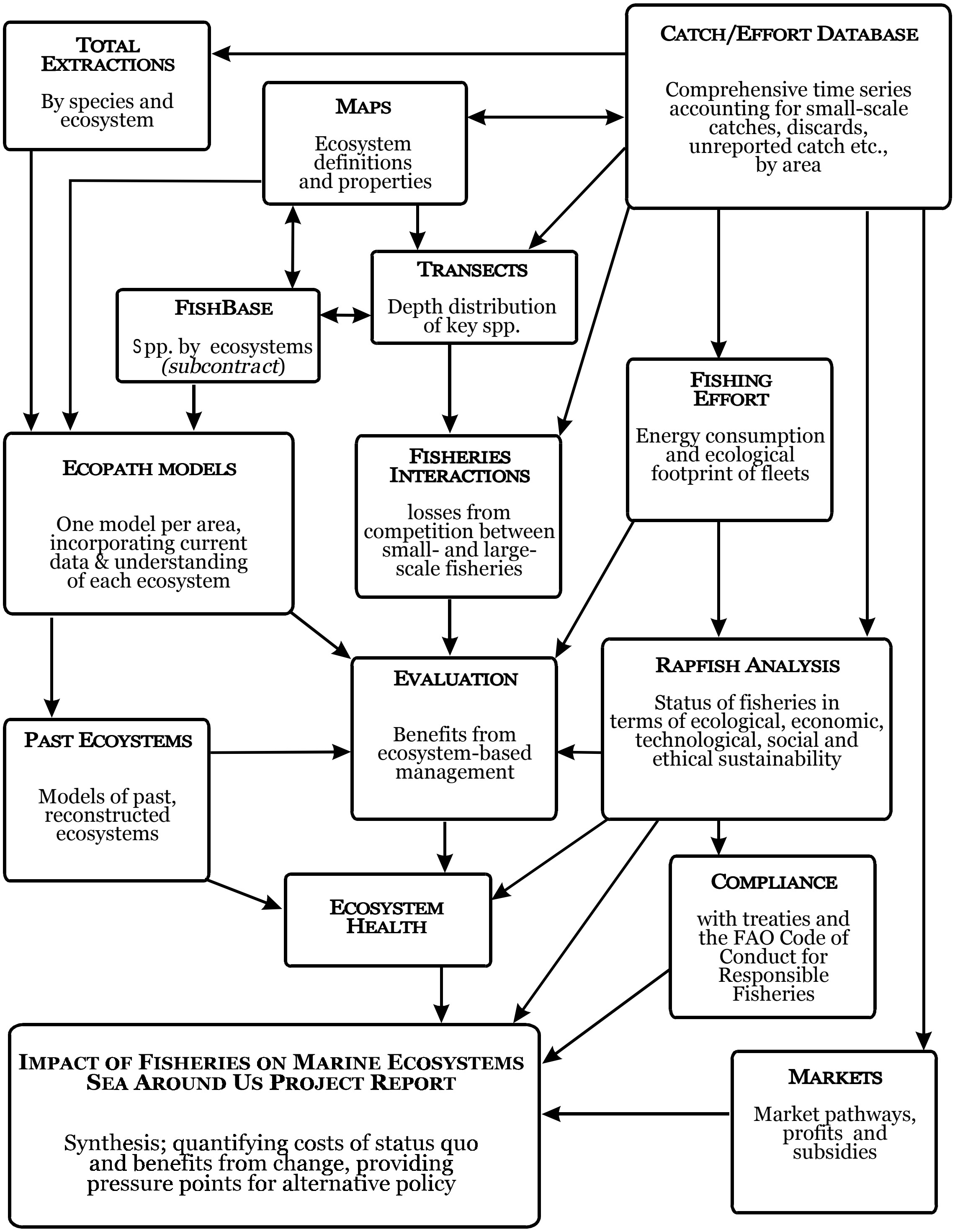

Figure 3. Conceptual diagram illustrating the relationships of the various methodological elements of the *Sea Around Us Project.*

CONCLUSIONS

The relationships among the various elements of the *Sea Around Us Project* are summarized in Figure 5. We anticipate that the synthesis to emerge from integrating the results of these modules will contain many surprises, both in terms of the ecological damage and economic waste presently generated by the North Atlantic fisheries, and the benefits that could be gained, were these economic and ecological issues addressed.

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