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UBC FISHERIES CENTRE

FISHERIES RESOURCES AND
FISHING OPERATIONS
IN HONG KONG WATERS
(PROJECT NUMBER 551055)

Working Paper on Stock Assessment Models for Fishery Resources in Hong Kong

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Executive Summary

Growth, mortality and current biomass values estimated from the present survey will be employed in two general approaches to the stock assessment of Hong Kong's inshore fished resources. The first approach evaluates the status of those species of highest commercial value using single and multi-species yield-per-recruit analyses to assess growth overfishing, estimates of unfished biomass and recruitment to assess recruitment overfishing. The second approach is based on ecosystem modelling and utilises recently developed, experimental software.

The utility of both approaches is dependent on the accuracy of input parameters, including current biomass values derived from the sampling programme backed up by values from the literature. Accurate values for the current catch of the inshore stocks included in the survey are critical for success.

Throughout the work, estimates of stock parameters and sustainable yields will consider parameter uncertainty and will be accompanied by probability distributions and confidence limits attached to the estimates.

Emphasis will be given to the benefits (biologically in terms of biodiversity and economically in terms of higher overall value and reduced fishing costs) that would result from a management regime that allows exploited biomass to recover from the present, extremely depleted level.

Introduction

This report outlines the methods to be employed by the UBC Fisheries Centre in assessing exploitation status and estimating sustainable yields of Hong Kong fish stocks. Data gathered in the present resource and fishing activities survey, historical data and information from the literature will be used. Assessment will cover only the inshore portion of fishery resources landed at Hong Kong, as sampled by the project's survey design.

Two complimentary approaches to the assessment of Hong Kong's fishery resources will be used. The first approach will provide conventional fishery stock assessments, complete with uncertainties, that will be as extensive and precise as the available data will permit. The second approach, which derives from research that is still in progress, is more experimental, but may provide evaluations that could be used in ecosystem management of Hong Kong's fishery resources.

The first approach will use estimates of population parameters for the most abundant and valuable species exploited in Hong Kong's multi-species, multi-gear fishery. Population parameters will be estimated from quantitative models of growth, mortality and spawning partitioned by area and season as far as the data from the project survey allows. Some data may be obtained from the literature. This work will employ state-of-the-art analytical methods to determine the extent to which stocks are overfished and what yield increase might reasonably be expected from a decline of fishing pressure. It will comprise a series of essentially single species analyses and will include parameter error bootstrapping to quantify uncertainty by providing probability distributions and confidence limits on estimates. Recent failures of this type of assessment methodology will cause the Fisheries Centre team to interpret yield estimates with considerable caution. Constraints on the interpretation of these results will be discussed: the principal concerns will likely be inestimable recruitment variability and ecosystem effects.

The second approach will be based on ecosystem modelling and will attempt to assess the marine ecosystem in Hong Kong's coastal waters using recently developed software. This approach considers primary and secondary production, trophic linkages and eco-physiological parameters in the food web to study relationships between all species groups in the ecosystem, not just those of commercial value. The method can describe the likely impacts of perturbations to these and other pivotal species in the system, and moreover, describe what the aquatic system might be like under both much higher and much lower levels of exploitation than current. Constraints on the interpretation of the results will be discussed: the principal concerns will likely be uncertainty in the ecosystem model parameters, missing values for diets and consumption rates, and lack of precise information about the nature of ecosystems around Hong Kong before exploitation increased.

The final report by the FC team will include a species-by-species evaluation of the assessment results, including comparisons between the results of the two approaches, and comparisons between the coastal ecosystem around Hong Kong with similar ecosystems in Southeast Asia.

Approach 1: Single Species Stock Assessment

Although over 100 species have been identified from the sampling programme, stock assessment will focus on the 20 species contributing most to total biomass and commercial value, based on results from the current sampling programme. These species have yet to be identified and agreed within the research consortium. Typically, 90% of a fishery's value and biomass can be accounted for by a relatively small number of species. In some cases where data availability and quality are poor, some assessments may be carried out by grouping species within genus or family, rather than on individual species.

It is important to emphasise that, compared to stock assessment work in many 'western' countries, we will not have a historical database of catch and fishing effort obtained from the fishery that might be used in a conventional assessment by production models, or by dynamic pool catch-at-age procedures (Pitcher & Hart 1981). The assessment procedure that we propose therefore relies on data gathered during the project survey, employs approximate and equilibrium-state methods, and comprises five sequential stages:

1) Population parameter estimation

comprises estimation of the growth, mortality and reproductive parameters necessary for stock assessment using data gathered in the survey, checked with data from the literature.

2) Equilibrium Status of stocks

utilises a yield-per-recruit assessment, assuming steady-state, and provides a determination of current exploitation status and evaluates the extent of growth overfishing

3) Biomass estimation

comprises estimation of current biomass from survey catch rate data, estimation of unexploited biomass from catch rates and fishing mortality, and hence evaluates stock status in terms of risk of recruitment overfishing

4) Sustainable yield estimated from population dynamics

derives from part 3 and estimates sustainable yields in relation to spawning stock, recruitment unexploited and current biomass

5) Sustainable yield estimated by approximate methods

derives in parallel from part 3, and comprises an evaluation of sustainable yield using a range of published approximate methods.

Relationships between these steps and the parameters required for stock assessment are diagrammed in Figure 1.

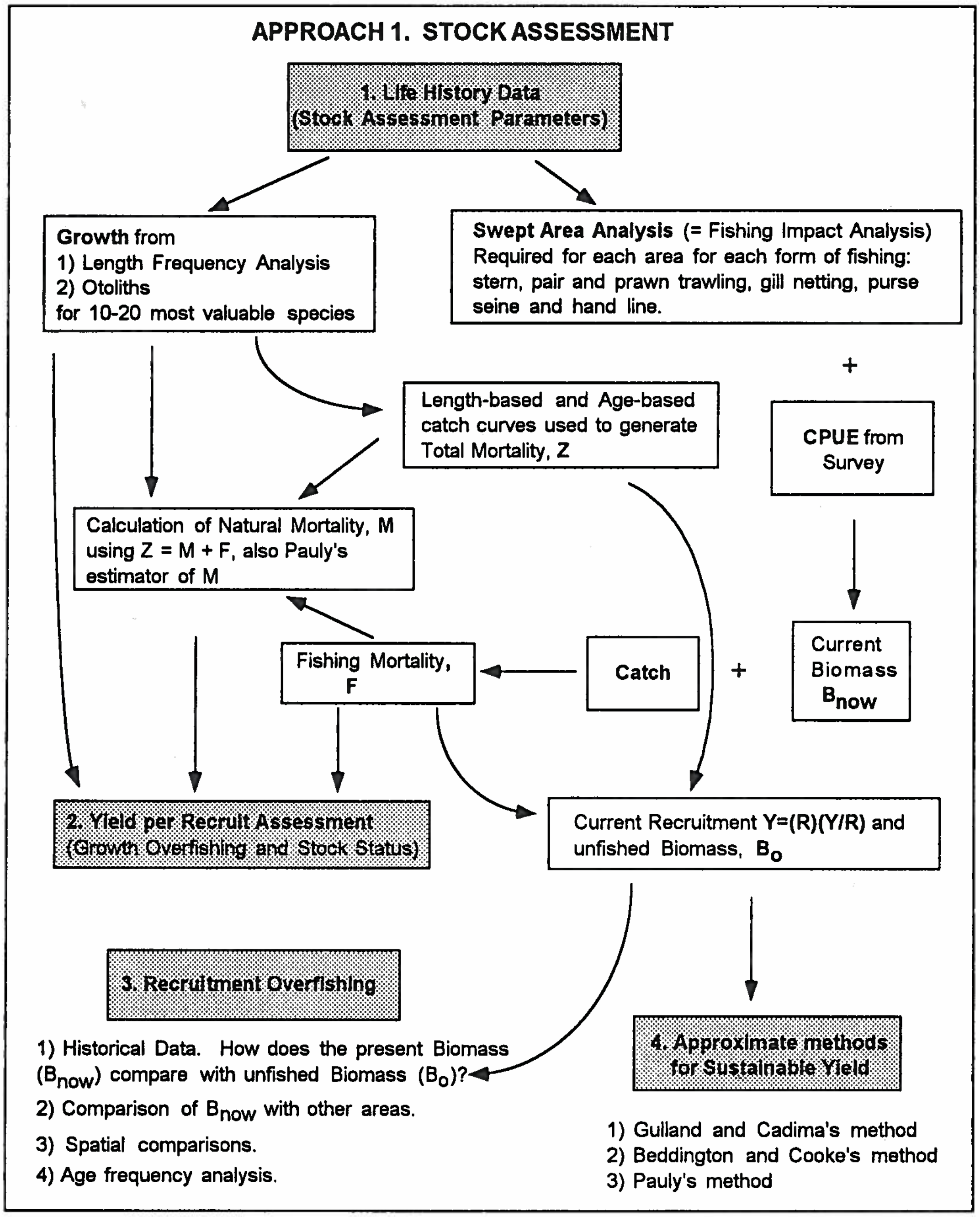

Figure 1. Diagrammatic representation of critical population parameters and stock assessment methods for Hong Kong's multi-species, multi-gear fishery. This approach will focus on species of major commercial value.

Confidence intervals on parameters and estimates

Throughout the project, confidence intervals for parameters and yield estimates will be obtained by a type of bootstrapping method. Error distributions for each input parameter to a model are specified and these distributions are randomly re-sampled 1000 times. This produces 1000 estimates of the model output, providing an error distribution and hence a means of attaching confidence limits on each output parameter. We will use a modern technique based on a spreadsheet that enables such error estimation to be performed for almost any model, simple and complex, that we be used in this project.

1) Estimation of Population Parameters

In order to assess stocks it is essential to obtain statistically robust estimates of their population parameters (i.e., growth and mortality rates, size/age at maturity). Consequently, much of the effort associated with stock assessment is given to deriving or estimating these population parameters. To this end, it should be noted that the value of stock assessments are largely dependent on the availability and robustness of these parameters. Some parameters, such as growth rates are relatively well documented and values are available that may be used to check our values, while others, particularly the mortality rates (natural and fishing mortalities) generally need to be derived.

Growth Parameters

The growth parameters for each assessed species and will be obtained from

a) length frequency analyses using estimation software such as ELEFAN (Pauly 1987), SLCA (Shepherd 1987, Pauly and Arreguin-Sanchez 1995) or MIX (Macdonald and Pitcher 1979),
b) age length keys determined from ageing of otoliths obtained from the current field sampling programme and,
c) from published values in the literature.

A single deterministic growth curve will be used for each species, unless reliable gender-specific length-at-age data are available for both sexes. The von Bertalanffy growth model is the most commonly used model to describe growth in exploited fish populations (Pitcher & Hart 1981) and will be fitted to age/length data using full least squares estimation and to length frequency data using maximum likelihood or least squares.

Since errors in growth estimates are easily made when samples derive from restricted part of the population (for example, when inshore samples miss larger and older fish that have migrated offshore), the validity of estimates will be checked by comparing their ϕ' values (Pauly and Munro 1984) from the literature using Froese and Pauly (1995) and from other sources.

Initial inspection of the survey data suggests that they are not yet extensive enough to use length-frequency methods to estimate growth parameters directly using ELEFAN or Mix techniques. This may be become possible later as the project database becomes more extensive.

Estimation of Mortality Rates

Knowledge of the mortality rate (the rate at which individuals in the population die) is essential in order to undertake stock assessment. In general, the total mortality rate, Z is comprised of two components; the natural mortality rate, M (deaths due to natural causes, such as predation) and fishing mortality F, (deaths due to fishing). In migratory species, emigration, E, can also be considered as an additional component of mortality, for modelling purposes, but is difficult to estimate without a fish tagging programme and we may have to ignore this in the Hong Kong survey. Knowledge of any two of the three mortality parameters allows estimation of the third.

$$Z = F + M + E$$

The simplest method for estimating total mortality Z, is the catch curve method (reference) in which the number of individuals, log-transformed, is plotted against age. Lengths are converted to ages for each species by using the von Bertalanffy growth model and the numbers in each sample at each age class plotted. This provides age-specific total mortality rates, and if the catch curve generates a straight line over several ages, an average estimate of Z can be obtained.

Alternative methods for estimating Z have developed out of a need to use length-based data directly. They include methods by Gulland (1969), Pauly (1984), Vakily *et al.* (1986) and Wetherall (1986), rely on the assumption that there will be fewer longer fish because of mortality and estimate mortality by using the growth curve as proxy for direct values of ages. Although they bypass time-consuming and difficult ageing using otoliths, these length-based methods need large length frequency samples that are unbiased by sampling and encompass all ages in the stock.

Mortality rates vary among ages, from one year to another, and between and within seasons. Total mortality, Z, is also partly dependent on fishing mortality, F, which is generally correlated with fishing effort. As such, both Z and F are likely to vary between the 17 designated fishing areas and therefore, spatial estimates of both parameters will be estimated for some species, if data allows (i.e., if catch rates by area become available for species whose biomass can be estimated from the survey).

Estimates of F may be obtained from biomass and catch rates in section 3, and indirectly from the yield-per-recruit analysis if mean sizes of fish are available, but may also be estimated by subtracting M from Z.

Direct estimates of the natural mortality rate, M, are difficult to obtain. If total mortality, Z, is known and fishery data can be obtained for a range of values of fishing effort, M can be estimated from a plot of total mortality, Z, against fishing effort, f:

$$Z = M + qf$$

where the slope q of the line gives the catchability and the intercept of the line gives an estimate of M (Paloheimo's method) This method may overestimate the true value of M. Paloheimo (1961) noted that the bias can be reduced by plotting averages of f over successive two-year periods against averages of Z. The absence of effort data means that will likely not be able to use Paloheimo's method.

A widely used empirical method for the estimation of M was put forward by Pauly (1980) and based on multiple regression analysis of 175 fish stocks from a wide range of taxa and habitats. Pauly's estimate of M is:

$$\log(M) = -0.0066 - 0.279\log(L_\infty) + 0.6543\log(K) + 0.4634\log(T)$$

where L_∞ and K are the von Bertalanffy growth parameters and T is the mean annual water surface temperature in °C. The method is deceptively easy to apply and is now widely used worldwide. A re-investigation of the work by Lijam (1990), using a larger data set and correcting some of Pauly's original data, gives encouragingly similar values. Confidence intervals are ±20% over most of the likely range.

We will be using this method to estimate average values of M for each species in the Hong Kong project, but it assumes that mortality is the same over all Hong Kong sampling sites and all ages in the stock. We may therefore adjust M values using the approach of Caddy (1991).

2) Equilibrium Status of Stocks

Beverton and Holt's (1957) yield per recruit model is a standard steady-state model widely used for stock assessment. Yield per recruit can be deployed to determine the level of fishing mortality and size/age at first capture required to maximise and sustain yield. Assessments based on yield per recruit help identify *growth overfishing* (when effort is so high that the total yield decreases with increasing effort).

In a steady state fishery, yield per recruit can be estimated by:

$$Y/R = \exp(-M(t_c - t_r)) \sum_{i=t_c}^{i=t_l} \{(F/(F+M)) \exp(-(F+M)(i-t_c))\,(1-\exp(-(F+M)))W_i\}$$

where,

Y = steady state yield of the fishery
R = number of recruits
M = instantaneous rate of natural mortality
F = instantaneous rate of fishing mortality
W_i = mean weight of fish aged i
t_r = age at recruitment to fishable stock
t_c = actual age of first capture
t_l = maximum age of fish in stock

A similar formula provides an estimate of stock biomass per recruit, *B/R*.

Some rigorous assumptions underlie the equilibrium yield per recruit:

(i) recruitment is constant, yet not specified (hence the expression yield per recruit)
(ii) all fish of a cohort are hatched on the same date
(iii) fishing and natural mortalities are constant over the post-recruitment phase
(iv) fish older than t_l make no contribution to the stock.

Yield per recruit analyses will be undertaken for the 20 major species in Hong Kong's coastal fishery, thus identifying stocks that may be experiencing growth overfishing. For any particular species, growth overfishing may be occurring in one area, but not in another. Thus, areas associated with overfishing will be identified. For those species where spatial resolution of the necessary parameters is poor, one or more areas will be pooled in order to undertake the analysis.

In addition, information on the status of the fishery can be obtained by examining the age/size distribution of the individuals obtained in the sampling programme with the size at which they mature and reproduce. A lack of individuals in mature age/size classes is indicative of heavy exploitation. We will examine these age-structure diagnostics for the species assessed in the Hong Kong project.

3) Estimation of Biomass

Biomass estimates are required to assess recruitment overfishing and sustainable yields.

Current Biomass

Estimates of current biomass, B_{now} will be obtained using the Swept Area Method and catch rate data from each stratum in the current survey. The area swept by the trawl gear is calculated as a function of ground trawl speed, head-rope length of the nets, the number of vessels and the time spent trawling, and a "wing-spread" factor, which generally varies between 0.5 and 0.7 (Shindo 1973, Klima 1976, Pauly 1980). The wing-spread factor of the beam trawls used by trawler operators in Hong Kong is likely to approximate 1.0. Current biomass B_{now}, for the area A, is calculated as:

$$B_{now} = \frac{(C_w/a)*A}{e}$$

where C_w/a is the mean weight of the catch per area swept, a and e is a fraction of the biomass in the path swept which is actually caught (generally considered to range between 0.5 and 1.0). The precision of the estimate can be increased by increasing the number of trawls in each area. Confidence limits may be obtained using the bootstrapping technique described above.

This method was used by Richards *et al.* (undated) to calculate the standing stock of demersal fish resources on the northern shelf of the South China Sea (in waters adjacent to the current field sampling programme but further offshore). When data are available, comparisons can be made between the current biomass estimate and with those obtained in the past, or from other locations. Fishing mortality F, of a stock in a given area can also be calculated from a knowledge of the area's biomass and catch taken by the fishery.

According to Garcia and Le Reste (1981), Baranov's (1918) swept area method can also be used to obtain a direct, approximate estimate of F in prawn trawl fisheries. This method assumes F is equal to the ratio of the total area swept by the fleet and the total area covered by the stock, if the prawns are uniformly distributed and all those present in the area are caught. However, depletion experiments (Joll and Penn 1990) indicate that the efficiency of trawl gear for prawns is significantly lower than 100% and therefore, an appropriate factor should be applied to the ratio if this method is used.

Unexploited Biomass

The most complete fishery assessments, those that include estimates of sustainable yield, must incorporate values for the unfished biomass of the stock, B_∞. Estimation of B_∞ is not straightforward. In surplus production fishery models it may be estimated by least squares, but we do not have the historical time series of catch and effort with which to apply this method. We make use of an approximate method. First, when the total annual yield is known in a steady state fishery, the number of recruits R, can be estimated for a given value of F by dividing the total yield, Y (catch in weight) by the yield per recruit, Y/R:

$$R_{now} = Y/(Y/R)$$

The current of value of F with which to estimate Y/R is obtained from the current biomass, B_{now}:

$$Y/B_{now} = F$$

An estimate of the minimum value of B_∞ is then obtained by calculating biomass per recruit at F=0.

$$B_{\infty min} = R_{now} \{B_{now}/(B/R)\}$$

Secondly, the literature will then be searched for likely values of the maximum $B_{\infty max}$ for each species in tonnes per km^2.

It is important to realise that our ability to make this vital calculation in the Hong Kong project will depend on our obtaining total catch figures for the inshore stocks we are assessing. Without the B_∞ estimates, further assessment beyond stage 2, yield per recruit, will not be possible.

4) Recruitment Overfishing

One serious drawback of the equilibrium form of Beverton and Holt's approach is that it disregards *recruitment overfishing* - the situation when fishing reduces the spawning stock (and therefore egg production) to the point where recruitment declines. Any range in fishing effort or size/age at first capture can be considered in a yield per recruit model and the results ignore possible impacts on the population's egg production and recruitment. Recruitment overfishing can bring about the collapse of fish stocks, and for this reason we will attempt to consider the effect of fishing effort on recruitment

It is difficult to determine by direct means if recruitment overfishing has occurred in a fishery. In order to do so, it is necessary to have an understanding of the relationship between spawning stock size (i.e., egg production) and subsequent recruitment strength (referred to as the spawning stock - recruitment relationship, SRR). The relationship takes several years of detailed monitoring of spawners and recruits to establish and once known, "safe" levels of fishing effort which do not reduce the spawning stock below a given size can be identified and implemented. Conversely, "excessive" levels of fishing effort can also be identified. Although it is widely agreed the relationship is fundamental to fisheries science and management (Caputi 1993), examples of statistically robust SRRs in the literature are rare. For most stocks therefore, it is very difficult to identify levels of fishing effort that are "safe" (ensuring recruitment does not decline) while maximising yield and value. Instead, we have opted to use some contrasting methods to consider the current status of the fishery.

First, the Swept Area Method and the catch per unit effort data from the research survey can be used to identify current biomass for each species, B_{now} in the designated areas. Comparisons of these values with B_∞ estimates (B_{now}/B_∞) for each area will provide an insight into which areas and species are heavily exploited. Generally values of this ratio less than 20% are considered unsafe because of high risk of recruitment collapse. This safety threshold varies with the type of fish for example, short-lived species require higher safety thresholds. We should be able to make some evaluations for most of the common Hong Kong species included in the assessment.

Secondly, the recruitment that would likely be associated with $B_{\infty max}$ can be calculated from stock biomass per recruit at zero F:

$$R_{max} = B_{\infty max}/(B/R)$$

The ratio of recruits R_{now}/R_{max} then provides an assessment of recruitment status.

5) Approximate Methods for Maximum Sustainable Yield (MSY)

Gulland's Method

Gulland's (1971) method has been applied mainly to sparsely investigated and lightly exploited stocks and can be expressed thus:

$$MSY = 0.5 M B_o$$

where ,

MSY = maximum sustainable yield
M = instantaneous rate of natural mortality
B_o = unexploited biomass of the virgin stock.

We can use our estimates of B_∞ from section 3 as a substitute for B_o. The formula is also unlikely to hold for stocks that have high M, such as prawns. Nevertheless, this method has been very widely used, especially by FAO in a series of stock surveys around the world.

Cadima's and Garcia's Methods

This formula was proposed by Cadima (in Troadec 1977) for exploited fish stocks that have limited stock assessment data and can be expressed thus:

$$MSY = 0.5(Y + MB_{ave})$$

where,

MSY = maximum sustainable yield

Y = total catch in a year
M = instantaneous rate of natural mortality
B_{ave} = average biomass of the area in a year.

Sparre, Ursin and Venema (1989) note that as most stocks are now already exploited this equation is more frequently used in developing and some developed fisheries where catch and effort time series are not yet available, but biomass estimates are occasionally obtained from trawling or acoustic surveys.

In an attempt to correct problems raised by Cadima's approximation, Garcia *et al.* (1989) presented two alternative formulations for *MSY*. One expressed as:

$$MSY = \frac{F_{msy} B}{2 F_{msy} B - Y}$$

and is based upon the Schaeffer (1954) production model where F_{msy} is the instantaneous coefficient of fishing mortality associated with *MSY* and *B* is biomass under exploitation. A further formula identified by Garcia *et al.* (1989) is based upon the Fox (1970) production model:

$$MSY = F_{msy} B \, e \left\{ \frac{F_{msy} B}{2 F_{msy} B - Y} \right\}$$

Beddington and Cooke's Method

Beddington and Cooke (1983) used Beverton and Holt's yield per recruit to obtain estimates of *MSY* for a range of values of *M, K* and ages at recruitment. They compared their results with those based on Gulland's (1971) method and concluded that in most cases, Gulland's method will overestimate *MSY*. For some parameter combinations the yield is overestimated by up to 200%. This could result in the implementation of management measures which result in overfishing. In general, the only situation when Gulland's method is appropriate for identifying *MSY* is when the age at recruitment and natural mortality rates are very high.

Beddington and Cooke also noted that for high ages at recruitment and high mortality rates, harvesting at *MSY* will lead to a substantial reduction in spawning stock biomass from its unexploited level. The result is that recruitment levels could decline. *MSY* is also dependent on recruitment levels, which are known to vary for most stocks, even when spawning stock levels remain relatively constant. Beddington and Cooke present a stochastic approach, based upon a known variance in recruitment, for identifying *MSY*. This type of approach can be used to identify *MSY* where there is considerable parameter uncertainty. The basic question to be answered here is "Once a specific value of *MSY* is identified, what is the probability that the spawning stock biomass will drop below some specified level in a fixed period of time?" This stochastic approach will be incorporated in the assessment of Hong Kong' fishery using Monte Carlo methods that provide probability distributions to estimates of *MSY*.

Assessment of penaeid prawn stocks

Any assessment of the penaeid prawn stocks is likely to receive special attention because (i) prawns are the numerically dominant species group in Hong Kong waters and have high commercial value, (ii) they are the basis of a distinct fishery with specific gear-type and (iii) they are a short-lived, highly fecund group usually managed on a seasonal basis to prevent growth overfishing (the risk of recruitment overfishing is generally considered to be low) and (iv) as crustaceans they have special considerations for the estimation of growth (because they possess no bony structures its difficult to obtain estimates of absolute age).

Prawn fishery computer models have been developed mainly as a tool to predict the effects of different harvest strategies on yield and value, and thus, to help minimise the risk of growth overfishing (Fox 1973, Sluczanowski 1984, Somers 1985, 1990, Glaister *et al.* 1990, Coppola *et al.* 1992, Die and Watson 1992a,b, Watson *et al.* 1993, Watson and Restrepo 1995, Gordon *et al.* 1995). These models incorporate traditional parameter estimates and mathematical relationships mentioned above, but are tailored to fit tropical penaeid life cycles.

These types of models do not assess the stock as such, but rather allow the user to model the fishery (if all the appropriate population parameters are known) and simulate "what if" type scenarios. The effects of proposed management changes to the fishery (ie., change in vessel numbers, change in gear type, temporal or spatial closures) can be determined, prior to their introduction. If market information on sale prices is known, the effects of such proposed changes can be calculated on the fisheries value, as well as yield.

Approach 2. Ecosystem Assessment

There is an emerging consensus among fisheries scientists and managers of aquatic resources, that traditional single-species approaches in fisheries management ought to be replaced by “ecosystem management” - that is with approaches which account for ecological interactions, especially those of a trophic nature, as well as for other uses of ecosystem resources than for fisheries (NRC 1996). This consensus is also reflected in some governments' policies which refer to ecologically sustainable development. There is more to this trend than the obvious concern that we cannot simply batter away at the parts of an ecosystem as though these parts were isolated. Taking an ecosystem view also invites the use of other instruments of management in addition to harvest regulation, such as enhancement of basic productivity, stock enhancement, and provision of physical structure or marine protected areas to moderate trophic interactions by providing refugia for prey in predator-prey interactions.

One approach for analysis of trophic interactions in fisheries resource systems is the ECOPATH II system of Christensen and Pauly (1992a,b), based on earlier work by Polovina (1984), and widely applied to aquatic ecosystems (fisheries resource systems, aquaculture ponds and natural systems, see contributions in Christensen and Pauly 1993), and recently also to farming systems (Dalsgaard et al. 1995). Like bioenergetics modelling, ECOPATH II has been appreciated by a wide variety of authors as an approach for summarising available knowledge on a given ecosystem, to derive various system properties and to compare these with the properties of other ecosystems. Also, systematic application of ECOPATH II has enabled a number of generalisations about the structure and functioning of ecosystems, and thus to revisit earlier inferences based on smaller data sets (Christensen 1995, Pauly and Christensen 1995, Pauly 1996). However, ECOPATH II provides only a static picture of ecosystem trophic structure (it answers the question: “what must trophic flows be to support the current ecosystem trophic structure and be consistent with observed growth and mortality patterns”). This precludes the use of its results for answering “what if” questions about policy or ecosystem changes that would cause shifts in the balance of trophic interactions.

It is possible to use the results of ECOPATH II assessments to construct dynamic ecosystem models, as systems of coupled differential equations that can be used for dynamic simulation and analysis of changing equilibria (Walters *et al.* submitted). This approach, which we call the ECOSIM module of ECOPATH II, will be applied to Hong Kong's marine ecosystem. One application of the model will represent the west coast of Hong Kong, influenced by the Pearl River, another will represent the more oceanic waters of the east coast. Both of these models will be used to reconstruct original biomass, given observed primary production, to predict catch composition changes given changes in fishing regime and to characterise the system might recover to if fishing pressure were reduced.

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