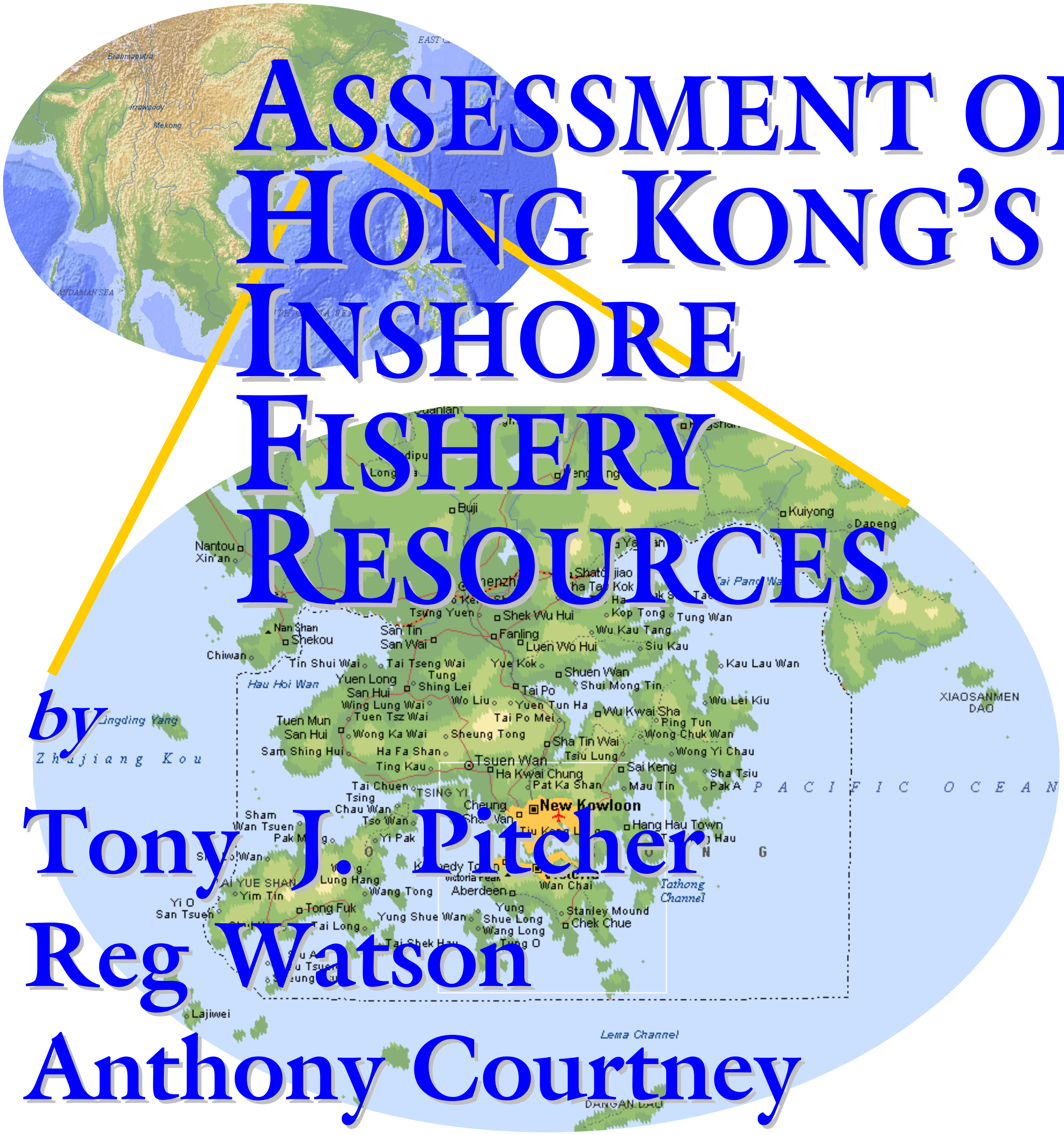

ASSESSMENT OF HONG KONG'S INSHORE FISHERY RESOURCES

by

Tony J. Pitcher
Reg Watson
Anthony Courtney
& Daniel Pauly

Fisheries Centre
University of British Columbia
July 1997

ASSESSMENT OF HONG KONG'S INSHORE FISHERY RESOURCES

by

Tony J. Pitcher
Reg Watson
Anthony Courtney
&
Daniel Pauly

FISHERIES CENTRE, UNIVERSITY OF BRITISH COLUMBIA

JANUARY 1998

TABLE OF CONTENTS

Biomass estimates

Single species assessments

Figures (130)

81 pages text (39,500 words) set in Lucida Bright 10 point & Galliard fonts; 130 Figures, 26 tables.

EXECUTIVE SUMMARY

This work aims to determine the exploitation status of Hong Kong's inshore fishery resources, and the likely impact of management measures on the coastal ecosystem. This report describes results of the assessment work performed by the Fisheries Centre, UBC, between April 1996 and December 1997. Biomass and catch have been estimated by season and sector with survey data: from regular monthly samples of benthic resources using a prawn trawl, from samples of pelagic resources using a purse seine, and from catch estimated from an interview survey of fishers. Benthic biomass is also estimated in 18 spatial sampling strata. Prawns are included but the work does not cover shellfish.

Total inshore resource biomass is estimated as about 9000 tonnes annual average (= 4.9 tonnes km^{-2}), of which 85% is comprised of pelagic species. There is a strong seasonal pattern, seen most strongly in the pelagic species, but also present in benthic resources, with total biomass peaking at over 27,000 tonnes (= 15 tonnes km^{-2}) in August and dipping to 1700 tonnes (= 0.9 tonnes km^{-2}) in February. These results are subject to uncertainties in estimating swept areas and in extrapolating from more detailed work on individual species.

Based on estimating the probability distribution of the catch rates of individual vessels in seven gear sectors and by species, the total catch in Hong Kong waters is estimated as 14,700 tonnes (7.8 tonnes km^{-2}). A detailed breakdown of this catch by gear sector and species is provided. Very wide confidence limits reflect a high variance in individual vessel catch rates, and the results are subject to considerable uncertainty deriving from the adoption of an interview protocol to estimate catch.

Detailed assessments of exploitation status have been carried out for 17 individual species, four of which are crustaceans. Growth parameters and mortality parameters have been fitted to survey data, and age data derived from otolith readings. Growth is fitted by least squares techniques, length frequency analysis, and estimates take account of many published values from the literature. Mortality includes total mortality, estimated largely by cohort slicing, offshore migration with age for certain demersal species, estimated by a novel method, and present fishing mortality calculated by two alternative methods. Yield- and biomass-per-recruit analyses have been employed to evaluate exploitation status. Uncertainties have been explicitly defined and addressed through confidence limits placed on most estimates using Monte Carlo simulation techniques. Twelve of the 17 species are heavily overexploited, while the remainder, principally the small high-turnover species, fall into the fully exploited category. Very approximate sustainable yield estimations based on calculating unexploited biomass suggest that catches of larger and slower-growing species might be roughly doubled with optimal management. A major uncertainty is the equilibrium assumption made by all of these methods, that recruitment will not be greatly affected by increases in abundance.

Multi-species bioeconomic analysis for the trawl fishery, based on parameters from the individual species, conflates the assessment optima for the individual species in terms of their relative value. The results suggest that long term yield for the 17 species might be roughly doubled by increasing mesh size, but are sensitive to assumptions made in estimating relative recruitment factors among the species.

A trophic mass-balance model of the Hong Kong inshore ecosystem is constructed from information derived from the analysis and from the literature. The model includes shellfish, marine mammals, and all living components of the system. The model is used to predict the impact of six scenarios of changes in management on the relative abundance of sectors of the resource. Halving the current fishing mortality results in considerable benefits for all fishery sectors, and those with a conservation focus such as marine mammals. The full benefits of such a policy may, however, take a decade to be realised.

INTRODUCTION

This report describes the catch, biomass and exploitation status of fished stocks in the 1820 km^2 of Hong Kong's coastal waters, the trophic structure of Hong Kong's inshore marine ecosystem, and the predicted impact of specified changes to fisheries management on the ecosystem. Two complementary approaches to the assessment of these resources are provided: single and multi-species equilibrium assessments, and evaluation using an ecosystem model.

We have used relatively conventional age-structured single species assessments made more rigorous by employing state-of-the-art Monte Carlo methods to evaluate uncertainty. Population parameters are calculated from a concurrent sampling program (March 1996 - March 1997). Methods are based on those set out in Pitcher and Hart (1981), Gulland (1983) and Hilborn and Walters (1992), except where noted below. Some parameters are estimated from the literature, mainly due to migration of larger fish to offshore waters. Probability distributions are derived for the parameter estimates using Monte Carlo simulations. Estimates of the catch by species and sector landed in Hong Kong waters are based on an interview survey of fishers. Biomass estimated by species, location, benthic and pelagic sectors is based on swept area and other techniques. Data from the prawn trawl survey is adjusted, using a novel technique, for lowered catch efficiency due to debris.

Growth and mortality parameters are estimated using least squares and other techniques, including a novel method for estimating offshore migration with size. The exploitation status of 17 of Hong Kong's most abundant and valuable species is assessed, pooled over the entire survey area, using fishery yield and value models that assume an equilibrium. Sustainable yields are evaluated using a range of approximate methods. Together these steps provide indicators of the sustainable harvest of each species, and provide some indication of the management measures that would be required to achieve them.

Parameters from the individual species assessments, together with current prices, are employed in a multi-species bioeconomic model using value-per-recruit analysis. This examines the effect of varying mesh size and fishing mortality on the assessed species simultaneously. The results illustrate an optimal trade-off between small fast-growing species that may be of high monetary value like prawns, or low value, like ponyfish, with larger, slower-growing high value fish species of table fish, like croakers. This approach also makes equilibrium assumptions and does not allow for changing recruitment, or the effect of biological interactions, such as predation, among the species.

The second approach is more experimental and based on a multi-species ecosystem approach to fisheries assessment and management. It utilises the ECOPATH software (Christensen and Pauly 1992a,b, 1993) to, first, construct a static trophic model of Hong Kong's coastal ecosystem and, secondly, to deploy the recently developed dynamic ECOSIM module (Walters et al. 1997) to predict long-term changes in the trophic groups, given various fishing mortality scenarios.

The ecosystem 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. By using ECOPATH and ECOSIM in conjunction, the likely impacts of perturbations, including management imposed changes to fishing effort, can be examined. Fisheries managers, and others can use this approach to examine and predict changes not only to commercially important fish stocks, but also to other components of the ecosystem, prior to the implementation of any management-related change. ECOSIM is deployed to examine the effects of six scenarios that vary fishing mortality on the different trophic groups.

METHODS

This section provides details and rationale for the methods we have used to estimate resource biomass from the shrimp trawl and purse seine surveys, catch from the interview survey, the single species assessment methods, multi-species assessment methods, and modeling performed to evaluate ecosystem impacts.

BIOMASS ESTIMATION METHODS

Benthic Species

Biomass of benthic species caught in the survey using the prawn trawl was estimated using the swept area method (e.g. Sparre & Venema 1992), with allowance for occasional reduction in the catching efficiency of the net caused by catching debris and, for prawns, allowance for smaller catch rates during the day. Biomass for each stratum for 12 benthic species, and the total of all species caught, was calculated from the weight caught in seven prawn nets towed simultaneously for 3000m, as measured by GPS.

area swept = net number * path width * trawl length
density = (sample weight/ area swept) * retention factor * debris factor
biomass = density * stratum area * prawn nocturnal factor

where net number = 7; path width = 2m; path length = 3000m; retention factor = 0.5; and stratum areas are given in Table M1.

Stratum	Area	Stratum	Area
T1	67.0	T11	76.6
T2	14.8	T12	90.1
T3	39.6	T13	64.9
T4	51.9	T14	42.9
T5	168.0	T15	149.5
T6	45.6	T16	78.2
T7	79.0	T17	63.9
T8	52.3	T18	133.5
T9	307.9	(T19)	(241.3)
T10	51.0	TOTAL	1817.9

Table M1. Areas, in km^2, of the 19 sampling strata used in the Hong Kong surveys. Note that stratum T19 has not been used in the calculations since sampling was not often possible there.

The *debris factor* was estimated by fitting a log normal distribution to the total weights caught in the 1553 individual net samples. To allow for the varying abundance of organisms, the log catch of each net was expressed as a difference from its mean. The resulting frequency distribution, Figure M1a, indicates a very poor fit for the log Normal because of excess values on the left flank. These derive from poor samples presumably caused by debris: perfect sampling with no debris would very likely produce a good fit to a log Normal. To allow for the debris, we fitted the distribution mixture shown in Figure M1b by determining the mean and shape of a second 'debris' component with least squares (Macdonald and Pitcher 1979). The improvement in fit is statistically significant ($P<0.0001$). We have used the mean of the 'pure sample' component (0.1), and the relative proportion of the 'debris' component to the total (8%) to calculate the debris adjustment factor (1.92).

The *prawn nocturnal factor* was measured as 2, based on the difference between the regular sample trawls during the day and some night trawl samples that had been undertaken. As the species composition of the prawns in the night trawls was different, this is a considerable approximation.

For each species, *biomass* was estimated for each month and each of the 18 strata. (On account of infrequent sampling, stratum 19 data were excluded from this analysis, except in as far as it contributed to the total HK area.) Sampling with the shrimp trawl is assumed to be a Poisson process, such that zeros in the trawl indicate that fish were not caught, rather than their being absent from the stratum. Accordingly, averages were taken over all non-zero catch records. This process is equivalent to assuming that strata with zero catch in fact contained fish at the average density for the whole survey.

Uncertainty in the biomass estimation was accounted for using a Monte Carlo bootstrapping simulation of 10000 trials with error distributions as follows:

Path length: normal distribution, s.d. = 100m
Retention factor: normal distribution, s.d. = 0.05
Debris factor: gamma distribution, origin = 1, scale = 0.05; shape = 2.7
Prawn nocturnal factor: gamma distribution, origin = 1; scale = 0.3, shape = 4

The gamma distribution origins were set to the logical lower threshold of possible values, and the shapes adjusted so the means fitted the calculated nocturnal and debris values.

Pelagic species

As Hong Kong inshore waters are very turbid, we have been able to use a variant of the swept area technique in order to estimate biomass for pelagic species sampled by the survey purse seine. The area swept was approximated as the area of the net, with the two ends brought together forming a circle, plus one half of a square whose side has the same diameter as the net circle. The proportion of fish in the swept area retained by the purse seine was assumed to lie between 0.5 and 0.95, with the mean halfway between.

As a light was used during the purse seine sampling, we have allowed for the potential concentrating effects of the lamp using a ‘lamp factor’, which is taken as the radius of the area from which the fish were drawn into the path of the net. This radius was assumed to lie between 20m and 125m. The fish density within the net was then raised to a total biomass (in tonnes) in the Hong Kong area for mean, upper and lower limits using the combinations of lamp factors and the proportions of fish retained which produced the lowest and highest raising factors.

For the sampling purse seine 140m long, radius 22.3m, the area of the circle was 1560m^2, square 462m^2, total swept area = 1773m^2. This area was greater than that affected by a lamp factor radius of 20m (1257m^2), therefore with an assumed retention factor of 0.5, this formed the basis for the largest raising factor of 2,143,491. In contrast, a lamp factor of 125m would concentrate fish from a 49,087m^2 area (which exceeds the area based on only a mechanical sweeping of 1773m^2) and with a retention rate of 0.95, means that the lowest raising factor is 40,744. Uncertainties were accounted for by Monte Carlo simulations based on the limits given above, but a major uncertainty, not able to be accounted for, is the schooling habit of pelagic fish species.

Estimation from fleet catches

A third method of calculating biomass has been used that is not based on swept area assumptions. Because some species may be under-represented in either pelagic or demersal sampling gear, and indeed many are reported caught by several sectors in the Hong Kong fishery (see catch section in Results), biomass has also been calculated from the proportion of the catch in pelagic and demersal sectors. This procedure effectively treats the combined sectors of the Hong Kong fishing fleet as if it were a giant sampling device, and assumes that catches are in proportion to density and, therefore, proportional to total abundance.

Catches from the hang trawls and purse seines were considered ‘pelagic’, and those from the shrimp trawls, stern trawls and miscellaneous vessels as ‘demersal’. As catches from the pair trawl could not be assigned strictly to either pelagic or benthic sector totals, the catch from this fishing gear was combined with sector totals on a species by species basis so that the total biomass estimate was maximised. For each of the assessed species, biomass in the two sectors was estimated as the proportion of the total catch in that sector multiplied by the total pelagic or benthic resource biomass (for the latter see Total aquatic resource biomass section in Results).

CATCH ESTIMATION METHODS

The survey of fishers undertaken on fishing vessels anchored in port in 1996-7 was based on interviewing approximately 27% (1,306) of the crews located on all vessels that are based in Hong Kong ports (4,857: AFD survey). We have estimated catch separately for fishery sectors of shrimp trawlers (SHT), hang trawlers (HT), stern trawlers (ST), small fishing vessels (P4/7), pair trawlers (PT) and purse seiners (PS). We have not been able to consider catches from 891 small vessels, which were not included in the Furano survey, and we have lumped all small vessels (<4 m long, <40Hp) in the survey using long-line (LL), gillnet (GN), hand-line (HL) into a miscellaneous category. For each sector, the number of these vessels that fish predominantly in Hong Kong waters, nk, is calculated as follows:

$$nk = na \cdot (s2/s1)$$

where

$s1$ = no of vessels in sector interviewed by Furano
$s2$ = no of vessels in sector reporting >50% catch in HK waters
na = total no of vessels in sector from AFD survey
nk = estimated no of vessels in sector fishing Hong Kong waters

and the results listed in Table M2.

	Shrimp Trawl	Hang Trawl	Stern Trawl	P4/7	LL,GN,HL MSC	Pair Trawl	Purse seine	Totals
# interviewed	272	22	71	873	458	149	85	1930
# interviewed fishing HK	113	22	13	562	207	4	85	1006
est. prop. fishing HK	*0.42*	*1.00*	*0.18*	*0.64*	*0.45*	*0.03*	*1.00*	*0.52*
# boats AFD survey	460	36	179	2610	891	546	135	4857
est. # boats fishing HK	**191**	**36**	**33**	**1680**	**403**	**15**	**135**	**2492**

Table M2. Vessels fishing in Hong Kong waters (row 5) estimated from the AFD vessel survey (row 4) and the Furano interview survey (rows 1 -3), by vessel type.

In practice, over 98% of vessels reported taking either 100% of their catch inside or 100% outside Hong Kong waters, and so there was no need to estimate the proportion of reported catch taken within HK waters. But, for catch by species, since not all vessels reported catching all species, mean catch required a multiplier, P, the probability of capturing (=reporting) a species,

$$P = ns/nv$$

where,

nv = no of vessels in sector interviewed in the Furano survey;
ns = no of vessels in sector that catch (=report) a species;
P = probability of capture for a species.

Annual catch was then calculated from the interview survey database by sector and species from the estimated log mean annual catch per individual vessel: 95% confidence limits were obtained from a fitted log Normal distribution in each case.

$$Cs = \exp(lm) \cdot P \cdot nk \text{ with confidence limits } \pm \exp(lm \pm cl) \cdot P \cdot nk$$

where,

Cs = total annual catch (=reported catch) of a species in a sector;
lm = mean of logs of catch weights for a species reported by individual vessels in sector;
cl = 95% confidence limits on lm;

and

$$\spadesuit Cs = \text{Total annual catch of a species over all sectors.}$$

Totals by sector and overall were obtained by adding the appropriate figures. Total catch over all species by sector (=vessel type) was also calculated separately by using the equation above without the individual species probability factor, and a log normal distribution fitted to each in order to validate the use of this distribution model. Figure M2a to M2g shows the log normal fits to reported annual vessel catches in each of the seven gear sectors.

Catches derived from the survey were recorded on a taxonomic basis, even though it is unlikely that the fishers know, or record their catch in this way. The penaeid prawns are an example in point; there are approximately 10 species in Hong Kong waters and it is very unlikely fishers differentiate their catches. Therefore, the catch of individual species will be unreliable. Similar taxonomic problems will apply to mantis shrimps and some fish species. Furthermore, approximately 21% of all product landed in Hong Kong waters was recorded in the survey as "MIXSPP", and so the species composition of nearly a fifth of the catch is unknown.

SINGLE SPECIES ASSESSMENT METHODS

There seems to be no long-term or on-going program recording the catch and fishing effort in Hong Kong waters. Catch and effort statistics have been collated irregularly over the last 20 years, mainly by way of surveys and crew interviews. Richards (1980, 1985), Richards et al. 1985) and Leung and Lee (1987) warned that estimates of the catch were associated with considerable uncertainty, while levels of fishing effort remain largely unknown. We have therefore been unable to use many of the standard assessment methods aimed at providing sustainable yield levels and absolute values for advised catches. The techniques we have used have therefore necessarily concentrated on equilibrium assumptions and consequently our assessment results must be treated with some caution.

Length-weight relationship

Data from the current sampling program were used to derive a length-weight relationship for each fish species by fitting a straight line to log transformed length-weight data. The absence of large fish has likely biased these estimates. Confidence limits on the length-weight conversion parameters (a and b) were also calculated (see section below on Incorporating uncertainty).

For the invertebrates, only individual body weight was measured. Additional data, used to generate length-weight relationships for the invertebrates, was supplied by Dr. Mak (Furano). These length-weight relationships were then used to convert all individual body weight measures for the invertebrates, into length measures. This was required in order to undertake length-frequency analyses.

Growth rates

Quantifying growth rates in fished species is essential for most stock assessment methods.

A total of about 1000 otoliths (approximately 50 for each of the assessed species) collected by the trawl survey were read by Dr Z. Zhang. Precision was assessed at over 95% by re-reading randomly chosen otoliths. Mean lengths at age (in years) were calculated with their coefficients of variation.

We had originally intended to use standard age-based methods of estimating growth by fitting the von Bertalanffy asymptotic growth model to mean lengths at age from the otolith data (see Pitcher & Hart 1981). Fitting the three parameters of this model (asymptotic length L_T, rate of approach K, and model starting point t_o) to data is carried out not by classical methods but by least squares using the 'solver' optimisation routine built into the Excel spreadsheet. However, because larger individuals for many of the fish species being examined migrate offshore and outside the sampling zone, the mean length of each age group read from otolith samples taken in the survey area was biased downwards. As the larger members of each cohort leave the inshore area, this bias becomes larger with age. One consequence of this process is the absence of estimates for mean length for older ages that have completely left inshore waters, but the biased mean lengths for ages that are present have a more serious effect in imposing a downward bias on the estimated growth rate parameter K. Accordingly, we have devised a new method to compensate growth for offshore migration and at the same time provide a value for the offshore migration rate with size.

Published estimates of the von Bertalanffy growth parameters K and L_T were obtained from the literature, many of which are summarised in the FishBase database (Froese and Pauly 1996). Growth and other population parameter estimates were also obtained from ASFA searches that were undertaken for each species for the period 1978-1996.

In addition we derived growth parameters using three different length-frequency analysis methods: Elefan (Pauly 1987), the projection matrix (Projmat) (Basson et al. 1988) and a modified Shepherd's method (SLCA), (Shepherd 1987, Pauly and Arreguín-Sánchez 1996). Growth estimated by length-frequency analyses will not be biased by offshore migration. All of these methods are included in the LFDA suite of programs (Holden & Bravington 1991). Two versions of Elefan were used, one from LFDA and a second, incorporating seasonal growth, from FiSAT. For some species that were poorly, or infrequently represented in length-frequency samples (such as some migratory pelagic fish), a fourth, generically different length-frequency method (mixture analysis: Macdonald and Pitcher 1979) was utilised.

Approximately monthly length-frequency based growth rate estimates were obtained from the trawl and quarterly from the purse seine sampling. For some pelagic fish species, additional length-frequency data, provided by Dr. S. F. Leung of the Hong Kong AFD and based on sampling commercial catches from the purse seine fishery for the period 1995-1996, were also analysed.

For each species we placed all of the relevant growth parameter estimates, from the literature and from our own length-frequency analyses, on an auximetric plot (Pauly 1979) of log K against log L_T. We calculated mean values for log K and log L_T after first checking that the cluster of points was normally distributed (we would have taken median values otherwise). Log means were back transformed to numbers. Relevance of the values obtained in the literature was judged by taking localities with similar water temperatures to Hong Kong: we excluded points from other places.

For fish species that had their otoliths aged, the next stage was to fit a second, observed value for the von Bertalanffy K through the otolith-derived data points using the true L_T. We fixed L_T because we had no size estimates for the missing older fish: if we allowed to L_T to vary as well as K, the fitted growth curve would not be robust, as L_T is biased downwards. The growth model time start parameter, t_o, was estimated by adjusting the horizontal position of the growth curve until hatch size was the same as for the growth curve fitted to the otolith data, using the Solver optimisation facility.

Otolith-derived estimates of K often differed markedly from what was published and from what we estimated from the length-frequency analyses. In general, the otolith-based estimates of K were well below other estimates. Although they were included in the auximetric plot for each species, the otolith-derived estimates were usually excluded from the mean estimate of K and L_T. Otolith-derived estimates have been used here to estimate t_o, offshore migration and mortality rates.

Length-frequency analysis was the sole technique used to quantify growth for species without any permanent bony structures such as prawns, crabs and mantis shrimp. Additional estimates were also obtained from the literature, and where appropriate, included in the estimation of the mean values of K and L_T.

Mortality rates

Knowledge of mortality rates in fished species is also critical for stock assessment. It can be problematic, however, to separate the overall mortality rate in a population, the instantaneous rate of total mortality, Z, into its various components, which include instantaneous rates of natural mortality (M), fishing mortality (F) and emigration (G). Although an equilibrium assessment can be made using Z, evaluation of current status requires an estimate of F.

Total mortality rate, Z

Estimates of the instantaneous rate of total mortality (Z) were derived using two different methods. First, we used a length-converted catch curve method (FiSAT: Gayanilo et al. 1990). This method requires large length-frequency samples that are unbiased by sampling and encompass all ages in the stock. Some of these assumptions are violated using the current benthic trawl samples, particularly for migratory species, and therefore are likely to overestimate Z. Secondly, we used the fitted growth parameters to slice the length-frequency distributions into cohorts. Because small differences in sampling efficiency, and seasonal movement in and out of the sample areas, can make a large difference to the sliced cohort numbers, to estimate Z, we chose only those portions of a cohort's history that showed consistent straight lines on a semi-logarithmic plot. In some cases with large length-frequency samples, Z values could be obtained from several cohorts. Where differences were not too large, we have averaged values from these two methods.

Unfortunately, three factors affecting the length-frequency data by reducing the number of large fish in the samples conspire to render our current estimates of Z very uncertain: a high fishing mortality rate; a high offshore migration rate; and size-selectivity of the principal sampling gear (the prawn trawl). Moreover, we are forced by small sample sizes to combine all of our data and hence we are unlikely to be able to provide estimates of total mortality separated by sampling strata or partitioned by season.

Natural mortality rate, M

The instantaneous rate of natural mortality M, for each fish species was derived using Pauly's (1980) empirical method which uses a multiple regression that predicts M from water temperature and the growth parameters K and L_T. A value of 23°C was used for the mean annual surface water temperature in Hong Kong. Confidence limits on M were taken from the study by Lijam (1990) (see section below on Incorporating uncertainty). This method, however, only applies to fish and so estimates of M for the invertebrates (prawns, crabs and mantis shrimps) were derived by averaging relevant values from the literature. The natural mortality rates of penaeid prawns are relatively high, possibly because prawns have a high energy content and are an attractive food source for predators (Dall et al. 1990). Garcia and Le Reste (1981) collated 16 estimates of M for seven species (six *Penaeus* spp. and one *Metapenaeus* spp.). Estimates for adult prawns range considerably, from 0.04 to 0.84 month^{-1}. Lucas et al. (1979) calculated M for *Penaeus merguiensis* to be 0.20 month^{-1}. Somers (1990) also used a value of 0.20 month^{-1} to model the effects of changes in fishing effort on *Penaeus esculentus* and *Penaeus merguiensis* in Australia's northern prawn fishery. Dredge (1990) estimated M in adult *Penaeus longistylus* to be 0.29 month^{-1}, while Glaister et al. (1990) found M ranged from 0.25-0.32 month^{-1} for *Penaeus plebejus*. Given these estimates, and the lack of published estimates of M for the penaeid prawns in Hong Kong waters, a single mean value of M from the above values of 3.6 year^{-1} (0.3 month^{-1}) was taken as representative for prawns in the present study. Similarly, estimates of M for mantis shrimps are scant and non-existent for stocks in Hong Kong waters. In the present study, mantis shrimps were assumed to have a slightly lower M, compared with the penaeids, and therefore we used a value of 3.0 year^{-1}.

Offshore Migration Rate, G

Our new method of estimating offshore migration rate relies on comparing true growth with that observed. The three main assumptions are, first, that within a cohort there is a log normal distribution of lengths for a given age, and secondly, that the coefficient of variation (COV) shown by the youngest age in the samples, and aged with otolith reading, remains constant in the true cohort as the fish grow older and larger. (The assumption of a constant COV with growth is validated in Macdonald and Pitcher 1979.) Thirdly, we assume a linear increase with age in the probability of a fish migrating offshore out of the sample zone. The consequence of this age-based process for the length structure of a cohort is that larger fish within each cohort migrate out of the inshore sample zone, and this tendency will affect a progressively larger proportion of the fish in the cohort as they get older. Eventually all of the fish will have migrated (probability of emigration $P = 1$).

Starting with a guessed value of the migration probability with size, for each length interval we calculate the proportion of each true cohort than remains in the sample zone. The mean lengths with age are calculated from the true growth curve, while the proportion of fish in each length interval comes from the location of the length interval relative to the mean and standard deviation. This is repeated for all length intervals in the sample range and the result is a curve that represents the length distribution of fish that have not yet migrated offshore. To fit the migration model, the mean and COV of this calculated curve are compared to the actual mean lengths and COVs of the fish aged using otoliths. Solver is employed to minimise the sum of the squares or differences between these actual and calculated values by altering the origin and slope of the migration probability line. Once the migration probability line is fitted by least squares, the proportion of fish remaining in the sample zone in relation to the total cohort is calculated using the log normal probability density function. This proportion estimates the offshore migration rate. Where this procedure covers several cohorts, Solver is used to minimise the differences over all means and COVs simultaneously. Migration rate is plotted against size for use in the rest of the analysis. This new method will be written up for publication as one of the outputs from the project.

Fishing Mortality rate, F

F by the difference method. One estimate of the instantaneous rate of fishing mortality (F) was derived by subtracting M and G from Z. As a consequence, if Z is overestimated, F is also likely to be overestimated. Most alternative methods of estimating F, for example from historical catch data using Virtual Population Analysis, are not available to us as there appear to be no time series of catches or effort for the inshore fishery.

F from catch and biomass. Provided that catch in weight (=yield) and average biomass are taken over the same period, (this should be short enough for catch to be less than biomass for high P/B ratio species, but annual figures should be OK for most species), and M is known and to the same time base, the 'Beverton and Holt' catch equation

$$Y = F / (F+M) . B . (1- \exp(-(F+M))$$

can be re-arranged to

$$1 – (Y. (F+M) / BF) = \exp(-(F+M))$$

where the value of F can be found when both sides of the equation balance, by iteration from a trial $F = M$. (Note that a second solution when $F = -M$ should be eliminated.) The problems inherent in estimating catches from the survey data indicate that the resulting estimates of F should be considered with caution.

Yield-per-recruit analysis

An equilibrium age-structured dynamic pool model in the form of yield-per-recruit was fitted to the growth and mortality parameters for each species (Beverton and Holt 1957; Pitcher and Hart 1981). Estimates of the size or age at first capture were derived using the nomogram and method described in Pauly (1984). Error distributions and confidence limits were established through Monte Carlo simulations using the error distributions of the growth, mortality and length-weight parameters, as detailed below.

This analysis sets out the long-term average yield (in relative terms) obtained over a range of fishing mortality rates and ages/size of first capture and is usually presented as a 3-dimensional 'map' that defines what is possible from the fishery. If current F and age of entry are known, the current location of the fishery can be plotted on the map and compared to more desirable locations. It thus provides a simple way of evaluating the exploitation status of a fishery, although for a number of technical reasons, the location and desired trajectory for reaching of the optimal goal of a fishery is not well represented by this equilibrium approach (see Pitcher and Hart 1981).

Reference points for single species assessments

We looked at two "map" locations as management goals, the optimum age at first capture (= age of entry), t_{opt}, and an optimum fishing mortality, $F_{0.1}$.

For each of the 17 species assessed, a probability distribution of the optimum age at first capture t_{opt}, was calculated using Monte Carlo simulation, given the uncertainty in the population parameters. The mean of this distribution is provided as a biological reference point that managers, biologists and fishers can use as the theoretical optimum age of entry, t_c, at which each species should be harvested to maximise long term average yield. Since this point is always at infinite fishing mortality, the t_{opt} age is best used for comparison rather than as an absolute measure (Pitcher & Hart 1981).

For a given age of entry to the fishery, t_c, F_{max} is the fishing mortality rate at which peak yield is obtained (Note: at t_{opt}, F_{max} = infinity). Another biological reference point commonly used by fisheries scientists and managers is $F_{0.1}$. This is a reference line on the yield-per-recruit 'map' where the derivative of the yield-per-recruit surface is 0.1 times the initial slope at the origin (Gulland 1983). $F_{0.1}$ is more conservative than F_{max}, allows for the large increase in fishing effort need to harvest the maximum yield, and is more practical as a management goal because of the t_{opt} problem above. For each species, a probability distribution of $F_{0.1}$ was calculated: means of the distributions are provided as our estimate of F_{opt}.

We have used the FAO categories of exploitation status, defined with reference to the confidence limits on F_{opt};

over exploited: current F is above the 95% confidence limits on F_{opt};
fully exploited: current F is within the 95% confidence limits on F_{opt};
partially exploited: current F is below the 95% confidence limits on F_{opt}.

Approximate methods for sustainable yields of single species

Several types of stock survey provide estimates of the fish biomass for the species of interest (acoustic, trawl, egg production). For virgin fisheries this will be an estimate of B_T, the 'carrying capacity' biomass. Gulland and Beddington & Cooke have devised methods of estimating the maximum sustainable yield from B_T.

Gulland's Method 1

Gulland (1971) suggested that

$$MSY = aMB_T$$

where,

MSY = maximum sustainable yield;
B_T = unexploited biomass ('virgin') average biomass of stock from survey, also termed B_0;
a = a constant, in range 0.3 to 0.5, generally taken as 0.5;
M = instantaneous rate of natural mortality.

There are clearly circumstances in which this formula would be unlikely to hold, for example when M is very high. Gulland examined the theoretical basis of his formula and concluded that it was valid whether one considered surplus yield (Schaefer) or dynamic pool (Beverton & Holt) models of the fishery. The method was formerly widely used, especially by FAO in a series of stock surveys around the world.

Gulland's Method 2 (Cadima method)

If a small fishery already exists then biomass has already been depleted by fishing to the value estimated as B by the stock survey. If total mortality, $Z = F + M$, where F = instantaneous rate of fishing mortality, then we could write $MSY = aZB$, but this is not very helpful since we will not have an accurate estimate of the F, which is small. However, if we can estimate Z (from a catch curve method for example) and can roughly know M using Pauly's temperature formula, since we have Y, the catch from the existing fishery, so substituting (F + M) for Z, expanding the brackets, and then substituting Y for FB, we get the equation in a useful form:

$$MSY = a(Y + MB)$$

The method, originally proposed by Cadima (Troadec 1977), works equally well on overall figures for stock biomass and catch as it does for figures transformed to densities by dividing by area.

Beddington and Cooke's Method

The rationale underlying the Gulland formula was examined in detail by Beddington and Cooke (1983), who came to the conclusion that it is misleading because growth rates and recruitment are not fully considered. Using simulation over a range of growth and recruitment regimes, these workers improved Gulland's formula for estimating MSY. For most realistic choices of age of entry to the fishery, t_c, even the simple constant-recruitment Beverton & Holt model gives an MSY well below $0.5MB_T$. The first stage of the method allows for growth, the second, for recruitment. In order to use the method, in addition to B_T and M, we need an estimate of growth in the form of the von Bertalanffy K, for the second stage, some measure of the variance of recruitment. In this project we can do the first stage of the method as we have no information about recruitment.

$$MSY = a\ B_T$$

In practice the multiplication factor, a, to obtain MSY from B_T is read off from a nomogram (Figure 1) in Beddington & Cooke's paper.

MULTI-SPECIES BIO-ECONOMIC ASSESSMENT METHOD

This analysis was carried out using a length-based yield-per-recruit approach (a 'Thompson & Bell' analysis), that sums yield-per-recruit (YPR) over all length classes. Length classes harvested are determined by mesh size in the trawl, and the amount caught determined by fishing mortality, F (see Sparre & Venema 1992). Growth and mortality parameters were taken from the individual species stock assessments. Since commercial fisheries are generally managed and regulated to maximise and sustain value rather than yield, value-per-recruit (VPR) was calculated from YPR by using prices.

VPR was summed over all length class in the stock up to 95% of L_T. This calculation was then repeated for values of F from zero to 4, and mesh sizes from 1 cm to 10 cm to produce a VPR isopleth surface for each of the 17 assessed species (13 fish and 4 invertebrates). Sexes of the invertebrates were considered separately. The overall multi-species VPR was obtained by summing the contributions of each of the species, weighted by their relative recruitment, as advised by Murawski (1984). In effect, we have programmed on a spreadsheet analysis equivalent to the BEAM software from FAO (Sparre & Willman 1993).

The following modifications to the standard method have been programmed in Visual Basic/Excel for this project (File *vmultivpr.xls* in software).

1. Fishing mortality per length class was modified by a gear selection ogive (= s-shaped curve) appropriate to either fish or prawns. Fish selection ogives centred on lc, the smallest length caught, were obtained from Pauly's (1984) nomogram based on fish shape using data from the survey. Selection ogives for prawns were obtained from Garcia and Le Reste (1981) who averaged literature values for large penaeids. They found that that if lc (mm carapace length) = b·m, where m is the mesh size (mm stretched), then b is 0.4 ± 0.1 Figure M3 shows the relationship fitted to the Garcia and Le Reste data, where b= 0.38. Figure M4 shows the two selection ogives used in the procedure, each centred on lc as the fish or invertebrate size at which 50% are retained by a given trawl mesh.

2. Increases in the unit price of larger fish were be taken account of by entering prices above and below a threshold length.

3. Relative recruitments were obtained by running a Beverton & Holt biomass-per-recruit (BPR) analysis for each species at the current estimated F and t_c = 1 year. Recruitment indices were then obtained by using the estimated biomass of the species, since B/R = BPR and so R = B/BPR.

4. Relative biomass for use in (3) was taken from the estimated proportion of each species caught in the trawl sector, (SHT+ST)/(PS+HT+PT), taken from the total Hong Kong catch estimations for each species by gear type.

This method makes assumptions that:

1. Recruitment is not important in determining average long-term catch or stock biomass (as in all other yield-per-recruit equilibrium assessment)

2. Only technological interactions (caught in the same gear) occur, and there are no biological interactions between the species.

3. Each fish species trawled is subject to the same selection ogive in relation to mesh size.

4. Each prawn species trawled is subject to the same selection ogive in relation to mesh size.

Market prices (in HK$/kg) for different species used in the value per recruit simulations were obtained from recent Fish Marketing Organisation statistics. Additional information was provided by ERM, based on surveying market prices (June 1997). The analysis assumes no change in price with quantity landed, and is not discounted to Present Value. Information on the value (price per kilogram) was incorporated in the yield-per-recruit equation, and the equivalent optima for t_{opt} and $F_{0.1}$ derived.

To take account of uncertainty, 500 Monte Carlo simulations, entailing error distributions on 63 input parameters, were used to draw up probability distributions and to obtain 95% confidence limits (this took 8.5 hours of computing time).

SPATIAL ANALYSIS AND SUSTAINABILITY INDICES

We had originally hoped to be able to provide growth, mortality, catch and biomass estimates partitioned by the sample strata of the survey, in order to examine relative exploitation status by area and hence improve our evaluation of the sustainability of the fishery.

Unfortunately, this has not been possible because, although we have biomass estimates by strata, we have been obliged to pool the survey samples to minimise errors in growth and mortality estimates. Moreover, the catch figures, already subject to great uncertainty because they were obtained from interviews, have very wide confidence limits which would be even wider if we attempted to break them down by area.

ECOSYSTEM ANALYSIS METHODS

ECOPATH is a software package based on the earlier work of Polovina (1984) that facilitates the construction and parameterization of mass-balance trophic models of aquatic and terrestrial ecosystems (Christensen and Pauly 1996). The resulting model represents a static "snapshot" of the ecosystem and provides a means of comparing Hong Kong's coastal ecosystem with others. The general approach used here was to firstly construct a static mass-balance trophic model of the ecosystem using the ECOPATH software, and then apply this model to the recently developed ECOSIM software to study the effects of fishing on the various trophic groups.

The basic equation used for 3each trophic group in the ECOPATH model is:

$$Bi\ .\ (P/B)i\ .\ EEi\ = \ni \left\{ (Bj\ .\ (Q/B)j + DCji \right\} + EXi\ + ac$$

where,

∋ = summation for j = 1 to n, predator trophic groups;
Bi = mean biomass of I;
Bj = mean predator biomass;
(P/B)i = production/biomass, or total mortality rate of i (equilibrium);
EEi = ecotrophic efficiency, the fraction of the production of i that is either consumed within the system or exported out of the system;
(Q/B)j = food consumption/biomass of the predator j;
DCji = fraction of i in the diet of predator j;
EXi = exports (catches + emigration) of I;
ac = accumulated biomass.

The equation can be rearranged to equal zero, and standard matrix algebra can be applied to solve a set of such simultaneous linear equations (Christensen and Pauly 1992a). The ecosystem in question has to be defined, making sure that the fluxes within the system are higher than between it and its surroundings. Biota are usually grouped on the basis of their trophic similarities, such as size, feeding habit or predators. Ecopath allows up to 50 functional groups or state variables (boxes) representing either a single, or group of, organisms. Units for the model are tonnes wet weight per kilometre per year (t km^{-2} year^{-1}). The program requires the dietary composition (DC), estimates of catch (fishery harvest), and other exports (biomass leaving the system), and three of the following for each group:

Biomass: the average weight per unit of water surface area B;

Productivity: the rate at which biomass is produced per unit area. Productivity is expressed as the ratio of production/biomass (P/B) and equals the instantaneous rate of total mortality Z when the system is in equilibrium (Allen 1971). Hence, P/B ratios used and derived by Ecopath provide additional information on the mortality rates used in the per recruit analyses;

Consumption: an integral over the entire age-structured population expressed as the consumption/biomass ratio (Q/B); and

Ecotrophic efficiency: the proportion of the production of a group that is either consumed (via predation, harvested and/or accumulated) within the system or exported out of the system, denoted EE. The program then calculates the remaining parameters.

After the parameters and diet matrix are entered there is some fine tuning of the model to ensure that respiration rates are not negative, as indicated by ecotrophic efficiency (*EE*) values that exceed unity. The model will not balance if consumption of any particular functional group exceeds its production; consumption can be due to predation (natural mortality), fishing mortality or other exports, such as emigration.

The output from the steady-state ECOPATH model can be used in the recently developed dynamic system simulation ECOSIM (Walters et al. 1997), and used to investigate impacts of management-imposed changes on the fishery and the ecosystem. ECOSIM is based upon setting the simple idea of setting the equation above to dB/dt instead of zero. For this project, ECOSIM has been deployed to examine six hypothetical management scenarios, as requested by the Hong Kong AFD.

UNCERTAINTY IN PARAMETERS

Wherever possible in this work we have explicitly quantified the impact of uncertainty on our estimated parameters using Monte Carlo simulations. A series of random values chosen from the probability distributions for each of the input parameters for a model each provide an estimate. The probability distribution of these Monte Carlo estimates is used to set confidence limits. This has been implemented with the aid of software that creates an add-in facility to the Excel spreadsheet *(Crystal Ball, Decisioneering Inc, Boulder, Co, USA, see Web site at http://www.decisioneering.com*). [Note: This software would have to be purchased by AFD for use with the Excel spreadsheets.]

Standard errors, obtained from the length-weight regression coefficients (a and b), were used to generate a probability distribution around the weight at L_T (= W_T) for each species, and for each sex in the case of the invertebrates (because males and females attain different W_T's). Confidence intervals, derived by Lijam (1990), were used to construct probability distributions around M for each fish species, (derived from Pauly's 1980 empirical method). For the invertebrates, probability distributions of M were constructed assuming a normal distribution with a mean of M and a COV of 10%.

Probability distributions of the von Bertalanffy parameter K were derived for each species using one of two methods. When otolith based estimates of K were used, the probability distribution was based on the variability in the estimate of size for each age class. When K was estimated from length-frequency analyses, its probability distribution was estimated from the 95% confidence limits of a normal curve fitted to the goodness-of-fit surface area of the K estimate. These probability distributions were also used in the multispecies analysis.

All probability distributions were generated from 1000 Monte Carlo simulations, with the exception of some invertebrates. Here, because t_{opt} and optimal $F_{0.1}$ were calculated for both sexes and yields then combined, simulations were reduced to 500 (for reasons of computing time).

It is possible, using the latest version of the software, to apply a similar approach to uncertainty in ECOPATH modelling, and it is hoped to investigate this further in future work.

RESULTS & DISCUSSION

We are not able to assess all 150 species in the catch database (232 in the trawl survey database): we undertook to assess about 20 of the most important. We have completed full assessments for 17 species, including four invertebrates, the sexes of each of which were analysed separately, making a total of 21 analyses. The species were chosen early in the course of the project, based on a) preliminary catches in the sampling program, b) species identified by Richards (1980, 1985) as being of major commercial importance in Hong Kong waters, c) a list of species that are targeted and of commercial importance in Hong Kong waters, provided by the Hong Kong AFD, and d) species for which a specific assessment was requested. In retrospect, a better selection of species might have been made, but this hindsight was only possible after the biomass, catch and value estimations had been performed, necessarily at the very end of the project when the survey results were complete. Further work on the entire project database would be valuable.

Apogon fasciatus	Broad-banded cardinal fish	*Alepes djedaba*	Shrimp scad
Collichthys lucidus	Lionhead croaker	*Decapterus russelli*	Indian scad
Engraulis japonicus	Anchovy	*Harpadon nehereus*	Bombay duck
Johnius belangerii	Belanger's croaker	*Leiognathus brevirostris*	Shortnose ponyfish
Sardinella jussieui	Sardine	*Saurida tumbil*	Greater lizardfish
Siganus canaliculatus	White-spotted rabbitfish	*Trachurus japonicus*	Japanese jack mackerel
Trichiurus lepterus	Largehead hairtail	*Oratosquilla oratoria*	Japanese mantis shrimp
Oratosquilla anomala	Mantis shrimp	*Metapenaeopsis palmensis*	prawn
Metapenaeopsis barbata	Prawn		

Table R1. List of the 17 species for which exploitation status has been assessed. Note that the both sexes of the mantis shrimp prawn species have been dealt with separately.

All of the calculations we have performed may be examined and checked in the Excel spreadsheet files delivered with the report. The spreadsheets also include most of the figures:

Benthic-biomass.xls	all biomass estimations from swept area of survey trawl
Pelagic-biomass.xls	all biomass estimations from swept area of purse seine
Catch-sum.xls	all catch estimations from interview data
Multispecies_data.xls	estimates and summary tables for all spp parameters
Vmultivpr.xls	multi-species and value-per-recruit model.
Vpr-cball.xls	stripped down version of VPR for Monte Carlo simulations.

and for each species:

<sp>population_parameters.xls	all growth and mortality estimates
<sp>ypr	Yield-per-recruit model and surface
<sp>F.1_uncertainty.xls	stripped down version of ypr for Monte Carlo simulations
*<sp>*t$_0$*_uncertainty.xls*	stripped down version of ypr for Monte Carlo simulations

where <sp> = species name. A more detailed guide to these spreadsheets will be provided on request.

BIOMASS ESTIMATES

Benthic species

Estimated biomass by stratum, by season and the average for Hong Kong waters based on the adjusted swept area from the prawn trawl survey is summarised with 95% confidence limits for all seventeen assessed species in Table R2.

However, the result of the Monte Carlo simulations suggested that the probability distribution of the biomass results were skewed and so more reliable total average biomass for each species are the means listed in column 2 of Table R3, which also lists 95% confidence limits on the mean, and on the upper 95% limit obtained from the samples. In all case sampling variance was very high considering that zero sample records were eliminated: the overall COV was 169%. The lowest variances were for prawns, mantis shrimps, pony fish and lizard fish, while the highest were for *Collichthys*.

For the 12 assessed benthic species the total average biomass was about 700 tonnes, equivalent to 0.4 tonnes km^{-2}, but 95% confidence limits were as high as 2556 tones (1.4 tonnes km^{-2}). Surprisingly, estimates based on all biomass sampled (a total sample weighing about 1.4 tonnes from 232 species) were about the same (first row of Table R3), probably because of the assumption that eliminated zero catches for individual species. (Further individual species estimates could be extracted from the database).

Based on the assessed species, we have performed an approximate analysis in order to make an estimate of the total benthic biomass in Hong Kong waters. The estimated average biomass for the 12 benthic species was regressed on the total amount sampled: the coefficient of determination was high at over 90%, and the regression highly significant ($P<0.0001$), slope = 1.260. In this way approximate biomass estimates were obtained for all 232 species in the trawl survey samples. By adding these values, the total benthic biomass was estimated as 1751 tonnes, with 95% confidence limits (from the regression) of 1145 to 1759 tonnes (0.96 tonnes km^{-2}, 0.65 to 1.12). Note that these confidence limits give a spurious sense of accuracy as the regression was based only on the means, not the full simulation reported in Table R3. Similar calculations can be applied to various groups of benthic species, for example, collectively, the 12 species of prawns, assuming a night-to-day factor of 2 (see methods), produce a total prawn biomass of around 207 tonnes (0.11 tonnes km^{-2}). Other benthic crustacea amount to 375 tonnes (0.2 tonnes km^{-2}), elasmobranchs amount to 113 tonnes (0.06 tonnes km^{-2}), while small demersal fish amount to 678 tonnes (0.36 tonnes km^{-2}), leaving about 379 tonnes (0.2 tonnes km^{-2}) among the other benthic resources.

Seasonal changes in biomass, based on the total of the 12 assessed benthic species is shown in Figure R1, together with the average and its confidence limits. The plot shows that benthic biomass dipped below the confidence limits on the mean for six months between January and May, and above the confidence limits in 2 months in June and August. This may be interpreted as benthic production reflecting the strongly seasonal nature of the South China Sea. Seasonal totals are estimated as, May: 692 tonnes; August: 3251 tonnes; November: 1013 tonnes; February: 381 tonnes, equivalent to 0.38, 1.79, 0.56 and 0.21 tonnes km^{-2} respectively.

Table R4 provides a further analysis of these seasonal trends by species. Four species show strong peaks of abundance in one month of the year; *Collichthys* in June, *Alepes* (= *Caranx)* in September, *Harpadon* in December; and to lesser degree, Saurida in April. In the case of *Saurida* and *Harpadon*, but not *Collichthys* or *Alepes*, these high biomasses derive from single exceptionally high trawl samples. *Apogon* peaks from July to September. Several species show dual peaks of abundance, *Siganus* in July/August and December, *Leiognathus* in April/June and October/November, *Johnius* in March/April and

Table R2. Summary of estimated biomass from the trawl survey, average total biomass, by sample stratum and by month, with upper 95% confidence limits.

BIOMASS ESTIMATES			**All spp**		
by strata			**by season**		
	tonnes	upCL		tonnes	upCL
T1	20.9	61.1	March/96	331.1	804.0
T2	1.7	4.0	April/96	532.8	1342.5
T3	17.4	58.9	May/96	287.1	748.9
T4	16.5	49.3	June/96	1172.8	3187.3
T5	37.6	103.9	July/96	917.1	2096.7
T6	38.7	203.7	August/96	1348.2	6991.7
T7	18.2	53.5	September/96	702.5	1568.3
T8	8.9	29.0	October/96	450.2	1055.8
T9	54.7	148.6	November/96	420.0	859.7
T10	10.8	27.4	December/96	640.1	2486.7
T11	27.9	86.3	January/97	225.9	531.9
T12	50.2	143.5	February/97	158.1	296.0
T13	22.1	61.5	March/97	211.0	740.0
T14	20.3	65.7			
T15	39.0	85.4		tonnes	tonnes km^{-2}
T16	13.9	49.3	**TOTAL**	**569.0**	**0.313**
T17	12.4	26.2	upCL	2492.7	1.371
T18	29.6	92.1			

BIOMASS ESTIMATES			**Saurida tumbil**		
by strata			**by season**		
	tonnes	upCL		tonnes	upCL
T1	2.5	8.3	March/96	23.4	
T2	0.1		April/96	45.4	159.6
T3			May/96	25.5	94.6
T4	0.3	0.5	June/96	28.1	119.9
T5	8.5		July/96	14.5	35.7
T6	1.6	3.2	August/96		
T7	3.2	8.9	September/96	4.6	
T8	0.2	0.4	October/96		
T9	4.4	14.9	November/96		
T10	0.0		December/96		
T11	0.3		January/97		
T12	0.2	0.2	February/97		
T13			March/97		
T14	0.1				
T15	1.3	3.4		tonnes	t.km2
T16	0.1		**TOTAL**	**29.9**	**0.016**
T17			upCL	115.4	0.063
T18	0.1				

BIOMASS ESTIMATES			**Siganus oramin (=S.canaliculatus)**		
by strata			**by season**		
	tonnes	upCL		tonnes	upCL
T1	22.0	73.9	March/96	11.1	
T2	0.5	1.3	April/96	94.0	407.7
T3	20.1	69.4	May/96	3.5	5.7
T4	6.1	33.8	June/96	87.3	385.8
T5	35.2	105.9	July/96	285.6	1364.8
T6	15.1	99.5	August/96	516.6	3292.7
T7	0.9	3.7	September/96	248.9	893.6
T8	0.1	0.5	October/96	146.7	810.3
T9	42.0	1.5	November/96	58.1	230.9
T10	0.2	0.2	December/96	493.1	3057.0
T11	0.5	1.1	January/97	1.4	3.4
T12	3.9	24.3	February/97	0.8	
T13	3.8	18.2	March/97	10.4	26.6
T14	3.0	14.3			
T15	0.4	1.1		tonnes	t.km2
T16	0.1	0.4	**TOTAL**	**215.7**	**0.119**
T17	0.3	1.2	upCL	1542.2	0.848
T18	0.7	2.2			

BIOMASS ESTIMATES			**Leiognathus brevirostris**		
by strata			**by season**		
	tonnes	upCL		tonnes	upCL
T1	1.3	4.2	March/96	10.6	30.0
T2	0.1	0.2	April/96	47.8	175.2
T3	0.6	3.0	May/96	35.5	114.5
T4	1.3	4.9	June/96	42.3	183.3
T5	1.4	5.0	July/96	34.7	142.8
T6	2.0	6.6	August/96	24.2	70.3
T7	0.3	0.6	September/96	16.9	61.3
T8			October/96	47.4	234.2
T9			November/96	64.7	204.4
T10			December/96	3.6	8.9
T11	0.2	0.7	January/97	20.6	105.0
T12	3.0	8.3	February/97	5.0	14.8
T13	0.3	1.0	March/97	0.0	7.8
T14	1.2	4.7			
T15	0.3	0.8		tonnes	t.km2
T16	1.5	7.5	**TOTAL**	**31.9**	**0.018**
T17	1.1	3.3	upCL	138.4	0.076
T18	0.6	2.2			

BIOMASS ESTIMATES			**Apogon fasciatus**		
by strata			**by season**		
	tonnes	upCL		tonnes	upCL
T1	0.3	1.1	March/96	12.0	37.8
T2	0.1	0.5	April/96	13.8	55.4
T3	0.3	1.6	May/96	8.1	19.5
T4	0.3	1.0	June/96	17.5	52.3
T5	0.3	1.3	July/96	36.5	182.2
T6	0.0	0.0	August/96	28.3	89.8
T7	0.6	1.5	September/96	24.8	74.3
T8	0.0	0.1	October/96	5.8	19.4
T9	0.1	0.2	November/96	8.4	23.8
T10	0.0	0.0	December/96	11.6	39.5
T11	0.1	0.3	January/97	5.0	25.3
T12	0.2	0.8	February/97	4.6	16.1
T13	0.5	1.5	March/97	0.0	17.7
T14	0.1	0.4			
T15	2.5	5.4		tonnes	t.km2
T16	0.9	3.3	**TOTAL**	**14.9**	**0.008**
T17	1.7	7.0	upCL	69.4	0.038
T18	0.9	3.6			

BIOMASS ESTIMATES			**Collichthys lucidus**		
by strata			**by season**		
	tonnes	upCL		tonnes	upCL
T1	0.1	0.1	March/96	25.5	134.0
T2	0.0	0.0	April/96	2.1	2.5
T3	0.0		May/96		
T4			June/96	462.6	2158.1
T5	0.9	2.0	July/96	42.6	132.5
T6	0.1	0.3	August/96	31.6	147.4
T7	0.3	1.2	September/96	18.2	53.5
T8	0.8	2.3	October/96	11.5	36.5
T9	3.2	10.5	November/96	19.1	60.4
T10	0.6	1.9	December/96	32.9	111.2
T11	0.6	1.9	January/97	22.2	68.2
T12	11.5	74.0	February/97	16.2	89.5
T13	4.5	24.7	March/97	10.3	22.5
T14	0.3	0.7			
T15	1.5	5.1		tonnes	t.km2
T16	0.9	3.6	**TOTAL**	**50.3**	**0.028**
T17	0.5	1.4	upCL	496.6	0.273
T18	3.9	14.4			

BIOMASS ESTIMATES			**Johnius belangerii**		
by strata			**by season**		
	tonnes	upCL		tonnes	upCL
T1	0.2	0.6	March/96	18.1	55.8
T2	0.0	0.0	April/96	18.1	63.4
T3			May/96	31.3	84.0
T4	0.1	0.2	June/96	27.0	71.9
T5	0.5	1.1	July/96	13.8	39.1
T6			August/96	15.3	44.5
T7	0.3	0.5	September/96	28.2	95.6
T8	0.2	0.5	October/96	15.9	58.1
T9	3.1	7.2	November/96	15.3	40.2
T10	0.9	2.1	December/96	12.6	29.8
T11	0.5	1.4	January/97	8.5	29.2
T12	1.2	2.9	February/97	7.3	17.7
T13	0.6	1.5	March/97	18.9	71.7
T14	0.6	1.8			
T15	2.0	6.2		tonnes	t.km2
T16	1.4	4.9	**TOTAL**	**17.0**	**0.009**
T17	0.5	1.6	upCL	56.0	0.031
T18	0.6	1.9			

BIOMASS ESTIMATES			**Alepes djedaba (=Caranx kalla)**		
by strata			**by season**		
	tonnes	upCL		tonnes	upCL
T1	0.0	0.1	March/96		
T2	0.1	0.2	April/96		
T3	0.0	0.1	May/96		
T4	0.1	0.2	June/96	6.7	19.1
T5	1.9	5.0	July/96	6.9	31.1
T6	0.2	0.5	August/96	4.8	20.2
T7	0.4	1.1	September/96	8.5	27.9
T8	0.0	0.1	October/96	3.9	11.7
T9	1.7		November/96	0.1	
T10	0.3	0.9	December/96		
T11	0.3	0.8	January/97		
T12	0.1	0.1	February/97		
T13	0.0	0.1	March/97		
T14	0.1	0.2			
T15	0.3	0.8		tonnes	t.km2
T16	0.1		**TOTAL**	**6.0**	**0.003**
T17			upCL	22.7	0.012

BIOMASS ESTIMATES			**Harpadon nehereus**		
by strata			**by season**		
	tonnes	upCL		tonnes	upCL
T1			March/96	2.8	
T2			April/96		
T3			May/96		
T4			June/96		
T5	0.8		July/96		
T6			August/96	14.9	14.9
T7	0.3	0.6	September/96	6.1	10.9
T8	0.0		October/96	5.4	11.9
T9	1.8	3.3	November/96	28.3	117.5
T10	0.8	3.6	December/96	618.8	2465.4
T11	25.9	104.0	January/97	27.9	67.4
T12	1.1	4.1	February/97		
T13	0.3		March/97		
T14					
T15				tonnes	t.km2
T16	0.1		**TOTAL**	**102.0**	**0.056**
T17			upCL	830.4	0.457
T18	1.1				

BIOMASS ESTIMATES			**Oratosquilla anomala**		
by strata			**by season**		
	tonnes	upCL		tonnes	upCL
T1	0.4	1.1	March/96	25.4	117.6
T2	0.1	0.1	April/96	49.6	152.8
T3	0.1	0.1	May/96	23.7	66.7
T4	0.5	1.5	June/96	31.5	113.8
T5	2.0	6.4	July/96	54.7	188.6
T6	0.4	1.2	August/96	68.7	255.9
T7	1.2	4.0	September/96	51.8	231.4
T8	0.5	1.6	October/96	21.5	78.6
T9	3.6	10.5	November/96	26.2	94.0
T10	1.0	2.3	December/96	43.7	153.1
T11	3.1	9.9	January/97	40.7	151.8
T12	4.7	11.1	February/97	29.3	87.6
T13	2.6	8.2	March/97	18.8	63.1
T14	3.0	7.5			
T15	3.4	8.7		tonnes	t.km2
T16	0.6	1.4	**TOTAL**	**37.4**	**0.021**
T17	0.3	0.6	upCL	146.4	0.081

BIOMASS ESTIMATES			**Oratosquilla oratoria**		
by strata			**by season**		
	tonnes	upCL		tonnes	upCL
T1	0.1	0.2	March/96	25.6	78.9
T2	0.0	0.1	April/96	55.1	230.4
T3	0.1	0.3	May/96	35.7	155.1
T4	0.2	0.6	June/96	51.9	226.4
T5	0.2	0.6	July/96	54.7	212.9
T6	0.0	0.1	August/96	44.1	227.0
T7	1.7	8.0	September/96	24.1	100.6
T8	0.9	4.6	October/96	27.4	88.8
T9	2.6	5.8	November/96	29.3	84.0
T10	1.4	3.3	December/96	29.9	112.3
T11	4.9	16.5	January/97	18.4	53.6
T12	3.3	9.7	February/97	3.5	9.4
T13	2.3	6.4	March/97	17.0	78.5
T14	0.5	1.5			
T15	2.5	7.1		tonnes	t.km2
T16	0.5	1.5	**TOTAL**	**33.5**	**0.018**
T17	0.4	1.1	upCL	150.4	0.083
T18	2.1	5.7			

BIOMASS ESTIMATES			**Metapenaeopsis palmensis**		
by strata			**by season**		
	tonnes	upCL		tonnes	upCL
T1	3.3	8.5	March/96	132.5	613.4
T2	0.7	1.6	April/96	250.0	989.2
T3	4.8	20.4	May/96	82.0	346.4
T4	6.8	15.9	June/96	55.1	166.6
T5	3.2	11.8	July/96	99.1	329.9
T6	2.6	8.4	August/96	117.1	411.2
T7	5.2	24.2	September/96	109.9	549.2
T8	1.8	7.8	October/96	23.4	76.7
T9	3.0	9.0	November/96	47.6	132.3
T10	1.0	2.5	December/96	55.4	186.4
T11	0.7	3.7	January/97	43.2	150.9
T12	0.9	5.4	February/97	65.0	199.8
T13	0.0		March/97	46.0	172.8
T14	0.0				
T15	0.8	2.3		tonnes	t.km2
T16	0.1	0.1	**TOTAL**	**84.1**	**0.046**
T17	0.0		upCL	389.9	0.214
T18	0.0	0.1			

BIOMASS ESTIMATES			**Metapenaeopsis barbata**		
by strata			**by season**		
	tonnes	upCL		tonnes	upCL
T1			March/96	16.2	74.4
T2			April/96	17.2	65.7
T3			May/96	1.7	
T4			June/96	37.8	119.0
T5	0.3		July/96	178.7	676.4
T6	0.0		August/96	85.3	371.4
T7	1.4	8.9	September/96	32.2	145.0
T8	0.9	5.3	October/96	6.3	15.1
T9	2.6	8.8	November/96	8.7	26.6
T10	0.9	3.6	December/96	6.5	18.9
T11	2.3	12.6	January/97	3.3	7.7
T12	5.1	30.8	February/97	4.7	11.1
T13	1.2	5.4	March/97	5.6	16.1
T14	0.5	2.7			
T15	1.8	8.0		tonnes	t.km2
T16	0.2	0.7	**TOTAL**	**33.6**	**0.018**
T17	0.1	0.2	upCL	229.5	0.126
T18	0.5	1.6			

	Initial mean	Mean from simulation	lo95 on mean	up95 on mean	up95CL	from simulation	lo95	up95
Total	650.3	700.5	527.8	1022.3	2557.7	2750.3	2088.1	3983.9
Saurida	29.9	32.2	24.3	47.0	115.4	124.3	93.7	181.4
Siganus	215.7	232.4	175.1	339.1	1542.2	1661.3	1251.7	2424.5
Leiognathus	31.9	34.3	25.9	50.1	138.4	149.1	112.4	217.6
Apogon	14.9	16.0	12.1	23.4	69.4	74.7	56.3	109.0
Collichthys	50.3	54.2	40.8	79.1	496.6	534.9	403.0	780.7
Johnius	17.0	18.3	13.8	26.7	56.0	60.3	45.4	88.0
Alepes	6.0	6.5	4.9	9.5	22.7	24.5	18.4	35.7
Harpadon	102.0	109.9	82.8	160.4	830.4	894.5	673.9	1305.5
O.anomala	37.4	40.3	30.3	58.8	146.4	157.7	118.8	230.2
O.oratoria	33.5	36.1	27.2	52.7	150.4	162.0	122.1	236.5
M. pal.	84.1	90.6	68.3	132.3	389.9	420.0	316.4	612.9
M. bar.	33.6	36.2	27.2	52.8	229.5	247.2	186.2	360.8
total of 12	**656.3**	**707.1**	**532.7**	**1031.9**	-	-	-	-

Table R3. Overall biomass of benthic species, and 95% upper confidence limit, estimated from the trawl survey, with final means and confidence limits obtained by Monte Carlo simulation.

September. All four invertebrates show peaks, like *Apogon*, from July through September, while the two mantis shrimp and *Metapenaeopsis palmensis*, but not *M. barbata*, peak in April as well. The number of peaks of abundance, for example the apparent gap between *Oratosquilla oratoria* in April and June, should be treated as rather uncertain as they seem to be affected by a few individual trawl samples.

	MONTH												
SPECIES	03	04	05	06	07	08	09	10	11	12	01	02	03
Saurida		52			-52		-85						
Siganus	-95	-56	-98	-60	32	32		-32	-73	129	-99	-100	-95
Leiognathus	-67	50		33			-47	49	103	-89	-35	-84	-100
Apogon			-45		146	90	67	-61	-44		-66	-69	-100
Collichthys	-49	-96		820		-37	-64	-77	-62	-35	-56	-68	-80
Johnius			84	59			66			-26	-50	-57	
Alepes							41	-35	-98				
Harpodon	-97					-85	-94	-95	-72	506	-73		
O.anomala	-32	33	-37		46	84	38	-43	-30				-50
O.oratoria		64		55	63	32	-28				-45	-90	-49
M.palmensis	57	197		-34		39	31	-72	-43	-34	-49		-45
M.barbata	-52	-49	-95		432	154		-81	-74	-81	-90	-86	-83

Table R4. Seasonal analysis of estimated biomass of 12 benthic species in Hong Kong waters. Columns are months of trawl survey from March 1996 to March 1997. Values in rows are percentages above and below the mean annual biomass, with values less than a threshold of 25% omitted for clarity. Boxes surround cells above the mean.

Figure R2 shows the overall benthic biomass estimated in the 18 sampling strata, compared to the biomass, and its 95% confidence limits, that would be expected in each stratum if the average density obtained. No stratum has significantly lower biomass than average, while only stratum 6 has significantly higher biomass. The rest of the strata lie well within the confidence limits. As there seem to be few divergent values, the spatial analysis of benthic biomass is not taken further in this report.

Pelagic species

Table R5 details biomass estimates for the five assessed pelagic species based on the purse seine swept area method. The overall biomass for these five species is estimated as 3787 tonnes, with 95% confidence limits from 217 to 7357 tonnes (mean 1.99 tonnes km^{-2}, 95% limits 0.11 to 3.87 tonnes km^{-2}).

Estimates partitioning biomass by season exhibit strong seasonal trends in all five assessed species: Figure R3 presents these results graphically. *Sardinella* peaks at a massive 9400 tonnes in May (5 tonnes per km^{2}), has low biomass in November and is virtually absent in May and February. *Decapterus* has similar patter, except that it is absent in November. The anchovy and horse mackerel, however, are almost out of phase with this pattern, peaking in May and February at just under 1 tonne per km^{2}. The data do not seem to warrant partitioning by area, as the sampling purse seines were employed for sampling in only 6 of the 19 strata.

Together with the 5 assessed species, the next nine species in the purse seine survey data make up over 90% of the purse seine samples. Biomass for these species was estimated using the same method, and further extrapolated to approximate the total pelagic biomass. Results give total average pelagic biomass in Hong Kong waters as 7550 tonnes (4.2 tonnes km-2). Seasonal totals for pelagic biomass were, May: 2953 tonnes; August: 24324 tonnes; November: 2013 tonnes; February: 1305 tonnes; or 1.6; 13.4; 1.1; and 0.7 tonnes km-2 respectively.

BIOMASS ESTIMATES – PELAGICS

estimated mean of pelagic biomass in tonnes by season

	Engraulis	*Sardinella*	*Trachurus*	*Trichiurus*	*Decapterus*	**total**
may	1538.2	0.0	1203.9	4.2	2.2	2752.9
Aug	12.8	9373.8	174.9	293.9	204.8	10469.8
Nov	3.6	190.2	3.5	1139.4	0.0	1336.7
Feb	450.6	2.2	14.7	122.2	0.0	589.7
average	501.3	2391.5	349.3	389.9	155.2	3787.3

upper limit of pelagic biomass in tonnes by season

	Engraulis	*Sardinella*	*Trachurus*	*Trichiurus*	*Decapterus*	**total**
may	3019.1	0.0	2407.9	8.1	4.3	5448
Aug	25.2	18397.9	0.0	576.8	402.0	20206
Nov	7.0	373.3	0.0	2236.2	0.0	2616
Feb	884.4	4.3	29.3	239.9	0.0	1158
average	983.9	4693.9	609.3	765.3	101.6	7357.1

lower limit of pelagic biomass in tonnes by season

	Engraulis	*Sardinella*	*Trachurus*	*Trichiurus*	*Decapterus*	**total**
may	57.4	0.0	0.0	0.2	0.1	58
Aug	0.5	349.7	349.7	11.0	7.6	734
Nov	0.1	7.1	7.1	42.5	0.0	57
Feb	16.8	0.1	0.1	4.6	0.0	22
average	18.7	89.2	89.2	14.5	1.9	217.5

estimated mean of pelagic biomass in tonnes/km^2 by season

	Engraulis	*Sardinella*	*Trachurus*	*Trichiurus*	*Decapterus*	**total**
may	0.81	0.00	0.63	0.00	0.00	1.45
Aug	0.01	4.93	0.09	0.15	0.11	5.51
Nov	0.00	0.10	0.00	0.60	0.00	0.70
Feb	0.24	0.00	0.01	0.06	0.00	0.31
average	0.26	1.26	0.18	0.21	0.03	1.99

upper limit pelagic biomass in tonnes per km^2 by season

	Engraulis	*Sardinella*	*Trachurus*	*Trichiurus*	*Decapterus*	**total**
may	1.59	0.00	1.27	0.00	0.00	2.9
Aug	0.01	9.68	0.00	0.30	0.21	10.6
Nov	0.00	0.20	0.00	1.18	0.00	1.4
Feb	0.47	0.00	0.02	0.13	0.00	0.6
average	0.52	2.47	0.32	0.40	0.05	**3.87**

lower limit pelagic biomass in tonnes per km^2 by season

	Engraulis	*Sardinella*	*Trachurus*	*Trichiurus*	*Decapterus*	**total**
may	0.03	0.00	0.00	0.00	0.00	0.0
Aug	0.00	0.18	0.18	0.01	0.00	0.4
Nov	0.00	0.00	0.00	0.02	0.00	0.0
Feb	0.01	0.00	0.00	0.00	0.00	0.0
average	0.01	0.05	0.05	0.01	0.00	**0.11**

Table R5. Estimated annual average and seasonal biomass for five pelagic species in Hong Kong waters from the purse seine survey. Top: tonnes; lower: tonnes km^{-2}.

Biomass of assessed species from Hong Kong fleet catches

Table R6a presents the final estimates of biomass for the 17 assessed species. We have summarised all of the estimates, including those resulting from the apportionment of the total benthic or pelagic biomass (calculated above) by relative catch rates in the pelagic and demersal sectors.

SPECIES	from catch			from swept area		final estimate	
	pelagic	demersal	total	Shrimp trawl	purse seine	method used	biomass
			b	St	Ps		tonnes
Sardinella jussieui	1034	5	1039	0	2190	ps	2190
Alepes djedaba	236	12	248	7	54	b	248
Trichiurus lepterus	233	10	243	0	357	av	300
Decapterus russelli	177	14	191	0	142	b	191
Engraulis japonicus	945	43	988	0	459	av	723
Trachurus japonicus	263	25	288	0	284	av	286
Collichthys lucidus	65	9	74	54	174	av	107
Siganus canaliculatus	231	138	369	232	1148	av	758
Leiognathus brevirostris	222	39	261	34	523	av	392
Johnius belangerii	0	24	24	18	0	av	21
Harpadon nehereus	0	<1	<1	110	0	st	110
Saurida tumbil	0	<1	<1	32	0	st	32
Apogon fasciatus	20	6	26	16	44	av	35
Oratosquilla oratoria	0	6	6	40	0	st	40
Oratosquilla anomala	0	19	19	36	0	st	36
Metapenaeopsis palmensis	0	2	2	91	0	st	91
Metapenaeopsis barbata	0	10	10	36	0	st	36

Table R6a. Calculation of final biomass values (tonnes) for the 17 assessed species. Columns 1-3: estimates from catch of pelagic and demersal sectors of the Hong Kong fishing fleet. Columns 4-5: swept area estimates from the shrimp trawl and purse seine survey. Final two columns indicate final biomass estimate and method used. For further explanation see text.

Values from the swept area analyses of purse seine and prawn trawl surveys are listed alongside. This table has been used to assemble final biomass figures for each assessed species according to the following rules.

If all three values are close, then they are averaged.

If there is little or no catch in the other sector, figures from the sector survey and the biomass predicted from the catch are averaged.

If a substantial catch is made in the other sector, the biomass derived figure is used.

The final column indicates the biomass estimate that has been used in further analysis.

Total aquatic resource biomass

Apportioning the total benthic biomass by the seasonal pattern seen in the 12 assessed species, and adding to the pelagic figures above, we can obtain approximate figures for seasonal changes in the biomass of the total aquatic resources in Hong Kong waters (Table R6b). The seasonal values are: May, 3585 tonnes; August, 27576 tonnes; November, 3026 tonnes; February, 1686 tonnes (2.0; 15.2; 1.7; 0.9 tonnes km^{-2} respectively). The average is 8922 tonnes (4.9 tonnes km^{-2}).

This analysis suggests that some 85% of the Hong Kong resource biomass is pelagic (seasonal values; May, 81%; August, 88%; November, 67%; February, 77%).

	May	Aug	Nov	Feb	Average
tonnes					

benthic-assessed	287	1348	420	158	569
pelagic-assessed	2753	10470	1337	590	3787
pelagic-rest	140	13855	676	715	3762
pelagic-total	2893	24324	2013	1305	7550
benthic-total	692	3251	1013	381	1372
TOTAL	3585	27576	3026	1686	8922
tonnes km^{-2}					
benthic-assessed	0.16	0.74	0.23	0.09	0.31
pelagic-assessed	1.51	5.76	0.74	0.32	2.08
pelagic-rest	0.08	7.62	0.37	0.39	2.07
pelagic-total	1.59	13.38	1.11	0.72	4.15
benthic-total	0.38	1.79	0.56	0.21	0.75
TOTAL	1.97	15.17	1.66	0.93	4.91
% pelagic	0.81	0.88	0.67	0.77	0.85

Table R6b. Estimates of total, pelagic and benthic biomass in Hong Kong inshore waters. For method, see text.

Table R6c lists some pelagic biomass values for comparison. Average Hong Kong values are comparable to Vietnam, but considerably lower than many other locations, although during august the biomass is comparable to many other tropical areas.

Model/Location	Species Included	Biomass	Primary Production	Source/Remarks
Maputo Bay, Mozambique	Small pelagics, mackerels	12	1100	De Paula e Silva et al. (1993)
Virgin Island Coral Reef	Small & large schooling fish	50	3500*	Opitz (1993)
Yucatan Shelf, Gulf of Mexico	"Herrings", *Scomberomorus*, jacks, pelagic crabs	5	3000	Arreguin-Sanchez et al. (1993)
Northern Gulf of Mexico Shelf	"Pelagic fish", mackerels, tuna	13	1200	Browder (1993)
Eastern Venezuela Upwelling	Small pelagics, carangids, mackerels	40	3150	Mendoza (1993)
Peruvian Upwelling System (1973-1979)	Anchovies, sardine, mackerel, horse mackerel & 50% of hake biomass	70	13,100	Jarre-Teichmann & Pauly (1993)
British Columbia Shelf, Canada	Herring & other small pelagics, spring dogfish & 50% of hake biomass	44	3500	Pauly & Christensen (1996)
Strait of Georgia, B.C., Canada	Small pelagics, some salmon, & 50% of hake biomass	40	2500	Pauly & Christensen (1996)
Vietnam & Southern China	Small pelagics, mackerels, cephalopods	5	3000	Pauly & Christensen (1993)

Table R6c. Some pelagic biomass values for comparison with the Hong Kong results. Biomass and production in tonnes wet weight per km^2. * = Assuming that coral reef primary production doubles the contribution of phytoplankton

---

CATCH ESTIMATES

Total annual catch by sector, estimated from individual vessel catch, and from species individual vessel catch, are listed in Table R7, together with their 95% confidence limits.

	SHT	HT	ST	P4/7	Misc.	PT	PS	Total
Mean log t per year per vessel	4.9	38.8	17.6	2.0	6.3	170.4	33.1	4.2
Lo95CL from log normal	1.3	14.8	3.9	0.4	0.6	31.7	4.2	0.9
Up95CL from log normal	18.3	102.1	80.1	5.7	17.2	916.8	262.0	20610
Estimated by vessel								
Catch	945	1398	577	3318	2551	2498	4468	15754
Lower 95% CL	256	531	127	657	261	464	564	2860
Upper 95% CL	3502	3677	2626	9576	6931	13439	35364	75116
Estimated by species & vessel								
Catch	879	1293	572	3964	2842	1563	3633	14747
Lower 95% CL	245	440	178	909	748	985	630	4134
Upper 95% CL	3930	5276	3388	23903	17157	260512	48556	362722

Table R7. Estimated catch by sector in the Hong Kong fishery. Estimations are based on the mean annual catch per vessel type from log Normal distributions (row 1). Two methods have been used (rows 5-7 and 9-11) as detailed in the text. (Note: Total catch per vessel type was obtained by division from lower right values)

The analysis suggests that pair trawlers have the highest annual catch per vessel at around 170 tonnes per vessel (95% limits, 32 - 917 tonnes). Hang trawlers are next with 39 tonnes (15-102); Purse seiners with 33 tonnes (4-262); stern trawlers with 18 tonnes (4-80); and shrimp trawlers with 5 tonnes (1-18). The category of miscellaneous small vessels catches about 6 tonnes (0.6-17), and the P4/7 vessels 2 tonnes per year (0.4-5.7). These estimates assume that vessels are homogenous within each sector, which is clearly not the case. More detailed information on vessel size and engine power is contained within the database, and could be usefully subjected to a deeper analysis of catch rates. It is, however, unlikely to make major differences to these figures.

Total catch by sector estimated using the two methods, 'catch by vessel type' and 'catch by species by vessel type', is graphed in Figure R4. The catch calculated by species and vessel is about 6% less than that calculated by vessel alone, but overall there is no significant difference between the two calculation methods (1-way Anova: P=0.65, NS). Although the catches estimated by the two methods are similar, the total catch by species and vessel is likely to be more accurate than by vessel type alone because a greater amount information from the database is used. (The catch estimated for pair trawlers show the largest, but non-significant, difference).

Total Hong Kong annual inshore catch over all gear sectors is therefore estimated at around 14747 tonnes (95% limits; 4134 - 362,000). The P4/P7s and the purse seine sectors catch the most with around 25% of the catch each at 3964 tonnes (909 - 23,900) and 3633 tonnes (630 - 48600) respectively. The miscellaneous sector catches 20% at 2842 tonnes (748 - 17157); pair trawlers catch around 11% at 1563 tonnes (985 - 260,000); hang trawlers catch 9% at around 1300 tonnes (440 - 5300); shrimp trawlers around 6% at about 900 tonnes (250 - 3900); and stern trawlers just under 4% at about 600 tonnes (200 - 3400).

Confidence intervals from the log normal distributions are very large, but the log normal distribution reflects accurately the distribution of catch rates reported for each vessel type from the interviews, as evidenced by the fitted distributions in Figures M3 to M8. However, since these catch figures are estimated from interviews of fishers, they should be regarded with some caution. In order to reduce the confidence limits below what we are able to present here, we recommend that a frame survey of actual landings, checked by market sales, and fishing effort by sector be designed and carried out.

Estimates of the annual catch by species (over all gear sectors) are listed together with their confidence limits in Table R8, which also shows the 17 species we have assessed. (In the event we have assessed 6 of the top 12 by catch). The top twelve species represent 42% of the catch.

Sardinella has by far the largest catch at about 1000 tonnes, 7% of the total. *Siganus* is next with 880 tonnes, or about 6% of total, followed by *Engraulis* at 740 tonnes, 5% of the total. There is then a drop in catch to croakers*, Argrosomus spp,* at 316 tonnes, 4.4% of the total. The remainder of the first twelve species comprise 19% of the total catch. The next twelve species in order of catch comprise 15% of the total, the next twelve species comprise 8%, while species 1-50 comprise 71% of the catch. Catch from the remaining 100 species each comprises less than 0.3% of the total. Note that the 'mixed species' category, excluded in the analysis above, makes up 21% of the reported catch, and may include juveniles of *Alepes*, *Siganus*, *Sardinella, Leiognathus* and *Clupanodon*, but it is unclear to us how the 'mixed species' figures may be used.

Estimated catch by species and gear sector is listed in Table R9. The P4/7 vessels report catching 105 species, the miscellaneous vessel sector 96 species, the shrimp trawls 58 species, the stern trawlers 55 species, purse seiners 46 species, hang trawlers 22 species, and the pair trawlers the least with 18 species. Only four species, the rabbit fish *Siganus*, horse mackerel, *Trachurus,* the hairtail *Trichiurus,* and squid, *Loligo* are reported caught by all seven fishery gear sectors.

For the hang trawlers, the largest catches in order are sardines *Sardinella,* shrimp scad, *Alepes,* and hairtails*, Trichiurus*, the latter two being by far the largest reported catch of these species, which are also caught by pair trawls, purse seines and stern trawls. Hang trawlers report catching one species category, monocle bream, *Scolopsis,* exclusively.

For the stern trawlers the top three species caught are Indian scad *Decapterus*, long-jaw herring *Thrissa* and horse mackerel, *Trachurus*. Of these the first and last species are caught in greater quantities by other sectors, but *Thrissa* is almost exclusively reported by stern trawlers. Stern trawlers report a species of monocle bream, *Scolopsis,* exclusively: it is possible this is actually the same species as the hang trawlers report.

For the shrimp trawlers the top 3 species are mantis shrimp, *Oratosquilla*, caught also in small quantities by other sectors; crab, *Portunus*, also caught by the miscellaneous sector; and a croaker, *Argyrosomus*, caught in greater amounts by the miscellaneous and P4/7 sectors. The shrimp trawlers report catching 16 species exclusively, six of them, not surprisingly, prawns, and including the lizardfish, *Saurida tumbil*.

For the pair trawlers the largest catch is of *Sardinella*, also caught in considerable quantity by the purse seiners and hang trawlers; next is *Engraulis* and other anchovies, caught in greater quantities by the purse seine sector; followed by the rabbit fish, *Siganus*, which seems to be caught by everyone.

The purse seiners top three species are *Engraulis*, *Sardinella* and *Caranx*, the latter comprising the bulk of the Hong Kong catch of this species. Purse seiners report exclusive catches of 4 species, ponyfish *Leiognathus bindus* and unspecified *Leiognathus* species, and sardines, *Sardinella aurita* and unspecified *Sardinella* species.

The P4/7 vessels report their top three species as the rabbit fish *Siganus*, rockfish *Sebasticus marmoratus*, and porgies, *Sparidae*. This sector catches 18 species exclusively, and for 33 species reports more than 80% of the catch.

Table R8. Estimated annual catch of each species in the catch interview database by all gear sectors in Hong Kong waters, tonnes.

Species	TOTAL	lo95cl	up95cl			TOTAL	lo95cl	up95cl			TOTAL	lo95cl	up95cl	
MIXSPP	3141.6	342.0	302284.3		EPISPP	44.4	8.9	225.7		LEISPP	4.8	4.8	4.8	
SARJUS	1024.6	676.9	3139.7	Assessed	SEPPHA	42.8	8.0	250.9		LUTARG	4.7	2.0	21.1	
SIGORA	876.9	192.4	5247.1	Assessed	CYNMAC	40.2	7.7	218.8		MUGCEP	4.7	1.6	17.0	
STOZOL	742.4	342.8	2896.9	Assessed	NIBDIA	37.7	9.1	174.4		CHRLEP	4.4	1.5	16.4	
ARGSPP	644.1	172.4	2477.6		AMBGYM	37.5	37.5	37.5		METJOY	4.2	0.3	53.7	
SEBMAR	517.4	149.3	1815.4		SOLCRA	37.4	5.3	262.7		LUTJOH	3.8	0.8	18.4	
CARANX	401.3	101.1	3410.6		THRSPP	37.2	18.6	74.9		SCOSPP	3.7	0.8	17.4	
LEIBRE	381.5	81.2	1996.4	Assessed	SILSPP	36.4	9.1	151.8		PENPEN	3.5	0.8	17.8	
TRAJAP	334.8	104.9	2516.2	Assessed	THESPP	35.6	7.5	844.4		URCHIN	3.4	3.4	3.4	
SPARID	329.3	71.3	1583.0		PARHUN	32.4	14.4	72.7		PARSPP	3.3	1.5	8.6	
ACETES	317.6	77.3	1535.3		METAFF	32.1	6.7	156.1		EPICHL	3.3	0.7	15.3	
PORPEL	283.4	39.7	2206.4		MPRAWN	31.5	5.4	183.4		EPITAU	3.2	1.3	9.6	
TRIHAU	274.5	149.1	997.8	Assessed	MYLMAC	30.8	4.1	243.3		NIBJAP	3.0	1.5	5.9	
PLAIND	255.9	71.1	981.8		LEIBIN	28.8	7.2	115.4		SARSPP	2.9	2.9	2.9	
CLUPUN	249.0	57.2	1724.9		MURTAL	28.5	8.2	145.4		SCOJAP	2.8	2.8	2.8	
CARKAL	240.5	33.8	2873.3	Assessed	STRSPP	26.7	6.9	135.2		SAUSPP	2.4	1.4	5.0	
STOSPP	232.7	142.3	1774.7		RHASAR	26.5	6.5	107.8		GERLUC	2.4	2.4	2.4	
DECLAJ	210.7	118.2	441.2	Assessed	SCYSER	26.4	3.0	254.2		EPIARE	2.4	0.8	10.0	
MCRAB	198.2	50.9	804.2		ORAORA	26.4	6.1	129.5	Assessed	CANMOD	2.3	0.7	7.4	
MURCIN	194.7	53.0	762.3		LATJAP	25.4	9.2	82.8		APONIG	2.0	0.8	10.7	
LOLIGO	190.5	47.8	977.7		GYMREE	25.3	3.9	166.2		NEMVIR	1.9	1.9	1.9	
PSECRO	171.6	35.9	1069.0		APOQUA	24.1	2.7	255.1	Assessed	HARNEH	1.9	1.9	1.9	Assessed
SARAUR	159.0	68.3	370.1		PAROLI	22.3	2.3	216.4		PINBIC	1.9	1.9	1.9	
MUGAFF	144.9	33.8	761.1		MYLLAT	21.8	2.2	224.3		CLAM	1.7	1.7	1.7	
PORSAN	141.4	36.6	656.2		CHRMAJ	21.7	3.8	141.6		OCTOPUS	1.7	1.7	1.7	
ELETET	135.6	41.4	843.2		SCOCOM	18.2	3.2	133.4		HILSA	1.7	1.7	1.7	
MURSPP	132.9	39.2	467.4		CHANAT	16.4	2.2	123.4		SCOGUT	1.7	1.7	1.7	
LOLEDU	131.5	27.3	658.2		EPIAWO	16.2	4.0	68.3		PENMER	1.5	1.3	1.9	
NEMJAP	126.9	18.0	1009.3		TAPPHI	15.0	0.1	1840.5		PORTRI	1.4	0.4	5.1	
ILIELO	118.0	31.8	530.9		ATUMAL	13.4	6.5	28.5		GERFIL	1.3	0.5	3.2	
JOHBEL	112.3	27.3	544.5	Assessed	THEJAR	12.5	2.7	66.6		STRSIN	1.2	1.2	1.2	
COLLUC	96.2	22.6	492.1	Assessed	MYLBER	12.4	2.0	80.7		SCAARG	1.1	1.1	1.1	
SEPLES	95.0	33.4	271.0		MYLSPP	12.4	3.6	67.2		EPIAKA	1.1	0.5	2.5	
PARTRI	94.4	21.0	425.9		CYNSEM	10.7	2.5	47.8		PARPIC	0.78	0.05	13.16	
ORASPP	89.1	27.0	314.9	Assessed	METPAL	9.8	2.1	45.3	Assessed	PARTEN	0.77	0.77	0.77	
STRARG	77.2	19.6	393.1		PLOANG	9.6	4.0	23.0		SAUTUM	0.72	0.72	0.72	Assessed
LUTRUS	73.2	16.6	336.1		PSEANO	9.4	6.1	32.1		LUTLIN	0.68	0.68	0.68	
GYMSPP	64.8	13.9	357.7		RASKAN	9.0	4.0	34.0		DREPUN	0.68	0.10	4.86	
CYNSPP	62.8	17.4	227.8		PENJAP	8.9	4.4	18.3		EPIFAS	0.62	0.62	0.62	
METSPP	61.8	23.8	162.0		FORNIG	7.8	7.8	7.8		ANABRO	0.55	0.55	0.55	
ACEJAP	55.5	55.5	55.5		POMHAS	7.5	2.0	30.4		BABSPP	0.55	0.55	0.55	
CHACRU	54.6	10.2	408.2		HARHAR	7.2	1.1	48.6		ALPSPP	0.44	0.44	0.44	
STOHET	52.5	10.6	455.2		SPHSPP	6.9	6.9	6.9		GONZON	0.43	0.09	2.04	
SEPIA	50.4	17.2	182.8		CEPPAC	6.5	2.1	22.5		NIBALB	0.34	0.34	0.34	
APOGON	49.4	12.1	212.3		TRACUR	6.4	1.4	30.0		PARUPE	0.34	0.34	0.34	
GERSPP	49.2	14.1	173.2		MUGSPP	6.1	1.4	33.4		APOELL	0.28	0.28	0.28	
MONCHI	46.8	13.5	179.1		TRYVAG	6.1	0.8	44.2		EPIBRU	0.28	0.28	0.28	
METBAR	46.6	11.3	233.2	Assessed	BABLUT	5.8	2.8	11.9		GIRMEL	0.17	0.17	0.17	
PLEPIC	46.0	11.7	183.1		PENSPP	5.4	2.9	10.1		PANVER	0.17	0.17	0.17	
SILSIH	45.6	9.6	224.6		ARGPAW	5.3	1.7	47.5		CYNTRI	0.14	0.14	0.14	

Table R9. Estimated annual catch by species and gear sector in the Hong Kong fishery. Bold indicates assessed species.

Species	HT	Misc.	PS	PT	SHT	ST	P4/7	TOTAL
totals	1292.6	2842.3	3633.3	1563.5	879.0	572.5	3964.1	14747.2
MIXSPP	432.5	194.2	1446.3	379.9	49.2	222.9	416.7	3141.6
SARJUS	**177.3**		**350.6**	**474.9**			**21.8**	**1024.6**
SIGORA	**10.6**	**129.6**	**97.0**	**116.3**	**7.7**	**1.7**	**514.1**	**876.9**
STOZOL	**50.2**	**24.8**	**501.9**	**142.5**			**23.0**	**742.4**
ARGSPP		316.3	1.0		67.6	12.0	247.2	644.1
SEBMAR		107.1	0.7				409.5	517.4
CARANX		55.5	263.2	45.1		3.3	34.2	401.3
LEIBRE	**3.3**	**59.7**	**159.9**		**11.4**	**28.0**	**119.1**	**381.5**
TRAJAP	**28.3**	**17.6**	**165.2**	**71.2**	**1.1**	**31.0**	**20.4**	**334.8**
SPARID		57.3	1.2	2.4	1.0		267.4	329.3
ACETES		275.8	15.3		26.5			317.6
PORPEL		57.9			9.3	3.1	213.1	283.4
TRIHAU	**122.8**	**14.0**	**7.8**	**95.0**	**2.2**	**25.5**	**7.1**	**274.5**
PLAIND		133.7	1.0		35.2	3.3	82.8	255.9
CLUPUN	49.0	16.3	47.0	23.7		0.8	112.1	249.0
CARKAL	**145.2**		**28.5**	**36.8**	**3.3**	**26.7**		**240.5**
STOSPP	46.9		23.5	118.7		3.3	40.2	232.7
DECLAJ	**92.3**		**37.7**	**23.7**		**56.9**		**210.7**
MCRAB		66.1	0.3		14.0	1.0	116.8	198.2
MURCIN		181.7	1.5				11.5	194.7
LOLIGO	13.8	15.7	74.7	7.1	5.5	18.4	55.4	190.5
PSECRO	1.0	85.1	38.9		1.4	0.2	45.1	171.6
SARAUR			159.0					159.0
MUGAFF	39.7	0.6	42.9	4.7	3.6		53.4	144.9
PORSAN		45.3			77.9	3.3	15.0	141.4
ELETET	3.7	81.8		10.4	0.2		39.4	135.6
MURSPP		116.8	0.8				15.4	132.9
LOLEDU		10.6	39.5			11.5	69.9	131.5
NEMJAP		65.3	0.2		22.1	21.7	17.6	126.9
ILIELO		77.7			1.3		38.9	118.0
JOHBEL		**59.5**	**0.1**		**21.6**	**5.0**	**26.2**	**112.3**
COLLUC	**12.0**	**30.7**	**36.1**		**9.8**	**3.4**	**4.3**	**96.2**
SEPLES		6.7	3.9				84.4	95.0
PARTRI		25.6	0.1				68.8	94.4
ORASPP		**3.9**			**81.9**	**3.3**		**89.1**
STRARG	22.6	18.7		2.4	1.2	28.6	3.9	77.2
LUTRUS		19.3	0.4				53.6	73.2
GYMSPP		35.0	3.2				26.6	64.8
CYNSPP		32.0			22.0		8.9	62.8
METSPP		8.0			46.9		7.0	61.8
ACEJAP		55.5						55.5
CHACRU		11.8			33.8	2.6	6.4	54.6
STOHET		5.6	9.4				37.6	52.5
SEPIA		11.9	0.5		2.8		35.3	50.4
APOGON		**4.2**	**14.5**		**18.8**		**11.9**	**49.4**
GERSPP		9.6					39.6	49.2
MONCHI		2.2					44.6	46.8
METBAR		**1.4**			**43.6**	**1.7**		**46.6**
PLEPIC		16.6	0.2				29.2	46.0
SILSIH		12.3			1.2		32.1	45.6
EPISPP		19.8					24.6	44.4
SEPPHA		2.2					40.6	42.8
CYNMAC		19.9			15.7		4.7	40.2
NIBDIA		31.1	0.9				5.7	37.7
AMBGYM		9.2	1.0				27.4	37.5
SOLCRA					37.4			37.4
THRSPP	0.5					36.6		37.2
SILSPP		5.5					30.9	36.4
THESPP		14.4					21.2	35.6
PARHUN					32.4			32.4
METAFF		1.8			29.0		1.3	32.1
MPRAWN					31.5			31.5
MYLMAC		4.3	0.1				26.4	30.8
LEIBIN			28.8					28.8
MURTAL		23.4				1.3	3.7	28.5
STRSPP	21.3	4.6				0.8		26.7
RHASAR		5.6					20.9	26.5
SCYSER		2.8					23.6	26.4
ORAORA					**25.2**	**0.8**	**0.3**	**26.4**
LATJAP		2.5					22.9	25.4
GYMREE		22.6					2.7	25.3
APOQUA					20.9		3.2	24.1

PAROLI		1.1					21.1	22.3
MYLLAT		7.2					14.6	21.8
CHRMAJ		4.8				0.3	16.5	21.7
SCOCOM	9.7	2.5		5.2		0.8		18.2
CHANAT		10.0			3.1		3.3	16.4
EPIAWO		15.5					0.8	16.2
TAPPHI							15.0	15.0
ATUMAL			8.6				4.8	13.4
THEJAR		0.6					11.9	12.5
MYLBER		4.2					8.3	12.4
MYLSPP		8.5				2.0	1.9	12.4
CYNSEM		5.6			0.2		5.0	10.7
METPAL					**9.8**			**9.8**
PLOANG							9.6	9.6
PSEANO	3.9				2.2	3.3		9.4
RASKAN		2.8	6.2					9.0
PENJAP					8.9			8.9
FORNIG				2.4		5.5		7.8
POMHAS		0.3					7.2	7.5
HARHAR					7.2			7.2
SPHSPP		6.9						6.9
CEPPAC		1.1					5.4	6.5
TRACUR					6.4			6.4
MUGSPP			5.8				0.3	6.1
TRYVAG					6.1			6.1
BABLUT		4.1			1.7			5.8
PENSPP		0.1			4.0		1.3	5.4
ARGPAW		1.4					3.9	5.3
LEISPP			4.8					4.8
LUTARG		1.4					3.3	4.7
MUGCEP	2.3		0.2				2.2	4.7
CHRLEP		0.6					3.8	4.4
METJOY					4.2			4.2
LUTJOH		0.1					3.7	3.8
SCOSPP	3.7							3.7
PENPEN					0.3		3.2	3.5
URCHIN							3.4	3.4
PARSPP		0.6					2.8	3.3
EPICHL		1.0					2.3	3.3
EPITAU		1.1	0.3				1.8	3.2
NIBJAP							3.0	3.0
SARSPP			2.9					2.9
SCOJAP		2.8						2.8
SAUSPP					1.6		0.9	2.4
GERLUC							2.4	2.4
EPIARE		2.0					0.4	2.4
CANMOD		0.8					1.5	2.3
APONIG		0.6					1.4	2.0
NEMVIR		1.9						1.9
HARNEH		**0.8**			**1.1**			**1.9**
PINBIC					0.6		1.4	1.9
CLAM							1.7	1.7
OCTOPUS							1.7	1.7
HILSA		1.7						1.7
SCOGUT						1.7		1.7
PENMER					1.1		0.4	1.5
PORTRI					1.4			1.4
GERFIL		1.3						1.3
STRSIN		0.1		0.9		0.1		1.2
SCAARG		1.1						1.1
EPIAKA		0.7					0.4	1.1
PARPIC							0.8	0.8
PARTEN					0.8			0.8
SAUTUM					**0.7**			**0.7**
LUTLIN							0.7	0.7
DREPUN							0.7	0.7
EPIFAS		0.3					0.3	0.6
ANABRO					0.6			0.6
BABSPP					0.6			0.6
ALPSPP					0.4			0.4
GONZON							0.4	0.4
NIBALB							0.3	0.3
PARUPE							0.3	0.3
APOELL		0.3						0.3
EPIBRU		0.3						0.3
GIRMEL							0.2	0.2
PANVER							0.2	0.2

CYNTRI	0.1	0.1

The miscellaneous vessel sector's top species, the croaker *Argyrosomus*, is also important for P4/7s and the shrimp trawlers, and is also caught by stern trawlers. The next two species, the silver shrimp *Acetes*, and the daggertooth pike conger *Muraenesox cincereus*, are caught in only small quantities by the other sectors. The miscellaneous vessel sector reports some 7 species caught exclusively, but also reports catching many of the species caught by other six sectors.

It would be informative to analyse this catch data by sector in more detail, adding a bio-economic evaluation using prices and vessel operating costs. (This has recently been done for the 1997/8 Artificial Reef/Marine Reserve project.)

SINGLE SPECIES ASSESSMENTS

Summary of Assessments

This section provides detailed information on the population dynamics, yield-per-recruit assessments and exploitation status of each of the 17 assessed species, in alphabetical order, with fish listed first, followed by 4 species of invertebrates. (Detailed graphical output from the software used to estimate these population parameters is available form the authors in form of an Appendix to this report). Summary tables of the single species assessments are provided in this section, and may be referred to from the appropriate species sections below.

Table R10 summarises the growth parameters fitted in this project, including confidence limits where appropriate. Table R 11 summarises the estimated mortality parameters, Z, G (by age group), and M, together with fishing mortality rates, F, estimated in two ways, first from the difference between Z and the sum of M and G, and secondly, by iteration using catch and biomass for those species where catch was less than estimated biomass. The final column shows the F values used in further analysis. Close F values were averaged, while the more likely of two different F values was chosen from divergent values.

Table R12 summarises the exploitation status of each of the 17 species. In the first part of the table estimated current F (from table R11) is compared with estimated $F_{0.1}$ and its confidence limits from the yield-per-recruit analyses. According to the definitions of status in the methods, none of the 17 assessed species fall into the under-exploited category, 12 are over-exploited, and 5 fully-exploited.

The second part of Table R12 summarises the current age of entry, t_c, compared to the estimated optimal age, t_{opt}, from the yield-per-recruit analysis. All species except for the prawns are harvested younger than the lower 95% confidence limit on t_{opt}, an indication of over-exploitation.

Table R13 summarises some estimates of sustainable yields for the 17 species. The first column shows estimates of unexploited biomass obtained from biomass-per-recruit (BPR) at the fitted value of F as a percentage of the maximum BPR at zero exploitation. (Here we have assumed that depleted populations have half the recruits of unexploited ones – the effect of this assumption needs to be explored in more detail). Current biomass and current catch are then listed together with sustainable yields calculated according to three different methods: the most credible of these are the Beddington & Cooke values in the final column.

It cannot be over-emphasised that Table R13 presents very approximate figures that have to be interpreted with caution. The present estimates take no account of uncertainties, and do not reflect the changes in the ecosystem that will occur when harvest patterns and levels are shifted, as set out in the ecosystem modelling section of this report below. As it stands the analysis suggest that yields of six species are unlikely to be much increased: *Apogon, Collichthys, Johnius, Leiognathus, O.anomala* and *M.barbata*. On the other hand, yields *of Saurida, Harpodon, Alepes, Siganus, Trachurus, Trichiurus* and *M.palmesis* might be considerably greater. Overall, this analysis suggest that the current catch of these 17 species of around 2.5 tonnes per km^2 might be more than doubled to around 5 tonnes per km^2 with good management.

Single Species Assessments

Alepes djedaba

According to Smith-Vaniz (1984), *Caranx kalla* is a junior synonym for *Alepes djedaba*, the shrimp scad, and therefore, we have undertaken all population parameter estimates and analyses on this premise. It is sold for about 5 HK$ per kg at 1997 prices.

Although *A. djedaba* is an important component of the purse seine fishery, the most robust length-frequency distributions in the sampling program were obtained by trawling. Additional length frequency data from the commercial purse seine fishery were provided by S. F. Leung, and analysed separately. Otolith readings and results from published studies provided additional information on growth rates.

The length-weight relationship is provided in Figure R5. Maximum length and weight of an individual in the samples was 12.5 cm FL and 28 g, respectively. Length frequency distributions obtained from trawling and from the commercial purse seine samples, were similar in that individuals larger than 12 cm FL were rare in both.

Mean estimates of K and L_T were 18.5 cm FL and 1.14 year^{-1}. This estimate of L_T was used to fit a von Bertalanffy curve to the otolith age-at-length data. However, the resulting estimate of K was well below all others (Figure R6) probably as a consequence of offshore migration, and therefore the otolith results were excluded from the estimation of the means.

Estimates of Z and M were 7.9 (Figure R7) and 2.03 year^{-1}, respectively. Instantaneous rates of emigration G (Figure R8) ranged from 1.4 year^{-1} for age 0+ years, to 3.2 year^{-1} for age 1+ years, to 3.5 year^{-1} for ages 2+ years. F by the difference method was 4.5, very close to the value from catch and biomass, and therefore this value was used in subsequent analysis.

The length at first capture is approximately 3 cm FL, which corresponds to an age of approximately 0.1 year. The yield-per-recruit surface (Figure R9) indicates maximum yield would be achieved by harvesting at a t_c of 0.3 years, well above the current t_c. When the uncertainty in K, M and W_T are considered, a probability distribution of t_{opt} is obtained (Figure R10) with a mean of 0.5yr, about five times that of the current t_c.

Table R 10. Summary of fitted growth parameters for the 17 assessed species.

SUMMARY OF GROWTH PARAMETERS			cls on Winf					length-weight relationship			
	Linf	Winf	lo95%cl	up95	k	se k	t0	a'	se a'	b	se b
	cm	*g*	*g*	*g*			*yr.*				
Alepes djedaba	18.5	62	52	76	1.14	0.11	-0.22	-3.886	0.035	2.75	0.220
Apogon fasciatus	12.5	31	26	37	0.79	0.08	-0.42	-4.040	0.035	2.96	0.019
Collichthys lucidus	21.8	101	81	121	1.21	0.10	0.00	-4.281	0.031	2.89	0.014
Decapterus russelli	25.6	251	164	387	1.39	0.10	-0.10	-4.852	0.070	3.20	0.030
Engraulis japonicus	18.6	67	20	184	1.32	0.13	0.00	-5.700	0.190	3.39	0.110
Harpadon nehereus	35.3	360	192	768	0.67	0.07	-0.08	-6.641	0.111	3.52	0.041
Johnius belangerii	32.7	462	362	594	0.67	0.07	-0.22	-4.725	0.050	3.11	0.020
Leiognathus brevirostris	13.9	44	38	53	1.09	0.10	-0.20	-3.863	0.040	2.91	0.020
Sardinella jussieui	18.7	100	64	153	0.56	0.06	-0.30	-5.109	0.080	3.31	0.040
Saurida tumbil	68.9	5169	2862	8683	0.23	0.02	-0.86	-6.256	0.100	3.50	0.040
Siganus canaliculatus	28.4	291	225	359	0.43	0.04	-0.30	-4.331	0.037	2.99	0.018
Trachurus japonicus	47.5	1573	1044	2132	0.33	0.03	-0.25	-4.427	0.060	3.05	0.030
Trichiurus lepturus	156.0	2273	2226	2320	0.32	0.03	0.00	-8.142	0.122	3.14	0.036
Oratosquilla oratoria	19.1	76	61	92	0.75	0.07	-0.16	-4.417	0.035	2.94	0.017
Oratosquilla anomala	19.3	76	63	89	0.89	0.90	-0.16	-4.327	0.030	2.92	0.016
Metapenaeopsis palmensis (Females)	25.6	13	17	9	1.61	0.16	-0.25	-6.304	0.068	2.72	0.025
Metapenaeopsis palmensis (Males)	18.6	7	5	9	2.22	0.21	-0.25	-7.314	0.067	3.15	0.025
Metapenaeopsis barbata (Females)	24.5	11	6	21	1.79	0.18	-0.08	-6.325	0.117	2.71	0.045
Metapenaeopsis barbata (Males)	20.1	7	3	13	1.94	0.19	-0.08	-7.224	0.157	3.06	0.062

Table R11. Summary of estimated mortality parameters for the assessed species.

SUMMARY OF MORTALITY PARAMETERS

	Z	G			M	F	F	F
		1	2	3		diff	C&B	used
Alepes djedaba	7.9	1.4	3.2	3.5	2.03	4.5	65.1	4.5
Apogon fasciatus	5.5	0.0			1.78	3.7	4.0	3.8
Collichthys lucidus	9.9	1.8	2.2	3.0	2.02	5.8	18.0	5.8
Decapterus russelli	9.4	0.0			2.11	7.3		7.3
Engraulis japonicus	7.2	1.3			2.25	3.6		3.6
Harpadon nehereus	8.25	–			1.20	7.1	0.03	7.1
Johnius belangerii	6.42	2.0	2.8		1.22	3.2		3.2
Leiognathus brevirostris	7.38	1.9	1.9		2.14	3.3	77.8	3.3
Sardinella jussieui	2.74	0.0			1.40	1.3	1.4	1.4
Saurida tumbil	7.7	0.8	1.8	3.8	0.49	3.4	0.1	3.4
Siganus canaliculatus	7.7	0.0			0.95	6.8		6.8
Trachurus japonicus	11.7	2.7	5.5		0.70	5.5		5.5
Trichiurus lepturus	7.5	0.6	2.8	4.7	0.49	2.3	5.4	3.9
Oratosquilla oratoria	5.5	–			3.00	2.5		2.5
Oratosquilla anomala	5.83	–			3.00	2.8	5.8	2.8
Metapenaeopsis palmensis (Females)	12.1	–			3.60	8.5	0.4	4.5
Metapenaeopsis palmensis (Males)	12.1	–			3.60	8.5	0.4	4.5
Metapenaeopsis barbata (Females)	10	–			3.60	6.4	0.6	3.5
Metapenaeopsis barbata (Males)	10	–			3.60	6.4	0.6	3.5

Table R12. Summary of current exploitation status of assessed species.

SUMMARY OF EXPLOITATION STATUS

	Current	F0.1	cl s on F0.1		Status	Present tc	topt	cls on topt	
	F		Lo95%cl	Up95%cl		*yr*	*yr*	*yr*	*yr*
Alepes djedaba	4.5	2.3	1.9	2.7	over	0.1	0.5	0.4	0.6
Apogon fasciatus	3.8	2.0	1.6	2.3	over	0.1	0.5	0.4	0.6
Collichthys lucidus	5.8	2.3	1.9	2.7	over	0.1	0.7	0.7	0.8
Decapterus russelli	7.3	2.5	2.2	2.7	over	0.1	0.5	0.4	0.5
Engraulis japonicus	3.6	2.5	2.2	2.9	over	0.1	0.6	0.6	0.7
Harpadon nehereus	7.1	1.4	1.2	1.7	over	0.1	1.3	1.1	1.4
Johnius belangerii	3.2	1.4	1.2	1.6	over	0.1	1.1	1.0	1.2
Leiognathus brevirostris	3.3	2.3	2.0	2.7	over	0.1	0.5	0.4	0.6
Sardinella jussieui	1.3	1.5	1.2	1.7	fully	0.1	1.0	0.8	1.1
Saurida tumbil	3.4	0.6	0.5	0.7	over	0.2	2.7	2.4	3.1
Siganus canaliculatus	6.8	1.1	1.0	1.3	over	0.1	1.6	1.4	1.7
Trachurus japonicus	5.5	0.8	0.7	1.0	over	0.1	2.3	2.0	2.5
Trichiurus lepturus	3.9	0.6	0.6	0.7	over	0.2	3.2	3.0	3.6
Oratosquilla oratoria	2.5	2.7	2.1	3.2	fully	0.2	0.5	0.4	0.5
Oratosquilla anomala	2.8	3.4	2.8	4.0	fully	0.2	0.4	0.3	0.5
Metapenaeopsis palmensis	4.5	3.9	3.3	4.7	fully	0.3	0.1	0.1	0.2
Metapenaeopsis barbata	3.5	3.5	3.0	4.1	fully	0.3	0.3	0.3	0.3

Table R13. Summary of sustainable yield estimates for the assessed species.

SUMMARY OF SUSTAINABLE YIELD ESTIMATES

	estimated B inf	current B	current catch	MSY estimates		
				Gulland 1	Gulland 2	B & C
	t	*t*	*t*	*t*	*t*	*t*
Alepes djedaba	881	248	241	894	1014	440
Apogon fasciatus	112	35	24	100	112	45
Collichthys lucidus	391	107	96	394	443	137
Decapterus russelli	654	191	211	690	795	262
Engraulis japonicus	2165	723	742	2435	2806	1299
Harpadon nehereus	957	110	2	574	578	239
Johnius belangerii	116	21	112	71	127	21
Leiognathus brevirostris	1103	392	382	1180	1371	276
Sardinella jussieui	7180	2190	1024	5026	5529	1292
Saurida tumbil	727	32	3	178	179	55
Siganus canaliculatus	15629	758	877	7424	7862	2188
Trachurus japonicus	6356	286	335	2224	2392	763
Trichiurus lepturus	8824	300	275	2162	2299	794
Oratosquilla oratoria	98	40	26	147	160	98
Oratosquilla anomala	84	36	89	126	170	84
Metapenaeopsis palmensis	196	91	10	352	357	215
Metapenaeopsis barbata	80	36	47	144	167	88

The probability distribution of $F_{0.1}$ (Figure R11) had a mean of 2.3) 0.06 year^{-1}. Current fishing mortality, F is estimated at 4.5 (Table R12), greatly exceeding the lower confidence limit on $F_{0.1}$, according over-exploited status to this species and strongly suggesting that fishing effort is too high.

Alepes biomass is estimated as 248 tonnes (= 0.14 tonnes km^2) from the catch method (Table R6). It is strongly seasonal from June to October, and most abundant in strata T5 to T9.

The reported catch of *Alepes* amounts to just over 2% of the total Hong Kong catch at 241 tonnes (95% confidence limits 34 - 2873 tonnes) equivalent to 0.13 tonnes km^{-2}. Over 60% of the catch is made by hang trawlers, with pair trawlers (15%), stern trawlers and purse seiners (11% each) each contributing approximately equal amounts. A small catch (1.4%) was made by the shrimp trawlers. P4/7s do not report a catch of this species. Richards (1980) indicated it was the sixth most important species (by weight) in the purse seine fishery. Today it is 13th in the purse seine and 16th overall.

Approximate analysis (Table R13) suggests that maximum sustainable yields might be of the order of 400 to 800 tonnes, (0.2 to 0.4 tonnes km^{-2}).

Other undifferentiated species of scad in the catch database provide catches almost twice as large, and so there is considerable uncertainty here that may only be resolved by a full frame survey.

Apogon fasciatus

According to Paxton et al. (1989), *Apogon quadrifasciatus* (Cuvier 1828) is a junior synonym of *Apogon fasciatus* (White 1790) and is therefore referred to as *A. fasciatus* herein. *Apogon fasciatus*, also known as the broad-banded cardinal fish, is a small species generally considered to be of low commercial value. In Hong Kong waters it is targeted by fishers and marketed at approximately HK$7/kg. It was the fourth most important fish in the benthic trawl samples (by weight). Catches in the purse seine and gill net samples were small. The population dynamics of *A. fasciatus* has received scant attention from researchers.

The length-weight relationship is provided in Figure R12. Maximum length and weight for an individual was 11 cm FL and 23.4 g, respectively. *Apogon fasciatus* were abundant in the trawl samples (3,317 individuals) and as a result, the length-frequency distributions used in the analyses were robust. Estimates of K and L_T are provided in the auximetric plot (Figure R13). The iterative least squares estimate of K, obtained by fitting the von Bertalanffy curve to the otolith readings, was well below the other estimates (Figure R13) and therefore, not included in the estimate of the means. Mean values for K and L_T were 0.79 year^{-1} and 12.5 cm FL, respectively. This estimate of L_T is consistent with maximum size sizes reported elsewhere (Masuda et al. 1984, Warburton and Blaber 1992). *Apogon fasciatus* weigh about 31 g at W_T.

Since most size classes were well represented in the length-frequency distributions, emigration out of the area was assumed to be negligible. Estimates of Z and M were 5.5 and 1.78 year^{-1}, respectively. Fishing mortality F, obtained by averaging the difference method and the catch/biomass method was 3.8 year^{-1} (Table R11).

The length at first capture was approximately 3 cm FL, which corresponds to an age at first capture, t_c of slightly less than 0.1 year. The yield-per-recruit surface plot (Figure R14) indicated maximum yield would be obtained by harvesting at a very young age (approximately 0.2 years). The probability distribution of t_{opt} (Figure R15) ranged from 0.4 to 0.6 years, with a mean of 0.54. The 95% limits on the probability distribution of $F_{0.1}$ (Figure R16) ranged from approximately 1.6 to 2.3 year^{-1}, with a mean of 2.0 year^{-1}.

Apogon fasciatus is a small, fast growing species. In order to maximise its yield it should be harvested at a relatively small size. The estimate of t_{opt} is older than the current age at first capture. Thus, a small increase in yield could be achieved by increasing the mesh size and therefore, increasing the t_c. The current fishing mortality rate of 3.8 is above the confidence limits on $F_{0.1}$, indicating that the species is over-exploited.

The biomass estimate of 35 tonnes (= 0.02 tonnes km^{-2}) is based on averaging the purse seine and catch methods (Table R6). *Apogon* has a strong peak of abundance in July but is found throughout the rest of the year at a density of about half the average. It is evenly distributed among the Hong Kong sampling strata.

The reported catch of *Apogon* provides an estimate of 24 tonnes amounts to about 0.2% of the total Hong Kong catch (95% confidence limits 3 - 255 tonnes) equivalent to 0.016 tonnes/km^2. Over 87% is caught by the shrimp trawlers, and the remaining 13% by the P4/7 vessel sector.

Maximum sustainable yield estimates (Table R13) for this cardinal fish range from 45 to about 80 tonnes, only slightly higher than the present catch.

Note that undifferentiated *Apogon* species are listed in the catch database yielding an estimated 50 tonnes (Table R9), together with two other small cardinal fish. It is possible that juveniles of *A. fasciatus* have been grouped in these other categories. This uncertainty would only be resolved by a full frame survey.

Collichthys lucidus

Collichthys lucidus, the small lion head croaker, contributes significantly to fisheries production in Hong Kong waters. It was the second most important (by weight) fish in the gill net samples, and third in the trawl samples. Minor catches were also taken in the purse seine sampling. He Baoquan and Li Huiquan (1988) estimated its growth rate and yield-per-recruit in the Pearl River estuary.

Growth and mortality rate estimates were based on the trawl sampling data and otolith readings. A comparison of the different estimates of K and L_T is provided in the auximetric plot (Figure R18). Otolith readings indicated a much lower estimate of K compared with the other methods, probably as a result offshore migration, and consequently, were excluded from the estimate of the means. The estimate of K by He Baoquan and Li Huiquan (1988) was considerably higher than that obtained by our length-frequency analyses, possibly because they sampled smaller size classes (and therefore faster growing fish) in the Pearl River estuary. Mean values of K and L_T were 1.21 $year^{-1}$ and 21.7 cm TL, respectively. An estimate of t_c of 0 years was derived using ‘Solver’ to fit a von Bertalanffy curve to the otolith data. The weight of *C. lucidus* at this estimate of L_T is approximately 100 g (W_T). Very few fish larger than 16cm (40g) were represented in the samples.

The estimate of M, based on these growth parameter estimates, was 2.02 $year^{-1}$. The instantaneous rate of total mortality, Z, from cohort slicing was Z was 9.9 $year^{-1}$. The instantaneous rate of emigration, G ranged from 1.8 $year^{-1}$ in 1+ year old fish to about 2.2 $year^{-1}$ in 3+ year old fish (Figure R19): an average value of 2.1 was used. Thus, fishing mortality, F, by the difference method comes to 5.8. This is the F value used in subsequent work as the estimate of F from the catch and biomass method was suspiciously high (Table R11) .

The three dimensional yield-per-recruit surface plot is provided in Figure R20. Maximum yield would be achieved by harvesting at a t_c of approximately 0.5 years. Currently, the small mesh size (1.5 cm) used by the trawl fleet (and, with less significance, the purse seiners) results in a t_c of approximately 0.1 year; well under the optimum indicated in the surface plot (Figure R21). When confidence intervals were placed around the population parameter estimates (W_T, K and M) and Monte Carlo sampling techniques deployed, a probability distribution of t_{opt} was obtained with a mean of 0.72) 0.06 years.

The probability distribution of $F_{0.1}$ (Figure R22) has a mean of 2.31) 0.28 $year^{-1}$, much lower than the current F value. At present, *C. lucidus* is being harvested at an age and rate indicative of heavy overfishing. Increases in yield could be achieved by increasing the mesh size and reducing effort, and therefore harvesting at a larger/older size/age. Maximum sustainable yield estimates (Table R13) suggest that the *Collichthys* harvest might be increased by 50% to 200%.

Collichthys biomass is estimated as 107 tonnes (= 0.06 tonnes km^{-2}), and it is highest in June and lowest in March and April. It is most abundant in strata T12, T13 and T18. Unexploited biomass might be more than 3 times this amount.

The reported catch of *Collichthys* amounts to less than 1% of the total Hong Kong catch at 96 tonnes (95% confidence limits 23 - 492 tonnes) equivalent to 0.053 tonnes km^{-2}. About 38% of this catch is made by the purse seiners, 29% by the miscellaneous vessels, 13% by hang trawlers and 10% by shrimp trawlers and a little (4% each) by the stern trawlers and P4/7 vessels.

Decapterus russelli

According to Smith-Vaniz (1984) *Decapterus lajang* is a synonym for *Decapterus russelli* and therefore we carried out all population parameter estimates and per-recruit analyses on this premise. *Decapterus russelli*, or Indian scad, is a commercially important, targeted species in Hong Kong waters.

The scad length-weight relationship is provided in Figure R23 and Table R10. Maximum length and weight in the samples were 15.5 cm FL and 55 g, respectively. No otolith readings were obtained for *D. russelli*. The trawl survey provided more robust and frequent samples than either the gill net or purse seine sampling programs, and therefore growth rate estimates were obtained from these data. Several estimates were obtained from the literature (Table R14) and included in the auximetric plot (Figure R24) and estimation of mean values of K and L_T. *Decapterus russelli* is a long slender fish with a high standard body length : body depth ratio. Its length at first capture is approximately 9 cm FL, which equates to a t_c of approximately 0.1 years.

The scad length-weight relationship is provided in Figure R23 and Table R10. Maximum length and weight in the samples were 15.5 cm FL and 55 g, respectively. No otolith readings were obtained for *D. russelli*. The trawl survey provided more robust and frequent samples than either the gill net or purse seine sampling programs, and therefore growth rate estimates were obtained from these data. Several estimates were obtained from the literature (Table R14) and included in the auximetric plot (Figure R24) and estimation of mean values of K and L_T. *Decapterus russelli* is a long slender fish with a high standard body length : body depth ratio. Its length at first capture is approximately 9 cm FL, which equates to a t_c of approximately 0.1 years.

L_∞ (cm, FL)	K (year^{-1})	t_0 (year)	Method	Locality	Reference	Ref. in Aux. Plot
26.00	0.186	–	FW	India	Sreenivasan (1982)	1
28.40	0.900	–	LF	Indonesia, Java Sea	Widodo (1988)	2
24.80*	1.150	–	LF	Indonesia, Jakarta Bay	Dwiponggo et al. (1986)	3
24.80*	1.180	–	LF	Indonesia, Jakarta Bay	Dwiponggo et al. (1986)	4
24.50*	0.950	–	LF	Indonesia, Java Sea	Dwiponggo et al. (1986)	5
26.00	0.900	–	LF	Indonesia, Idi, Malacca St	Tampubolon & Merta (1987)	6
25.20	1.080	–	LF	Indonesia, Java Sea	Suwarso et al (1995)	7
24.50	0.950	–	LF	Indonesia, Java Sea	Suwarso et al. (1995)	8
24.80	1.010	–	LF	Malaysia	Isa (1987)	9
22.00	0.810	–	LF	Malaysia	Isa (1987)	10
25.70	0.562	0.17	–	Mozambique	Rodriguez & Sousa (1988)	11
25.60	0.573	−0.18	Ot	Mozambique	Sousa & Glaister (1987)	12
22.80	0.560	−0.10	LF	Mozambique	Gjosaeter & Sousa (1983)	13
31.00	0.360	–	LF	Philippines	Jabat and Dalzell (1988)	14
33.70	0.650	–	LF	Philippines	Padilla (1991)	15
30.40	0.450	–	LF	Philippines	Ingles and Pauly (1984)	16
27.60	0.540	–	LF	Philippines	Ingles and Pauly (1984)	17
24.80	0.800	–	LF	Philippines	Ingles and Pauly (1984)	18

24.80	0.690	–	LF	Philippines	Ingles and Pauly (1984)	19
23.90	0.730	–	LF	Philippines	Ingles and Pauly (1984)	20
23.20	1.080	–	–	India	Murty (1991)	21
19.40	0.750	–	LF	Pakistan	Iqbal(1991)	22
21.40	1.132	–	LF	Philippines	Pauly (1978)	23

Table R14. Published growth parameter estimates for *Decapterus russelli*. (* = adjusted from total length to fork length using FL=0.92*TL). LF = length frequency. FW = Ford/Walford plot. Ot = otolith annuli.

Mean values of K and L_T were 1.4 year^{-1} and 25.6 cm FL, respectively. The origin of the growth curve, t_o, cannot be calculated from the length-frequency analyses, and in the absence of any otolith data that could be used to derive an estimate of t_o, we constrained this parameter to a value of -0.2 years, which is generally consistent with the limited number of estimates in Table R14.

Given these growth parameter estimates, estimates of Z and M were 9.4 and 2.11 year^{-1}, respectively. No estimates of G were obtainable, due to the lack of otolith readings, but we think that this small scad is unlikely to migrate offshore to any large extent. F was estimated by difference as 7.3 (Table R11): no other estimate was obtainable as catch was more than the estimated biomass.

The yield-per-recruit surface plot (Figure R25) indicates maximum yield would be achieved by harvesting at a t_c of approximately 0.35 years. When the uncertainty in the population parameter estimates for K, M and W_T were considered, a probability distribution of t_{opt} was obtained (Figure R26) with a mean of 0.46) 0.05 years, slightly more conservative than the surface plot indicated and approximately four times older than the current t_c (Table R12). When the uncertainty in the population parameter estimates is considered on the estimation of $F_{0.1}$, a probability distribution with a mean of 2.45) 0.27 year^{-1} was obtained (Figure R27), less than half the current fishing mortality rate. The exploitation status is therefore ‘over-exploited’ (Table R12).

The estimated catch of *Decapterus* from the interview survey amounts to just under 1.5% of the total Hong Kong catch at 211 tonnes (95% confidence limits 118 - 441 tonnes), equivalent to 0.15 tonnes km^{-2}. Almost 44% of this catch is made by the hang trawl sector, with 27% by stern trawlers and the remainder by the purse seiners (18%) and pair trawlers (11%). Shrimp trawlers, P4/7s and miscellaneous vessels do not report this species. Richards (1980) listed *Decapterus* spp. as the most important (by weight) fish species in Hong Kong's purse seine fishery. However, the interview results indicate that it is now 16h in overall catch order (Table R8) and 12th in the purse seine fishery (Table R9). These results suggest the relative abundance of *Decapterus russelli* has declined in Hong Kong waters since Richards collated his estimates.

Decapterus biomass is estimated (from catch) as an average 191 tonnes (0.11 tonnes km^2), with a strong seasonal peak in August, a similar pattern to *Sardinella*. Estimates from the purse seine samples were lower (Table R6). Unexploited biomass may be of the order of 600 tonnes (Table R13), but these values must be regarded with considerable caution. Maximum sustainable yield may be around 50% greater than the current yield (Table R13).

Engraulis japonicus

Stolephorus zollingeri seems to be a new combination of *Engraulis zollingeri* (Bleeker 1849) which is a junior synonym of the anchovy, *Engraulis japonicus* (Temminck and Schlegel 1846). As such, it will be referred to, and considered as, *E. japonicus* herein. The anchovy is important in Hong Kong fisheries, being sold for a surprising 20.5 HK$ per kg.

The length-weight relationship is provided in Figure R28. Maximum length and weight of fish obtained in the samples was 17 cm FL and 50 g, respectively. It was poorly represented in both the trawl and gill net samples and therefore, length-frequency analyses were based on the limited (quarterly) number of purse seine samples. Although four purse seine sampling trips were conducted during the course of the study, two (August and November 1996) produced insignificant catches of *E. japonicus*. Additional analyses were carried out on length-frequency data provided by S. F. Leung. Maximum sizes of fish obtained from these two different sampling methodologies were very similar in that individuals larger than 12 cm FL were rare.

Although otolith readings were obtained for *E. japonicus*, they proved to be of little value in deriving a robust growth rate estimate, because only two age classes were represented in the samples (0+ and 1+ years). Fitting a growth curve to only two length-frequency distributions (March 1996 and February 1997) obtained from the sampling program would have produced very unreliable estimates, and therefore, mixture analysis was used to fit two subcohorts to these data and a von Bertalanffy curve fitted through the means identified in the Mix analysis. The derived estimates of K and L_T, as well as those obtained from the literature, are presented in the auximetric plot (Figure R29). The otolith data were not included in the estimation of the means, which were 18.1 cm FL for L_T and 1.32 $year^{-1}$ for K (Figure R29), while t_0 was estimated as 0 years.

Total mortality Z was determined as 7.2 by following the fate of cohorts using mixture analysis (Figure R30). From the growth parameters, natural mortality, M = 2.25 (Table R11). *Engraulis japonicus* is mobile and pelagic, and as such, likely to move in and out of Hong Kong waters. This is strongly indicated by the seasonal biomass estimates from the purse seine samples (Table R5). The anchovy is therefore not likely to have a consistent offshore emigration rate with size. If we assume no net emigration (G=0), an estimate of F equal to 3.6 $year^{-1}$ is obtained by difference. Estimated catch was greater than average biomass, so no estimate was possible using that method.

Engraulis japonicus is elongate and therefore has a high standard length : body depth ratio. As a consequence, its length at first capture is large compared with the other species. Even so, the small mesh size used by the purse seiners (1.5 cm) results in a very low (young) t_c of approximately 0.25 years. The three dimensional yield-per-recruit surface plot (Figure R31) indicates maximum yield-per-recruit would be obtained by harvesting at an older age of approximately 0.5 years. The probability distribution for t_{opt} (Figure R32) fixes this at 0.59 - 0.71 years, with a mean of 0.64 years. This estimate of t_{opt} is more than twice that of the current t_c, indicating that the anchovy is currently being harvested well below its optimum age at first capture, resulting in overfishing. The 95% limits on the probability distribution of $F_{0.1}$ range from 2.2 – 2.9 $year^{-1}$ with an optimum of 2.53 (Figure R33). This about 2/3 of the existing fishing mortality. Thus, *E. japonicus* is currently harvested well below the size/age and above the rate associated with the optimum yield. Long term average yield could be increased (by approximately 30%) by increasing the mesh size, particularly in the purse seine fishery, which is the principle gear type used for this species.

The reported catch of *Engraulis* amounts to 5% of the total Hong Kong landings at 742 tonnes (95% confidence limits 343 - 2897 tonnes) equivalent to 0.41 tonnes km^{-2}. 67% of the catch is made by the purse seiners, 19% by the pair trawlers, 7% by the hang trawlers and about 3% each by the P4/7 and miscellaneous vessels.

Average *Engraulis* biomass is estimated as 723 tonnes (= 0.4 tonnes km^{-2}, CLs 0.27 to 0.52) (Table R6) as an average between the catch estimate and the purse seine samples. There is a strong peak of nearly 9000 tonnes in May and a lower one in February (Figure R3). Table R13 suggests that unexploited biomass may be three times as large as present, and, given optimal management, maximum sustainable yields are estimated at about twice existing landings.

There are two other anchovy categories in the catch interview database that could have been confused with this species, in particular undifferentiated anchovies with an estimated catch of 233 tonnes. These uncertainties in the catch would only be resolved by a frame survey.

Harpadon nehereus

Harpadon nehereus, also known as Bombay-duck, is an important commercial, targeted fish species in Hong Kong waters worth 8HK$ per kg. It was the seventh most important fish (by weight) in the trawl samples. Although pelagic, it contributed only very small amounts to the gill net and purse seine samples. *Harpadon nehereus* was not included in the list of commercially important pelagic fish species by Richards (1980).

The length-weight relationship is provided in Figure R33. Maximum length and weight of an individual in the samples was 27 cm FL and 160 g, respectively. No otolith readings were obtained for this species. The only robust length-frequency distributions were based on a relatively small number of individuals (239) sampled in the trawl survey. Additional growth parameter estimates were obtained from the literature and included in the auximetric plot (Figure R34). The estimate of K derived by Krishnaya (1968) was well below all other estimates, and therefore, growth parameter estimates from this study were excluded from the estimation of the means. Mean values of K and L_T were 0.67 year^{-1} and 35.1 cm FL, respectively (Table R10). Because no otolith readings were obtained, we could not obtain an estimate of t_0 by fitting a growth curve to the age-at-length data. An estimate of t_0 equal to -0.08 years was therefore obtained from the table of t_0 estimates provided in the Elefan module of LFDA.

Using cohort slicing we obtained a Z of 8.25 (Figure R35). From the growth parameters, the estimate of M was 1.2 year^{-1}. The catch and biomass method gave a value of F = 0.1, clearly an underestimate, we have therefore used the value of 7.1 from the difference method in subsequent work. No estimates of the instantaneous rate of emigration G were possible, due to the lack of otolith readings (Table R11).

The length at first capture was 3.8 cm, which, based on the above growth parameter estimates, corresponds to a t_c of approximately 0.1 year. The yield-per-recruit surface plot (Figure R36) indicates maximum yield would be achieved by harvesting at a t_c of approximately 1.0 year - ten times the current age at first capture. When the uncertainty in the estimates of K, M and W_T was considered, a probability distribution of t_{opt} was obtained with a mean of 1.25) 0.01 years (Figure R37), much older than the current t_c. The probability distribution of $F_{0.1}$ had a mean of 1.41) 0.19 year^{-1} (Figure R38), four times lower than the existing F, indicating an overfished status for this species (Table R12).

The reported catch of *Harpadon* amounts to 1.9 tonnes (95% confidence limits not calculable) equivalent to 0.001 tonnes km^{-2} or less than 0.01% of the total Hong Kong catch. Just over half of the catch (58%) was made by the shrimp trawlers, with the rest in the miscellaneous vessel sector, these being the only gear sectors reporting a catch of Bombay duck. Sustainable yield (Table R13) is estimated as more than 20 times more than existing catches, although this figure must be treated with considerable caution because this is a single species analysis.

Our biomass estimates for *H. nehereus* are associated with a great deal of uncertainty, because few individuals were sampled. Also, *H. nehereus* is a pelagic species, but because it was poorly represented in the purse seine samples, we estimated its biomass using the benthic trawl data (Table R6). Average *Harpadon* biomass is 110 tonnes (= 0.06 tonnes km^{-2}) from the swept area trawl method, and it is found from August to January, peaking in December. It is present in strata T7 to T13 and T18, but most abundant in T11. Unexploited biomass may be more than five times existing levels (Table R13).

Johnius belangerii

Johnius belangerii, known as Belanger's croaker, is one of Hong Kong's commercially important, and targeted, fish sold for around 24HK$ per kg. It was the eighth most important fish in the trawl samples, third in the gill net samples, by weight. *Johnius belangerii* appears to be strongly demersal, since it was completely absent from the purse seine samples, which is consistent with Richard's (1980) report. Although known by several synonyms, the population dynamics of *J. belangerii* have received little research attention.

Johnius belangerii is demersal, and therefore, the most robust length-frequency samples were obtained from the trawl survey. The length-weight relationship is provided in Figure R39.

Maximum length and weight of an individual in the samples was 22 cm TL and 150.4 g, respectively. The asymptotic length, L_T, was unknown and therefore we used an estimate of 30 cm TL, based on the maximum size of an individual reported by Bianchi (1985), to commence fitting growth curves to the length-frequency distributions. The derived estimates of K and L_T are provided in the auximetric plot (Figure R40). The mean estimate of L_T was 32.8 cm TL, which, using the above length-weight relationship, has a corresponding W_T of 460 g. This value of L_T was then used to fit a growth curve to the otolith data, in order to estimate t_o, and obtain an additional estimate of K. However, as can be seen in the auximetric plot, the estimate of K from the otolith data was very low - about half that obtained from the length-frequency analyses. It was therefore concluded to be biased by offshore migration, and excluded from the estimation of the mean K. Thus, while the otolith data were not used to estimate mean values of K or L_T, they were used to obtain an estimate of t_o of -0.22 years. The mean value of K was 0.67 year^{-1} (Table R10).

Figure R42 shows the total mortality estimate, Z, as 6.42 from cohort slicing of one of the two cohorts deconvoluted from the length frequency data. From the growth parameters, M was 1.22 year^{-1}. As a result of the large difference between the otolith based estimates of age and those based on the true growth curve, the emigration rate estimates were relatively high, ranging from 2.0 year^{-1} at an age of 1+ years to 2.8 year^{-1} at 2+ years of age (Figure R43). Fishing mortality by the difference method was therefore 3.2, which is the value we have used as there was no estimate possible from catch and biomass (Table R11). Length at first capture was estimated to be approximately 4 cm TL, which corresponds to t_c of 0.1 years. The yield-per-recruit surface plot (Figure R44) indicates maximum yield would obtained by harvesting older the current t_c. When the uncertainty in the population parameter estimates was considered, a probability distribution of t_{opt} was obtained with a mean of 1.09) 0.09 years (Figure R45). The probability distribution of $F_{0.1}$ has a mean of 1.42) 0.16 year^{-1} (Figure R46), which is half the value of the current F. *Johnius* is therefore considered over-exploited (Table R12).

The estimated catch of this croaker amounts to 112 tonnes (95% confidence limits, 27 - 545 tonnes) equivalent to 0.06 tonnes km^{-2} and less than 1% of the total Hong Kong catch Just over half of this catch (53%) is reported by the miscellaneous vessel sector, with 24% by the P4/7 vessels and 19% by the shrimp trawls. Small amounts are caught by the stern trawlers (4%) and the purse seiners (0.1%). The species is not reported by pair trawls or hang trawls.

Average croaker biomass is estimated at 21 tonnes (= 0.012 tonnes km^{-2}), a consistent average from the shrimp trawl sampling and from demersal catch. It appears to be present evenly through the year and throughout the Hong Kong area. Unexploited biomass might be 4 to 5 times as large, but sustainable yield levels may not be any larger than at present (Table R13). These estimates are inconsistent and need further investigation. The very large discrepancy between the estimate of biomass, which appears one of the more consistent figures from this work, and catch, five times as large, estimated from the interview survey, requires some explanation. It is possible that this valuable, familiar, but heavily over-fished species is being over-reported in the interviews, or that fish caught outside of the Hong Kong waters are being included in the reported catch.

Leiognathus brevirostris

Leiognathus brevirostris, known as the short-nose ponyfish, is a small common species of commercial importance in Hong Kong waters worth about 8 HK$ per kg. It inhabits shallow waters to a depth of about 40 m and was within the top 10 fish species (by weight) in each of the trawl, gill net and purse seine samples. Relatively little has been published on the population dynamics of *L. brevirostris*. The length-weight relationship is provided in Figure R47. Maximum size of individuals in the samples was about 13 cm FL, with a corresponding weight of about 40g.

Trawl sampling provided the most robust length-frequency samples for analysis. Additional length-frequency distributions, from commercial purse seine catches (provided by S. F. Leung), were also analysed. Otoliths provided a third source of information on growth. Length frequencies obtained from the trawl sampling program and the purse seine fishery were very similar. Individuals larger than 12 cm FL were rare in both types of samples. All estimates of K and L_T are presented in the auximetric plot (Figure R48). Again, mean values of K and L_T were based only on length-frequency results and reports in the literature (Armada and Silvestre 1981, Corpuz et al. 1985). The otolith based estimate of K was considered to be too low and therefore, was excluded from the estimation of the means, which were 13.9 cm FL for L_T and 1.09 $year^{-1}$ for K (Table R10). The growth curve start parameter, t_o, was estimated as -0.2 years. The difference between this 'true' growth rate, and that derived from the otoliths, is readily apparent in Figure R49.

Pauly's (1980) empirical method was used to obtain an estimate of M equal to 2.14 $year^{-1}$. The length converted catch curve method in FiSAT estimated average Z at 3.9 $year^{-1}$. Figure R50 shows the more accurate cohort-sliced estimate of Z as 7.4. The instantaneous rate of emigration G (Figure R51) was comparatively high at 1.9 $year^{-1}$ and remained constant over the age classes examined. Thus F by the difference method comes to 3.3, and as the estimate from the catch and biomass method was an unreasonable 78, this was used in subsequent analyses (Table R11).

Leiognathus brevirostris is a relatively short, round fish with a low standard length : body depth ratio. As a consequence it is first harvested at the relatively small size of approximately 3.0 cm FL, which equates to an age of approximately 0.2 years. The yield-per-recruit surface plot (Figure R52) indicates maximum yield would be obtained by harvesting at a t_c of 0.5 years. When the uncertainty in the parameter estimates was considered and Monte Carlo methods deployed, a probability distribution of t_{opt} was obtained (Figure R53) with a 0.5) 0.06 years. The probability distribution of $F_{0.1}$ (Figure R54) had a mean of 2.34) 0.27 $year^{-1}$, about 2/3 of the current level outside the lower 95% confidence limits. It is therefore considered over-exploited (TableR12). This result is not surprising considering that such high turn-over species are favoured by the heavy fishing exploitation seen in the South China Sea.

L. brevirostris is a small demersal species and therefore, its biomass should in theory be estimated reasonably well with the swept area method from the shrimp trawl. But we found that the ponyfish biomass was better estimated as 392 tonnes from an average of the catch method and purse seine samples (= 0.22 tonnes km^{-2}). Abundance is low from December to March and highest in T6 and T12. Unexploited biomass may be about three times existing levels (Table R13) provided that species composition of the system did not alter.

The reported catch of *Leiognathus* amounts to just under 3% of the total Hong Kong catch at 382 tonnes (95% confidence limits 81 - 1996 tonnes) equivalent to 0.2 tonnes km^{-2}. Over 42% of this pony fish is caught in the purse seine sector, 32% by the P4/7 vessels, 16% by the miscellaneous vessel sector, 7% by stern trawlers, and a little by shrimp trawlers (3%) and hang trawlers (1.1%). Only the pair trawlers do not report a catch of this species. The sustainable yield appears to be about the same as the present catch (Table R13).

Note that this species may well have been confused with 2 other categories of ponyfish in the catch database. Purse seiners report a 30 tonne catch of *Leiognathus bin*, and 5 tonnes of undifferentiated ponyfish. These amounts, however, would not alter the assessment status.

Sardinella jussieui

According to Whitehead (1985), *Sardinella dayi* is a synonym of *S. jussieui*. While very little has been published specifically on *S. jussieui*, some studies pertaining to *S. dayi* provide some relevant parameter estimates that can be included current assessment. The recent sampling program results indicated *S. jussieui* was the most important (by weight) species in the purse seine samples, while only very minor catches were obtained in the trawl and gill net sampling programs.

The length-weight relationship is presented in Figure R55. Maximum length and weight for an individual were 14.5 cm FL and 29 g, respectively. No otolith readings were obtained for this species, and therefore all parameter estimates were derived from length-frequency distributions obtained from the purse seine sampling program (conducted quarterly) and additional data from the purse seine fishery, provided by S. F. Leung. The number of robust length-frequency distributions that could be examined was very limited, and therefore the parameter estimates should be considered with caution. Only two (August and November 1996) of the four purse seine sampling trips obtained reasonable samples. Furthermore, of the 24 monthly length-frequency samples (1994-6) provided by S. F. Leung, *S. jussieui* was only adequately represented in four months. The lack of robust samples was likely due to seasonal movements of the fish into, and out of, Hong Kong waters.

Mixture analysis was used to identify, and follow modal size classes in the length-frequency distributions. From this analysis growth was concluded to be rapid from August to September, and to slow down in November. Only one cohort was present in these length-frequency distributions and Z was estimated from the decrease in numbers as over 35, but this was on account of the cohort migrating out of Hong Kong waters.

Estimates of K and L_T are provided in the auximetric plot (Figure R56). Annigeri's (1982) estimate of K for *S. dayi (= S. jussieui*) off India's coast was slightly higher than our estimates, and therefore was not included in the estimate of the means, which were 18.7 cm FL and 0.56 year^{-1}, for L_T and K, respectively (Table R10). An estimate of t_0 equal to -0.3 years was obtained by fitting a von Bertalanffy curve to the age at length estimates obtained from the Mix analysis.

Given these growth parameter estimates, an estimate of M equal to 1.4 year^{-1} was derived, using Pauly's (1980) empirical method. The length-converted catch curve method in FiSAT was used to estimate Z to equal to 2.74 year^{-1}. It was not possible to estimate the instantaneous rate of offshore emigration, G, because no otolith readings were obtained and in any case it is unlikely that systematic offshore migration with size occurs in this migratory pelagic species. Current F is estimated by the difference method as 1.34 and by the catch and biomass method as 1.39, giving a consistent average of 1.37 (Table R12). The probability distribution of $F_{0.1}$ (Figure R59) ranges from 0.9 to 2.1 year^{-1} with a mean of 1.5)0.21 year^{-1}, which includes the present rate, so *Sardinella* is assessed as having a fully exploited status (Table R12).

Sardinella jussieui are first caught in the purse seine fishery at approximately 3-4 cm FL which equates to an age of approximately 0.1 year, using the above growth parameter estimates. The yield-per-recruit surface plot (Figure R57) indicates maximum yield would be obtained at a t_c higher than this The current yield, therefore, is below what could be achieved on average, if the mesh size was increased. When the variability in our estimates of W_T, K and M is considered, the resulting probability distribution of t_{opt} ranges from approximately 0.7 to 1.3 years of age, with a mean of 0.95 years (Figure R58). This is considerably older than the current t_c.

Sardinella average biomass is estimated from the purse seine samples as 2190 tonnes (= 1.2 tonnes km^{-2}, (95% cls; 1.0 – 1.85) with a strong seasonal peak (up to 10,000 tonnes) in August. Unexploited average biomass may be in the same range (Table R13), but the present analysis does not take account of the strong seasonal occurrence pattern.

The reported *Sardinella* catch amounts to almost 9% of the Hong Kong catch at 1024 tonnes (95% confidence limits 677 - 2129 tonnes), equivalent to 0.6 tonnes km^{-2}. Richards (1980) listed *Sardinella* spp as second to *Decapterus* as most important species in Hong Kong's purse seine fishery; our catch figures show that it is now the largest single species caught. About 47% of the catch is made by pair trawls, 35% in the purse seine fishery and 18% by hang trawls, while a small amount (2%) comes from the P4/7 sector. Table R13 suggests that maximum sustainable catch may be a little higher.

Saurida tumbil

Saurida tumbil, known as the greater lizardfish, is a commercially valuable, targeted species in Hong Kong's waters sold for around 5 HK$ per kg.

Length-weight data (Figure R60) indicate the maximum weight of individuals in the samples is about 120g and the maximum size obtained in the sampling program was well below the L_T's reported in the literature, individuals larger than 22 cm FL being rare. Many authors (Table R15) have reported that L_T exceeds 60 cm FL for *S. tumbil*. The reason for the absence of the larger size classes is likely to be either a) not all size classes were adequately sampled, b) large individuals were emigrating out of the sampled area, c) the stock in Hong Kong waters exhibits a much lower L_T compared with others, d) the stock is heavily overfished, or a combination of these.

L_∞ (cm)	K (year−1)	t_0 (year)	Method	Locality	Reference	Ref in Aux. plot
69.5 (TL)	0.286	−0.28	–	East China Sea	Shindo (1972)	11
68.7 (FL)	0.118	−1.40	Sc	Taiwan	Yeh *et al.* (1977)	10
74.2 (FL)	0.104	−1.42	Sc	Taiwan	Yeh *et al.* (1977)	9
83.0 (–)	0.111	–	–	Taiwan	Xu Xucai Zhang Qiyong (1988)	8
63.7 (TL)	0.249	–	LF	India (Bay of Bengal)	Rao (1984)	7
37.5 (TL)	1.03	–	LF	Philippines (Manila Bay)	Corpuz *et al.* (1985)	4
41.0 (FL)	0.7	–	LF	Philippines (Visayan Sea)	Corpuz *et al.* (1985)	3
43.0(FL)	0.64	–	LF	Philippines (Samar Sea)	Corpuz *et al.* (1985)	2
43.6 (TL)	0.431	–	–	Philippines (Manila Bay)	Tiews *et al.* (1972)	1
45.0 (FL)	0.55	–	LF	Philippines (Visayas)	Federizon (1993)	5
53.0 (FL)	0.7	–	LF	Philippines (Ragay Gulf)	Corpuz *et al.* (1985)	6
78.3 (FL)	0.079	−1.79	Sc	Vietnam	Yeh *et al.* (1977)	12
79.5 (FL)	0.096	−1.54	Sc	Vietnam	Yeh *et al.* (1977)	13

Table R15. Summary of growth rate estimates for *Saurida tumbil* obtained from the literature. LF = length frequency. FW = Ford/Walford plot. Ot = otolith annuli. Sc = scale annuli. - = not stated.

Although several sets of growth parameters for *S. tumbil* are reported in the literature (Table R15), some estimates of K are very high, probably because they were derived from warmer regions and are hence unlikely to reflect the growth rates in Hong Kong coastal waters. Mean estimates of K and L_T calculated from the auximetric plot (Figure R61) excluded these high estimates. Similarly, the means also excluded the otolith-based estimates of K and L_T because the they were considered to be affected by emigration and therefore not to reflect adequately the true growth. By including only estimates derived from areas with similar water temperatures to those of Hong Kong, and the length-frequency based estimates, an overall mean K of 0.23 year^{-1} was derived with an associated L_T of 70.3 cm FL. An estimate of t_0 = -0.86 years was obtained fitting a von Bertalanffy growth curve which incorporated the above values of K and L_T (Table R10).

The difference between the otolith-based growth rate estimates and those based on the literature and length-frequency analyses can be attributed to emigration rates. Individuals of age 1+ years experience an instantaneous emigration rate, G = 0.8 year^{-1}, while 2+ year old fish experience an G = 1.8 year^{-1} and 3+ fish, a rate of 3.8. This emigration rate accounts for the lack of large individuals in the samples (Figure R62). By 4 years of age (approximately 28 cm FL) all *S. tumbil* have moved out of the sampling area. The instantaneous rate of natural mortality M, was estimated to be 0.49 year^{-1}. The instantaneous rate of total mortality Z, was approximately 7.7 year^{-1}, based on the cohort slicing method. After losses due to M (0.49 year^{-1}) and G (3.8) are considered, F is estimated by difference as approximately 3.4 year^{-1}. The catch and biomass method gave an F of only 0.1, and so the difference method value was chosen for subsequent analysis (Table R11).

The length at first capture for *S. tumbil* in Hong Kong waters is approximately 5.0 cm FL, which equates to an age of approximately 0.2 years. This is a very small size/age to harvest the lizardfish and is due to the small mesh (1.5 cm) used by the shrimp trawls. The effect of harvesting at this small size is of even more concern when it is considered that this species has the potential to approach an L_T of approximately 70 cm.

Thus, fishing mortality, F, is very high for this species (several times greater than M), while the size at first capture is very small. The three-dimensional yield-per-recruit surface plot (Figure R64 suggests that under the population parameters considered, yield-per-recruit would be maximised by harvesting at a later age of first capture.. When the uncertainty in the population parameters (K, M and W_T) is considered, the optimum age at first capture t_{opt} is estimated as 2.74) 0.31 years (Figure R65). At present S. tumbil is harvested at an age of 0.2 years. When the uncertainty in the population parameters is considered the optimum level of fishing mortality, $F_{0.1}$ is 0.59) 0.08 year^{-1} (Figure R66). Our current estimate of F is several times greater than the upper confidence limit, indicating an overexploited status. At present, the fishery is operating well beyond the optima, therefore resulting in overfishing (Table R12).

Average *Saurida tumbil* biomass is estimated as 32 tonnes (= 0.02 tonnes km^{-2}). Abundance is highest in April (Table R2) and it appears to be absent from October to March. The highest samples were in strata T1, T5, T7 and T9. As the results indicate *S. tumbil* can attain an L_T of 70 cm, and therefore, it is likely to be able to out-swim the prawn trawl. Unexploited biomass may be more than twenty times the current level (Table R13).

The reported catch of *Saurida* amounts to less than 0.01% of the total Hong Kong catch at 0.7 tonnes (95% confidence limits not calculable) equivalent to 0.001 tonnes km^{-2}. Catches of the lizard fish were reported only by shrimp trawlers. The average yield of *S. tumbil* from Hong Kong's waters could be more than quadrupled if the age at first capture t_c was increased, and/or fishing mortality F, was decreased.

Shrimp trawlers catch about 1.5 tonnes of unspecified lizardfish, and P4/7 vessels report catching just under a tonne of undifferentiated. It is possible that, especially juveniles, were confused with this species. Total catch may therefore actually be nearer to 3 tonnes.

Richards (1980) indicates that bulk of the catch was taken during bottom trawling, but it was, however, also an important component of the gill net and purse seine fisheries. Today no catches of this species were reported by any other sector in this survey. Our estimated catch of about 3 tonnes was the smallest of our 17 assessed species, caught almost entirely in the shrimp trawls, and near the bottom of the list of all species caught (Table R8).

Siganus caniculatus

According to Woodland (1990) *Siganus oramin* is a synonym for *Siganus canaliculatus*, commonly referred to as the white-spotted spinefoot or white-spotted rabbitfish. For this reason it will be referred to here as *Siganus canaliculatus*. Results from the recent sampling program indicated it is the most important species in the trawl fishery samples, and second most important in the purse seine samples, in terms of weight. It is sold for around 8 HK$ per kg.

The relationship between length and weight is presented in Figure R67. Maximum weight of individuals in the samples was about 90 g. There was little difference between the trawl and purse seine length-frequency distributions for *S. canaliculatus*; both indicated the incidence of fish larger than 15 cm FL was rare. However, length-frequency analyses were undertaken on the trawl data because they were obtained more frequently (monthly) than purse seine samples (quarterly), and subsequently produced more robust distributions. Additional length-frequency data provided by S.F. Leung of the AFD was also analysed. Otolith readings were also obtained for *S. canaliculatus* and used to estimate growth.

Estimates of L_T for *S. canaliculatus* reported in the literature exceed 25 cm FL (Pauly 1978, Hortsmann 1975, Kitalong and Dalzell 1994). Reasons why the larger size classes were absent from the samples obtained in Hong Kong waters are likely to be the same as those given for *S. tumbil*. It was assumed that these large size classes exist in the populations of *S. canaliculatus* in Hong Kong waters and therefore, von Bertalanffy growth curves were fitted to the size class frequency distributions under this assumption. The resulting growth parameter estimates are presented in the auximetric plot (Figure R68). The mean estimate of L_T was 28.4 cm FL. At this size individuals weigh approximately 290 g (W_T). A von Bertalanffy curve was then fitted to the otolith data using this estimate of L_T, and estimates of K and t_0 derived using solver. The estimate of t_0 was -0.3 years. The resulting otolith-based estimate of K was very close to that obtained from the length-frequency analyses (Figure R68 & Table R10). Because there was reasonable corroboration between the true growth rate estimates and those based on the otoliths, offshore emigration by *S. canaliculatus* out of the area was considered to be minimal (Table R11).

Cohort slicing (average of two cohorts) provided an estimate of the instantaneous rate of total mortality Z = 6.8, and natural mortality M was 0.95 $year^{-1}$ from the growth parameter method. Hence, the instantaneous rate of fishing mortality by the difference method was 6.8 $year^{-1}$, and this was the value chosen for subsequent work as there was no estimate possible from the catch and biomass method (Table R11).

Siganus canaliculatus is a relatively round shaped fish with a low standard length : body depth ratio of 2.8. The mesh size used by fishers in Hong Kong waters is small (1.5 cm) and, as a consequence, the size at first capture is also small. Length at first capture was estimated to be about 4 cm FL, which corresponds to an age of 0.2-0.3 years. The three dimensional yield-per-recruit surface plot for *S. canaliculatus* is presented in Figure R70. When the uncertainty in the population parameters was considered, a probability distribution of t_{opt} was obtained (Figure R71) with a mean of 1.56) 0.14 years. The probability distribution of $F_{0.1}$ is provided in Figure R72, indicating an estimate of 1.13) 0.14 $year^{-1}$. These results indicate that the fishing mortality F is currently too high and the status of the rabbit fish is therefore overexploited. This equilibrium yield-per-recruit analysis suggests that considerable increases in yield, in the order of 100%, could be obtained by increasing t_c and/or decreasing F, provided that recruitment is not affected.

Although *S. canaliculatus* is a demersal herbivore, its significant contribution to the purse seine and pair trawl catches suggests it spends much of its time in the water column. Thus, biomass estimates based on the swept area method and benthic trawl survey are highly likely to underestimate true biomass. The rabbit fish biomass is therefore estimated from an average of the catch method and purse seine samples as 758 tonnes (= 0.42 tonnes km^{-2}), the largest of our assessed demersal species (Table R6). Abundance is high from July to December, and in strata T1, T5 and T9. Unexploited biomass may be more than ten times this amount (Table R13).

The estimated catch of *Siganus* from the interview survey amounts to 6% of the total Hong Kong catch at 877 tonnes (95% confidence limits 192 - 5247 tonnes) equivalent to 0.48 tonnes km^{-2}. The rabbit fish is caught by all seven fishery sectors: about 58% is caught by the P4/7 vessels, 15% by the miscellaneous vessel sector, 13% by the pair trawlers, 11% by the purse seiners, about 2% each by hang trawlers and shrimp trawlers, and a little by the stern trawlers. Maximum sustainable yield of rabbit fish may be twice as great as current catch (Table R13).

In 1980, Richards indicated it contributed significantly to both trawl and purse seine catches, and was the fourth most important species in the purse seine fishery. Today it is in a similar, if not more important, position. It is the second species overall, and top species in the P4/7 sector, second for the purse seine and pair trawls and important for purse seines.

Trachurus japonicus

Trachurus japonicus, also known as the Japanese jack mackerel, is an important fish to all sectors of the Hong Kong fishery and worth about 19 HK$ per kg.

The length-weight relationship is provided in Figure R73. Maximum length and weight of individuals in the samples was 21 cm FL and 133g, respectively. Two of four purse seine sampling trips produced robust samples. Additional length-frequency distributions were obtained from the trawl sampling program data, and the purse seine fishery data, provided by S. F. Leung. These data were combined to produce a single composite series of length-frequency distributions that were then analysed. Distributions from each of three gear types were similar, in that the incidence of individuals larger 12 cm FL in each was rare. Otolith readings provided additional information on growth, although only 22 readings were obtained for this species. Published growth rate estimates by Mukarami and Shindo (1949), Yamada and Kazihara (1955), Mitani and Ida (1964) and Kim et al. (1969) were also included in the auximetric plot (Figure R74), and included in the estimation of mean values of K and L_T. A mean estimate of L_T of 47.4 cm FL was obtained, based on estimates from the length frequency analyses and the literature. This value of L_T was then used to fit a von Bertalanffy curve to the mean length-at-age estimates, obtained from the otolith data. The resulting estimates of K and t_0 were 0.092 year^{-1} and -0.25 years, respectively. Again, the otolith-derived estimate of K was well below all other estimates and therefore not included in the estimation of the means. Mean values for L_T and K were 47.4 cm FL and 0.33 year^{-1}, respectively (Table R10 shows 95% confidence limits).

Given the above growth parameter values, the estimate of M was 0.7 year^{-1}., The estimate of Z at 11.7 by cohort slicing is extremely high (three portions of history of possibly the same cohort: Figure R75), as might be expected by the disparity between the maximum size of individuals in the samples (approximately 12 cm FL) and L_T (47.4 cm FL). Emigration rates G (Figure R76) therefore ranged between 2.7 year^{-1} for fish aged 1+ years, to 5.5 year^{-1} for fish aged 2+ years. After the effects of M and G are considered, F is still extremely high at 5.5 (Table R11).

The length at first capture was estimated to be approximately 3 cm FL, which equates to a t_c of approximately 0.1 years. The yield-per-recruit surface plot (Figure R77) indicates maximum yield would be obtained by harvesting at a t_c greater than this. When the uncertainty in the population parameter estimates for W_T, K and M are considered, a probability distribution of t_{opt} was obtained (Figure R78) with a mean 2.3) 0.2 years. The probability distribution of $F_{0.1}$ (Figure R79) had a mean of 0.84) 0.11 year^{-1}, the upper confidence limit of which is about one third of the current level of fishing mortality. Thus, both the current t_c and F greatly exceed the optimums indicated by our analyses and indicate that*T. japonicus* has an overexploited status in Hong Kong waters (Table R12).

Trachurus biomass is estimated from a consistent average (Table R6) of the catch method and the purse seine samples as 286 tonnes (= 0.2 tonnes km^{-2}), with a strong peak in May and a lesser one in February, the same seasonal pattern as *Engraulis*. Unexploited biomass may be more than 10 times as large (Table R13).

The estimated catch of *Trachurus* amounts to 335 tonnes (95% confidence limits 105 - 2516 tonnes) equivalent to 0.16 tonnes km^{-2} and almost 3% of the total Hong Kong catch. *Trachurus* is caught by all sectors of Hong Kong's fisheries, over half (55%) in purse seines, a quarter (23%) in pair trawls, about 10% in each of stern trawlers and hang trawlers, and a little (0.4%) in shrimp trawls. Sustainable yield may be 3 times as great (Table R13). Interestingly, Richard's (1980) report does not list it as a component of Hong Kong's purse seine fishery landings, but today it comprises the eighth largest catch overall, and third largest for the both the hang trawl and stern trawl sectors.

Trichiurus lepterus

According to Nakamura and Parin (1993) the species of *Trichiurus* reported in Hong Kong waters is *Trichiurus lepterus*. We have therefore calculated the population parameter estimates and carried out the assessment on the assumption that this species is *T. lepterus*, commonly known as the largehead hairtail. *Trichiurus lepterus* was the fourth most important fish species (by weight) in the purse seine sampling program. Catches in the trawl and gill net samples were very small. It is important to all sectors of the Hong Kong fishery and is worth about 11 HK$ per kg.

L_∞ cm TL	K Year^{-1}	t_0 year	Method	Locality	Reference	Ref. in Aux.plot
98.0	0.200	–	–	India	Banerji & Krishnan (1973)	1
145.4	0.290	–	FW	India	Narasimham (1976)	2
43.4	0.298	–	FW	Japan	Pauly (1978)	3
45.4	0.411	–	Ot	Japan	Pauly (1978)	3

50.5	0.286	–	Ot	Japan	Pauly (1978)	3
147.0	0.296	–0.46	Ot	Mauritania	Pauly (1978)	3
64.5	0.410	–	El	Philippines	Ingles and Pauly (1984)	4
66.0	0.460	–	El	Philippines	Ingles and Pauly (1984)	4
78.0	0.700	–	El	Philippines	Ingles and Pauly (1984)	4
146.8	0.292	–	–	South Africa	Torres (1991)	5
129.0	0.271	–0.22	FW	Taiwan, East coast	Chen and Lee (1982)	6
131.0	0.340	–0.39	Ot	Taiwan, Southwest coast	Chen and Lee (1982)	6
133.0	0.289	–0.76	Ot	Taiwan, Southwest coast	Chen and Lee (1982)	6
151.0	0.250	–0.08	Ot	Taiwan, East coast	Chen and Lee (1982)	6
109.0	0.640	–	–	India	Somvanshi & Joseph (1989)	7
129.7	0.503	–	–	India	Chakraborty (1990)	8

Table R16. Published estimates of von Bertalanffy growth parameters for *Trichiurus lepterus*. LF = length frequency. FW = Ford/Walford plot. Ot = otolith annuli. Sc = scale annuli. El = Elefan.

The length-weight relationship is provided in (Figure R80). Maximum length and weight of an individual in the samples was 71cm TL and 232g, respectively. Although it contributed significantly to the weight of the purse seine samples, the number of length-frequency observations obtained from the purse seine samples was very low. Length-frequency analyses were therefore carried out using the trawl sampling data and data provided by S. F. Leung. Otolith readings provided additional information on growth. Several growth rate estimates have been published (Table R16) and were included in the auximetric plot (Figure R81) and estimation of mean values of K and L_T. The otolith-derived estimate of K was well below all other estimates and was therefore excluded from the estimation of means. Mean values for K and L_T were 155cm TL and 0.32 $year^{-1}$, respectively. The estimate of t_0, obtained by fitting a growth curve to the otolith readings, was 0 years (Table R10). *Trichiurus lepterus* is long and slender with a high standard body length:body depth ratio. The length at first capture was therefore relatively long, at approximately 9 cm TL, which corresponds to a t_c of approximately 0.2 years, given the above growth parameter estimates.

Natural mortality rate, M, was estimated to be 0.49 $year^{-1}$. The Instantaneous rates of emigration G (Figure R81) varied with age, from 0.60 $year^{-1}$ at 0+ years, to 2.83 $year^{-1}$ at 1+ years, to 4.72 $year^{-1}$ at 2+ years. The Hong Kong fishery catches most fish in their first 1.0-1.5 years of age and by approximately two years of age (approximately 70 cm TL) most individuals have migrated to offshore waters. Z was estimated as 7.5 from cohort slicing (two cohorts: Figure R82). F by the difference method was 2.3 and 1.1 from the biomass and catch method 5.4, hence the average F = 3.9 was employed (Table R11).

The yield-per-recruit surface plot (Figure R83) indicates maximum yield would be obtained by harvesting at a t_c more than the current 0.2 years. When the uncertainty in the population parameter estimates was considered, a probability distribution of t_{opt} was obtained (Figure R84) with a mean of 3.26) 0.24 years. Its noteworthy that this optimum age at first capture is more than 10 times older than the current t_c. The probability distribution of $F_{0.1}$ (Figure R85) indicates the optimum level of fishing mortality is 0.64) 0.08 $year^{-1}$, the upper confidence limit of which is 4 times lower than the current F. The stock is therefore assessed as being heavily over exploited (Table R12).

Average *Trichiurus* biomass is estimated as 300 tonnes (= 0.2 tonnes km^{-2}), as a consistent average of the total estimated by the catch method and from the purse seine samples. Abundance exhibits a broad seasonal peak from August to February, with a maximum in November. Unexploited biomass may be very much larger than current levels.

The reported catch of *Trichiurus* amounts to just over 2% of the total Hong Kong catch at 275 tonnes (95% confidence limits 149 to 998 tonnes) equivalent to 0.15 tonnes km^{-2}. About 45 % of this is made by the hang trawl sector, with about 34% by the pair trawlers, 9% by the shrimp trawlers and small amounts in all other sectors. Maximum sustainable yields may be five times as great as current catch (Table R13). *Trichiurus* spp. was the 17th most important species (by weight) in the purse seine fishery according to Richards (1980). Our figures suggest that it is 3rd most important species in the hang trawlers, 5th in the pair trawls, 6th in the shrimp trawls, but of very little importance in the purse seine fishery (approx 22nd in rank order).

Oratosquilla anomala

The mantis shrimp, *Oratosquilla anomala* is an important targeted species in Hong Kong's fishery. Market prices range from approximately 50-70 $HK per kg for large specimens and about 26 HK$ per kg for small shrimp. *Oratosquilla anomala* was the most important invertebrate species (by weight) in the trawl samples (second to the rabbitfish, *S. canaliculatus*). Minor catches were also taken in the gill net samples. There was no record of catch in the interview survey of fishers specifically for *O. anomala*, but we have taken the category of ORASPP to refer to this species since interviewees distinguished *Oratosquilla oratoria*., the only other species recorded.

No statoliths were obtained for any of the invertebrate species. All growth, and other population parameter estimates, were therefore derived from length frequency analyses and published reports. Also, the additional data provided by S.F Leung pertained only to commercially important fish in the purse seine fishery. Thus, the only source of robust length frequency data used to assess the invertebrates was from the trawl survey. The length-weight relationships for female and male *O. anomala* are graphed in Figure R86. Maximum length and weight of a female was 16.4cm TL and 51g, respectively. Maximum length and weight for a male was 16.3cm TL and 47g, respectively. Estimates of K and L_T are presented for both sexes in the auximetric plot (Figure R86). There were no significant differences between the growth of mantis shrimp sexes, so they were combined for subsequent analysis. A single estimate of t_0 equal to -0.16 years was obtained from the Elefan module in LFDA, and incorporated in the description of growth (Table R10).

We used a single guessed estimate of M equal to 3.0 year^{-1} for both sexes. Estimates of Z, based on cohort slicing, was 5.83 year^{-1} (Figure R87). Offshore migration was assumed to be negligible. By the difference method, F = 2.8 (one of two cohorts: Table R11). It is difficult to estimate the size at first capture for *O. anomala*. We could not use Pauly's (1984) nomogram for estimating the size at first capture for fish, and we had no data with which to devise a method similar to that we have used for prawns. In the trawl samples individual *O. anomala* as small as 3.5 cm TL were retained. However, there were very few of these individuals, possibly because most past through the nets. We therefore estimated the approximate size at first capture for the mantis shrimps to be 5.0 cm TL, which, using the above growth parameter estimates, corresponds approximately to an age of 0.2 years. (Note: in the multispecies analysis below we have used a prawn relationship derived from the literature.)

The yield-per-recruit surface plot (Figure R88) indicates maximum yield would be achieved by harvesting at a t_c of 0.4 years - about twice the current age at first capture. When the uncertainty in the parameter estimates of K, M and W_T were considered (for both sexes), a probability distribution of t_{opt} was obtained (Figure R89) with a mean of 0.39) 0.04 years. The mean of the probability distribution for $F_{0.1}$ was 3.38) 0.49 year^{-1} (Figure R90). Confidence limits on this optimum level of fishing mortality contains the current level, and so the status of this species is assessed as fully exploited (Table R12).

The estimated catch of *Oratosquilla anomala* amounts to under 1% of the total Hong Kong catch at 89 tonnes (95% confidence limits 26 - 315 tonnes) equivalent to 0.05 tonnes km^{-2}. Nearly 95% are caught in the shrimp trawls, with small amounts reported by the stern trawlers (3.8%) and miscellaneous vessels (2.1%).

O. anomala biomass is estimated as 36 tonnes (= 0.02 tonnes km^{-2}), is present throughout the year, peaking in August, and is most abundant in strata T5 through T15. Unexploited biomass (Table R13) is likely to be only about twice current levels, although MSY could be about twice present catch, mainly to be achieved by altering mesh size.

Oratosquilla oratoria

Oratosquilla oratoria, also known as the Japanese mantis shrimp, contributes significantly to Hong Kong's commercial fishery with prices effectively the same as *O. anomala*. Results from the sampling program indicate it was the third most important invertebrate in the trawl samples. Relatively small amounts were also caught in the gill net sampling. The population dynamics of this species have received more attention than those of *O. anomala*, particularly in Japan (Hamono and Morrisy 1992, Ohtomi and Shimizu 1994).

The length-weight relationship for females and males is presented in Figure R91. Maximum length and weight for a female was 17.3 cm TL and 44.8 g, and for a male was 14.3 cm TL and 32.2 g, respectively. Growth parameter estimates obtained from length-frequency analyses and the literature are provided for both sexes in the auximetric plot (Figure R92). Mean values of K and L_T for females were 19.5 cm TL and 0.692 year^{-1} while means for the males were not significantly different at 18.4 cm TL and 0.748 year^{-1}. Mantis shrimp sexes have therefore been combined for further analysis (although the ypr uses joint values using both sexes). An estimate of t_0 equal to -0.16 was used for both sexes and obtained from the Elefan table of estimates of t_0 routine in LFDA (Table R10).

The estimate of M was the same as that used for *O. anomala* (3.0 year^{-1}). Z was estimated from cohort slicing (one of two cohorts for both sexes – Figure R93) as 5.5. Again, offshore migration with age in the mantis shrimps was assumed to be negligible. Thus, F was estimated to be 2.5 year^{-1} by the difference method (Table R11). The catch and biomass method gave a high value of 5.8.

Given the similar morphology to *O. anomala*, the size at recruitment was also assumed to be 5.0 cm TL, which corresponds to a t_c of approximately 0.2 years. The yield-per-recruit surface plot (Figure R94) indicates maximum yield would be achieved by harvesting at a t_c higher than this. When the uncertainty in the population parameter estimates was considered, a probability distribution of t_{opt} was obtained (Figure R95) with a mean of 0.46) 0.4 years. This optimum is slightly more conservative than the estimate of t_c associated with maximum yield in the surface plot, and the lower confidence limit only slightly older than the current size at first capture. When the uncertainty in the population parameter estimates was considered on the optimum level of fishing mortality, a probability distribution of $F_{0.1}$ (Figure R96) was obtained with a mean of 2.64)0.49 year^{-1}. Confidence limits on this optimum level of fishing mortality contains the current level, and so this species is assessed as fully exploited (Table R12).

O. oratoria biomass is estimated as 40 tonnes (= 0.02 tonnes km^{-2}), is present throughout the year, peaking from June to August, and is commonest in strata T1 to T9. It therefore appears to be partially spatially and seasonally separated from the other mantis shrimp species.

The reported catch of this mantis shrimp amounts to under 1% of the total Hong Kong catch at 27 tonnes (95% confidence limits 6 - 130 tonnes) equivalent to 0.015 tonnes km^{-2}. Nearly 95% are caught in the shrimp trawls, with small amounts reported by the stern trawlers (3.8%) and miscellaneous vessels (2.1%). Sustainable yield is unlikely to be much more than twice the present catch (Table R13).

Metapenaeopsis palmensis

Metapenaeopsis palmensis , the velvet prawn, was the most important (by weight) penaeid prawn in the trawl samples, and the second most important invertebrate. Penaeids demand high market prices in Hong Kong (HK$ 26-75 kg^{-1}) and are targeted by trawlers. Very minor catches were also obtained in the gill net samples. Sommai & Thubthinmsang (1988) have assessed this species in the Gulf of Thailand. Watson and Keating (1989) have published on Torres Straight velvet prawns.

Male and female prawns of the same species generally display differences in growth rate, L_T, W_T, mortality rates (Z and M), and length-weight relationships. We therefore calculated these parameters separately for each sex. All yield-per-recruit assessments, estimates of t_{opt} and optimal $F_{0.1}$ were obtained by pooling the results for each sex, after the analyses were carried out separately. The length-weight relationship for females and males is presented in Figure R97. Maximum length and weight for a female was 27.5 mm CL and 14.2 g, and for a male was 22.1 mm CL and 10.6 g, respectively. Growth parameter estimates obtained from length-frequency analyses are provided for both sexes in the auximetric plot (Figure R98). Mean values of K and L_T for females were 25.6 mm CL and 1.61 year^{-1}. Means for the males were 18.5 mm CL and 2.22 year^{-1}. These maximum asymptotic lengths are consistent with the maximum sizes in samples of *M. palmensis* obtained by Watson and Keating (1989) in Torres Strait, northern Australia. The t_0 was estimated to be -0.25 for both sexes, based on the SLCA estimate of t_0 in LFDA (Table R10).

No attempt was made throughout the course of the study to quantify M for the penaeid prawns and therefore we have used an estimate of 3.6 year^{-1}, based on several published reports (Lucas et al. 1979, Garcia and Le Reste 1981, Glaister et al. 1990, Dredge 1990, Somers 1990). Z was estimated from cohort slicing (one of two cohorts for both sexes: Figure R99) as 12.1 year^{-1}. Offshore migration rate with size for the penaeid prawns was assumed to be negligible. Thus, F was estimated to be 4.5 year^{-1}. By averaging with the value from the catch and biomass method (Table R11).

Given the small size of the trawl mesh (1.5 cm), we estimated the length at first capture using the method outlined above to be approximately 14 mm CL, which equates to a t_c of 0.25 years. The yield-per-recruit surface plot (Figure R100) indicates maximum yield would be achieved by harvesting at a very young t_c of approximately 0.15 years. This is because the prawns are very fast growing and have high natural mortality rates. When the uncertainty in the population parameter estimates was considered for both sexes, a probability distribution of t_{opt} was obtained (Figure R101) with a mean of 0.13) 0.03 years. When the uncertainty in the population parameter estimates was considered on the optimum level of fishing mortality, a probability distribution of $F_{0.1}$ (Figure R102) was obtained with a mean of 3.93) 0.56 year^{-1}. Current F is just inside these confidence limits and therefore the species is assessed as fully exploited (Table R12).

Biomass estimates were derived using the swept area method and the trawl sampling data. Penaeid prawns are largely nocturnal, and therefore, biomass estimates derived from the trawl sampling program, which was conducted during daylight, were likely to be biased downwards. In order to compensate for this, the estimates were doubled, based on results from a limited number of day-night trawl comparisons. *M. palmensis* biomass calculated in this way is 91 tonnes (= 0.05 tonnes km^{-2}), is present throughout the year, peaking from March to May, and is most abundant in strata T1 through T12. Unexploited biomass may be about twice the present levels (Table R13).

The reported catch of this prawn amounts to 10 tonnes (95% confidence limits 2 – 45 tonnes) equivalent to 0.006 tonnes km^{-2}, under 0.5% of the total Hong Kong catch. Over 95% is caught in the shrimp trawls, with small amounts (3.8%) reported from stern trawls. Catch reports may well be confused with the other prawn species. Maximum sustainable yield maybe ten times the present level (Table R13).

Metapenaeopsis barbata

Metapenaeopsis barbata, the whiskered velvet prawn, was the second most important penaeid prawn (by weight) in the trawl samples. Its population dynamics have received scant attention from researchers.

The length-weight relationship for females and males is presented in Figure R103. Maximum length and weight for a female was 21.1mm CL and 9.7g, and for a male was 18.7mm CL and 5.9g, respectively. Growth parameter estimates obtained from length-frequency analyses are provided for both sexes in the auximetric plot (Figure R104). Mean values of K and L_T for females were 24.4 mm CL and 1.79 year^{-1}. Means for the males were 20.0 mm CL and 1.94 year^{-1}. t_0 was estimated to be -0.08 for both sexes, based on the Elefan table of t_0 values in LFDA. Length at first capture was assumed to be the same as that for *M. palmensis* (14 mm CL), which, using the above growth rate parameters, equates to a t_c of 0.25 years (Table R10).

We used the same estimate of M as that for *M. palmensis* (3.6 year^{-1}). The cohort slicing estimate of Z was 10 year^{-1} (Two cohorts for both sexes: Figure R105). Thus, F was estimated to be 6.4 by the difference method (Table R11).

The yield-per-recruit surface plot (Figure R106) indicates maximum yield would be achieved by harvesting at a t_c of approximately 0.35 years. When the uncertainty in the population parameter estimates was considered for both sexes, a probability distribution of t_{opt} was obtained (Figure R107) with a mean of 0.31) 0.03 years, slightly younger than that indicated in the surface plot. When the uncertainty in the population parameter estimates was considered on the optimum level of fishing mortality, a probability distribution of $F_{0.1}$ (Figure R108) was obtained with a mean of 3.52) 0.44 year^{-1}. Since the current F is within the 95% confidence levels for F01, the species is assessed as fully exploited (Table R12).

M. barbata biomass (Table R6) is estimated from the shrimp trawl samples as 36 tonnes (= 0.011 tonnes km^{-2}), is most abundant from June to September, and is found in strata T5 to T18. This species was absent from many combinations of sampling times and stations. Unexploited biomass (Table R13) may be slightly larger than the present value.

The reported catch of this prawn amounts to under 0.1% of the total Hong Kong catch at 47 tonnes (95% confidence limits 11 - 233 tonnes) equivalent to 0.03 tonnes km^{-2}. It is reported exclusively by the shrimp trawlers. Maximum sustainable yield is not likely to be much larger than the present reported catch (Table R13), but catch reports may well be confused with the other prawn species. The prawn catch as whole should be subjected to further detailed assessment.

MULTI-SPECIES BIO-ECONOMIC ASSESSMENT

This analysis is necessarily confined to the trawl fishery, relative species biomass values were apportioned according to estimated catch in the trawl fishery. Relative recruitment factors were calculated by dividing total biomass by biomass-per-recruit values: results are listed in Table R17. Prawns, mantis shrimp, ponyfish, rabbitfish, Bombay duck and *Collichthys* contribute most to the recruitment. Note that this form of equilibrium analysis assumes that recruitment remains the same over all biomass levels to which the stocks are depleted by harvest. Prices we have used are also listed in Table R17, obtained from ERM; threshold values for premium prices are largely guesswork, roughly based on market stalls in Lantau markets.

Relative weightings of the species from column 2 in Table R17 above, and from combining these values with the base price in column 3, are illustrated in Figure R109a. The final value-per-recruit (VPR) surface, plotted against mesh size and fishing mortality, is shown from two perspectives in Figure R109b. (VPR surfaces for all 21 individual analyses may be found in the file *vmultivpr.xls*.).

The VPR surface (Fig 109b) exhibits a ridged summit at low F (1 to 1.25), peaking at a mesh size of 3cm, and, at 90 degrees, a narrow ridge running up to higher F values. A second region of high VPR, separated by a trough, occurs at large meshes of 8-10 cm over a broad set of F values. The peaks in the VPR surface may be compared to the present location of the fishery, at 0.5cm mesh size and F in the region of 3 to 4, indicated on the plotted surface by red arrows. 95% confidence limits on optimal mesh size were from 2.75 to 3.25 as determined by the Monte Carlo simulation. $F_{0.1}$ for this mesh size was 0.6, with 95% confidence limits from 0.54 to 0.69.

The VPR surface (Fig 109b) exhibits a ridged summit at low F (1 to 1.25), peaking at a mesh size of 3cm, and, at 90 degrees, a narrow ridge running up to higher F values. A second region of high VPR, separated by a trough, occurs at large meshes of 8-10 cm over a broad set of F values. The peaks in the VPR surface maybe compared to the present location, at 0.5cm mesh size and F in the region of 3 to 4, indicated on the plotted surface by red arrows. 95% confidence limits on optimal mesh size

were from 2.75 to 3.25 as determined by the Monte Carlo simulation. $F_{0.1}$ for this mesh size was 0.6, with 95% confidence limits from 0.54 to 0.69.

Species	relative recruitment Factor	base price *HK$/kg*	price threshold *cm*	premium price *HK$*
Alepes	0.0606	4.75	18.5	4.8
Apogon	0.0568	8.09	12.5	8.1
Collichthys	0.0146	24.07	21.8	24.1
Decapterus	0.0627	4.75	25.6	4.8
Engraulis	0.0172	20.49	18.6	20.5
Harpadon	0.0343	8.09	35.3	8.1
Johnius	0.0104	24.07	30	36.1
Leiognathus	0.0836	8.09	13.9	8.1
Sardinella	0.0120	14.89	18.7	14.9
Saurida	0.0116	4.86	50	7.3
Siganus	0.0691	8.09	28.4	8.1
Trachurus	0.0086	19.07	40	28.6
Trichiurus	0.0109	11.24	100	16.9
O'squilla o.	0.0706	26	12	74.7
O'squilla a.	0.0635	26	12	74.7
Met. Palm.	0.2164	26	12	74.7
Met. Bar.	0.1969	26	12	74.7

Table R17. Relative recruitment factors and prices for 17 Hong Kong species used in the multispecies trawl fishery assessment. Sexes of invertebrates were considered separately in the analysis. Relative recruitment factors calculated from biomass per recruit and estimated biomass (see text). Price information from June 1997. Premium prices largely by guesswork.

There are two major conclusions. First, even at the present F, the prawn fishery itself could reduce growth overfishing and gain about 50% more long-term average yield by increasing mesh from the present 0.5cm to about 3cm. Secondly, economic value can be maximised, approaching double the present value, by reducing F to allow optimal harvest of the fish species in the catch as well as the prawns. The high VPR area at very high mesh sizes represents harvesting delayed until we reach the t_{opt} plateaus for the larger, slower growing fish in the analysis such as the Bombay duck, lizard fish and croakers, but in present circumstances this region is likely not a practical option.

We determined the robustness of the shape of the VPR surface in an additional way by examining the effects of eliminating various species and groups from the analysis. The ridge shape remained when we eliminated the three major pelagic species, *Sardinella* and *Engraulis* and *Decapterus*, either singly or in combination. Eliminating both groups of invertebrates removed the ridge extending to high F values. Eliminating *Siganus* flattened out the surface, but the peak was located in the roughly the same position.

So, although we have to urge caution in the precise interpretation of these results, as only 17 of 141 species have been included and some input parameters to the analysis might be better estimated, our general conclusion remains robust. This analysis suggests that, in the long term, the average value of Hong Kong's trawl fisheries might be increased, perhaps doubled, by increasing mesh size.

The ridged peak VPR itself is quite broad at low F because the present Hong Kong catch is dominated by small fast-growing fish and invertebrates. The peak gets narrower as F increases, largely on account of the prawns and mantis shrimps. If mesh size were to increase, the relative recruitment values assumed constant in this analysis, would, in fact, alter as the stocks of larger, slower-growing, but high-value table fish recovered as their juveniles would be no longer caught so heavily. The species composition of Hong Kong waters could be expected to shift in favour of such species: perhaps in part restoring the former inshore ecosystem. Unfortunately, there is no way to use this type of equilibrium analysis to predict quantitatively what might happen. The VPR surface always be strongly influenced by the necessity of having a fishery for the valuable fast growing prawns, and this would likely set limits on the degree of restoration that might be possible without closing areas to trawl fishing. It is hoped that these issues might be explored in future analyses which have less uncertainty in the catch and biomass data.

Comparisons with other multispecies trawl fisheries in the region are provided in Table R17, adapted from a similar table in Pauly (1988). Most of these studies involve far more species than was possible here, and have produced a single optimum mesh size of between 4.5 and 7 cm, greater than the mesh currently in use (usually less than 2cm). Pauly therefore considers 2cm or less mesh nets to lead to considerable growth overfishing.

Area/Country	No. of Species (groups) incl. in Analysis	Optimum cod-end mesh size (cm)	Sources and Remarks
Southern South China Sea	44	4.5 - 5.5	Sinoda *et al.* (1979), based on original method derived from Jones (1976). Results apply to landed weights and values.
Inner Gulf of Thailand	51	4.5 - 5.5	Meemeskul (1979), based on Sinoda *et al.* (1979).
San Miguel Bay, Philippines	16, incl. penaeids	5.3 - 5.4	Smith *et al.* (1983), using method of Sinoda *et al.* (1979); based on landed weight or value.
Northwest Shelf of Australia*	35	5.5 - 7.0	Sainsbury (1984) using original method.
Hong Kong	17, incl. penaeids	3.0	This study, landed value.

Table R18. Optimum mesh size for the cod-end of Southeast Asian trawlers as estimated using multispecies methods. In all cases the present mesh size is 2cm or less. * Taiwan-based trawlers operating off northern Australia are required to use larger mesh size than trawlers operating in Southeast Asia (i.e., 6 cm).

In contrast, in Hong Kong waters, the ridged, almost bimodal value-per-recruit surface suggests that we may be seeing an even more drastic consequence of chronic overfishing. Fish are so heavily depleted by fishing, and the increasingly pelagic fish species left are of such low value, that the high-value prawn fishery nets tend to produce a clear peak at high F, as well a second peak at lower F and higher mesh for the higher value fish that are left in the system. Even these are not the traditional high value demersals (there are virtually no large demersal fish in the present day, as reflected in our ecosystem model), but comprise faster growing smaller representatives of each taxa (e.g. the smaller faster growing croakers and groupers).

ECOSYSTEM ANALYSIS

Two separate ecosystems can be identified in the coastal waters surrounding Hong Kong; an estuarine system in the west, influenced predominantly by the Pearl River, and an oceanic ecosystem in the east. However, for this report, and in order to examine the effects of varying fishing effort, a single model was constructed and incorporated in the ECOSIM simulations.

Fifteen trophic groups were identified, based on the current sampling program and available literature: phytoplankton, zooplankton, zoobenthos (comprised mainly of meiobenthos), benthic crustacea, benthic molluscs, penaeid prawns, cephalopods (squids and octopus), elasmobranchs (small sharks and rays), estuarine pelagic fish, oceanic pelagic fish, small demersal fish, medium demersal fish, migratory demersal, fish marine mammals (dolphins and porpoises) and detritus. The two pelagic fish groups were distinguished so that later models on the East and West areas of Hong Kong could be drawn up. Full details of the composition of these groups is given below.

The production to biomass ratio (*P/B*), is equivalent to the instantaneous rate of total mortality, *Z* (Allen 1971). Estimates of *P/B* used in the model were therefore based on estimates of *Z* that were obtained from the assessments. For species that were poorly represented in the sampling program, estimates of *Z* or *P/B* were either obtained from the literature or derived by ECOPATH.

Biomass (*B*) estimates were derived from the values in the stock assessments above or from major categories analysed from the catch method. For those groups whose biomass could not be calculated using survey data (i.e., phytoplankton, zooplankton, marine mammals) estimates of *B* were either obtained from the literature, or derived by ECOPATH during the model-balancing procedure. We used biomass estimates from the catch method for the trophic groups. Catch estimates, including that for the P4/7 gear sector, became available after the first draft of this report, and have been employed extensively in this revision of the model. Both of these values are subject to considerable uncertainty on account of the interview protocol.

Parameters input to the model, and those estimated by ECOPATH, are listed in Table EC2.

Assembly of trophic groups

Phytoplankton and zooplankton

Phytoplankton and zooplankton estimates of *B* and *P/B* were obtained from the literature, notably Nguyen (1989), with estimates from Vietnam coastal waters and Plyakarnchana (1989) and Aryuthaka (1991) from the Gulf of Thailand. ECOPATH assumes that 0.2 of the food consumed by each trophic group is not assimilated, but rather passes as urine or faeces to the detritus. The fraction is higher for herbivores and therefore a value of 0.3 was used for zooplankton (Christensen and Pauly 1996).

Zoobenthos

The small zoobenthos groups is comprised of several taxa of small macrobenthos and meiobenthos which typically include: Foraminifera, Nematoda, Harpaticoida, Ostracoida, Turbellaria, Copepoda, Ciliata, Gnathostomulida, Gastrotricha, Polychaeta, Oligochaeta, Kinorhyncha, Mystacocarida, Cephalocarida, Tanaidacea, Bryozoea, Cnidaria, Sepunculidae, Nermertini and Tardigrada (Sarma and Wilsanand 1994, Thompson *et al.* 1980, Shin and Thompson 1982). From the commercial catch we unidentified only sea urchins.

Zoobenthos composition varies and depends upon habitat type. For example, the mangrove system along the east coast of India has 11 major taxa in the zoobenthos with nematodes as the dominant group. In salt marshes, the composition differs; harpaticoid copepod density is two times higher than in mangroves (Sarma and Wilsanand 1994). In the Arabian Sea, zoobenthos in sea grass meadows has 4 distinct groups of taxa, also dominated by nematodes and copepods. Metazoan meiofauna eat bacteria, microalgae, protozoa, detritus and meiofauna. Nematodes and harpaticoids feed on microalgae. In deep waters (> 100 m) the zoobenthos feeds mainly on fresh detritus. Predator nematodes also derive a substantial portion of their diet from metazoa while some polychaetes feed on nematodes and copepods (Kennedy 1994). A summary of some published zoobenthos biomass estimates are presented in Table EC1.

Location	Biomass (t km^{-2})	Source
Norway	0.38	Jensen *et al.* (1988)
Malaysia	3.6	Van Dam *et al.* (1993)
“	0.7	Delos-Reyes (1993)
Philippines	7	"
Lake Israel	5	Walline *et al.* (1993)
Uganda	10.8	Moreau *et al.* (1993)
France	18.6	Palomares *et al.* (1993)
Mexico	10.8	Abarca-Arenas (1993)
Mexico	32.7	Chavez *et al.* (1993)
“	0.0007	Pfannkuche (1993)
“	65	"
“	41	"
Mexico	7	De la Cruz-Arguero (1993)
France	13.1	Palomares *et al.* (1993)
South China Sea	4.173	Silvestre *et al.* (1993)
California	1.5	Olivieri *et al.* (1993)
South China Sea	5	Pauly *et al.* (1993)
	Mean = 13.3	

Table EC1. Published zoobenthos (comprised mainly of meiobenthos) biomass estimates. All estimates have been converted to standard units.

Eighty-three species were identified in the zoobenthos of Tolo Harbor/Channel (Thompson and Horikoshi 1980, Thompson *et al.* 1980). Bivalve molluscs (65%) dominated the benthos. A number of studies indicate that the diversity and biomass of Hong Kong's coastal zoobenthos are affected by pollutants (Ka-ling and Wan-Young 1980, Shin and Thompson 1982, Wu 1988). Hong Kong harbour is reported (Huang and Mak 1980) as full of serpulid worms, particularly *Hydroides elegans*. Shin and Thompson (1982) undertook a comprehensive study of the faunal benthos in Hong Kong's coastal waters. The mean biomass (converted to t km^2) for all sampling stations was (35.2 t·km^2), which is high compared with studies undertaken elsewhere (Table EC1), probably because Shin and Thompson included heavily polluted and disturbed stations located in Victoria Harbour, that had a very high mean faunal biomass (155.2 t·km^2). Nevertheless, Shin and Thompson's (1982) study was very comprehensive and their estimate of the mean has been included in the ECOPATH model. The *P/B* ratio for the zoobenthos was 4.0, consistent with values reported in Greze (1978).

Benthic crustacea

Species constituting the benthic crustacea functional group include *Scylla* (mangrove crab), crabs *Portunus pelagicus, P. sanguinolentus* and *Portunus trituberculatus, Palinurus* (spiny lobster), *Charybdis cruciata, C. natator,* mantis shrimps *Harpiosquilla harpax, Dictyosquilla foveolata, Oratosquilla anomala, O. nepa, O. oratoria.* A *P/B* ratio of 3.7 year was derived by ECOPATH, which is generally consistent with estimates used elsewhere (Christensen and Pauly 1993).

Benthic molluscs

This group comprises Arcidae (*Anadara*, cockle), Buccinidae (*Babylonia*, whelk), and Veneridae (*Tapes*, clam).

Penaeid prawns

The main species are *Metapenaeopsis palmensis, Metapenaeopsis barbata, Parapenaeopsis, Metapenaeus affinis, Metapenaeus ensis, Metapenaeus joyneri, Solenocera crassicornis* (mud shrimp)*, Penaeus penicillatus, Penaeus monodon, Penaeus merguiensis* and *Penaeus latisulcatus* and the Sergestidae including *Actes japonica*, silver shrimp. Obtaining a robust estimate of biomass is complicated by the fact that many of these species are nocturnal and yet the trawl samples were obtained during daylight. As described above, a correction factor (x2) was used from the limited number of night-time trawl samples. ECOPATH derived a value of *P/B* for the penaeids to be 3.4 year, which is generally consistent with estimates in the literature, and very similar to the values in our assessments. Dietary composition of the prawns was based on the work of Liao and Su (1984).

Cephalopods

This group includes octopus, all Loliginidae (*Loligo edulis*, *Loligo* sp. *Sepioteuthis lessoniana*); squids, Pinnidae (*P. bicolor,* fan mussel), cuttlefish Sepiidae (*Sepia pharaonis*, and other *Sepia* spp.).

Elasmobranchs

The sharks reported from Hong Kong waters (Compagno 1994a, 1994b, Chan and Tseng 1980) are gray bambooshark (*Chiloscyllium griseum*), whitespotted bambooshark (*Chiloscyllium plagiosum*), Japanese wobbegong (*Orectolobus japonicus*), whale shark (*Rhincodon typus*), graceful shark (*Carcharhinus amblyrhynchoides*), hooktooth shark (*Chaenogaleus macrostoma*), snaggletooth shark (*Hemipristis elongatus*), straight-tooth weasel shark (*Paragaleus tengi*), pygmy ribbontail catshark (*Eridacnis radcliffei*), coral catshark *(Atelomycterus marmoratus*), great white shark (*Carcharodon carcharias*), blackbelly lanternshark (*Etmopterus lucifer*), Japanese spurdog (*Squalus japonicus*), shortnose spurdog (*Squalus megalops*), milk shark or sharp-nosed shark (*Rhizoprionodon acutus*) and smooth hammerhead shark (*Sphyrna zygaena*). Information on the rays is based on the current sampling program and that previous work by AFD and includes the pale-edged stingray (*Dasyatis zugei*), *Gymnura japonica*, *Raja hollandi* and *Raja kwangtunensisi.*

Sharks, which are generally long lived and slow-growing, are nowadays rare in Hong Kong waters, probably on account of fishing in the past, but are readily marketed when caught. There is very little local literature on their population dynamics. This was confirmed by the trawl samples, which consisted mainly of rays, with only one small unidentified shark. Parameters for this functional group are therefore derived mainly from data on rays. Many smaller shark species, have similar life histories and diet preferences to those of rays (Stevens & McLoughlin 1991) and therefore can be included in the group. Elasmobranchs are generally long lived with low fecundity and therefore the *P/B* value is low. The estimate of *P/B* is based on values in Christensen and Pauly (1993) and Pauly and Christensen (1993). The estimate of *Q/B* (from the same sources) is about 2% of body weight/day, which is low compared to teleosts (Wetherbee 1990).

According to AFD reports (Richards 1980, 1985) commercial catches of rays in Hong Kong waters are negligible. Although rays are generally considered as benthic feeders, diet varies with age and species (Randall 1967, Ajayi 1982, Berestovskiy 1990, Smale and Cowley 1992). Large rays generally eat more fish, including pelagics, and larger crustaceans than the smaller rays. Most of the rays obtained from the sampling program were relatively small. The diet composition was calculated using the same method described below for the marine mammals. Each prey group was given an electivity index based on diet composition from various sources (Randall 1967, Ajayi 1982, Berestovskiy 1990). The preferred food is benthic crustaceans followed by molluscs, but prawns and demersal fishes are also important. Worms and small crustaceans are also likely to be an important component of the diet but most of the zoobenthos is probably buried or too small.

Small demersal fish

Demersal fish were classed as "small" if their asymptotic length (L_∞) was less than 30 cm and included Ambassidae, Apogonidae *Apogon quadrifasciata, Apogonichthys niger, Apogon* *semilineatus,*, Carangidae, Clupeidae, Cynoglossidae, Gerreidae, Gobiidae, Leiognathidae *Leiognathus brevirostris*, Mullidae, Nemipteridae *Nemipterus japonicus*, Pomacentridae, Sciaenidae *Collichthys lucidus*, Scorpaenidae *Sebasticu*s *marmoratus*, Serranidae and Siganidae *Siganus oramin*.

Medium demersal fish

Demersal fish with L_∞ greater than 30 cm were classed as medium. (There were no 'large' (> 50 cm) demersal fish group, which were presumably fished out many years ago.) Many species contributed to the biomass of this trophic group, Carangidae, Drepanidae, Haemulidae, Lethrinidae, Lutjanidae, Monachantidae, Mugilidae, Muraenesocidae, Muraenidae, Nemipteridae, Paralichtydae, Percichthyidae, Platycephalidae, Plotosidae, Polynemidae, Scatophagidae, Sciaenidae, Serranidae, Sillaginidae, Sparidae, Stromateidae, Synodontidae, Terapontidae, and Trichuridae.

Migratory demersals

This group comprises some Sparids (*Chrysophrys major*, variously called red seabream or red pargo) and a few other species whose Q values (approx 3) are much more like pelagic fish than demersals (7 to 16).

Oceanic pelagic fish

Species included in this group were Engraulidae *Engraulis japonicus,* Clupeidae *Sardinella jussieui, Trichiurus lepterus* and *Decapterus russelli* Carangidae, Centrolophidae, Cheilodactylidae, Haemulidae, Kyphosidae, Sciaenidae, and Scrombridae. These species more likely to be found in the oceanic conditions in East Hong Kong waters. *Q/B* values used for this group were based on those published for a similar model of the Brunei Darussalam coastal area, south of Hong Kong (Silvestre *et al.* 1993).

Estuarine pelagic fish

This group is distinguished from the previous group by being more likely to be found in the estuarine conditions in west Hong Kong. It comprises shads and herring, members of the Clupeidae (*Clupanodon punctatus*, *Hilsa* spp); mackerel Scombridae (*Scomber commerson, S. guttatus, S. japonicus, Scomber* sp), barracuda, Sphyraeniodae (*Sphyraena* sp); Bombay duck Syndontidae (*Harpadon nehereus*).

Marine mammals

Species reported from the area (Jefferson *et al.* 1993) include; ginkgo-toothed beaked whale (*Mesoplodon ginkgodens*), Indo-Pacific humpback dolphin (*Sousa chinensis*), rough-toothed dolphin (*Steno bredanensis*), Pacific white-sided dolphin (*Lagenorhynchus obliquidens*), bottlenose dolphin (*Tursiops truncatus*), pantropical spotted dolphin (*Stenella attenuata*), striped dolphin (*Stenella coeruleoalba*), common dolphin (*Delphinus delphis*) and finless porpoise (*Neophocaena phocaenoides*). The Indo-Pacific humpback dolphin and the finless porpoise are likely to be encountered in the western, estuarine area (Harrison & Bryden 1992). The remaining species are more oceanic.

Jefferson (1997) presented preliminary results indicating that there are about 150 hump-back dolphins in the North Lantau area. According to a media report (The Sunday Chronicle August 18, 1996) the number of cetaceans in Hong Kong waters is estimated to be around 150 dolphins and 100 porpoises. The mean weight of the porpoises is estimated to be 50 kg and the dolphins 100 kg (Evans 1990), resulting in the total cetacean biomass of 0.02 $t \cdot km^2$.

The mortality and production rates of cetaceans are low compared with other marine animals. About 5-10% of the population die annually (Evans 1990). The rate is higher for smaller species, such as those in Hong Kong's coastal waters. The area is also polluted and busy with ship traffic, increasing mortality. The mortality rate is therefore assumed to be 15-20%, which equates to an approximate instantaneous total mortality rate or *P/B* ratio of 0.2 year.

Although whales consume a great deal, much is allocated to maintaining body temperature. It is estimated that small whales require about 10% of their body weight per day as food (Evans 1990, Kastelein *et al.* 1993) which equates to a *Q/B* of 36.5. Estimates of *Q/B* for marine mammals from other sources (Pauly and Christensen 1993, Browder 1993, Olivieri *et al.* 1993, Trites *et al.* in press) give similar values. A mean *Q/B* ratio of 40 was therefore used in the current model. In order to estimate the food consumption of marine mammals, each food group was allocated an electivity index ranging from 0 to 1; 1 being most preferred prey, 0 the least. The predicted percentage of each prey species in the diet was then calculated thus:

$$DCi = \left\{ Ei \,.\, Bi \right\} / \backepsilon \left\{ Ei \,.\, Bi \right\}$$

where DC_i is the proportion of prey *i* in the diet, E_i is the electivity index of prey *i* in the diet and B_i is the biomass of the prey *i* in the system. This method of calculating diet composition can only be utilised if the biomass of the prey is known. Here, the electivity index is not known but estimated from Harrison & Bryden (1992), Evans (1990) and Pauly *et al.* (1995) assuming that the main prey species are squids and pelagic fishes, closely followed by demersal fishes and prawns.

Results

Table EC3 lists ECOPATH parameters for the Hong Kong inshore ecosystem; entries in bold are those fitted by the model, while those in plain type are input parameters. In practice, the balancing of the model is not quite as simple as this statement implies, since several iterations of input ecological efficiencies and biomass values have to be performed to balance the model.

Marine mammals are the top predators in the system (Trophic level = 3.8, Table EC2), followed by cephalopods (3.6) and migratory pelagic fish (3.5). The trophic level estimate for marine mammals is similar to that reported for this group elsewhere in the Pacific (Trites *et al.* in press). Phytoplankton (defined as 1) is the lowest trophic groups, followed by zoobenthos (2.0). ECOPATH also calculates the fishery's trophic level, which in this case is 4.0, similar to a top predator.

Trophic group	Biomass (t·km^2)	*P/B* (year^{-1})	*Q/B* (year^{-1})	*EE*	Catch (t·km^2 year^{-1})	Trophic Level
Phytoplankton	13.00	231	–	**0.89**	0	1.00
Zooplankton	17.30	40	192.0	**0.50**	0	2.11
Zoobenthos	35.20	5.5	30.0	**0.39**	0.01	2.01
Benthic crustacea	**0.46**	7.0	30.0	0.95	0.6	2.76
Benthic molluscs	**1.09**	3.4	50.0	0.95	0.01	2.86
Penaeids	**0.04**	7.0	30.0	0.95	0.16	2.75
Cephalopods	0.40	**2.0**	7.3	0.95	0.35	3.60
Elasmobranchs	0.06	0.3	7.0	**0.72**	0.01	3.33
Oceanic Pelagic fish	**0.65**	4.5	15.0	0.95	1.12	3.12
Estuarine pelagic fish	**0.52**	2.2	10.0	0.95	0.17	3.53
Small demersal fish	**1.07**	4.0	15.0	0.95	3.23	2.84
Medium demersal fish	**0.88**	3.5	8.0	0.95	1.66	3.07
Migratory demersal fish	**0.28**	2.5	10.0	0.95	0.01	3.43
Marine mammals	0.01	0.3	40.0	0	0	3.79
Detritus	–	–	–	**0.69**	0	–
TOTALS	70.96	–	–	–	7.33	–

Table EC2. Input data (normal type), and parameters estimated (in bold) by ECOPATH for the trophic mass-balance model of Hong Kong's ecosystem.

The ecotrophic efficiency (*EE*) is generally high (0.7 to 0.9) for most groups. Low values for the zooplankton (0.5) and zoobenthos (0.4) indicate these groups are not fully consumed. The lower *EE* values for the marine mammals (0.7) and elasmobranchs (0.7) are expected, because these groups have few predators.

Trophic flows between groups are presented in Figure EC1. The ecosystem's total biomass estimated by the model (excluding detritus) is about 71 t·km^2. Low trophic level groups (< 3.0) comprise about 92% of the total system biomass. Zoobenthos has the largest biomass of all groups (35.2 t·km^2), followed by zooplankton (17.3 t·km^2) and phytoplankton (13.0 t·km^2). Catch is estimated as about 7.4 tonnes km^{-2}

The impact of each trophic group, including the fishery, upon the others is presented in Figure EC2. In general, the low trophic level groups, particularly the zoobenthos and detritus, have a relatively large positive impact on the biomass of other groups (Figure EC2). The elasmobranchs, penaeids, benthic crustacea, benthic molluscs and marine mammals have very low impact on the other groups. The fishery has mostly negative impacts, particularly on the benthic crustacea and small demersal fish. Interestingly, the model indicates the fishery has a small positive impact on benthic molluscs, possibly because it removes their predators.

The ECOPATH model of Hong Kong's coastal ecosystem can be compared with others. Trophic transfer efficiencies, biomass estimates and the number of trophic levels within an ecosystem can be presented graphically, using pyramid diagrams (Figure EC3). Biomass estimates for the Hong Kong ecosystem are intermediate between those of British Columbia's Strait of Georgia (Pauly and Christensen 1996) and the oceanic South China Sea (Pauly and Christensen 1993). This is consistent with the lower biomass estimates generally associated with open oceanic systems. There is also a greater number of trophic levels in the Strait of Georgia compared with the Hong Kong ecosystem.

Scenario modelling

Here, ECOSIM and the ECOPATH model of Hong Kong's coastal estuarine ecosystem are deployed to examine six hypothetical management scenarios, at the request of the Hong Kong AFD.

In order to predict the impact of such changes in fishing mortality, ECOSIM requires additional information on the value of *F* for each gear sector on each trophic group. Here we have used the seven gear sectors analysed in the rest of the work; hang trawls, miscellaneous vessels, purse seines, pair trawls, stern trawls, shrimp trawls and the P4/7 sector. Table EC3 shows the values used, partitioned the Fs of the ECOPATH groups by gear type using data from the interview survey.

	Gear sector in Hong Kong inshore fishery							
ECOPATH **group**	**HT**	**Misc.**	**PS**	**PT**	**SHT**	**ST**	**P4/7**	**Rel. F**
Phytoplankton	0	0	0	0	0	0	0	0
Zooplankton	0	0	0	0	0	0	0	0
Elasmobranchs	0	0	0.006	0	0.060	0	0.088	0.022
Cephalopods	0.017	0.020	0.055	0.006	0.010	0.087	0.085	0.040
Migratory demersal fish	0	0.002	0	0	0	0.001	0.005	0.001
Migratory pelagic fish	0.059	0.007	0.022	0.020	0.001	0.002	0.033	0.021
Penaeids	0	0.005	0	0	0.245	0.005	0.004	0.037
Benthic crustacea	0	0.084	0	0	0.333	0.041	0.111	0.081
Benthic molluscs	0	0.002	0	0	0.003	0	0.005	0.001
Zoobenthos	0	0	0	0	0	0	0	0
Small demersal fish	0.508	0.374	0.430	0.604	0.236	0.434	0.428	0.431
Medium demersal fish	0.293	0.426	0.120	0.108	0.108	0.279	0.182	0.217
Pelagic fish	0.123	0.079	0.367	0.262	0.004	0.151	0.060	0.149
Marine mammals	0	0	0	0	0	0	0	0
Detritus	0	0	0	0	0	0	0	0

Table EC3. Relative fishing mortalities by ecopath group for the 7 gear sectors for the Hong Kong ECOPATH model. Columns show the relative Fs by gear type. Row values indicate the relative fishing mortality per ECOPATH group for the standard run.

The nine scenarios examined were:

1) Increase fishing mortality to 1.5 the current level, for all fishing sectors.
2) Decrease fishing mortality to 0.5 the current level, for all fishing sectors.
3) Decrease fishing mortality to 0.1 the current level, for all fishing sectors.
4a) Decrease fishing mortality in the shrimp trawl sector to 0.5 of the current level (keeping *F* in the remaining sectors at present levels).
4b) Decrease fishing mortality in the all three benthic trawl sectors (sht, st, pt) to 0.5 of the current level (keeping *F* in the remaining sectors at present levels).
5a) Decrease fishing mortality in all sectors to 0.5 current levels, except for the shrimp trawling sector (which is kept at current levels).
5b) Decrease fishing mortality in all sectors to 0.5 current levels, except for the three benthic trawl sectors (sht, pt, st) which are kept at current levels.
6a) Decrease fishing mortality to 0.1 of the current level for the shrimp trawling sector.
6b) Decrease fishing mortality to 0.1 of the current level for the three benthic trawl sectors (sht, pt, st).

For each scenario, the fishery was simulated, using ECOSIM, at current mortality levels for five years. The imposed scenario was then introduced for five more years, and then removed, whereby the fishery was allowed to change back to its current levels of fishing mortality, and then allowed to run its due course for 10 years. Thus, the predictions of each scenario are based on simulations of 20 (= 5+5+10) year time periods.

Scenario 1. Increase fishing mortality to 1.5 the current level, for fishing sectors.

The results from this scenario suggest that if fishing mortality is increased across the fishing sectors considered, the biomass of most trophic groups would decline. Large declines in the order of 80-90% would occur in the penaeids, benthic crustacea and small demersal fish. A decline in the order of 50% would occur in the pelagic fish. Benthic molluscs are one of the few groups to increase significantly in biomass, possibly as a result of increased fishing mortality lowering the abundance of their predators. Benthic crustaceans also experience a slight increase, possibly due to reduced predation. The increased fishing mortality appears to have little effect on the biomass of the phytoplankton, zooplankton and detritus.

Interestingly, the simulations indicate the biomass of the medium demersal fish declines in the first years after the change is imposed, then increases to levels which exceed its current biomass. After the five year period of increased fishing mortality is completed and fishing mortality declines back to original levels, the biomass declines back to its initial level. The initial decline is likely to be due to increased fishing mortality. The increase which follows the decline is due to the increase in the biomass of the benthic molluscs, which are a principal food item of the demersal fish. The response pattern for the migratory demersal fish group is similar.

Scenario 2. Decrease fishing mortality to 0.5 the current level, for all fishing sectors

The results from this scenario contrast well with scenario 1. The simulations suggest there would be an increase in the biomass of most trophic groups if fishing mortality was reduced by 50% across fishing sectors. The largest increase, in the order of 300%, would occur in the benthic crustacea. Penaeids and small demersal fish show increases in the order of 150-200%.

Again, the medium demersal fish show a complex response which appears related to the benthic molluscs; an initial increase, followed by a decline as their principal food group also declines. Pelagic fish show an increase in the order of 80%. Marine mammals show an increase in the order of about 60%. After the fishery returns to its current levels of fishing mortality, the elasmobranchs and marine mammals take the longest period (> 10 years) to return to current biomass levels.

Decreasing fishing mortality in this way appears to have little effect on the phytoplankton, zooplankton and detritus.

Scenario 3. Decrease fishing mortality to 0.1 the current level, for all fishing sectors

This scenario is similar to that of scenario 2, in that there is a general increase in biomass for most trophic groups. The most significant increase occurs in the small demersal fish, in the order of 500%, while the most significant decrease of almost 100% occurs in the benthic molluscs. Zoobenthos show a greater decline than in scenario 2, possibly because the predation upon them has increased more. Elasmobranchs, marine mammals, and interestingly, the benthic molluscs require the longest periods for their biomasses to return to current levels, after the imposed change is removed.

Scenario 4a) Decrease fishing mortality in the shrimp trawl sector to 0.5 of the current level (keeping F in the remaining sectors at present levels).

These simulations suggest that the trophic groups that would experience the greatest increase in biomass from a 50% reduction in trawl fishing mortality are the penaeids, benthic crustacea and small demersal fish. Relatively small increases, in the order of 5-10%, would also be obtained in migratory and non-migratory pelagic fish groups, and medium demersal fish. Benthic molluscs would experience the largest decline in biomass. Marine mammal biomass would be largely unaffected by such a reduction in shrimp trawling mortality. Elasmobranch and benthic mollusc biomasses would take several years to approach their current levels, after the five year period of decreased trawl fishing mortality was over.

Scenario 4b) Decrease fishing mortality in the all three benthic trawl sectors (sht, st, pt) to 0.5 of the current level (keeping F in the remaining sectors at present levels).

These simulations suggest that reducing all demersal trawling produces an exaggerated version of scenario 4a, and is broadly similar to scenario 2. Prawns, large and small demersals show the largest increases. Elasmobranchs, some pelagics, cephalopods and marine mammals show slow increase in biomass.

Scenario 5a) Decrease fishing mortality in all sectors to 0.5 current levels, except for the shrimp trawling sector (which is kept at current levels).

ECOSIM simulations indicate that the biomass of small demersal fish would increase by approximately 100% under this scenario. Both migratory, and non-migratory pelagic fish would also increase in the order of 20-40%. Cephalopods and marine mammals show an increase of approximately 15%. Gill netting was assumed to be the only source of fishing mortality on the marine mammals. Thus, any reduction in gill netting would be expected to result in an increase in marine mammal biomass.

Medium demersal fish show an initial increase, but slowly decline over the remainder of the five year period. They also exhibit a sharp decline when the fishery reverts back to its current mortality rates. The response by the benthic molluscs is complex, but appears related to the medium demersal fish. Benthic molluscs decline initially, possibly as a result of the increased predation by the demersal fish groups. After about two years, their biomass increases and peaks just after the sharp decline in the medium demersal fish biomass. Interestingly, after an initial rise, this scenario results in a decline in penaeid shrimp biomass, possibly due to increased predation.

Scenario 5b) Decrease fishing mortality in all sectors to 0.5 current levels, except for the three benthic trawl sectors (sht, pt, st) which are kept at current levels.

ECOSIM simulations indicate significant gains for pelagics and for some demersal sectors under this scenario, probably due to the wide spectrum of fish species caught in the non-trawl sectors. Results are broadly similar to scenario 5a.

Scenario 6a) Decrease fishing mortality to 0.1 of the current level for the shrimp trawling sector.

This scenario results in a rapid and large increase in prawns, paralleled by medium demersals. Elasmobranchs and marine mammals increase, while benthic molluscs and benthos declines due to higher predation. Pelagics show a small increase at the outset, but then level out and stabilise at a slightly higher level than baseline.

Scenario 6b) Decrease fishing mortality to 0.1 of the current level for the three benthic trawl sectors (sht, pt, st).

The simulation presents a more dramatic version of scenario 6a, with, however, broadly similar trends. There are very significant gains for medium and small demersals, prawns, and pelagics with slow increases in elasmobranchs, marine mammals, cephalopods, and zoo benthos. This scenario shows decreases in benthic crustacea, and phytoplankton.

REFERENCES CITED

Abarca-Arenas, L.G. and Valero-Pacheco, E. (1993) Towards a Trophic Model of Tamaihua, a Coastal Lagoon in Mexico. Pages 181- 185 in Christensen, V. and Pauly, D. (eds.) Trophic Models of Aquatic Ecosystems. ICLARM Conf. Proc. 26. 390pp

Ajayi, T.O. (1982) Food and feeding habits of *Raja* species (Batoidei) in Carmarthen Bay, Bristol Channel. J. Mar. Biol. Ass. U.K. 62:215-223.

Allen, K.R. (1971) Relation between production and biomass. J. Fish. Res. Board Can. 28: 1573-1581.

Annigeri, G.G., (1982) On the fishery and biology of *Sardinella dayi* (Regan) at Karwar, India. J. Mar. Biol. Assoc. India 24(1-2): 133-140.

Armada, N. and G. Silvestre (1981) Demersal fish resource survey in the Samar Sea and Carigara Bay. UP-NSDB Project 7811.1c. College of Fisheries, University of the Philippines in the Visayas, Iloilo City, Philippines. 56pp.

Arreguin-Sanchez, F., Seijo, J.C., & Valero-Pacheco (1993) An application of Ecopath II to the north continental shelf ecosystem of Yucatan, Mexico. Pages 269-278 in Christensen, V. & Pauly, D. (eds) Trophic Models of Aquatic Ecosystems. ICLARM Conf. Proc. 26, Manila. 390pp.

Aryuthaka, C. (1991) Meiofaunal community in Khung Kraban Bay, Chanthaburi, East Thailand. Mar. Fish. Res, Bull. 2: 47-57.

Banerji, S.K. and Krishnan, T.S. (1973) Acceleration of assessment of fish populations and comparative studies of similar taxonomic groups. Pages 158-175 in Proceedings of the Symposium on Living Resources of the Seas Around India. Spec. Publ. Cent. Mar. Biol. Res. Inst., Cochin, India. 748pp.

Basson, M., Rosenberg, A.A. and Beddington, J.R. (1988) The accuracy and reliability of two new methods for estimating growth parameters from length-frequency data. J. Cons. int. Explor. Mer. 44: 277-285.

Beddington, J.R. & J.G.Cooke (1983) The potential yield of fish stocks. FAO Tech. Pap. 242: 1-47.

Berestovskiy, E. G. (1990) Feeding in the skates, *Raja radiata* and *Raja fyllae*, in the Barents and Norwegian Seas. J. Ichthyol. 29(8): 88-96.

Beverton, R.J.H. (1963) Maturation, growth and mortality of clupeid and engraulid stocks in relation to fishing. Cons. Perm. Int. Explor. Mer, Rapp. p.-v. Réun. 154: 44-67.

Beverton, R.J.H. and Holt, S.J. (1957) On the dynamics of exploited fish populations. Fish. Invest. Min. Agric. Fish Food G.B. (2. Sea Fish.), 19: 533 p.

Bianchi, G. (1985) FAO species identification sheets for fishery purposes. Field guide to the commercial marine and brackish-water species of Pakistan. Prepared with the support of PAK/77/033/ and FAO (FIRM) Regular Programme. FAO, Rome. 200 p.

Biradar, R.S. (1989) Stock assessment of Bombay duck *Harpadon nehereus* off Maharashtra, India. Pages 31-44 in S.C. Venema and N.P. van Zalinge (eds.) Contributions to tropical fish stock assessment in India. FAO/DANIDA/ICAR National Follow-up Training Course on Fish Stock Assessment, Cochin, India, 2-28 November 1987. FI:GCP/INT/392/DEN/1.

Browder, J. (1993) A pilot model of the Gulf of Mexico continental shelf. Pages 279-284 in Christensen, V. & Pauly, D. (eds) Trophic Models of Aquatic Ecosystems. ICLARM Conf. Proc. 26, Manila. 390pp.

Chakraborty, S.K. (1990) Fishery, age, growth and mortality estimates of *Trichiurus lepturus* Linnaeus from Indian waters. Indian J. Fisheries 37(1): 1-7.

Chan, K. and Tseng, W. (1980) A comparative study of the benthic fishes of Tolo Harbor and the northeastern waters of Hong Kong. Proceedings of the first international marine biological workshop: the marine flora and fauna of Hong Kong and Southern China. Hong Kong.

Chavez, E.A., Garduno, M. and Arreguin-Sanchez, F. (1993) Trophic Dynamic Structure of Celestun lagoon, Southern Gulf of Mexico. Pages 196 -205 in Christensen, V. and Pauly, D. (eds) Trophic Models of Aquatic Ecosystems. ICLARM Conf. Proc. 26. 390pp.

Chen, W.Y. and Lee, S.C. (1982) Age and growth of the ribbonfishes *Trichiurus* (Perciformes: Trichiuridae) of Taiwan. Bull. Inst. Zool. Acad. Sin. 21(1): 9-20.

Christensen, V. and Pauly, D. (1992a) ECOPATH II - a software for balancing steady-state models and calculating network characteristics. Ecol. Modelling 61: 169-185.

Christensen, V. and Pauly, D. (1992b) A guide to the ECOPATH II program (version 2.1) ICLARM Software 6: 72 p.

Christensen, V. and Pauly, D. (eds) (1993) Trophic models of aquatic ecosystems. ICLARM Conf. Proc. 26, 390 p.

Christensen, V. and Pauly, D. (1996) ECOPATH for Windows - a users guide. ICLARM, Manila Philippines. Draft of 18. October, 1996.

Compagno, L.J.V. (1984a) FAO species catalogue, vol. 4, part 1: Sharks of the world. FAO Fisheries Synopsis No. 125. 249 pp.

Compagno, L.J.V. (1984b) FAO species catalogue, vol. 4, part 2: Sharks of the world. FAO Fisheries Synopsis No. 125. 406 pp.

Corpuz, A., J. Saeger and V. Sambilay (1985) Population parameters of commercially important fishes in Philippine waters. Tech. Rep. Univ. Philipp. Visayas, Dept. Mar. Fish. (6): 99pp.

Dall, W., Hill, B.J., Rothlisberg, P.C. and Staples, D.J. (1990) Predation on Penaeids. Adv. Mar. Biol. 27: 357-377.

De La Cruz-Arguero, G. (1993) A preliminary Model of Mandinga Lagoon, Veracruz, Mexico. Pages 193-196 In Christensen, V. and Pauly, D. (eds) Trophic Models of Aquatic Ecosystems. ICLARM Conf. Proc. 26. 390pp.

De Paula e Silva, R., Sousa, M.L., & Caramalo, A.M. (1993) The Maputo Bay ecosystem, Mozambique. Pages 214-223 in Christensen, V. & Pauly, D. (eds) Trophic Models of Aquatic Ecosystems. ICLARM Conf. Proc. 26, Manila. 390pp.

Delos-Reyes, M.R. (1993) Fishpen culture and its impact on the ecosystem of Laguna de Bay, Philippines. Pages 74-84 in Christensen, V. and Pauly, D. (eds.) Trophic Models of Aquatic Ecosystems. ICLARM Conf. Proc. 26. 390pp.

Dredge, M.C.L. (1990) Movement, growth and natural mortality rate of the red spot king prawn, *Penaeus longistylus* Kubo, from the Great Barrier Reef lagoon. Aust. J. Mar. Freshwater Res. 41(3): 399-410.

Dwiponggo, A., Hariati, T., Banon, S., Palomares, M.L. and Pauly, D. (1986) Growth, mortality and recruitment of commercially important fishes and penaeid shrimps in Indonesian waters. ICLARM Tech. Rep. 17, 91 pp.

Evans, P.G.H. (1990) The natural history of whales and dolphins. Facts on File, New York. 343 pp.

Federizon, R. (1993) Using vital statistics and survey catch composition data for tropical multispecies fish stock assessment: application to the demersal resources of the central Philippines. Doctoral thesis, Alfred-Wegener-Institut für Polar- und Meeresforschung, Bremerhaven, Germany. 201pp.

Froese, R. and Pauly, D. (1996) *Fishbase 96*: a biological database on fish. Concepts, design and data sources. ICLARM, Manila, Philippines. 179pp.

Garcia, S., and Le Reste, L. (1981) Life cycles, dynamics, exploitation and management of coastal penaeid shrimp stocks. FAO Fisheries Technical Paper 203. 215 pp.

Gayanilo, F.C., Jr., Sparre, P. and Pauly, D. (1994) The FAO-ICLARM Stock Assessment Tools (FiSAT) User's Guide. FAO Computerised Information Series (Fisheries) No. 7. Rome, 124pp.

Gjosaeter, J. and Sousa, M.I. (1983) Reproduction, age and growth of the Russell's scad *Decapterus russelli* (Rüppell 1829) (Carangidae) from Sofala Bank, Mozambique. Rev. Invest. Pesq. Maputo 8: 83-108.

Glaister, J.P., Montgomery, S.S., and McDonall, V.C. (1990) Yield-per-recruit analysis of eastern king prawns, *Penaeus plebejus* Hess, in eastern Australia. Aust. J. Mar. Freshwater Res. 41: 175-97.

Greze, V.N. (1978) Production in Animal Populations. Pages 89-114 in O. Kinne (ed.) Marine Ecology. A comprehensive, integrated treatise on life in oceans and coastal waters. Volume IV: Dynamics. John Wiley and Sons, New York.

Gulland, J.A. (1983) Fish stock assessment: a manual of basic methods. Chichester, U.K., Wiley Interscience, FAO/Wiley series on food and agriculture. 1: 223 p.

Gulland, J.A. (1971) The Fish Resources of the Ocean. Fishing News Books, Surrey, UK 255pp.

Hamano, T. and Morrissy, N.M. (1992) Growth of *Oratosquilla oratoria* (De Haan, 1844) (Stomatopoda) in the sea of Suo-Nada, Japan. Crustaceana 63(3): 264-276.

Harrison, R. and Bryden, M.M. (1992) Whales dolphins and porpoises. Blitz editions, Leicester, UK 240 pp.

He Baoquan and Li Huiquan (1988) Stock assessment of *Collichthys lucidus* in Pearl River Estuary. Journal of Fisheries of China. 12(2): 125-132.

Hilborn, R. and Walters, C. J. (1992) Quantitative Fisheries Stock Assessment Choice, Dynamics and Uncertainty. Chapman and Hall, New York, USA. 570pp.

Holden, S. and Bravington, M. (1991) Length Frequency Data Analysis (LFDA). MRAG Ltd., London UK.

Horstmann, U. (1975) Some aspects of the mariculture of different siganid species in the Philippines. Philipp. Sci. 12: 5-20.

Huang, Z. G. and Mak, P.M.S. (1980) Studies on biofouling in Tolo Harbour, Pages 767-788 in B. Morton and C. K. Tseng (eds.) Proceedings of the first international Marine Biological Workshop: The Marine Flora and Fauna of Hong Kong and Southern China, Hong Kong.

Ingles, J. and Pauly, D. (1984) An atlas of the growth, mortality and recruitment of Philippines fishes. ICLARM Tech. Rep. 13. 127pp.

Iqbal, M. (1991) Length-based fish stock assessment methods: their application in estimation of the growth and mortality rates of Indian scad *Decapterus russelli* (Carangidae) in Pakistani waters: Northern Arabian Sea. Proc. Pakistan Congress of Zool. 11.

Isa, M.M. (1987) On the status of the *Rastrelliger* and *Decapterus* fisheries of the west coast of peninsular Malaysia in 1984-1985. Pages 81-100 in Investigations on the mackerel and scad resources of the Malacca Straits. Bay of Bengal Programme, BOBP/REP/39.

Jabat, M. and Dalzell, P. (1988) Preliminary stock assessment of the Davao ring net fishery for bullet tunas and small pelagic fishes in the Camotes Sea, Central Visayas, Philippines. BFAR Tech. Pap. 11(1): 34pp.

Jarre-Teichman, A. and Pauly, D. (1993) Seasonal changes in the Peruvian upwelling system. Pages 307-314 in Christensen, V. & Pauly, D. (eds) Trophic Models of Aquatic Ecosystems. ICLARM Conf. Proc. 26, Manila. 390pp.

Jefferson, T.A. (1997) Multi-disciplinary research program on the Indo-Pacific hump-back dolphin population. Third quarterly progress report. 13pp.

Jefferson, T.A., Leatherwood, S. and Webber, M.A. (1993) Marine Mammals of the World. FAO species identification guide. FAO, Rome. 320 pp.

Jensen, P. (1988) Nematode assemblages in the deep-sea benthos of the North Sea. Deep Sea Res. 35(7A): 1173-1184.

Jones, R. (1976) Mesh Regulation in the Demersal Fisheries of the South China Sea, FAO/UNDP South China Sea Fisheries Development and Coordinating Programme, SCS/76/WP/36, Manila, 79 pp.

Ka-ling and Wen-Young Tseng (1980) A comparative study of the benthic fishes of Tolo Harbour and the Northeastern waters of Hong Kong. Pages 801-814 in B. Morton and C. K. Tseng (eds) Proceedings of the First International Marine Biological Workshop: The Marine Flora and Fauna of Hong Kong and Southern China, Hong Kong.

Kastelein, R.A., McBain, J., Neurohr, B., Mohri, M., Saijo, S., Wakabayashi, I. and Wiepkema, P.R. (1993) The food consumption of Commerson's dolphins (*Cephalorhynchus commersoni*) Aquatic Mammals 19(2): 99-121.

Kennedy, A.D. (1994) Predation within meiofaunal communities: Description and results of a rapid freezing method of investigation. Mar. Ecol. Prog. Ser. 114 (1/2): 71-79.

Khan, M.Z. (1985) Observations on the fishery of Bombay duck, *Harpadon nehereus* along the Saurashtra coast. Indian J. Fish. 32(4): 431-438.

Khan, M.Z. (1989) Population dynamics of the Bombay duck, *Harpadon nehereus* (Ham.), off Saurashtra coast. Indian J. Fish. 36(2): 93-101.

Kim, W.S., Hiyama, Y. and Nose, Y. (1969) Age and racial studies of Japanese jack mackerel. I. Age and growth as determined by urohyal. Bull. Jap. Soc. Sci. Fish. 35: 178-86.

Kitalong, A.H. and Dalzell, P. (1994) A preliminary assessment of the status of inshore coral reef fish stocks in Palau. Inshore Fish. Res. Tech. Doc. No. 6, South Pacific Commission, Noumea, New Caledonia.

Krishnaya, C.H. (1968) Age and growth of *Harpadon nehereus* and its fishery in the Hooghly estuarine system. J. Zool. Soc. India 20(12): 129-147.

Liao, I.C. and Su, M.S. (1984) Preliminary studies on the distribution and stomach contents of some commercial prawns from the coast of Tungkang, Taiwan. TML Conference Proceedings 1: 57-71.

Leung, A.W.Y. and Lee, C.K.C. (1987) On the application of catch and effort information from the Hong Kong trawl fishery, and associated problems. IPFC Symp. on the Exploitation and Management of Marine Fishery Resources in Southeast Asia, Darwin (Australia). FAO Reg. Off. for Asia and the Pacific, Bangkok Thailand 1987. 10: 306-323.

Lijam, N. (1990) Natural mortality estimation from water temperature and growth: confidence limits and scope. MSc thesis, University of Wales, Bangor, UK. 120pp.

Lucas, C., Kirkwood, G., and Somers, I. (1979) An assessment of the stocks of banana prawns *Penaeus merguiensis* in the Gulf of Carpentaria. Aust. J. Mar. Freshwater Research 30: 639-652.

Macdonald, P.D.M. and Pitcher, T.J. (1979) Age-groups from size-frequency data: a versatile and efficient method of analysing distribution mixtures. J. Fish. Res. Board. Can. 36: 987-1001.

Masuda, H., Amaoka, K., Araga, C., Uyeno, T. and Yoshino, T. (1984) The Fishes of the Japanese Archipelago. Vol. 1 (text). Tokai University Press, Tokyo, Japan. 437 pp.

Meemeskul, Y. (1979) Optimum mesh size for the trawl fishery in the Gulf of Thailand. Indo-Pac. Fish. Counc., RRD/II/79/INF/13, 20 pp.

Mendoza, J. (1993) A preliminary biomass budget for the northeastern Venezuela shelf ecosystem. Pages 285-297 in Christensen, V. & Pauly, D. (eds) Trophic Models of Aquatic Ecosystems. ICLARM Conf. Proc. 26, Manila. 390pp.

Mitani, F. and E. Ida. (1964) A study on the growth and age of the jack mackerel in the East China Sea. Bull. Jap. Soc. Sci. Fish. 30(12): 958-977.

Moreau, J., Christensen, V. and Pauly, D. (1993) A Trophic Ecosystem Model, of Lake George, Uganda. Pages 124-129 in Christensen, V. and Pauly, D. (eds) Trophic Models of Aquatic Ecosystems. ICLARM Conf. Proc. 26. 390pp.

Mukarami, S. and Shindo, S. (1949) Studies on the stocks of some economically important marine fishes caught around Amakusa. V. Consideration on the age of *Trachurus japonicus* (Temn. and Schl.) Bull. Jap. Soc. Sci. Fish. 15(4): 155-157.

Murawski, S.A. (1984) Mixed species yield-per-recruitment analyses accounting for technological interactions. Can J. Fish. Aquat. Sci. 41: 897-916.

Murty, V.S. (1991) Observations on some aspects of biology and population dynamics of the scad *Decapterus russelli* (Ruppell) (Carangidae) in the trawling grounds off Kakinada. J. Mar. Biol. Assoc. India (1991) 33(1-2): 396-408.

Nakamura, I. and N.V. Parin. (1993) FAO species catalogue. Snake mackerels and cutlassfishes of the world (Families Gempylidae and Trichiuridae) FAO Fish. Synop. 15(125): 136 p.

Narasimham, K.A. (1976) Age and growth of ribbonfish *Trichiurus lepturus* Linnaeus. Indian J. Fish. 23(1/2): 174-182.

Nguyen, Tac An. (1989) Energy balance of the major tropical marine shelf ecosystem of Vietnam. Biologya Morya (Sov. J. Mar. Biol.) 15(2): 78-83.

Ohtomi, J. and Shimizu, M. (1994) Theoretical growth during the recruitment period and estimation of growth parameters of the Japanese mantis shrimp *Oratosquilla oratoria* in Tokyo Bay. Bull. Jap. Soc. Fish. Oceanogr. 58(1): 21-25.

Olivieri, R. A., Cohen, A. and Chavez, F. P. (1993) An ecosystem model of Monterey Bay, California, Pages 315-322 in Christensen, V. and Pauly, D. (eds) Trophic models of aquatic ecosystems. ICLARM Conf. Proc. 26. 390pp.

Opitz, S. (1993) A quantitative model of the trophic interactions in a Caribbean coral reef ecosystem. Pages 259-267 in Christensen, V. & Pauly, D. (eds) Trophic Models of Aquatic Ecosystems. ICLARM Conf. Proc. 26, Manila. 390pp.

Padilla, J.E. (1991) Managing tropical multispecies fisheries with multiple objectives. Ph.D. thesis, Simon Fraser University, Canada. 235pp.

Palomares, M. L., Yulianto, B., Puy, L., Bengen, and Belaud, A. (1993) A preliminary Model of the Garonne River (Toulouse, France) Ecosystem in Spring. Pages 172-179 in Christensen, V. and Pauly, D. (eds) Trophic models of aquatic ecosystems. ICLARM Conf. Proc. 26. 390pp.

Pauly, D. (1978) A preliminary compilation of fish length growth parameters. Berichte aus dem Institut für Meereskunde an der Christian-Albrechts-Universität Kiel 55: 200pp.

Pauly, D. (1979) Gill size and temperature as governing factors in fish growth: A generalization of von Bertalanffy's growth formula. Berichte aus dem Institut für Meereskunde an der Christian-Albrechts-Universität Kiel. 63: 156pp.

Pauly, D. (1980) On the inter-relationships between natural mortality, growth parameters and mean environmental temperature in 175 fish stocks. J. Cons. Int. perm. Explor Mer. 39: 175-92.

Pauly, D. (1984) Fish population dynamics in tropical waters: a manual for programmable calculators. ICLARM, Manila. 325pp.

Pauly, D. (1987) A review of the ELEFAN system for analysis of length-frequency data in fish and aquatic invertebrates. Pages 7-34 in Pauly, D. & Morgan, G.R. (eds) Length-based Methods in Fisheries Research. ICLARM, Manila, Philippines and KISR, Safat, Kuwait.

Pauly, D. (1988) Fisheries research and the demersal fisheries of Southeast Asia. Pages 329-34 in Gulland, J.A. (ed) Fish Population Dynamics. 2nd edition. Wiley, Chichester, UK. 422pp.

Pauly, D. and Christensen, V. (1993) Stratified models of large marine ecosystems: a general approach and an application to the South China Sea. Pages 148-174 in Sherman, K., Alexander, L.M. & Gold, B.D. (eds) Large Marine Ecosystems: stress, mitigation and sustainability. AAA Press, Washington, DC, USA. 376pp.

Pauly, D. and Arreguín-Sánchez, F. (1995) Improving Shepherd's length composition analysis (SLCA) method for growth parameter estimations. Naga, ICLARM Q. 18(4): 31-33.

Pauly, D., Christensen, V. & Haggan, N. (1996) Mass-balance models of North-eastern Pacific ecosystems. University of British Columbia, Fisheries Centre Research Report 4(1), 131pp.

Paxton, J.R., D.F. Hoese, G.R. Allen and J.E. Hanley. (1989) Pisces. Petromyzontidae to Carangidae. Zoological Catalogue of Australia, Vol. 7. Australian Government Publishing Service, Canberra. 665 pp.

Pfannkuche, O. (1993) Benthic response to the sedimentation of particulate organic matter at the BIOTRANS station, 47 degree N, 20 degree W. JGOFS. The north Atlantic bloom experiment. (Ducklow, H. W., Harris, R. P., Eds) 40 (1-2):135-149.

Pitcher, T.J. and Hart, P.J.B. (1981) Fisheries Ecology. Chapman and Hall, London. 414pp.

Plyakarnchana, T. (1989) Yield dynamics as an index of biomass shifts in the Gulf of Thailand. Pages 95-142 in: Sherman, K. and Alexander, L.M. (eds) Biomass, Yields and Geography of Large Marine Ecosystems. AAAS symposium 111. Westview Press, Boulder. USA.

Polovina, J.J. (1984) An overview of ECOPATH model. ICLARM, Fishbyte 2(2): 5-7.

Randall, J. E. (1967) Food habits of reef fishes of the West Indies. Stud. Trop. Ocean. Miami 5:665-847.

Rao, K.V.S. (1984) Age and growth of lizardfishes (*Saurida* spp.) from the norwthwestern Bay of Bengal. Indian J. Fish. 31(1): 19-30.

Richards, J. (1980) The status of fisheries in Hong Kong waters. Agriculture and Fisheries Department, Hong Kong Government. 28pp.

Richards, J. (1985) Fisheries Production in Hong Kong Waters. Agriculture and Fisheries Department, Hong Kong Government. Manuscript Report. 9pp.

Richards, J., Chong, C.K., Mak, P. and Leung, A.W.Y. (1985) Country report: Hong Kong. The demersal fish resources of the northern shelf of the South China Sea. FAO/SEAFDEC Workshop on Shared Stocks in Southeast Asia, Bangkok (Thailand). FAO FISH. REP. FAO FIRM 337: 63 71.

Rodriguez, M.I. and F.E. Sousa (1988) Sources of bias in growth and mortalilty estimation of migratory pelagic fish stocks, with emphasis on *Decapterus russelli* (Carangidae) in Mozambique. Pages 288-307 in S.C. Venema, J.M. Christensen and D. Pauly (eds.) Contributions to tropical fisheries biology. FAO/DANIDA Follow-up Training Course on Fish Stock Assessment in the Tropics, Denmark, 1986.

Sainsbury, K.J. (1984) Optimum mesh size for tropical multispecies trawl fisheries. J. Cons. Int. Explor. Mer, 41: 129-39.

Sarma, A.L.N. and Wilsanand, V. (1994) Littoral meiofauna of Bhitarkanika mangroves of river Mahanadi system, east coast of India. Indian J. Mar. Sci. 23(4): 217-220.

Shepherd, J.G. (1987) A weakly parametric method for the analysis of length composition data. Pages 113-120 in D. Pauly and G.P.Morgan (eds) Length-based Methods in Fisheries Research. ICLARM, Manila, 468pp.

Shin, P.K. and Thompson, G.B. (1982) Spatial distribution of the infaunal benthos of Hong Kong. Mar. Ecol. Prog. Ser. 10: 37-47.

Shindo, S. (1972) Note on the study of the stock of lizard fish, *Saurida tumbil* in the East China Sea. Proc. IPFC 13(3): 298-305.

Silvestre, G., Selvanathan, S., and Salleh, A.M.H. (1993) Preliminary Trophic Model of the Coastal Fisheries Resources of Brunei Darussalam, South China Sea. Pages xxx in Christensen, V. and D. Pauly (eds) Trophic models of aquatic ecosystems. ICLARM Conf. Proc. 26. 390pp.

Sinoda, M., Tan, S.M., Watanabe, Y. and Meemeskul, Y. (1979) A method for estimating the best cod-end-mesh size in the South China Sea area, Bull. Chosi Mar. Lab., Chiba Univ., 11: 65-80.

Smale, M.J. and Cowley, P. D. (1992) The feeding ecology of skates (Batoidea: Rajidae) off the Cape South Coast, South Africa. S.A. J. Mar. Sci. 12: 823-834.

Smith, I.R., Pauly, D. and Mines, A.N. (1983) Small-scale fisheries of San Miguel Bay, Philippines: options for management and research, ICLARM Technical Reports, 11, 80 pp. Institute of Fisheries Development and Research, College of Fisheries, University of the Philippines in the Visayas, Quezon City and the International Center for Living Aquatic Resources Management, Manila, Philippines.

Smith-Vaniz, W.F. (1984) Carangidae. In W. Fischer and G. Bianchi (eds.) FAO species identification sheets for fishery purposes. Western Indian Ocean Fishing Area 51. Vol. 1. FAO, Rome.

Somers, I.F. (1990) Manipulation of Fishing Effort in Australia's Penaeid Prawn Fisheries. Aust. J. Mar. Freshwater Res. 41: 1-12.

Sommai, Y.S.S. and W. Thubthimsang (1988) An assessment of the southern velvet shrimp (*Metapenaeopsis palmensis*) (Penaeidae) off the coast of Rayong Province, Gulf of Thailand. Contributions to tropical fisheries biology. Papers prepared by the participants at the FAO Danida follow up training course on fish stock assessment in the tropics. Hirtshals, Denmark, 5-30 May 1986 and Manilla, Philippines, 12 January - 6 February 1987. Venema, S.C., Christensen, J. M. Pauly, D. (eds.) no. 389. pp. 117-125.

Somvanshi, V.S. and Joseph, A. (1989) Population dynamics and assessment of *Trichiurus lepturus* Linnaeus stock in north-west coast of India. Studies on fish stock assessment in Indian Waters. Fishery survey of India, Bombay, India, Bombay, India, FSI.

Sousa, M.I. and J. Glaister (1987) A revision of growth parameters of some commercially exploited fishes from Mozambique. Rev. Invest. Pesq. (Maputo) 16:19-40.

Sparre, P., and Venema, S.C. (1992) Introduction to tropical fish stock assessment. Part 1. Manual. FAO Fish. Tech. Pap. 306(1): 376pp.

Sparre, P.J. and Willman, R. (1993) Software for the bio-economic analysis of fisheries. BEAM 4. Analytical bio-economic simulation of space-structured multi species and multi-fleet fisheries. FAO Computerized Information Series (Fisheries) No 3., Vol 1: 86p.

Sreenivasan, P.V. (1982) Age and growth of the scad *Decapterus dayi* Wakiya. Indian J. Fish. 29 (1/2): 145-150.

Stevens, J.D. and McLoughlin, K.J. (1991) Distribution, size and sex composition, reproductive biology and diet of sharks from northern Australia. Aust. J. Mar. Freshwater Res. 42(2): 151-199.

Suwarso, B., Sadhotomo and S.B. Atmaja (1995) Growth parameters of the main small pelagic species. Pages 85-96 in M. Potier and S. Nurhakim (eds.) Biology, dynamics, exploitation of the small pelagic fishes in the Java sea. *Publisher missing*

Tampubolon, G.H., and Merta, I.G.S. (1987) Mackerel fisheries in the Malacca straits. BOBP/REP/39: 101-116.

Thompson, G.B. and Horikoshi, M. (1980) Distribution of subtidal benthos collected by trawling in Tolo Harbour and Tolo Channel, Honk Kong, Pages 733-744 in B. Morton and C.K. Tseng (eds) Proceedings of the first international Marine Biological Workshop: The Marine Flora and Fauna of Hong Kong and Southern China, Hong Kong.

Thompson, G.B., Wu, R.S.S. and Phillips, D.J.H. (1980) A trawl survey of the benthos of Tolo Harbour and Tolo Channel in 1978. Pages 745-760 in B. Morton and C. K. Tseng (eds.) Proceedings of the First International Marine Biological Workshop: The Marine Flora and Fauna of Hong Kong and Southern China, Hong Kong.

Tiews, K., A. Mines and I.A. Ronquillo (1972) On the biology of *Saurida tumbil* (Bloch 1801), Family Synodontidae in Philippine waters. Proc. IPFC 13(3):100-120.

Torres, F. Jr. (1991) Tabular data on marine fishes from Southern Africa, Part II: Growth parameters. Fishbyte 9(2): 37-38.

Troadec, J.-P. (1977) Méthodes semi-quantitatives d'évaluation. FAO Circ. Peches, 701: 131-141.

Trites, A.W., Pauly, D. and Christensen, V. (in press) Competition between fisheries and marine mammals for prey and primary production in the Pacific Ocean. J. North West Atl. Fish. Sci. (in press).

Van Dam, A.A., Chikafumbwa, F.J.K.T., Jamu, D.M. and Costa-Pierce, B.A. (1993) Trophic Interactions in a Napier Grass (*Pennisetum purpureum*) - fed Aquaculture Pond in Malawi. Pages 65-68 in

Christensen, V. and Pauly, D. (eds.) Trophic Models of Aquatic Ecosystems. ICLARM Conf. Proc. 26. 390pp.

Walline, P.D., Pisanty, S., Gophen, M. and Berman, T. (1993) The Ecosystem of Lake Kinneret, Israel. Pages 103-109 in Christensen, V. and Pauly, D. (eds.) Trophic Models of Aquatic Ecosystems. ICLARM Conf. Proc. 26. 390pp.

Walters, C., Christensen, V. and Pauly, D. (1997) Structuring Dynamic Models of Exploited Ecosystems from Trophic Mass-Balance Assessments. Rev. Fish Biol. Fish. 7: 139-172.

Warburton, K. and Blaber, S.J.M. (1992) Patterns of recruitment and resource use in a shallow-water fish assemblage in Moreton Bay, Queensland. Mar. Ecol. Prog. Ser. 90(2): 113-126.

Watson, R.A., and Keating, J. A. (1989) Velvet shrimps (*Metapenaeopsis* spp.) of Torres Strait, Queensland, Australia. Asian Fisheries Science 3: 45-56.

Wetherbee, B. (1990) Diet, food habits, and consumption in the lemon shark, *Negaprion brevirostris*. Pacific Science 44(2): 196-205.

Whitehead, P.J.P. (1985) FAO species catalogue. Vol.7. Clupeoid fishes of the world. An annotated and illustrated catalogue of the herrings, sardines, pilchards, sprats, shads, anchovies and wolf-herrings. Part 1 - Chirocentridae, Clupeidae and Pristigasteridae. FAO Fish. Synop. 7: 303pp.

Widodo, J. (1988) Population biology of Russell's scad (*Decapterus russelli*) in the Java Sea, Indonesia. Pages 308-323 in S.C. Venema, J.M. Christensen and D. Pauly (eds.) Contributions to tropical fisheries biology. FAO/DANIDA Follow-up Training Course on Fish Stock Assessment in the Tropics, Denmark, 1986 and Philippines, 1987. FAO Fish. Rep. (389).

Woodland, D.J. (1990) Revision of the fish family Siganidae with descriptions of two new species and comments on distribution and biology. Indo-Pac. Fish. (19): 136pp.

Wu, R.S.S. (1988) Marine pollution in Hong Kong. Asian Mar. Biol. 5: 1-23.

Xu Xucai Zhang Qiyong (1988) Age and growth of *Saurida tumbil* in the fishing ground of South Fujian and Taiwan Bank. J. Oceanogr. Taiwan Strait/Taiwan Haixa 7(3): 256-263.

Yamada, K and Kazihara, M. (1955) Taushima warm current. Proc. 3rd Symp. *(full ref missing)*

Yeh, S.Y., Lai, H.L. and Liu, H.C. (1977) Age and growth of lizard fish *Saurida tumbil* (Bloch) in the East China Sea and Gulf of Tonkin. Acta Oceanogr. Taiwan, 7: 134-145.

LIST OF SYMBOLS AND THEIR DEFINITIONS

F	instantaneous rate of fishing mortality, i.e. rate of mortality, of dimension time^{-1}, due to fishing gears, whether or not the killed fish are caught and landed
$F_{0.1}$	an arbitrary limit to fishing mortality, set at a level such that the marginal increase in yield per recruit is one-tenth of its value at the origin of the curve
K	growth parameter of the von Bertalanffy growth model (VBGF), of dimension time^{-1}, and expressing the rate at which L_∞ (or W_∞) is approached
L_∞	parameter of the VBGF, expressing the asymptotic length, i.e. the mean length the fish in a population or stock would reach if they were to grow indefinitely; often close to the length of very old fishes
W_∞	asymptotic weight, as above
M	instantaneous rate of natural mortality, i.e. rate of mortality, of dimension time^{-1}, due to all causes other than fishing
t_0	parameter of the VBGF, expressing the theoretical age the fish would have at length zero *if* they had always grown according to that equation; t_0 almost always takes non-zero, negative values, because small fish grow faster than predicted by the VBGF
t_c	mean age at which fish become liable to capture by a certain gear
t_{opt}	the optimum age at first capture t_c, estimated using Monte Carlo sampling
G	instantaneous rate of emigration, i.e. rate of emigration, of dimension time^{-1},
Z	instantaneous rate of total mortality, of dimension time^{-1}; with $Z = M + F$