REPORT ON THE SHRIMP AND GROUNDFISH WORKSHOPS CONDUCTED IN GUYANA (NOVEMBER 2003), BELIZE (DECEMBER 2003) AND TRINIDAD (JANUARY 2004)

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Caribbean Regional Fisheries Mechanism
Belize City
Belize

Contents

1. Introduction

Three workshops were conducted concerned with shrimp and groundfish resources in the Caribbean region. The main aim of the workshops was to carry out stock assessments on the shrimp and groundfish resources identified as most important by the participating countries. As well as stock assessments, some training was undertaken.

The individual stock assessment reports have a standard format. The format is attempting to serve two purposes: to make scientific reports easier to maintain as part of a management plan and to improve readability. In particular, management advice has been summarised to make it easier for managers to understand. The focus of the assessments is to provide scientific advice pertinent to making management decisions.

This set of workshops focused on those territories that exploit their shrimp and groundfish resources. These countries were Belize, Guyana, Jamaica, Suriname and Trinidad and Tobago. Haiti was to be involved in the workshop held in Belize, but was unable to send a participant.

2. Background

The Fisheries Component of the Integrated Caribbean Regional Agriculture and Fisheries Development (ICRAFD) Programme main objective is to extend the activities of the CARICOM Fisheries Resource Assessment and Management Program (CFRAMP) to include the Bahamas, Suriname, Dominican Republic and Haiti to ensure their integration into the regional initiative to improve the sustainable development and utilization of the fisheries resources of the region. The project will also extend benefits in fisheries surveillance and enforcement, marketing, processing, and training to all the CARIFORUM countries that have already benefited under the CIDA supported CFRAMP project.

Based on the recommendation of the joint meeting of the CFRAMP Shrimp & Groundfish Subproject Specification Workshop (SSW) and the Fourth Meeting of the WECAFC Ad Hoc Group on the Shrimp and Groundfish Fishery of the Guiana – Brazil Shelf in 1996, CFRAMP, in collaboration with the FAO, convened a series of Workshops in 1997, 1998, 1999 and 2000 to assess the status of the shrimp and groundfish stocks being exploited by the fishery along the Guiana -Brazil Shelf.

Following on the assessment activities of the Workshops, a Meeting of Fisheries Managers and Ministers of the WECAFC ad hoc Working Group of the Brazil - Guianas Shelf was convened in Port of Spain, Trinidad, from the 26 to 29 March, 2001, with the following objectives: to review the results of the stock assessment and bio-economic analyses obtained by the *ad hoc* Working Group on the Brazil-Guianas Shelf over the past five years; to inform decision-makers on the status of shrimp and groundfish resources in the Brazil-Guianas Shelf; to consider management measures to address the sustainable utilisation of the fishery resources in the Brazil-Guiana Shelf; and to identify appropriate strategy or strategies for the implementation of effective co-operation in fisheries research and management in the Brazil-Guiana Shelf.

Using the results and experience of the ad hoc Working Group of the Shrimp and Groundfish Fisheries on the Brazil-Guianas shelf, the CRFM-FORUM in 2003, approved the formation of the CRFM Shrimp and Groundfish Working Group (S&GWG) with the following objectives: to maintain the dynamics of the working group process which has contributed to capacity building in the participating countries, the development of preliminary standardised stock assessment methodologies for various species and species groups in the region and stock assessment reports for management purposes; to continue to create a more focussed approach to stock assessments in the countries and enable the participants to concentrate their efforts and obtain the necessary support at the national level; to continue to develop an information bank to support fisheries management decision-making; to provide a mechanism for interaction at the biological (stocks), technological (fleet), and human (experts) levels that provide a regional perspective of the various commercially important fisheries in the region; and to continue to provide a mechanism for the sharing of data and information for stock assessment and management purposes.

3. Purpose and Objective

In keeping with the above as well as with the undertaking of the countries to conduct more inter-sessional work that would be supported by in-country workshops to prepare detailed country reports on data collection, analyses, and other research activities on the management of their shrimp and groundfish fisheries prior to each S&GWG meeting, the CRFM Secretariat will conduct a series of in-country shrimp and groundfish stock assessment workshops with the aim of:

- reviewing existing catch, effort and biological data on shrimp and groundfish;
- based on the types of data available and the management objectives for the shrimp and groundfish fisheries, conduct appropriate analyses to obtain information for decision making and fisheries management;
- developing the skills of national staff in data analysis and report preparation.

In order to prepare for and conduct the workshops, the CRFM Secretariat will utilise the services of a resource assessment consultant with experience relating to small scale and industrial shrimp and groundfish assessments and management.

The objectives of the Consultancy were:

- to liaise and advise countries on the preparation of existing catch, effort and biological data on shrimp and groundfish for the workshops;
- based on the types of data available and the management objectives for the shrimp and groundfish fisheries of the respective countries, propose appropriate statistical and assessment analyses and assist Fisheries Officers in the analysis of the catch, effort and biological data during the workshops; and
- train Fisheries Officers in statistical analysis and stock assessment techniques as well as guide them in the preparation of the resulting resource assessment reports.

4. Belize Shrimp Fishery (*Penaeus notialis*)

4.1 Status of Stocks

The *Penaeus notialis* stock is severely overfished. This appears to have been true throughout the available catch and effort time series. It is possible that the state of the stock is not as bad as the assessment indicates as there are no observations from when the stock was lightly exploited. This can only be tested by applying a recovery programme.

4.2 Management Advice

Access to the fishery needs to be limited to 4 vessels. This is estimated as close to the optimum number of vessels.

A recovery programme needs to be implemented. Projections indicate that the stock should grow if a maximum of 4 vessels are given access to the resource. It will be important to monitor the recovery.

An *ad hoc* short closed season control can be used as part of the recovery programme for the stock and to maximise yields. With controls on effort, the closed season may become unnecessary. However, seasonal patterns in size composition may become apparent allowing closed seasons to be used to improve the exploitation pattern. Closed seasons can be implemented for 1-2 months based on a decision rule using observer length frequency samples. It is important to note that the closed season may invalidate the current catch-effort data time series, and therefore more detailed data should be collected on effort in future (e.g. days at sea).

4.3 Stock Assessment Summary

A biomass dynamics model was fitted to the available catch and effort data. It was used to estimate the optimal fleet size. The results indicated that the stock was only 7% of the unexploited stock size and well below the overfishing point (Figure 1). This indicated that the number of vessels given access should be limited to 4 to allow recovery of the stock. After applying this control, the stock should recover rapidly. This can be tested by reassessing after 3 years.

A catch-at-age model was fitted to the commercial size categories. This assessment was designed to look at trawl selectivity. However, it was considered less reliable as it depends on assumed growth and mortality which have not been researched.

A decision rule for temporary closure of the fishery was also developed. The rule uses sample length compositions taken from the trawl catches. The decision to close the fishery is taken if the expected gain in yield growth exceeds losses from mortality for the catch.

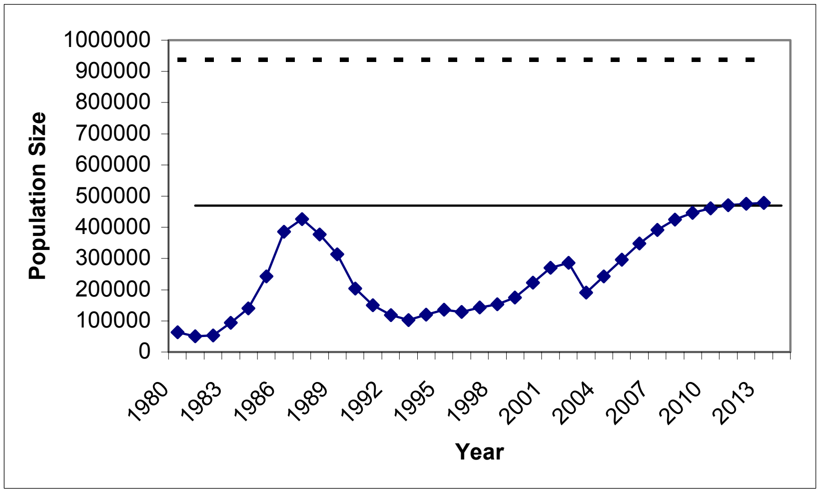


Figure 1 Estimated population size and projection assuming limited access for only 4 vessels. The population should recover back to the MSY level by 2011. The MSY and unexploited level (- - -) are also shown. Catches should dramatically increase during this period.

4.4 Special Comments

The measure of fishing effort is poor. This has not been an apparent problem in this stock assessment, however with changes in gear and operations, the current measure (number of vessels) may well prove inadequate.

Regular size compositions each month would allow development of a length-based model in future which may produce more reliable stock assessments. However, better growth and mortality information will also be required.

Information is required on maturity, fecundity and sex ratios to properly assess spawning stock size. This information will allow fine tuning of the exploitation pattern of the stock and improve economic returns.

4.5 Scientific Assessments

4.5.1 Objectives

- Determine the status of the shrimp stock and set the number of trawlers required to exploit the stock optimally.
- Develop a control rule to apply temporary closures.

4.5.2 Data Used

Name	Description
Landings and effort data per trip from trawlers	
Number of vessels	

operating and total landings weight	
Observer catch length compositions	

4.5.3 Assessment 1

Objective

Fit a simple biomass dynamics model to the catch and effort data to obtain the current state and estimate reference points for the fishery.

Method/Models

The logistic model was fitted to the available catch and effort data. Hilborn and Walters (1992) describe the general method for fitting non-equilibrium biomass dynamics models. Punt and Hilborn (1996) provide the methodology and Visual Basic routines for implementing the model fit in MS Excel.

In addition, a decision theory approach based on PFSA software (see PFSA 2003) was used to identify target and limit reference points. A brief summary of the method is presented here; details can be found in the software help file.

PFSA software was used to generate a probability distribution for parameters from a bootstrap frequency. Parameter values were drawn from this probability distribution and projected forward under different management controls. The management controls in this case are the number of vessels operating in the fishery.

The limit reference point was found as the effort point where the probability of overfishing exceeded 10%. Overfishing was defined as the state of the stock being below 50% of the unexploited stock size. The probability was defined as the chance that a stock would be in an overfished state when drawn at random from any of the projected states.

The target reference point was defined as the control which maximised the expected utility from the fishery. A simple linear price-cost function is used to represent utility. The global price-cost ratio function requires a single Price : Cost Ratio parameter (PCR) which weights the proportion change in catch relative to the proportional change in effort from the current situation such that:

$$U_t = \alpha c_t - f_t$$

If the score is proportional to profit, the weight might be calculated as the current value of the catch divided by the current catching cost: PCR = α = (Price*Catch)/(Effort*Cost). Clearly, the higher the PCR value, the more important changes in catch are relative to changes in effort. The default value is 1.0, so, for example a 10% increase in catch coupled with a 10% increase in effort will be viewed as the same as no change in either. In the absence of any economic information, the default PCR=1.0 was used.

Given a time series of projected catch and effort changes from the current catch and effort (c_t, f_t), the time series of utility can be obtained. The discounted mean preference score is calculated as:

$$U = \sum_{t=0}^{T-1} U_t e^{-\delta t} + \frac{U_T e^{-\delta T}}{1 - e^{-\delta}}$$

where U_t is the PCR score at time t and δ = discount rate. The discount rate was assumed to be global discount of 10% per year. Note the sum is continued until an equilibrium state is attained (i.e. c_t and f_t no longer change) at some time T, where after that the infinite sum can be calculated.

The target reference point was found by identifying the control which maximised the PCR score averaged over all projections.

Results

The general results suggest the stock is grossly overfished (Table 1) and has been overfished since the beginning of the time series. The current catches are well below the estimated maximum sustainable yield. The implication is that too many vessels have been given access to the resource and the shrimp population has been kept well below the state where it maximizes productivity.

The model fits the catch per unit effort data well despite the poor measure of effort (Figure 2; Figure 3), which is measured as the number of vessels registered for access to the resource. However this does indicate that no more than 4 vessels should be licensed.

The decision analysis indicates setting the number of vessels to 4 is appropriate. This should meet a reasonable precautionary principle (10% chance of overfishing in the long term) and therefore is also very likely to allow recovery of the stock.

Table 1 Results from fitting the biomass dynamics model. The model suggests the stock has been heavily overfished through the available data time series. Although the stock is very productive, it is small, so only a few vessels are required to harvest it. The MSY limit reference point for the stock size is 50%, implying the current 7% is too low. The implication is that the yearly catch should be kept below 132 thousand pounds to allow the stock to grow. The average catch over 2002 was 267 thousand pounds.

Comment: check units

Parameters			
Initial Stock State	r	B_∞	Q
0.067	0.87	938196	0.137

Reference Points				
MSY	Effort at MSY	F at MSY	Current Stock State (% Unexploited)	Current Sustainable Yield
204125.11	4.15	0.57	7%	132 514.09

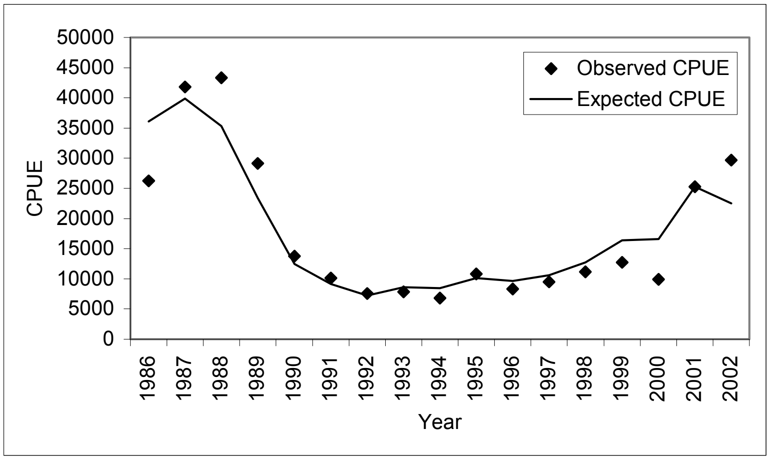


Figure 2 Observed and expected catch per unit effort (CPUE) for shrimp trawlers. The increase in CPUE suggests the stock size has been increasing 1998-2001.

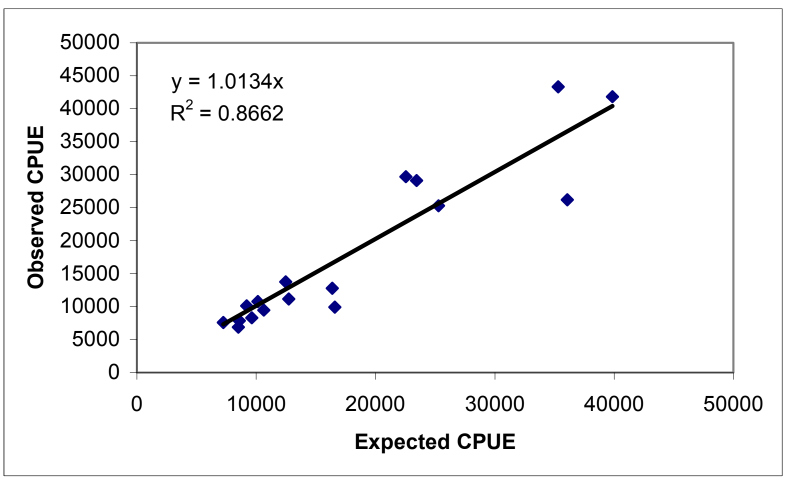


Figure 3 Observed and expected catch per unit effort (CPUE) for shrimp trawlers. The model explains about 87% of the variation in the observed CPUE.

The Bayesian analysis gave similar results (Table 2). The target reference point was not based on proper economic information and therefore may need revision when economic information becomes available. Nevertheless, it implies maximum returns will be obtained with between 3 and 4 vessels (Figure 4). A limit of 4 vessels will reduce the chance of overfishing to 10% (Figure 5). In fact, the probability of continued overfishing is lower than this as the fishery should be regularly reassessed. The 4 vessels should allow a recovery and there should be a clear increase in CPUE over four years reaching the 2002 landings level by 10 years. In contrast to 2002, the catch should be sustainable and landed by only 4 instead of 9 vessels.

Table 2 Results from Bayesian decision analysis giving target and limit reference points for the control. In this case the control is the number of vessels which should be licensed for access to the shrimp resource in the year.

Target Number of Vessels	Limit Number of vessels
3.52	4.01

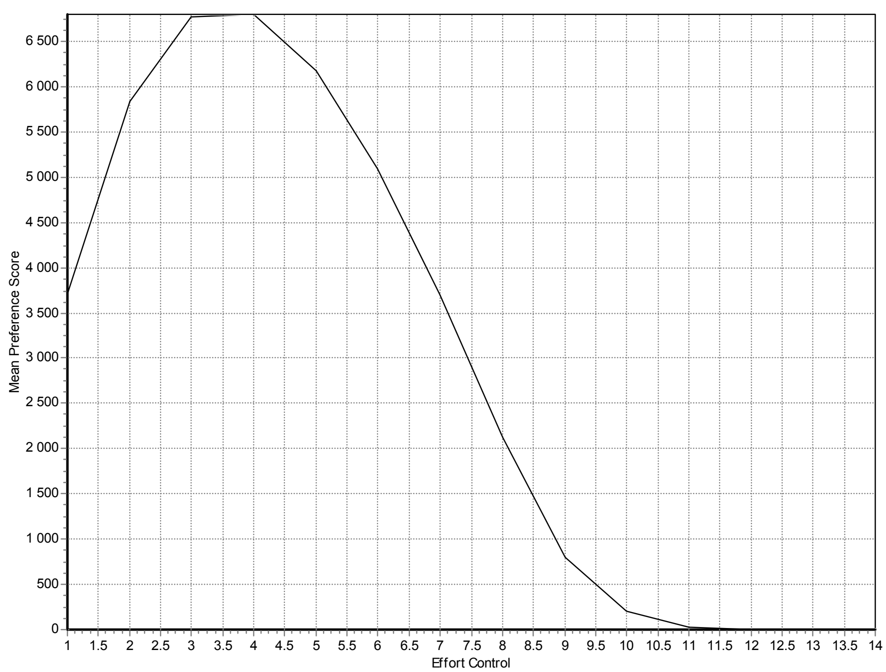


Figure 4 Relative net discounted benefits from the fishery as a function of effort (vessels given access). There is a clear maximum between 3 and 4 vessels.

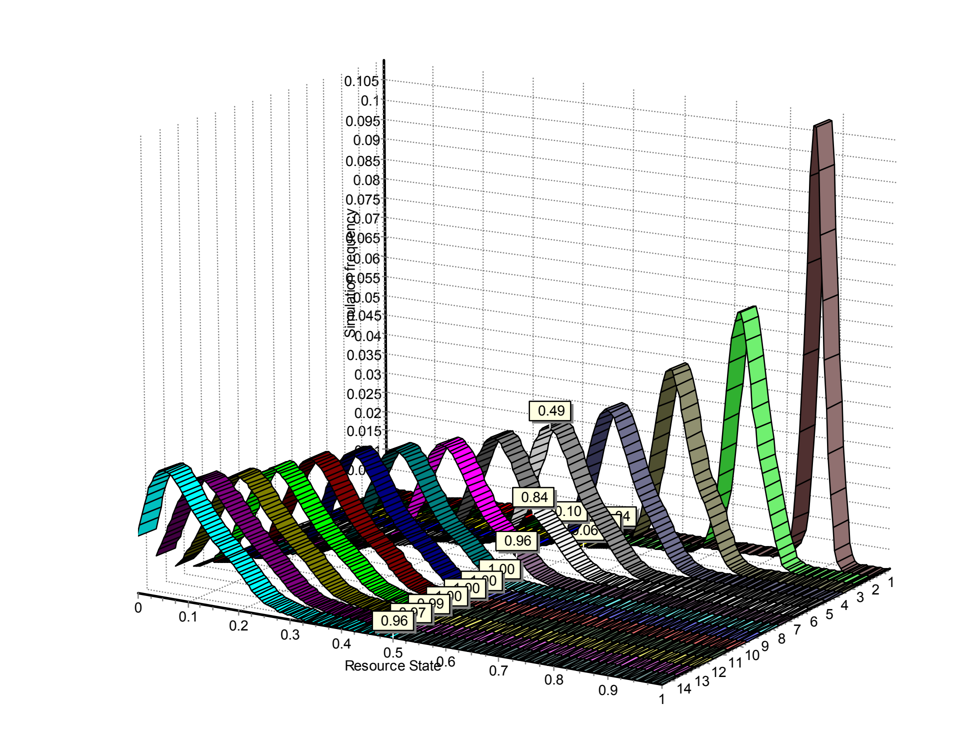


Figure 5 Probability distributions for the state of the resource with from 1 to 14 vessels given access. States below 0.5 (proportion of the unexploited stock size) are considered overfished. It is not possible to predict what will happen exactly, but it is possible to indicate what is likely to happen under different access arrangements using mathematical probability. Results range from certain overfishing for 8 vessels and above to certain not overfishing for 2 vessels or less. There is a 0.10 chance of overfishing with 4 vessels. As better information is obtained, this risk should decrease.

Discussion

This stock is clearly overfished. There are considerable potential economic benefits both to the fishing industry and to the public from reducing fishing effort in this fishery. It is expected that not only can the catch rate be increased substantially, but the total catch could probably be raised to a much higher sustainable level.

It is strongly recommended that only four vessels are given access to this fishery for a period of at least three years and the subsequent recovery is monitored. Clearly, catches will initially fall, but should rise rapidly over the next few years.

It is important that management costs are recovered and that a fair rent is paid for access to the resources. For example, the four vessels could pay a substantial fee for access and a tax could apply to landings or exports. The tax should reflect the catch rate, and therefore should increase as the recovery takes place. This will ensure not only that the proper rent is paid for access and the management service, but also reduce the chance of overfishing in future.

4.5.4 Assessment 2

Objective

Fit a catch-at-length model to the available commercial size category data to obtain estimates of selectivity for a yield-per-recruit model.

Method/Models

The catch size classes were converted to age using an age-length key developed from a growth model with parameters supplied from previous studies (Table 3). Thereafter a standard catch-at-age model was applied. It was fitted by minimising the squared difference between the population model log-fishing mortality and the expected fishing mortality using selectivity parameter for each age and the effort data.

Construction of the Age-Length Key

The age length key is a matrix of probabilities. Each cell in the matrix is the probability that a fish is within the age and size class defined. It is calculated from the joint log-normal distribution where the mean is given by the age at length from the deterministic von Bertalanffy growth model. The probability is then apportioned to discrete age and size classes by integration.

$$P(c) = \int_{a_c}^{a_{c+1}} \int_{s_c}^{s_{c+1}} N(a, s|\mu, \sigma)\, ds\, da \tag{1}$$

where $P(c)$ = probability that a shrimp is in class c with size and age lower and upper limits as s_c, s_{c+1}, a_c, a_{c+1} respectively. The mean log-length at age is given by the log of the von Bertalanffy growth curve:

$$\mu_a = \ln(L_\infty) + \ln\left(1 - e^{-K(a-t_0)}\right) \tag{2}$$

where a is the age, and L_∞, K and t_0 are the standard von Bertalanffy growth parameters. Other probability distributions besides the log-normal could be used, but the log-normal is convenient and assumes the variance in length increases with age, which is likely.

The proportion of fish of a particular age in any length class were calculated as the difference between the cumulative normal distribution of the two log-length class boundaries. This function is available in MS Excel (*NormSDist((x-μa)/σ)*). This represents the inner integration in equation (1). A numerical approximation to the integral (Simpson's rule) over one year's aging was applied to approximate the outer integral in equation (1). So the proportion of cohort age a in length class i (p_{ai}) was calculated as:

$$\begin{aligned} p_{ai} = \tfrac{1}{2}\big[&\left(\mathrm{N}(\ln(l_{i+1}); \mu_a, \sigma) - \mathrm{N}(\ln(l_i); \mu_a, \sigma)\right)/3 \\ &+ \left(\mathrm{N}(\ln(l_{i+1}); \mu_{a+0.5}, \sigma) - \mathrm{N}(\ln(l_i); \mu_{a+0.5}, \sigma)\right) 4/3 \\ &+ \left(\mathrm{N}(\ln(l_{i+1}); \mu_{a+1}, \sigma) - \mathrm{N}(\ln(l_i); \mu_{a+1}, \sigma)\right) /3\big] \end{aligned} \tag{3}$$

where $\mathrm{N}(\,)$ is the cumulative normal distribution, l_i is the lower limit for length class i. The probability that a shrimp is in any particular age group, given its length class, is calculated as the probability (equation 3) normalized by the sum of probabilities over the age groups for this size. That is, we know the shrimp is in this size group, but the age group remains unknown. The rows of probabilities for each length class can be combined into a matrix. A row of catches at length can then be converted to catches at age by matrix multiplication:

$C_{lt}\,P = C_{at}$ (4)

where C_{lt} = Catch-at-length row vector for a particular month, P= the age-length key matrix which has rows summing to 1.0, and C_{at} = the catch-at-age row vector resulting from the conversion.

The growth model parameters, weight-length conversion parameters and natural mortality were obtained from previous workshop reports.

Comment: Need a reference for where these came from.

Table 3 Parameters used for the catch-at-length model. The growth model was used to convert length to age. L_∞ (mm) was estimated as part of the model. All other parameters were fixed at the values shown. These are the approximate appropriate values expected for this species based on its life history. The Sigma (Coefficient of variation) measures the variability of length from the mean given by the von Bertalanffy growth equation.

Growth Model Parameters				Natural Mortality
K (Month^{-1})	**L_∞ (mm)**	**T_0 (Months)**	**Sigma (CoV)**	**M (Month^{-1})**
0.2	152.71	0	0.1	0.2
Weight-Length Conversion				
a	**b**			
0.00000876	3.064			

Fitting the Population Model

A separable VPA approach is used to fit the catch-at-age model. Fitting takes place at two levels. Firstly, the population model is fitted using the available catches assuming they and the natural mortality rate are known exactly. This leaves a single parameter to fit, which in this case is the initial recruitment rather than the “terminal F”, although the result is the same. At the higher level the selectivity parameters are fitted to the “observed” fishing mortality from the population model using the observed fishing effort.

$$
\begin{aligned}
P_1 &= P_0 e^{-M} - C_0 e^{-0.5M} \\
P_2 &= P_1 e^{-M} - C_1 e^{-0.5M} = \left(P_0 e^{-M} - C_0 e^{-0.5M}\right) e^{-M} - C_1 e^{-0.5M} \\
&= P_0 e^{-2M} - C_0 e^{-1.5M} - C_1 e^{-0.5M} \\
&\vdots \\
P_a &= P_0 e^{-aM} - \sum_{t=1}^{a} C_{t-1} e^{-(t-0.5)M}
\end{aligned} \tag{5}
$$

and in natural logarithm terms

$$\Pi_a = Ln(P_a) = Ln\left(e^{-aM+\Pi_0} - \sum_{t=1}^{a} C_{t-1} e^{-(t-0.5)M}\right) \tag{6}$$

$$LnF_a = Ln\left(\Pi_a - \Pi_{a+1} - M\right)$$

The aim is to find an initial population that will minimise the squared difference between the log fishing mortalities from the population model and the log fishing mortalities estimated from a selectivity curve and effort data.

$$L(\Pi_0)=(Ln(q_a f_t)-LnF_a)^2 \qquad (7)$$

$$\frac{dL}{d\Pi_0}=-2(Ln(q_a f_t)-LnF_a)\frac{dLnF_a}{d\Pi_0} \qquad (8)$$

and the second derivative can be approximated by

$$\frac{d^2L}{d\Pi_0{}^2}\approx 2\left(\frac{dLnF_a}{d\Pi_0}\right)^2 \qquad (9)$$

$$\frac{d^2L}{d\Pi_0{}^2} = \{\Pi_0\}_{old} - \left[\sum_{a=0}^{A}(Ln(q_a f_t)-LnF_a)\frac{dLnF_a}{d\Pi_0}\right]\left[\sum_{a=0}^{A}\left(\frac{dLnF_a}{d\Pi_0}\right)^2\right]^{-1}$$

$$P_a\left(1-e^{-Z_a}\right)=\frac{C_a Z_a}{F_a}=C_a\frac{M}{F_a}+C_a \qquad (10)$$

and, again based upon Pope's approximation,

$$P_a\left(1-e^{-Z_a}\right)\approx P_a\left(1-e^{-M}\right)-C_a e^{-0.5M} \qquad (11)$$

and by substitution and rearranging, we get:

$$C_a\left(1+\frac{M}{F_a}+e^{-0.5M}\right)+\left(1-e^{-M}\right)\sum_{t=1}^{a}C_{t-1}e^{-(t-0.5)M}=P_0\left(e^{-aM}-e^{-(a+1)M}\right) \qquad (12)$$

Given the fishing mortality at each age (F_a), the left hand side is determined for each age in a cohort and can be used as the dependent variable in a regression. The recruitment for the cohort (P_0) can be estimated using least-squares as:

$$\hat{P}_0=\frac{\sum_a\left(C_a\left(1+\frac{M}{F_a}+e^{-0.5M}\right)+\left(1-e^{-M}\right)\sum_{t=1}^{a}C_{t-1}e^{-(t-0.5)M}\right)\left(e^{-aM}-e^{-(a+1)M}\right)}{\sum_a\left(e^{-aM}-e^{-(a+1)M}\right)^2} \qquad (13)$$

This estimate is then further refined using a Newton-Raphson algorithm and the catch equation rather than Pope's approximation (See Appendix 1 for the visual basic routine).

Link Model

The link model connects the population model to the observations, in this case fishing effort. A separable VPA model was used to divide up the sources of fishing mortality into the exploitation rate (effort) and selectivity at age. The expected effort can be calculated from the model as:

$$E(\ln(f_t))=\ln(F_{at})-\ln(S_a) \qquad (14)$$

where S_a is the selectivity at age. The model can then be fitted by minimising the squared difference between the observed and expected log-effort, thereby obtaining the log-normal maximum likelihood estimates. The results should be very similar to fitting *ln(CPUE)* to the log population size. The fishing mortality model should be better where the fishing mortality (i.e. effort) is very high within a month, but in this case the differences are trivial and the results should be very similar to previous models.

The model was fitted in a spreadsheet. The least squares (log normal maximum likelihood) estimates for selectivity can be found directly through calculation. The selectivity is simply the difference between the average log fishing mortality (at age) and the average log effort for each age. The remaining parameters were found using Solver add-in software in MS Excel.

The model was fitted excluding an outlying month, June 1999, which appears to have unusual CPUE data. These and other months in the time series need to be checked. In particular, catches are assumed accurate in the model and care should be taken that all removals from the population are recorded and used.

Results

The estimated selectivity increases in older shrimp (Figure 6). This leads to a maximum yield at a relatively low level of effort (Figure 7). The current level of effort is above this limit reference point (Table 4), suggesting growth overfishing is taking place.

Although it was not fully explored in this assessment, the results are very sensitive to choice of the various growth parameters (Table 3). The asymptotic length was fitted, but the remaining parameters were fixed as there was not enough information in the data to fit them all.

Table 4 Target and limit reference points for trawl fishing based on a yield-per-recruit analysis using the estimated selectivity. Effort, in the form of trips in each month, is used as a proxy for fishing mortality. The target is based on the *ad hoc* reference point, $F_{0.1}$. The maximum yield per recruit is obtained at F_{msy}. The current effort level lies above the MSY point, suggesting yield-per-recruit could be increased by reducing the number of trips. There are potential significant increases in returns to the costs of effort and investment. The impact on recruitment has not been assessed in this analysis.

	$F_{0.1}$	$F_{current}$	F_{msy}
Trips	0.55	2.86	2.18
Yield per recruit (g)	15.13	23.31	23.77

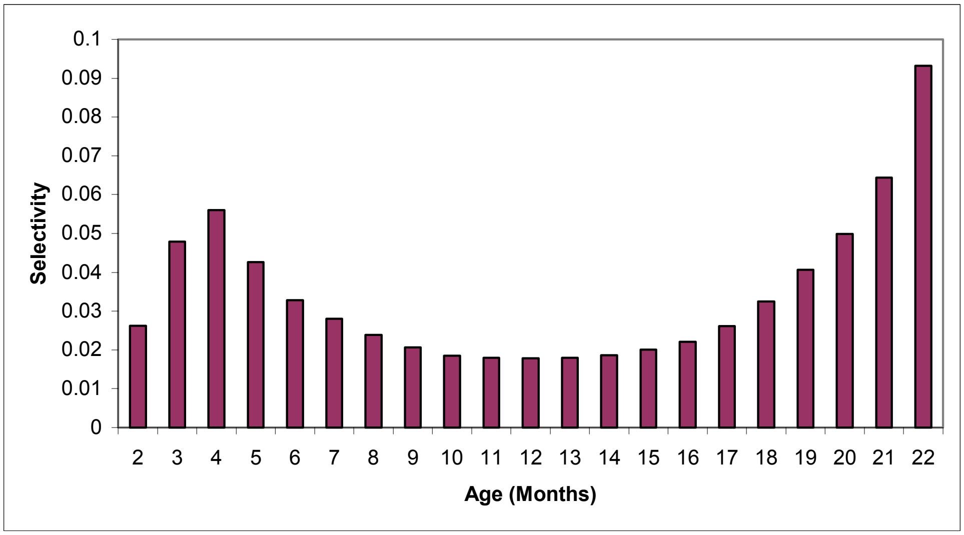


Figure 6 Selectivity relating fishing effort to fishing mortality at each age. Notice that selectivity increases towards older shrimp. This implies these age groups are more common in the catches than expected. However, the results are dependent on small amounts of data and sensitive to small changes in natural mortality and growth parameter values.

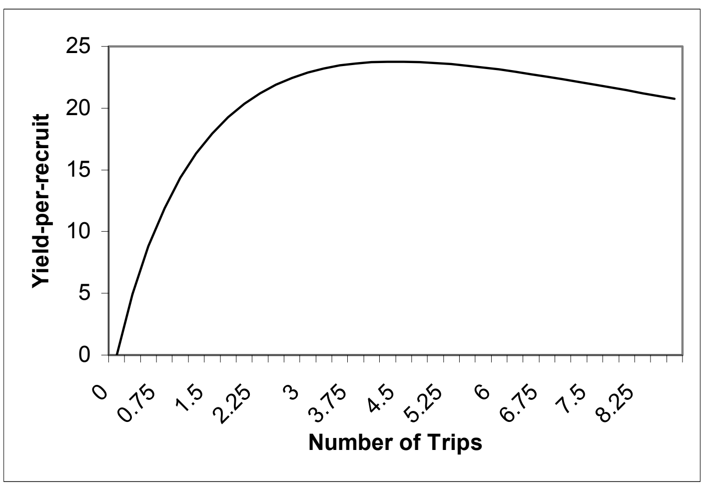


Figure 7 Yield-per-recruit for shrimp based on the estimated selectivity.

Discussion

The selectivity curve indicates that older animals are more common in the catches than expected. The resulting increase selectivity towards older animals encourages leaving shrimp to grow and catching them when they are older. That is the advice depends very much on selectivity of these older shrimp, which is unreliable.

Importantly, the spawner-per-recruit has not been addressed in this assessment, and therefore F_{MSY} may not be an appropriate reference point.

The result from this analysis broadly supports the biomass dynamics assessment. However, the simpler biomass dynamics model approach (Section 4.5.3) is preferred to this assessment. As with all such size structured assessments, there is a strong dependence on the supporting growth and mortality models. It is likely that estimates of reference points are inaccurate and will need to be reassessed in future if this approach is used.

4.5.5 Assessment 3

Objective

Develop an empirical decision rule to close or open the fishery based on a length composition sample taken from trawl catches.

Method/Models

The aim is to assess whether a closed season should be implemented based upon a sample taken from trawl catches. The approach is to look at actual size compositions in the catches and decide whether overall it would have been better to leave the animals in the sea longer to grow rather than catch them now. The rule is relatively independent of recruitment, but would reflect current catch composition and would change in relation to these effects. Hence, a strong recruitment might well lead to advice to reduce fishing mortality.

For any particular size composition, the net gain in leaving the animals in the sea can be derived from the growth and mortality models:

$$S_p = \sum_i \left(\int_{t=t_i}^{\infty} W_{it} F e^{-(F+M)(t-t_i)} dt \; - \int_{t=t_i+t_p}^{\infty} W_{it} F e^{-(F+M)(t-t_i)} dt \right)$$

where S_p is difference in the potential yield of the length composition sample between catching now and closing the fishery for t_p months. The weight of the i^{th} shrimp in the catch (sample) is W_{it}, given its age is t_i and natural mortality plus the discount rate is M. The score, S_p, is summed over the sample. A positive number will indicate that overall greater gains would be made by leaving these shrimp in the sea and catching them later.

For the von Bertalanffy growth model, the yield equation for each shrimp in the catch composition becomes through integration:

$$\int_{t=t_i}^{\infty} F W_{it} e^{-(F+M)t} dt \;\left[e^{-M t_p}\right] = \int_{0}^{\infty} F W_{\infty} \left(1 - e^{-K(t+t_i)}\right)^3 e^{-(F+M)t} dt \;\left[e^{-M t_p}\right]$$

$$= F W_{\infty} \left(\frac{1}{F+M} - \frac{3e^{-Kt_i}}{F+M+K} + \frac{3e^{-2Kt_i}}{F+M+2K} - \frac{e^{-3Kt_i}}{F+M+3K} \right) \left[e^{-M t_p}\right]$$

$$t_i = -\ln\left(1 - \frac{L_i}{L_\infty}\right) \Big/ K + t_0 \left[+t_p\right]$$

where the t_p term is added to the second yield integral only. Although not done in this model, the method is easily adapted to changes in selectivity with age or length and could be improved with, for example, probabilistic models of growth and mortality to take full account of risks (Medley 1998).

Table 5 Parameters used in the decision rule. These must be provided and they will clearly influence the result. The growth model refers to carapace length. The asymptotic weight (W_∞) is not necessary. The natural mortality and discount rate have the same effect. The projection time should be set to the planned closure. Closure is much less likely the larger the projection time is. The fishing mortality is set according to the number of trips to be undertaken (the number of vessels operating in the fishery) derived from the assessment (Section 4.5.4).

L_∞	K	t_0	b
80	0.2	0	3
F (per vessel)	**M (Month^{-1})**	**t_p (closure)**	**Discount (Month^{-1})**
0.060	0.25	1	0.0126

Results

The decision rule is sensitive to the choice of parameters. It is possible to set reasonable parameters and never get a sample which would allow a fishery to open or to close depending on parameter values. Therefore it seems reasonable to choose parameters which show reasonable open/close behaviour and then test that the rule works as expected.

This was done using three sample length compositions (Figure 8). Two frequencies show a significant peak around 30mm CL, while the other is more evenly spread. Although the sample in March has a peak at the smallest size, the greater spread to the larger sizes makes the gains from the closed season much lower. Hence according to the decision rule, March remains open over a wider range of options compared to the other months (Table 6).

Table 6 The decision on 1 and 2 month closures for different numbers of vessels for each test sample. The values of interest are where a closed season decision changes from closed to open for a closure of 1 and 2 months respectively. This indicates that a first sampling should indicate a closure for one month and the decision based on repeated sampling at the end of the month should indicate opening the season if the decision rule works.

Number of Vessels	March		July		September	
	1	**2**	**1**	**2**	**1**	**2**
1	Open	Open	Open	Open	Open	Open
2	Open	Open	Close	Open	Close	Open
3	Close	Open	Close	Close	Close	Close
4	Close	Close	Close	Close	Close	Close

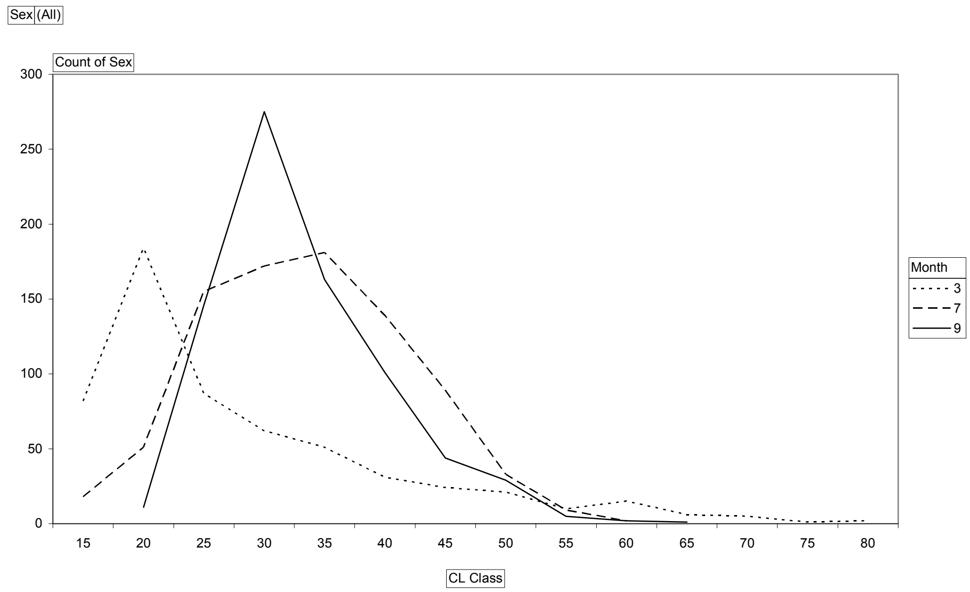


Figure 8 Sample length composition of shrimp taken in March, July and September 2003. Although there is a peak at a smaller size in March, the size composition is much more evenly spread. July and September show the same pattern.

Discussion

It is recommended that the projection is kept short and set to a time to the next sampling and reassessment. Clearly the sample should be measured and entered on the computer very quickly to be able apply the rule.

The method should be tested by applying the rule and checking whether the gain in growth can be detected after a closure. This can be done by checking the projected size composition from the first sample approximately equals that from a sample taken a month later.

The closure should not be seen as a replacement for reducing effort. Maintaining such a system is difficult and expensive compared to simply reducing the number of licences.

4.5.6 Management

Effort should be reduced to allow stock recovery. The assessment suggests the stock is severely overfished. This can only be tested by reducing effort and checking whether the stock grows at the expected rate. The best level of effort appears to be reached by giving access to 3-4 vessels.

As well as reducing effort, it is recommended that a decision rule is adopted to close the fishery to improve the size structure of the catches. If effort is reduced, it may become unnecessary to close the fishery at all. However, as an interim measure the closure rule should be implemented. The rule itself should automatically take account of improvements due to effort reduction. It may also prove valuable by allowing management to account for seasonal variations in recruitment.

Catch and effort data collection should be improved. Vessels should be required to complete log-books recording the date and time for the start and finish of each haul and the catch taken. This new data would compliment the current observer programme.

5. Guyana Bangamary (*Macrodon ancylodon*)

5.1 Status of Stocks

There is no clear indication as to the state of the bangamary stock. There is no evidence of overfishing as there are no trends in CPUE and mortality estimates are not large relative to natural mortality. This is partly because there is no directed fishery at this species.

5.2 Management Advice

Although there is no evidence of overfishing overall, there is concern that Chinese seine takes immature bangamary. Discards may be high. With only limited information, there is a risk this species is being overfished.

Reduction of bycatch and in particular discards should be a priority in this fishery. This might be achieved by changes to mesh size and controlling where vessels fish. More information on selectivity would be required for this.

Management of this stock should form part of a multi-species adaptive management system. Management of bangamary as a single species is not possible as it is largely caught as bycatch.

5.3 Stock Assessment Summary

There is no consistent overall trend in CPUE during 1995-2003. CPUE is often used as an indicator of stock size, so there is no clear evidence that the stock size has changed over this period.

5.4 Special Comments

There are inadequate data to do full stock assessments. However the data can be used to indicate general trends and status of the stock.

5.5 Policy Summary

There is no policy for development of a bangamary fishery. The species is caught as by-catch in several fisheries. Catches of immature fish needs to be discouraged to reduce the chance of reducing the spawning stock to unsustainable low levels.

5.6 Scientific Assessments

5.6.1 Background

The artisanal fishery is made up of approximately 1300 vessels ranging in size from 6 to 18 metres. Vessels are powered by inboard or outboard engine or sails (Chinese seine & pin seine). It is an open access fishery to all Guyanese.

Bangamary is mainly caught by chinese seine, gillnet and trawl (Figure 9). Chinese seine target white-belly shrimp, but also take immature bangamary, butterfish, catfish and other

Comment: State what each of these vessels are targeting finfish as bycatch. A 1997 boat census found 373 vessels. Juvenile fish is caught and then discarded. The chinese seine net is 16 m long by 4 m wide and mesh size 1-6 inches. They usually fish one mile from shore, and each trip last from 6 to 12 hours. The crew consists of two to four persons. Operators are required to have a fish pen permit for each pen.

A 1997 boat census found 441 gill net vessels spread along the entire coast of Guyana. Vessels may spend 2-3 days at sea or land their catch every 12 hours. The crew consist of 4 to 6 persons and the net mesh size is usually from $1\frac{1}{4}$ to 2 inches.

Comment: If they are accounting for all the gillnet vessels here, the ones going further out for grey snappers and gillbackers have bigger mesh sizes??.

The industrial trawl net fishery also makes significant catches of bangamary as bycatch.

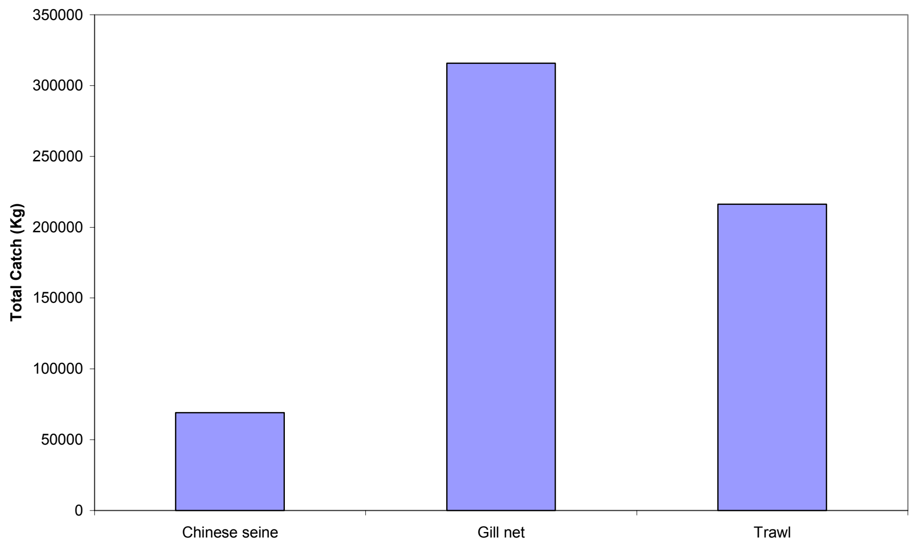


Figure 9 Total catch of bangamary by the main gear types in Guyana based on catch and effort estimates. The results suggest most catches are taken by gill net and trawl which tend to select older fish. There is also a significant by-catch of immature fish by Chinese seine.

5.6.2 Objectives

Conduct a preliminary analysis to estimate fishing mortality or other indicators as to the general state of the fishery.

5.6.3 Data Used

Name	Description
Trip interview programme	Trip catch and effort sampling for 1995 – 2003 provides total catch and effort. All landings are monitored.
Catch sampling	Samples from landings of the length frequency taken in 2000.

Comment: Are samples raised

Comment: Check year

5.6.4 Assessment 4

Objective

Monitor the CPUE for the main gears and attempt fitting a stock assessment model.

Method/Models

The CPUE was calculated from the landings sampling as the catch per trip. There were adequate data for two gears, chinese seine and gill nets. All chinese seine and gill net type gears were combined to produce two groups for the data representing these gears.

The logistic biomass model (Schaefer) was used to see whether a biomass dynamic biomass model could be used for stock assessment.

Results

There is no overall trend in CPUE (Figure 10). Gill net CPUE appears to have been increasing over much of the period. This may be due to changing fishing practice, increasing biomass due to stronger recruitment or recovery from past overfishing. The lack of a similar trend in chinese seine makes the former quite likely.

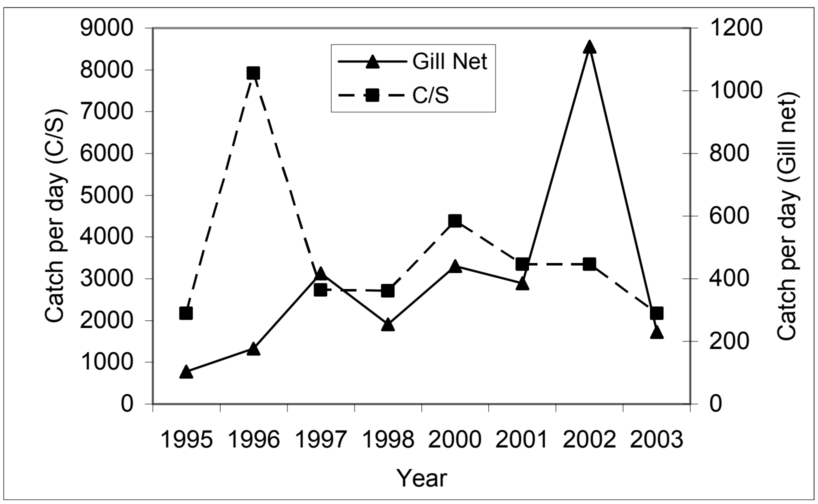


Figure 10 Catch per day for Chinese seine (C/S) and gill net gears.

The lack of trend or fluctuations in CPUE time series means the logistic model cannot be fitted to these data.

Discussion

It is not possible to estimate the state of the stock without more information, but without a clear downward trend, it does appear that the stock is stable and not in immediate danger of further depletion.

5.6.5 Assessment 5

Objective

Estimate the mean total mortality for two gear types.

Method/Models

A length converted linearized catch curve (see Sparre and Venema 1992, pg 132) was used with length frequency sample data for two gears. The slope of the curve should be equal to the total mortality if the mortality rate is constant and gears are not selective. The initial increasing trend in the catch-at-length was ignored as it is assumed to be affected by selection. The catch curve was fitted using least-squares.

Results

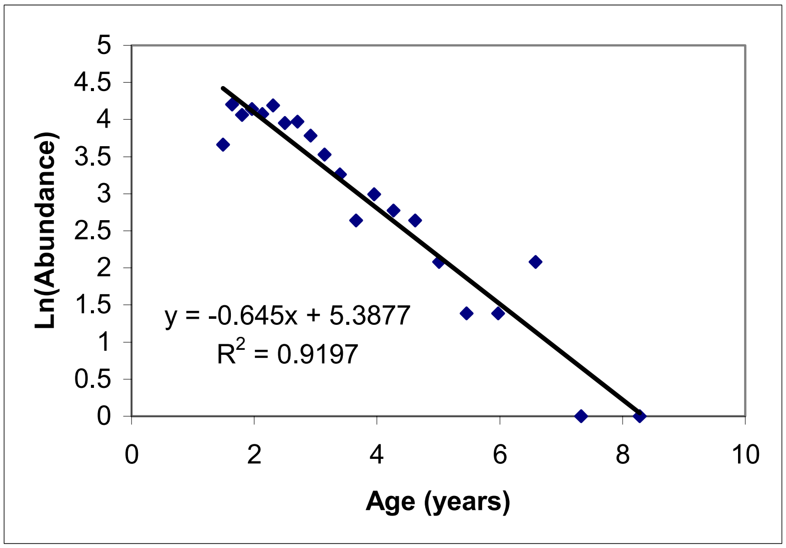


Figure 11 Length-converted catch curve for chinese seine vessels

Analysis of chinese seine catches indicates a total mortality of 0.65 $year^{-1}$ (Figure 11). Chinese seine tends to catch small and hence young bangamary, so it is possible the gear tends to select preferentially these smaller animals which will lead to overestimate of mortality.

A similar analysis of the trawl bycatch data estimates mortality to be a much lower value of 0.35 $year^{-1}$ (Figure 12). Trawls select older fish, but once fully selected, selection probably does not change making this a reasonable estimate.

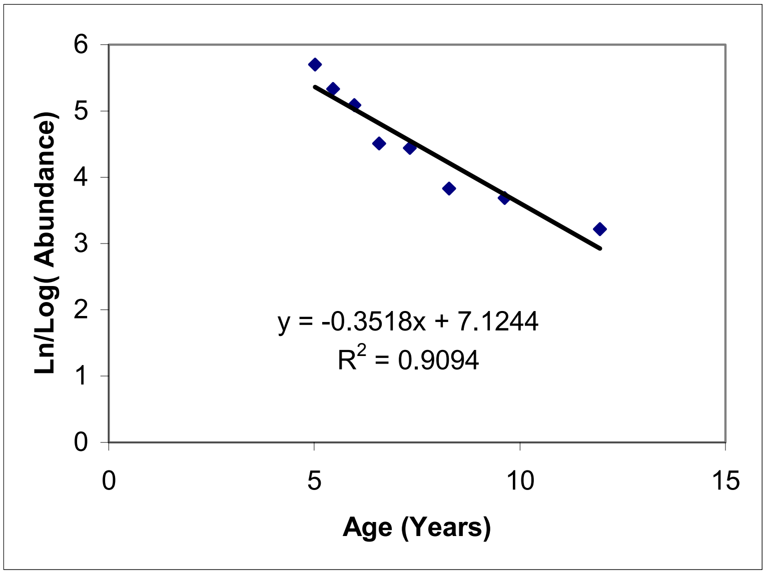


Figure 12 Length corrected catch curve for trawl over a four year period (2000 – 2003).

Discussion

It is not clear how accurate mortality estimates are. There are no estimates of natural mortality for this species, so it is not possible to obtain indications of fishing mortality. Nevertheless, the low total mortality for trawl and presence of older fish in the catches indicates no immediate cause for concern.

5.6.6 Management

There are no clear recommendations for management. Estimates of mortality are not excessive and larger fish are still present in the catches. Greater expansion in fishing effort, particularly of chinese seine, could threaten this stock.

Adaptive management proposals to obtain more information on this species are recommended. For example, monitoring stock recovery in a closed area would give information on the potential recovery of this stock.

Studies of this species should form part of a multi-species fishery assessment.

6. Guyana Red Snapper (*Lutjanus campechanus*)

6.1 Status of Stocks

The status of the red snapper is unclear as further data on the production of the fishery is needed (i.e. all species as well as southern red snapper). However, there is a worrying recent decrease in recruitment (CPUE) which could be caused by overexploitation.

6.2 Management Advice

It is recommended that effort is controlled and decreased. The recent decrease in recruitment (CPUE) and the small size composition of the catch indicates that the fishing effort could be safely reduced with considerable chance of benefit. It is not clear how much the reduction should be. The assessment suggests a target reference point of about 40% of the current effort. A more realistic reduction to 80% over 3 years will allow future assessments to adjust the target when more information comes available.

6.3 Stock Assessment Summary

A catch-at-age model was fitted to the available catch data for this species alone. Catches were allocated to each length class using length frequency data. The assessment allowed selectivity and recruitment to be estimated from 1996-2002.

The selectivity appears to favour young fish, although this may be an artefact of missing catches from the analysis. The resulting yield-per-recruit suggests that the current effort is well above the target (optimal) effort, but below the limit reference point (Table 7). Recruitment increased and declined during the period (Figure 13), following changes in CPUE. Both indicators suggest a decrease in effort is appropriate to conserve the stock and improve economic benefits from the fishery.

Table 7 Yield per recruit reference points for red snapper based on the catch-at-length model. While the target ($F_{0.1}$) suggests a decline in effort would benefit the fishery, the current effort lies below the limit (F_{msy}).

	$F_{0.1}$	$F_{current}$	F_{msy}
Effort (days at sea)	176	461	1150
Yield (g)	568.5	859.2	943.9

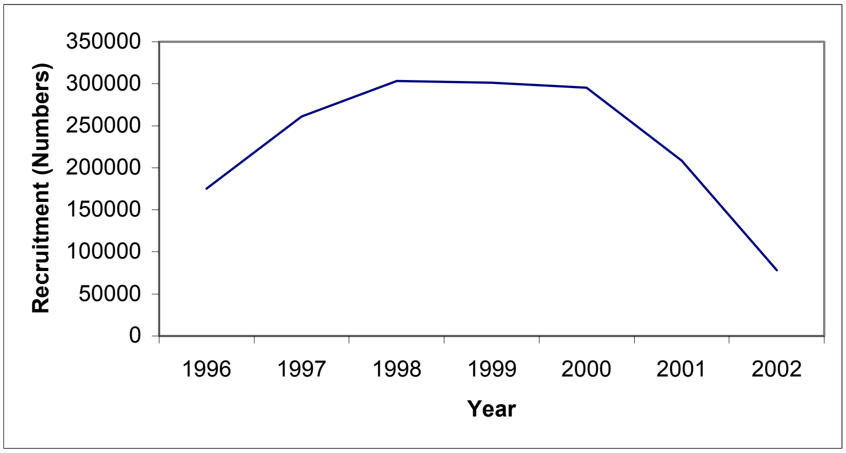


Figure 13 Recruitment estimated from the catch-at-length model. The recruitment follows approximately the catch-per-unit-effort trend.

6.4 Special Comments

All catches need to be assembled for this multispecies, multigear fishery. Total catch data by gear is required on the other species, namely vermillion snapper, lane snapper, mutton snapper and silk snapper.

6.5 Policy Summary

According to the Draft Marine Fishery Management Plan for Guyana (1992), the management objective for this Fishery is to optimise production for the export and tourist markets which are developing. The proposed management strategy was to limit the entry of vessels into this fishery until suitable data was collected and analysed. The suggested number of vessels was 30.

6.6 Scientific Assessments

6.6.1 Background

The red snapper fishery of Guyana consists of a semi-industrial fleet. Fishing occurs mainly on the continental slope.

In 1995 there was a decline in the local red snapper fishery; the highest number of boats was about eleven (11), but that dropped to seven (7) in 1997. The decline was because some operators had reverted to using the gillnet polyethylene (drift seine) as they did not have as efficient technology for catching snapper as their counterparts in Trinidad & Tobago and Venezuela.

Since then there has been an expansion of the fleet over the years. Guyana now has a licensed fleet of seventy five (75) vessels; forty (40) are Venezuelan owned and leased to Royal Caribbean Inc. and thirty five represent the local fleet, which has, expanded from six (6). Thirty five Guyanese vessels use pots and traps, the remaining forty vessels use hooks and line. The average fishing trip is 14 – 29 days at sea.

Management Units for the snapper/grouper fishery should be considered at two levels. The first relates to the distribution of juveniles over the continental shelf and to the slope/edges and the other to the shared nature of the stocks on the Guianas-Brazil shelf, with the data (FAO/NORAD Survey 1988) suggesting overlap of the lutjanid stocks with Suriname to the south and possibly with Venezuela to the north.

6.6.2 Objectives

Determine the status of the red snapper fishery and identify target and limit reference points for fishing effort.

6.6.3 Data Used

Name	Description
Catch and effort	Log sheets submission with catches per day for hand line vessels for 1996 to 2003. Catch and effort data taken from the ongoing landings sampling programme for the Offshore Industrial and Inshore Artisanal Fisheries for the pot and trap vessels from 2001 to October 2003.
Length frequency data	Length frequency data taken from the ongoing landings sampling programme for the offshore industrial and inshore artisanal fisheries for the pot and trap vessels from 2001 to October 2003.

6.6.4 Assessment 6

Objective

Estimate fishing mortality and selectivity suitable for a simple yield-per-recruit assessment.

Method/Models

A catch-at-length method was used. An age-length key was constructed using the von Bertalanffy growth model with fixed parameters and a coefficient of variation of 10% to convert length to age (Table 8). Total catches at each length are necessary for the assessment, and these are converted to catch-at-age used in a standard cohort analysis. These have been estimated from the catch sampling, the total catch weight and the mean weight at each length from the length-weight conversion. The population model was fitted assuming catches are exact and minimising the squared difference between the model expected log-effort and the observed log-effort. See the section 4.5.4 for details.

Table 8 Parameters for Von Bertalanffy growth model, length weight conversion and natural mortality used in the assessment to convert length to age and in the yield-per-recruit model.

Growth Model Parameters			
K ($year^{-1}$)	L_∞ (cm)	T_0	CoV
0.106	94.26	0	0.1
Length-Weight Conversion		**Natural Mortality**	
a	b	M	
0.0141	2.99	0.25	

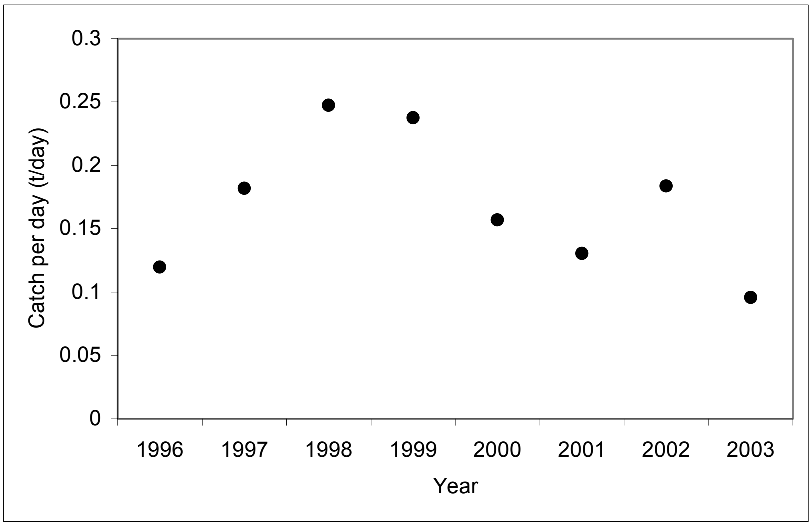


Figure 14 Catch per unit effort in tonnes per day at sea for all fleets. There has been a decline in catch rates since 1998.

Results

It should be noted that the first three year's length frequencies are very different to the later samples (Figure 15). This cannot be easily explained, and could be an artefact of the data collection programme, making the assessment less reliable.

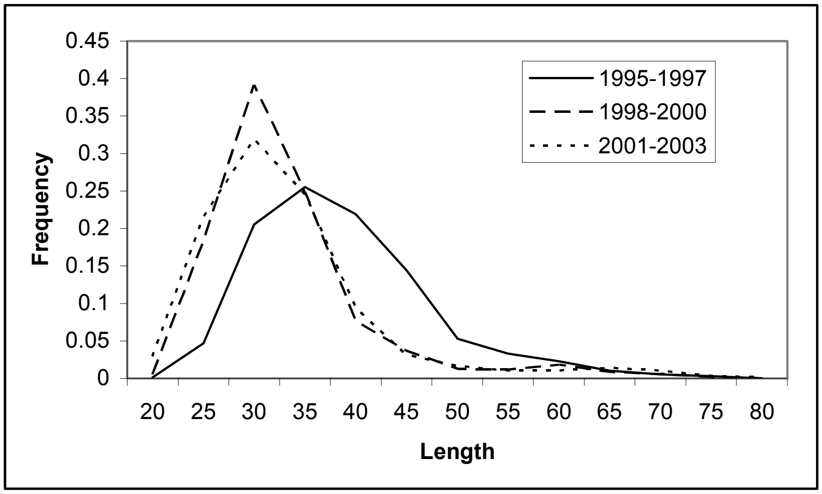


Figure 15 Size frequency data collected 1995-2003 grouped into tri-annual samples. The period 1995-1997 indicates a different pattern to the next 6 years. This distinctly different pattern cannot be explained with the available information, and could an artefact of the sampling programme.

The selectivity indicates 3.5 - 5.5 year olds are more vulnerable to the fishery (Figure 16). There is quite heavy exploitation of these ages before they are fully grown. Recruitment appears to be following the CPUE trend with a decline in the last few years (Figure 17).

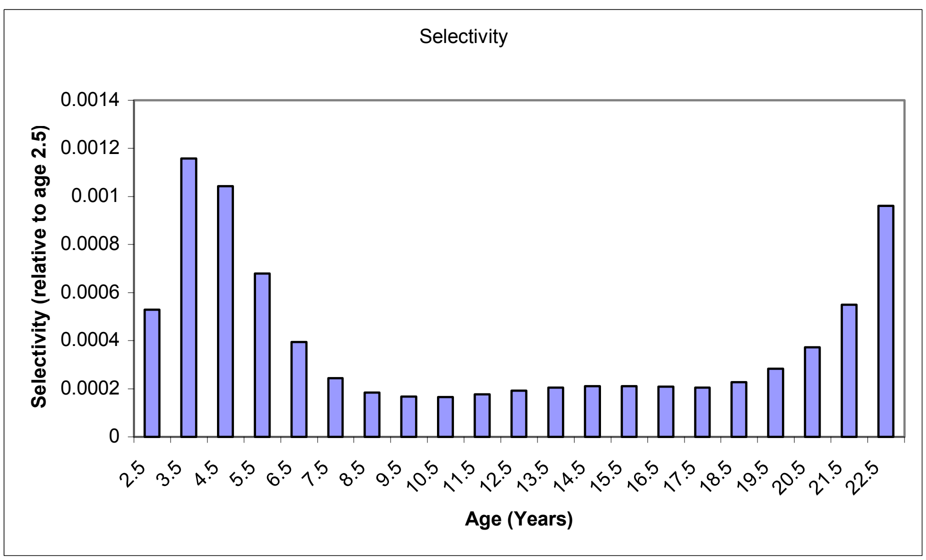


Figure 16 Selectivity for current gears estimated from the catch-at-length data. The increasing selectivity for later ages is reliant on very small sample.

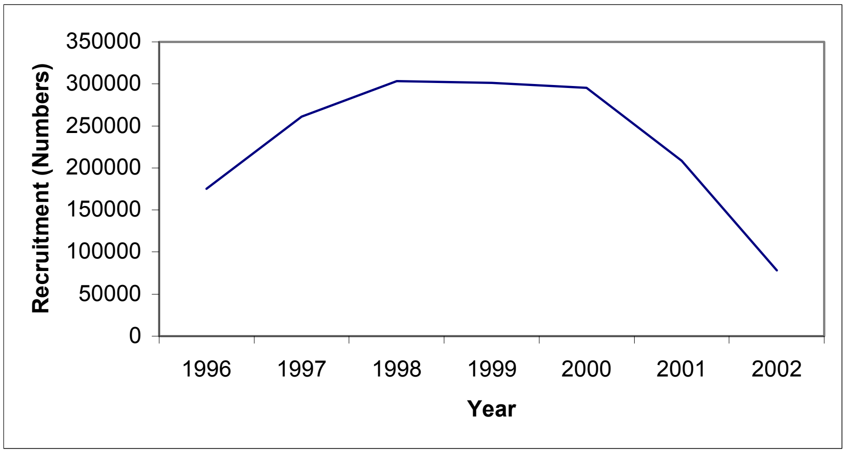


Figure 17 Recruitment estimated from the catch-at-length model. The recruitment can be seen to follow approximately the catch-per-unit-effort trend (Figure 14).

The yield-per-recruit based on the estimated selectivity suggests a very high maximum (Figure 18) and is much higher than the current effort (Table 9). However, the same assessment suggests the target ($F_{0.1}$) is lower than the current effort. The target will obtain 60% of the potential yield from the fishery but for only 15% of the effort and therefore at much lower costs.

Table 9 Yield per recruit reference points for red snapper based on the catch-at-length model. While the target ($F_{0.1}$) suggests a decline in effort would benefit the fishery, the current effort lies below the limit (F_{msy}).

	$F_{0.1}$	$F_{current}$	F_{msy}
Effort (days at sea)	176	461	1150
Yield (g)	568.5	859.2	943.9

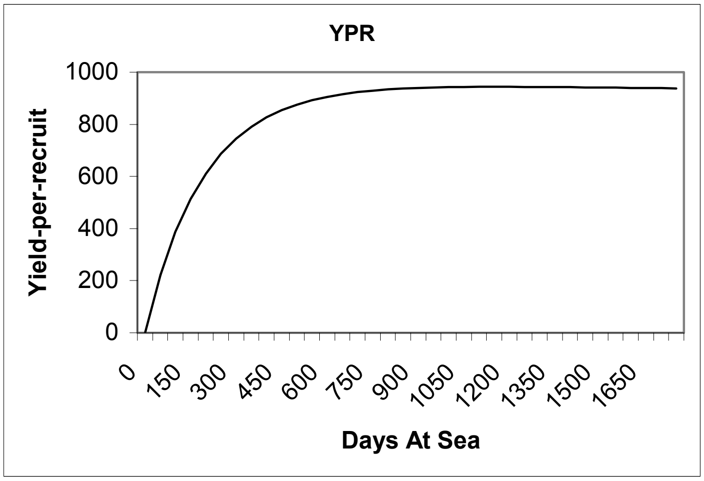


Figure 18 Yield-per-recruit estimated from the catch-at-length model. The asymptotic shape of the curve leads to a maximum yield-per-recruit far to the right, a result of selectivity being focused on younger fish.

Discussion

The data time series was not long enough to do a full reliable assessment. However, the data collected is evidently of value and adequate for a basic assessment. It is likely detailed advice will change as more information comes available.

This fishery is being heavily exploited. The yield-per-recruit suggests fishing mortality is excessive, and 66% of the current yield can be produced with only 40% of the current effort.

Perhaps of greater concern is the recent reduction of recruitment. This needs further monitoring as it may be a natural fluctuation, but also could be a result of overfishing. The spawning stock biomass should be monitored to assess whether it has fallen to a low value. This would require further data on maturity and fecundity.

The total catches for the red snapper fishery were not accounted for. The data included in the assessment was one species and one gear type. It would be valuable to expand the data and develop a model to include other gears and ultimately other species. Such a model may show the selectivity pattern to be an artefact of unrecorded catches by other gears. More sophisticated modelling would depend less on conversions, but fitting to the raw data. This is probably more reliable as the modelling is done in a single testable unit.

6.6.5 Management

The assessment implies that effort should be reduced. The recent reduction in recruitment and the target reference point indicate that a lower effort would exploit the fishery with less risk and greater economic returns. The precise optimal level of effort is not reliably known. Further extension of the model to include all catches and other species is required to set proper reference points.

It may be possible to improve the exploitation pattern as well as alter the overall effort. This technical solution to improving yields may include changes in mesh size and gear types.

7. Guyana Sea Trout (*Cynoscion virescens*)

7.1 Status of Stocks

The state of the stock is not known as the main gear, gillnet, cannot be assessed using the available data. However, the assessment suggests that trawl mortality is low and gill net catches fish close to their maximum size, probably after their age at first maturity. These features make it difficult for the fishery to overfish this species.

7.2 Management Advice

There is no evidence that the current fishing effort should be reduced. There is also no evidence that an increase in fishing effort is sustainable, so the advice is to maintain the current effort levels, or let them fall, while data is collected on the trawl and gill net catch and effort, and/or samples are aged.

The exploitation pattern of gillnet is clearly better than trawl. Trawl bycatch of this species should be minimised.

7.3 Stock Assessment Summary

The size frequency pattern for trawls appears to be consistent with selecting a wide range of sizes starting at young juveniles. Gill nets, in contrast, specifically select larger fish close to their asymptotic size (Figure 19).

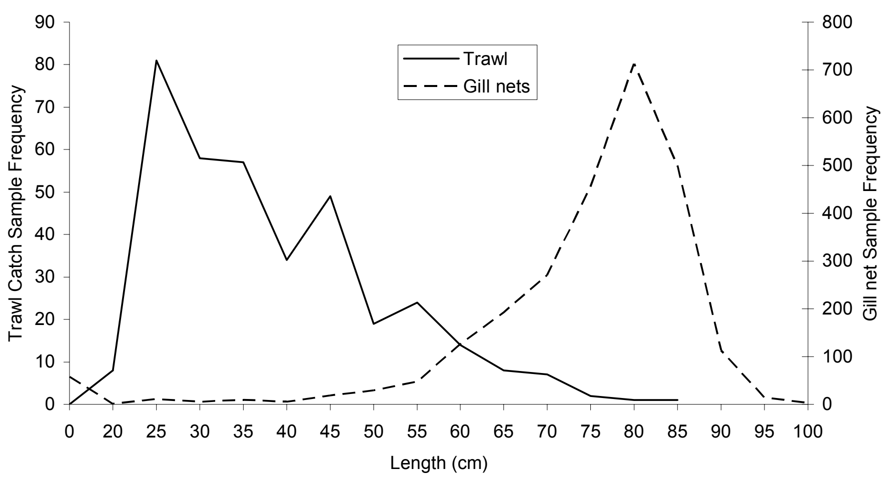


Figure 19 Length frequencies for the two major gear types catching sea trout in Guyana show very different selectivity. Trawl selects much younger fish than gill net.

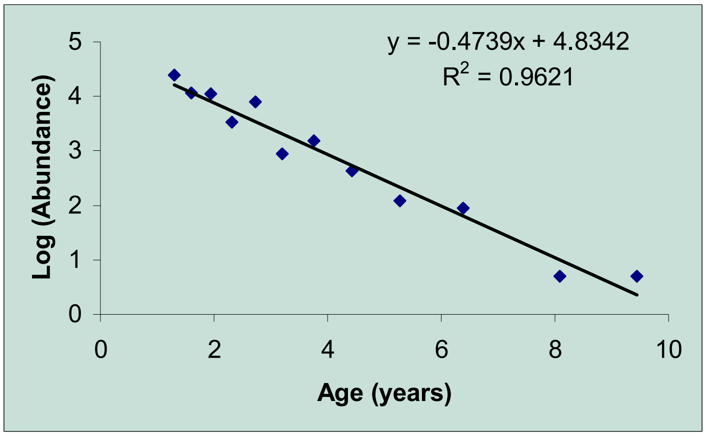


Figure 20 Length converted catch curve for all points in the length frequency left from the frequency mode. The slope, 0.4739, should be equal to the average total mortality for the stock across all ages. The growth rate is assumed to be 0.3 year^{-1}.

The slope of a linearized length-converted catch curve for trawl (Figure 20) indicates that the total mortality is 0.474 year^{-1}. Subtracting an estimate of natural mortality suggests fishing mortality for trawl is around 0.014 year^{-1}. This is a relatively small value, so trawl probably has only a small impact on this species.

It was not possible to conduct a similar analysis for gillnet. Firstly there are too few points to the right of the frequency mode to obtain a good estimate of the slope (Figure 19). Secondly, the mode itself lay on the mean asymptotic length. The implication is that the downward slope to the right of the mode is the result of variation in asymptotic size, not age. Hence it is not possible to use this method to estimate gill net mortality.

7.4 Special Comments

Alternative data sources for monitoring gillnet need to be developed. Either samples need to be aged using hard parts, such as scales or otoliths, or catch and effort monitoring needs to be conducted.

Trawl length frequency provides useful information on the stock. Length frequency sampling from trawl should be expanded.

7.5 Policy Summary

There is no specific policy for this fishery. This makes it difficult to define acceptable reference points.

A policy towards this species needs to be developed, particularly in relation to the exploitation of other species caught by the same gears. This would involve identifying appropriate target and limit reference points for this species based on data which can be realistically collected routinely to monitor the fishery.

7.6 Scientific Assessments

7.6.1 Objectives

The objectives for these analyses were to provide management recommendations through three analyses:

1. Estimate the fishing mortality (F) using a length-converted linearized catch curve.
2. Estimate the fishing mortality (F) using a probability catch curve model.
3. Estimate the status of the stock based on reference points from Beverton and Holt's yield per recruit model.

7.6.2 Data Used

There are two main gears catching sea trout in Guyana. Trawlers catch mainly small sea trout as bycatch, ranging from 25-45 cm. Gillnets catch larger fish, mainly ranging from 60-90 cm.

Four years data were used for the period of 2000-2003. Length frequencies were grouped into length classes using a low class boundary of 20 cm and an upper class boundary of 100 cm.

Name	Description
Length frequency data	Landings were sampled from artisanal vessels 2000-2003 based on a sampling program.

7.6.3 Assessment 7

Objective

The objective was to fit length converted catch curves to the available length frequency data to estimate total mortality which would be used as the basis of a yield-per-recruit.

Method/Models

The methods used were the length-converted linearized catch curve model (see Sparre and Venema 1992, pg 126). Length conversion to age requires a growth model. Parameters for the growth model were provided from previous assessments and were considered approximate (Table 10).

Table 10 Parameters for Von Bertalanffy growth model, length weight conversion and natural mortality used in the assessment to convert length to age and in the yield-per-recruit model. Natural mortality was estimated from Pauly's "empirical" equation based upon the assumed growth parameters. See Table 11 for growth parameter estimates based on the length frequency data.

Growth Model Parameters			
K ($year^{-1}$)	L_∞ (cm)	T_0	
0.3	85.0	0	
Length-Weight Conversion		**Natural Mortality**	
a	b	M	
1.18E-05	3.00	0.46	

Results

Sample data for the period of 2000-2003 were used to obtain length frequencies with a lower class boundary of 20 cm and an upper class boundary of 100 cm. It can be seen majority of the sea trout captured by trawls and gillnets are within this range (Figure 19). The size frequency pattern for trawls appears to be consistent with knife edge selection. Gill nets, in contrast, select larger fish. This can be due to the location fished as well as the mesh size.

The downward trend on the right of each frequency evident for both gears can be used to fit the catch curve. This assumes that the downward trends to the left of the mode are due to mortality and growth alone. It can be seen that trawl covers many more length classes than gill net and it is also likely the selectivity of this gear will have a smaller effect on the slope of the curve.

Figure 20 shows the log-abundance plotted against the age as calculated from length. The R^2 goodness-of-fit statistic implies the line explains 96% of the variation in the abundance index (i.e. the length frequency). The slope of the line gives an indication of the total mortality. Subtracting the natural mortality gives an estimate of the fishing mortality, F, which is in this case 0.474 - 0.46 = 0.014 $year^{-1}$. The estimate for natural mortality was obtained from Pauly's empirical equation (see Sparre and Venema 1992 for discussion of this).

It was not possible to conduct a similar analysis for gillnet, although the attempt was made. Firstly there are too few points to the right of the mode to obtain a good estimate of the slope. Secondly, the mode itself lay on the mean asymptotic length. The implication is that the downward slope is the result of variation in asymptotic size, not age. Hence it is not possible to gill net mortality using this method.

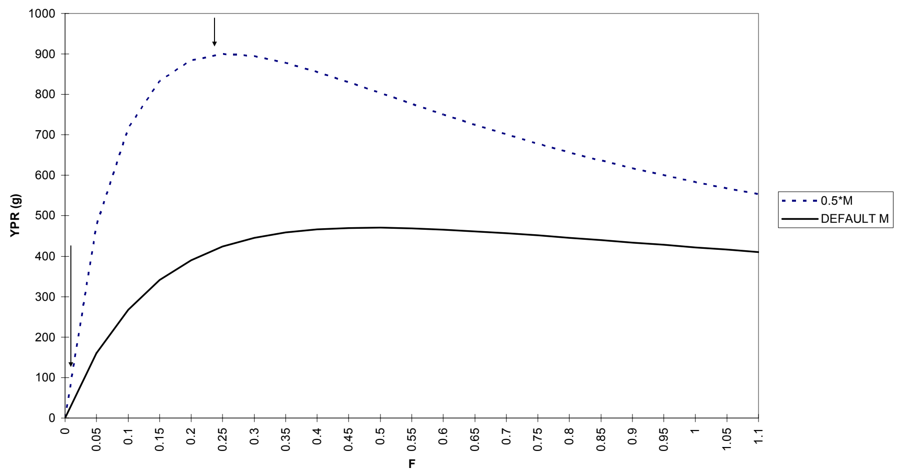


Figure 21 Yield-per-recruit illustrating sensitivity to the estimate of M. The left arrow represents the current F for the default M of 0.46. It is well to the left of F_{MSY}, suggesting the stock is only lightly exploited by this gear. However, reducing M to half this value sets current F close to F_{MSY} (right arrow). The true value for M is likely to lie somewhere at or between these two values.

Discussion

The fishing mortality for trawl is relatively low compared to natural mortality. This implies this gear is not overfishing, although the mortality rate is still significant. The estimate is clearly dependent on the natural mortality estimate, which is only approximate. Also, the trawl catch is a bycatch, and only makes up a relatively small proportion of the catch of this species. It is possible that the trawl fishing mortality is close to the lower value for the default M.

The length frequency data by themselves cannot be the basis of a full assessment. As gillnets catch fish close to their asymptotic size, differences in size probably do not represent differences in age. Catch curves can still be generated for this species, but will require aged animals. Otolith and scale samples should be taken for aging purposes.

Alternatively assessments could use catch and effort data. However it may be many years before an assessment can be conducted on this basis. Catch and effort assessments require long time series and significant changes in both catch and effort to be able to fit the relevant assessment models.

7.6.4 Assessment 8

Objective

Conduct the full assessment as in section 7.6.3, but use a lower growth rate of 0.25 instead of 0.3 year^{-1}.

Method/Models

See section 7.6.3 for the methodology.

Results

Setting the lower growth rate reduces the mortality as the decline in abundance is spread over a greater age (Figure 22). The estimated total mortality (0.39) is less than the estimated natural mortality using Pauly's empirical equation (0.40). This suggests trawl fishing mortality is small if the growth rate is low.

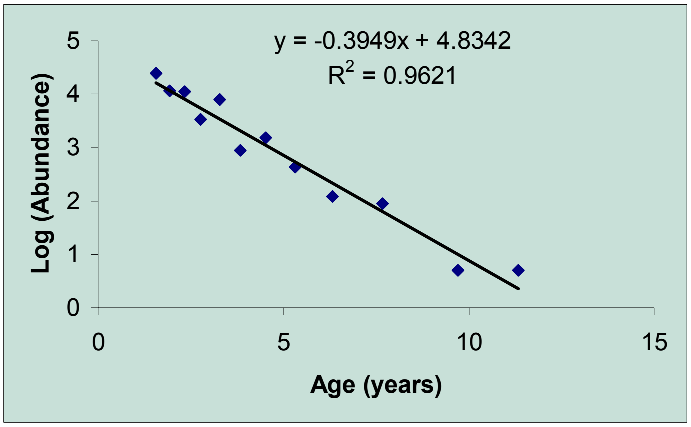


Figure 22 Trawl length converted catch curve for all points in the length frequency left from the mode. The growth rate is assumed to be 0.25 year^{-1}.The slope, 0.3949, is less than the natural mortality estimated by Pauly's empirical equation.

Discussion

F is too low to distinguish from zero. Hence, the Z estimate for trawl can probably be used as a natural mortality estimate if the lower growth rate is adopted. This assessment depends on Pauly's equation estimate. These estimates of natural mortality are poor, so any estimate of F based on this is likely also to be poor.

7.6.5 Assessment 9

Objective

Fit an age-length key probability-based catch curve to length composition data for both trawl and gill net simultaneously. The method will estimate growth parameters, gillnet selectivity and fishing mortality.

Method/Models

The probability catch curve is based on a probabilistic age-length key model. The catch curve follows the standard negative exponential model, but length is converted to age based on an age-length key calculated from the growth model. The marginal distribution of the age-length key can be used to estimate the proportion expected in each length class from random samples taken from each gear.

The method is more realistic in that growth variability is accounted for and, by using both gears, the growth parameters and gill net selectivity can be estimated. Gill net selectivity was assumed to be normally distributed around the asymptotic length.

Construction of the Age-Length Key

The age length key consists of the probability that a fish taken at random from the population is both of a particular age and particular size. It is calculated from the joint log-normal distribution where the mean is given by the age-at-length from the deterministic von Bertalanffy growth model and a negative exponential population model. The probability is then apportioned to discrete age and size classes through integration.

$$P(c) = \int_{a_c}^{a_{c+1}} \int_{s_c}^{s_{c+1}} N(a, s | \mu, \sigma)\, ds\, \frac{e^{-Za}}{Z}\, da \qquad (15)$$

where $P(c)$ = probability that a shrimp is in class c with size and age lower and upper limits as s_c, s_{c+1}, a_c, a_{c+1} respectively. The mean log-length at age is given by the log of the von Bertalanffy growth curve:

$$\mu_a = \ln(L_\infty) + \ln\left(1 - e^{-K(a-t_0)}\right) \qquad (16)$$

where a is the age, and L_∞, K and t_0 are the standard von Bertalanffy growth parameters. The proportion of fish of a particular age in any weight class were calculated as the difference between the cumulative normal distribution of the two log-weight class boundaries. This function is available in Excel (*NormSDist((x-μa)/σ)*). This represents the inner integration in equation (15). A numerical approximation to the integral (Simpson's rule) over one year's aging was applied to approximate the outer integral in equation (15). So the proportion of cohort age a in length class i (p_{ai}) was calculated as:

$$\begin{aligned} p_{ai} = \tfrac{1}{2}\Big[&\left(\mathrm{N}(\ln(l_{i+1});\, \mu_a, \sigma) - \mathrm{N}(\ln(l_i);\, \mu_a, \sigma)\right)e^{-Za}/3 \\ &+ \left(\mathrm{N}(\ln(l_{i+1});\, \mu_{a+0.5}, \sigma) - \mathrm{N}(\ln(l_i);\, \mu_{a+0.5}, \sigma)\right)e^{-Z(a+0.5)}\ 4/3 \\ &+ \left(\mathrm{N}(\ln(l_{i+1});\, \mu_{a+1}, \sigma) - \mathrm{N}(\ln(l_i);\, \mu_{a+1}, \sigma)\right)e^{-Z(a+1)}/3\Big] \end{aligned} \qquad (17)$$

where N( ) is the cumulative normal distribution, l_i is the lower limit for length class i. The marginal size composition can be found by summing over all age classes for each length class. This size composition, once normalized to sum to 1.0, represents the probability that any fish taken at random from the population will be in any length class. As for the length-converted catch curve, it assumes constant recruitment and mortality, and no gear selection. Multiplying the marginal length class probability by the number of fish in the length composition sample gives the expected number of fish in each length class. The model can be fitted by minimising the Poisson log-likelihood (or least squares) between this observed and expected values.

If more than one gear is represented, selectivity can be estimated relatve to some standard gear. A selectivity function is required. In this case, trawl is assumed to be non-selective and hence the reference gear. Gill net is assumed to have a normally distributed selectivity relatve to length. Hence, the probability that a fish is in each length class is adjusted by multiplying by a normal function with mean and variance fitted to the observations, the x-variable being the mid-point of the length class.

Results

Not all parameters could be estimated as many of the parameters were correlated. The growth parameter values (Table 11) appear reasonable for this species, although they suggest a slower growth than that assumed in the previous assessments. Although gillnet selectivity could be estimated, fishing mortality due to this gear could not, as it was correlated with other parameters such as F and M (Table 12). Trawl was used to estimated Z which appears larger for this model than fitted previously (0.58 year^{-1}).

The model fits the data, although it ignores much of the detailed structure in the length frequency samples (Figure 24;Figure 26). There is also evidence for bias in estimates with the problem being greatest in trawl (Figure 25;Figure 27).

Table 11 Maximum likelihood parameters fitted for the von Bertalanffy growth model fitted to the combined length frequency samples, including a parameter for individual variation in growth (Sigma, a coefficient of variation). Parameter t_0 was assumed to equal 0.

K	L_∞	Sigma (CoV)
0.22	83.06	0.066

Table 12 Maximum likelihood parameters fitted to the combined length frequency samples. The mean gillnet selectivity was (mode for the normal curve) was not fitted, but fixed at the asymptotic length (L_∞). The gillnet fishing mortality was indistinguishable from zero. The overall Z was found to be 0.58 year^{-1}. From this, and using Pauly's empirical equation (using K and L_∞ in Table 11), trawl F was estimated.

Gillnet	Gaussian Selectivity	
F	Mean	Sigma
0	83.06	12.40
Trawl	Knife-edge Selectivity	
F	Age at first Capture	
0.201	1.55	

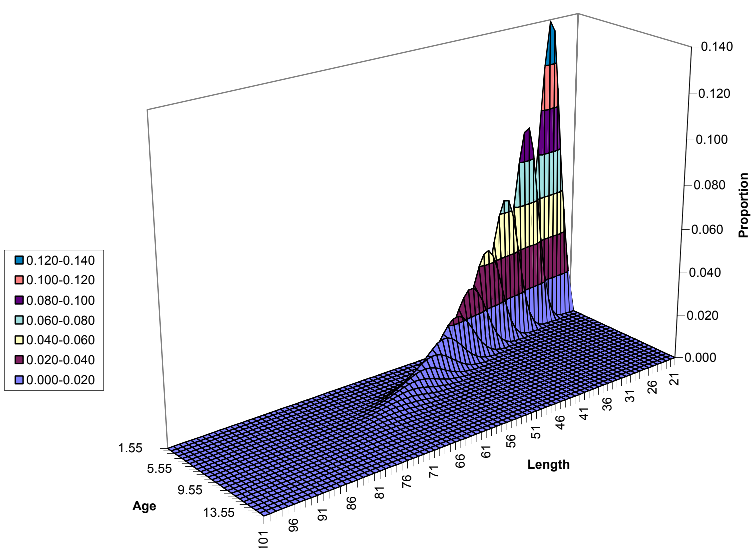


Figure 23 Probability model of population at age and size used as the basis for the model of the length frequency data. The model shows an exponential decline in population size with age and von Bertalanffy growth relating length to age. The marginal probability for length should represent the length frequency compositions after passing a selectivity filter.

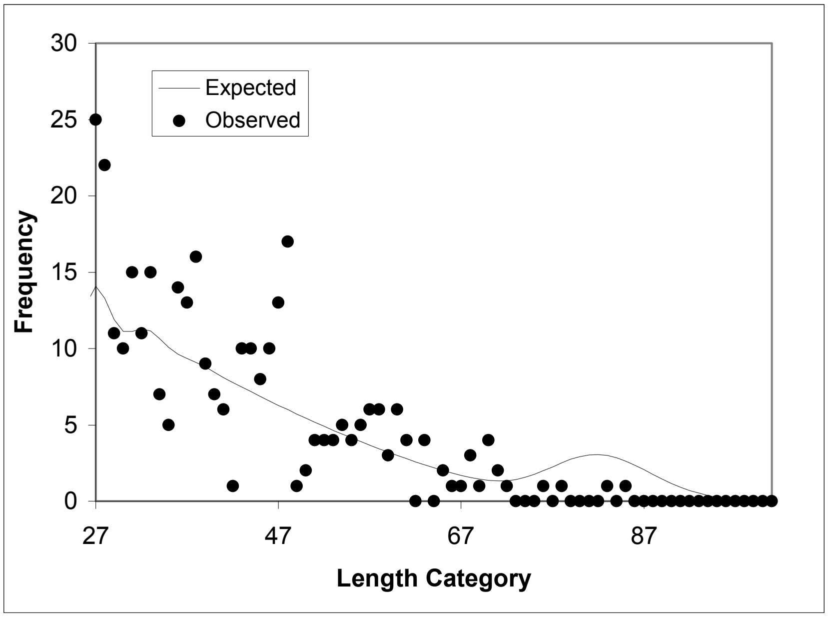


Figure 24 Observed and expected length composition for trawl. Although the length composition is variable, there is some indication of several modes which are not accounted for. Catch curves assume continuous constant recruitment and ignore such patterns.

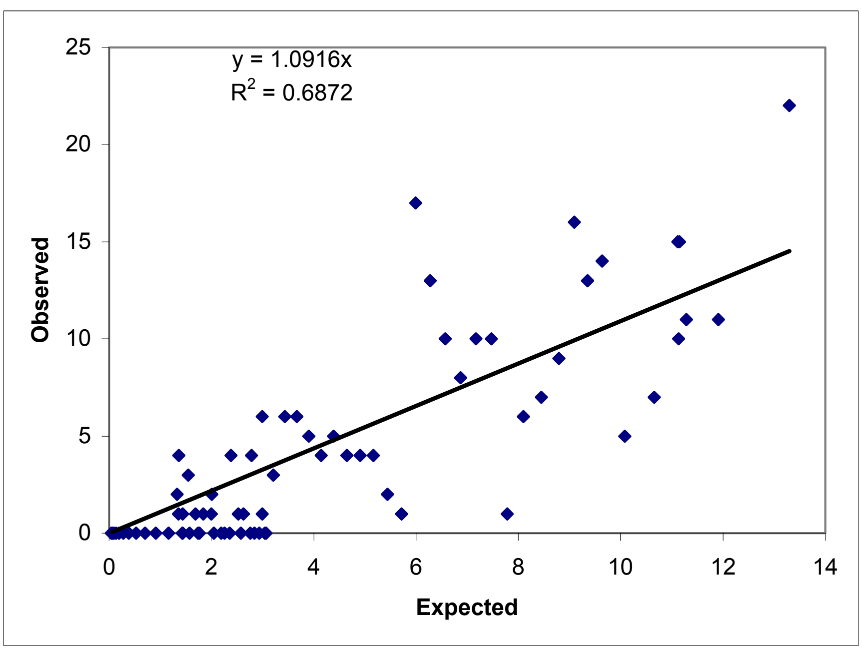


Figure 25 Trawl observed and expected length frequency sample. The relationship is significant, although the observed sample number is 9% higher than the expected, indicating bias.

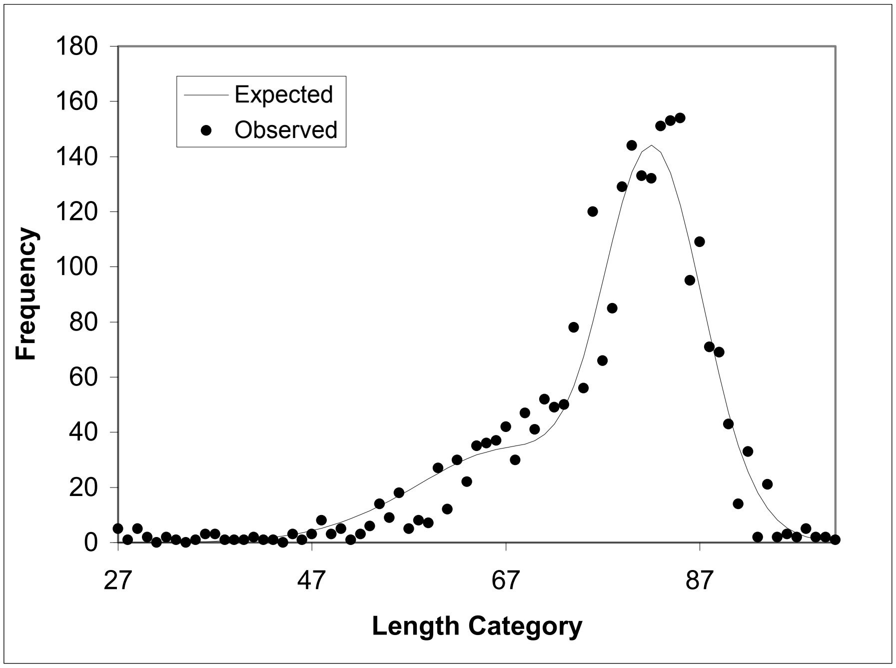


Figure 26 Observed and expected length composition for gillnet. The model fits the data well, although it was not possible to fit all parameters, in particular gillnet fishing mortality.

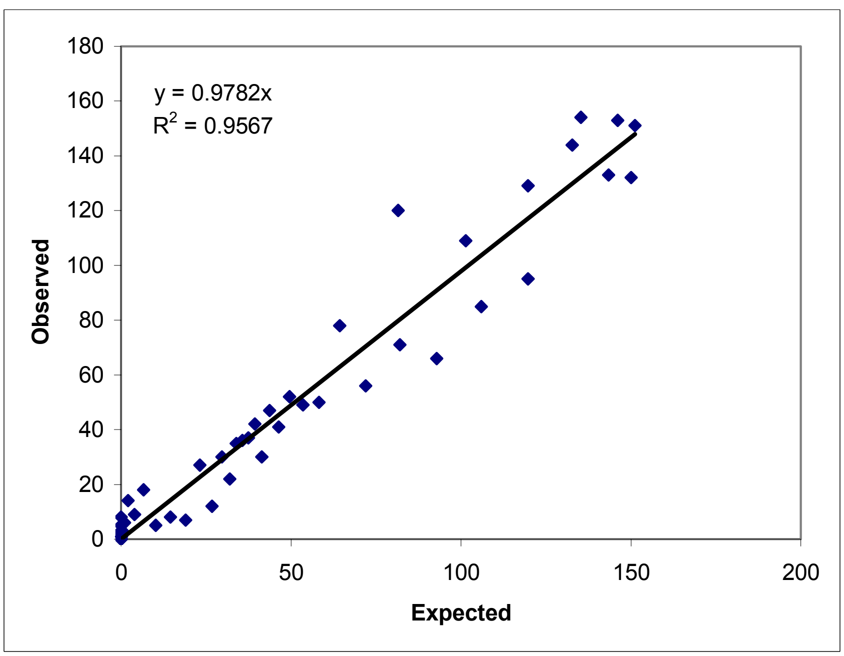


Figure 27 Gillnet observed and expected length frequency sample. The bias is small and the model fits the data well compared to the trawl data (Figure 25). The sample size for gillnet is much larger than for trawl gear.

Discussion

Gillnet selectivity and the growth parameters from this assessment may be reasonable estimates. The gillnet model appears to fit the data well. The trawl data fits less well with some significant bias. As the model relies on the trawl data to estimate the mortality, the mortality estimates are probably unreliable. Overall, this analysis should be considered exploratory, but there does appear to be scope for developing this approach.

Trawl data appears to provide important information on the stock. Sampling should be significantly increased for this gear. It may be possible to fit mode-searching models, such as Elefan or Multifan, to these data.

This assessment appears to provide reasonable estimates of growth and selectivity parameters which can be used in future assessments. However, for management purposes, gillnet fishing mortality is clearly critical and cannot be estimated. Alternative data and methods need to be developed to estimate gillnet fishing mortality. The most obvious and most likely method to work is to take a sample, say 500 fish, across the size range and have them aged. This would allow the same approach but avoid problems with converting size to age. It would also allow direct estimates of growth parameters.

7.6.6 Management

Without an assessment based on gillnet, it is difficult to assess the state of the stock and therefore provide advice. The stock is probably not overexploited, however. The trawl fishing mortality is clearly low and gillnets are exploiting fish around the asymptotic size, presumably beyond age at first maturity. This would make recruitment and growth overfishing difficult to achieve using gillnets.

Increasing trawl mortality will deprive gillnets of catch, as trawls begin catching this species before gillnets. The gillnet exploitation pattern is better than trawl as it allows the fish to grow to full size before exploitation. Any reduction in sea trout catch by trawls will be beneficial to the fishery for this species.

To conduct an assessment will require more detailed monitoring of the gillnet fishery. The results from this assessment suggest that size frequency is not informative of age for gillnet catches. Either direct age data is required or an assessment based on total catch and effort can be conducted. More length frequency sampling of trawl would be valuable, however.

8. Guyana Seabob Fishery (*Xiphopenaeus kroyeri*)

8.1 Status of Stocks

Recent declines in catch-per-unit-effort suggest that the stock has become overfished. Stock assessment models support this, although various problems in the data and models make detail from the assessments unreliable.

8.2 Management Advice

The stock would appear to be at risk as the current fishing mortality, expressed as days fishing, surpasses the fishing mortality required to obtain the maximum sustainable yield. It would appear that the greatest yield and economic benefits may be obtained by approximately halving the current numbers of days fishing per month.

The assessment implies that current effort exceeds that necessary to exploit optimally this resource. This suggests that fishing effort urgently needs to be controlled and reduced, if not to improve the state of the resource, then to improve economic benefits from the fishery.

Given the uncertainty in the assessment, a precautionary reduction is warranted by capping the number of trips in each month to no more than 150. Resulting yields should be carefully monitored for improvement. The current level of the fleet should be reduced from 100 to 50 or fewer vessels.

Methods to control and limit fishing in this fishery need to be developed and implemented urgently to move the fishery to a sustainable state.

Improved stock assessment advice may be obtained by improving data collection and ensuring current data is correct. Data from 2002 in particular may contain significant errors.

8.3 Stock Assessment Summary

Two models were fitted to the data:

- A biomass dynamics model attempted to explain an increase in catch-per-unit-effort 1998-2001 and the decrease in 2002 as a result of population size changes (Figure 28). The best fit model suggested the stock is overfished and a significant reduction in effort is needed. Catches should be kept below 1.6 million pounds per month to allow the stock to rebuild.
- A catch-at-age model was fitted to the commercial size categories. This was shown to be sensitive to natural mortality and the growth model parameters. However, it too indicated a significant reduction in fishing effort is required to reach a target fishing mortality.

Catch and effort data and the supporting growth and mortality models need to be reviewed. Although both models gave similar advice, both used data which have a number of problems and some of the indications seem unrealistic.

The recent downward trend in CPUE during 2002 needs to be verified. If it is correct, the basic advice, that a significant reduction in effort is urgently required, will not change even with improvements in the assessment models.

It is very likely that future assessments will recommend significant reductions in fleet size. It is strongly recommended that preparation is made to look at controlling and reducing fishing effort in this fishery.

More information is required on growth and natural mortality, and maturity, fecundity and sex ratios are required to properly assess spawning stock size.

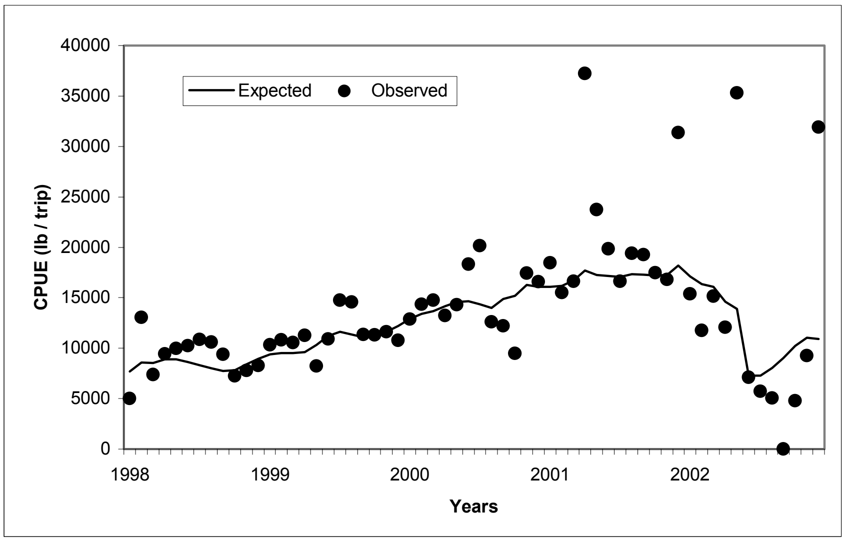


Figure 28 Observed and expected catch per unit effort (CPUE) for seabob trawlers. The increase in CPUE suggests the stock size has been increasing 1998-2001, thereafter there has been a sharp decline which could be due to increase catches. Outliers in the data suggest that they should be carefully checked particularly for 2002.

8.4 Special Comments

All data needs to be carefully reviewed. The implied CPUE for the current data appeared unreasonable. No data was available on the Chinese seine.

There is a need to collect length frequency data within the commercial size categories to conduct a full catch-at-length assessment.

More accurate growth and mortality estimates are required to improve catch-at-size based assessments.

A joint assessment with Suriname should be conducted. There is evidence that CPUE follows a similar trend in this fishery, and hence stocks may be connected or influenced by similar external factors.

8.5 Policy Summary

The seabob fishery is reserved for Guyanese nationals, with it being mainly an export oriented fishery earning foreign exchange.

This fishery was relatively underexploited (mainly by Chinese seine operations) in the past, but from 1985, with the advent of a number of seabob processing plants it is now being more heavily exploited by Chinese seines and trawlers.

In the Draft Management Plan for the Marine Fisheries of Guyana, it was suggested that until more information was available on the seabob resource a precautionary approach should be exercised in terms of fleet expansion.

In keeping with this approach, it was recommended that the limited entry fleet method should be maintained, with consideration being given to the restriction of trawling for seabob to areas of high adult abundance in order to reduce conflicts with artisanal fishermen and damage to nursery grounds. It was also recommended that the limit of 30 vessels should be reviewed.

The National Consultation Workshops for 2000 and 2002 recommended that the seabob fleet levels should be capped at the fleet sizes existing at the time of the Workshops. Effort has since been allowed to increase.

8.6 Scientific Assessments

8.6.1 Description of the offshore Seabob Fishery

The offshore industrial shrimp trawl fleet exploits mainly penaeids (*Penaeus* spp.) and seabob (*Xiphopenaeus kroyeri*). Seabob are also caught by the Chinese seine operators in the inshore artisanal fishery.

At present, there are 100 trawlers registered and licensed to catch seabob. The seabob is processed at six plants located along the East Bank of the Demerara River. There are about 373 Chinese seine vessels catching seabob and white belly shrimp (*Nematopalaemon schmitti*).

The management unit is considered to be one or more stocks located over the continental shelf of Guyana. It is possible that these stock(s) are shared with Suriname.

8.6.2 Objective

Determine the status of the seabob stock and the fishing effort required at MSY.

8.6.3 Data Used

Name	Description
Landings data per trip from trawlers in the seabob fishery.	The total catch weight (lbs) for each trip and days fishing on each trip were obtained from vessel data for all six seabob processing companies. The data covered the period January 1998 to December 2002.
Catch by size category after processing	Weight by commercial size category for each vessel trip were collected from six seabob processing companies. The data covered the period January 1998 to December 2002.

Comment: Or days at sea? And why are we using number of trips as the measure of effort?

Data was combined to total catch by size category and number of trips for each month.

Chinese seine catches were not available.

8.6.4 Assessment 10

Objective

Fit a simple biomass dynamics model to the catch and effort data to obtain current state and estimate reference points for the fishery.

Method/Models

A standard logistic biomass dynamics model was fitted to the monthly catch and effort time series data. The model was fitted minimising the squared difference between the observed and expected log-catch. See Punt and Hilborn (1996) for details of fitting these models in spreadsheets.

Results

The general results suggest the stock is grossly overfished (Table 13) and has been overfished since the beginning of the time series. The current catches are well below the estimated maximum sustainable yield.

The model can fit the catch per unit effort data (Figure 29), although CPUE data appears to be much poorer later in the series. The large drop in CPUE in 2002 suggests significant overfishing. The increasing CPUE before this implies not only recovery, but that the stock has been overfished before 1998 as well. An alternative interpretation is that catchability has been increasing with improvements in gear or fishing techniques. In either case, the decline in CPUE in 2002 indicates overfishing.

The model's expected catch does not fit the observed data well mainly due the occurrence of outliers (Figure 30). This points to a problem with the data, either in the way the catch or the way the effort is recorded. Effort in particular would be better recorded as days fishing or number of hauls rather than number of trips.

Table 13 Results from fitting the biomass dynamics model. The model suggests the stock has been heavily overfished through the available data time series. The MSY limit reference point for the stock size is 50%, implying the current 7% is too low. The implication is that the monthly catch should be kept below 1.6 million pounds to allow the stock to grow. The average catch over 2002 was 2.6 million pounds.

Comment: Check all units. I have no idea what units these are.

MSY	Effort at MSY	F at MSY	Current Stock State (% Unexploited)	Current Sustainable Yield
7 604 062	70	0.10	7%	1 655 601

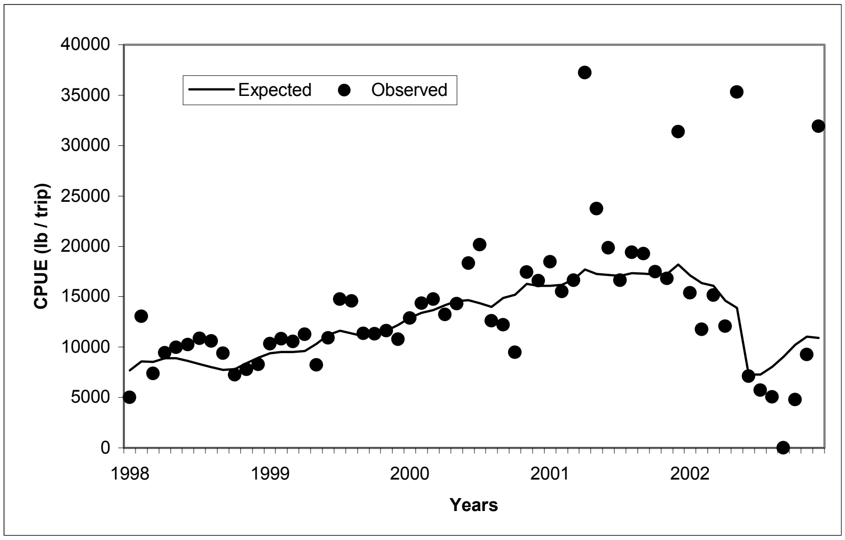


Figure 29 Observed and expected catch per unit effort (CPUE) for seabob trawlers. The increase in CPUE suggests the stock size has been increasing 1998-2001, thereafter there has been a sharp decline due to increase catches. There are a number of months with significant outliers, suggesting the data should be carefully checked.

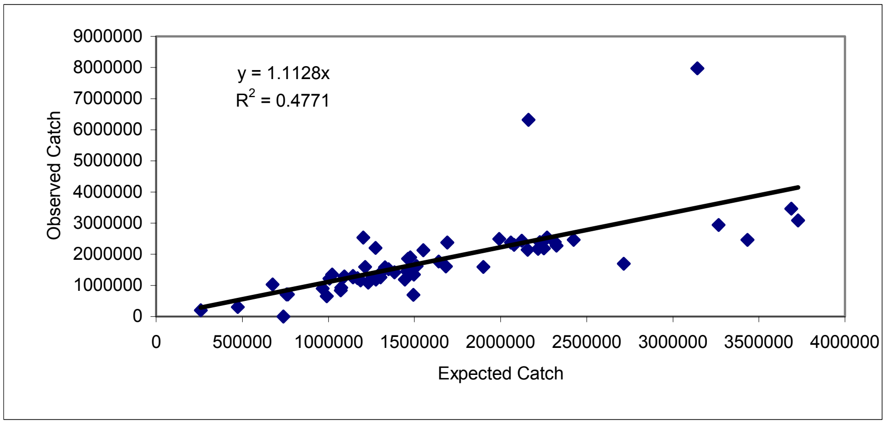


Figure 30 Observed and expected catch for seabob trawlers. The model explains about 50% of the variation in the observed catch. The relatively poor fit is due to the outliers, when catches were much larger than expected.

Discussion

While there are significant problems with this assessment, the general results strongly suggest a reduction in fishing effort is warranted. The current state of the stock implies much higher catch rates and catches must have been taken in the past. There is no evidence for this. However, the recent rapid decline in CPUE should cause great concern.

The model requires total catches. Catches for the Chinese seine fleet were not available. Although this is a problem, as long as they have not changed much over the period, it should not introduce a very large bias in the results.

8.6.5 Assessment 11

Objective

Fit a catch-at-length model to the available catch commercial size category data to obtain estimates of selectivity for a yield per recruit.

Method/Models

The catch size classes were converted to age using an age-length key developed from a growth model with parameters supplied from previous studies. Thereafter a standard catch-at-age model was applied. It was fitted by minimising the squared difference between the population model log-fishing mortality and the expected fishing mortality using selectivity parameter for each age and the effort data. See the methods section 4.5.4.

The growth model parameters, weight-length conversion parameters and natural mortality were obtained from previous workshop reports (Table 14).

Comment: Need a reference for where these came from.

Table 14 Parameters used for the catch-at-length model. The growth model was used to convert length to age. The Sigma (Coefficient of variation) measures the variability of length from the mean given by the von Bertalanffy growth equation.

Growth Model Parameters				Natural Mortality
K ($Month^{-1}$)	L_∞ (mm)	T_0 (Months)	Sigma (CoV)	M
0.2	35	0	0.1	0.92

The model was fitted excluding two outlying months, September and December 2002 which appear to have unusual CPUE data. These and other months in the time series need to be checked. In particular, catches are assumed accurate in the model and care should be taken that all removals from the population are recorded and used.

Results

The model does not fit the data well. The selectivity appears unrealistic for trawl (Figure 31). The relative decline of older larger seabob in the catches is interpreted as an artefact of selectivity. In fact it may well be due to high mortality.

General results indicate effort is relatively high (Table 15). While the effort at F_{MSY} is high even compared to current effort (Figure 32), an incorrect selectivity will bias the estimate upwards. The estimated target $F_{0.1}$ is close to that recommended by the biomass dynamics model.

Table 15 Target and limit reference points for trawl fishing mortality based on a yield-per-recruit analysis using the estimated selectivity. Note that the F_{msy} limit is high because the selectivity declines significantly for older ages. This may not be realistic. The current fishing mortality ($F_{current}$) is well above the target, implying management should aim to reduce effort to 50% of its current level. It can be seen that large increases in effort do not produce much greater yield than the target.

	$F_{0.1}$	$F_{current}$	F_{msy}
Fishing Days	83	173	230
Yield per recruit (g)	6.97	9.23	9.47

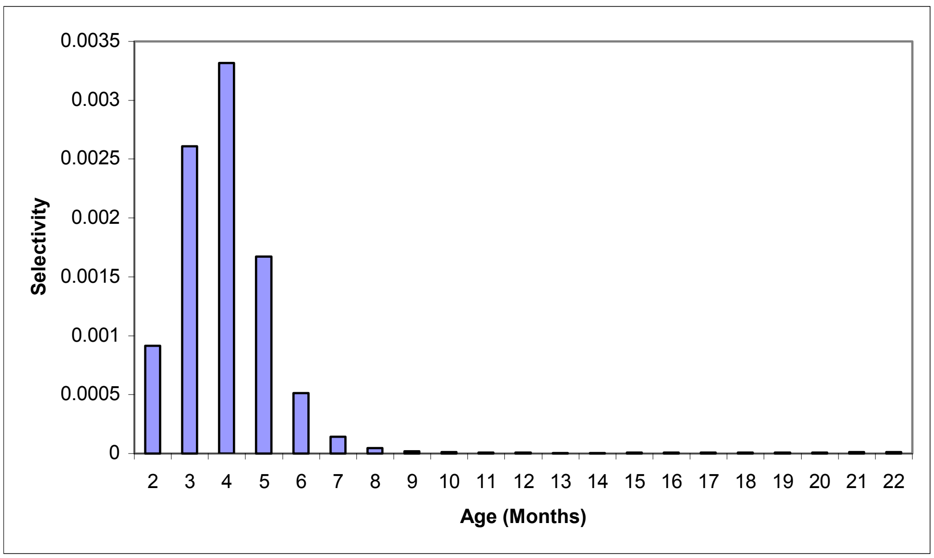


Figure 31 Selectivity relating fishing effort to fishing mortality at each age. Notice that selectivity reduces expected fishing mortality to effectively zero for ages greater than 12 months. For trawl gear, this would seem to be unlikely.

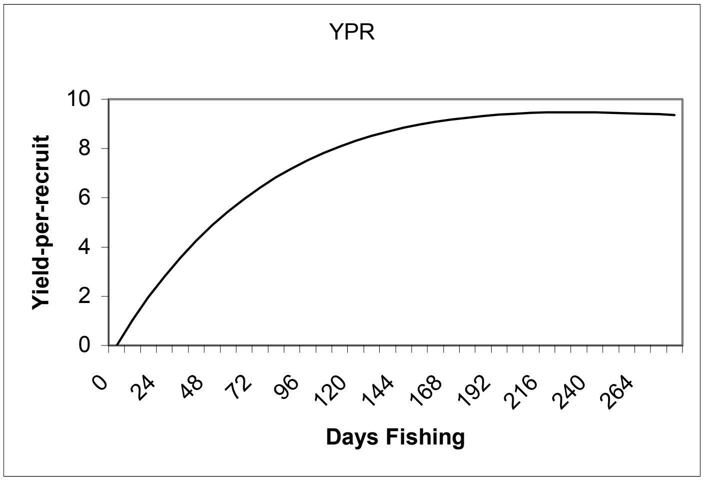


Figure 32 Yield-per-recruit for seabob based on the estimated selectivity. The maximum is reached at very high effort mainly due to the peaked selectivity.

Discussion

The selectivity curve indicates that older animals disappear from the catches much more quickly than expected. While this may be a genuine selectivity effect, it may also be an artefact from a poor fitting model. Such a high selectivity seems unlikely for trawl gear and this suggests that the disappearance of larger seabob may be due to high mortality or could be due to a poor growth model.

As with all such models, there is a strong dependence on the supporting growth and mortality models. The sensitivity to these was explored in the next assessment. However, it is likely that estimates of reference points are inaccurate and will need to be reassessed in future.

As with the biomass dynamics model, there is considerable uncertainty over the validity of the catch and effort data in 2002. These data need to be examined for errors.

Despite problems with the model, it is worth emphasising that the optimal yield-per-recruit ($F_{0.1}$) occurs at about the same effort level as that required for MSY in the biomass dynamics model. Both these quite different approaches suggest significant reductions in effort are warranted.

8.6.6 Assessment 12

Objective

Test the effect of changes in natural mortality on the catch-at-size model in section 8.6.5.

Method/Models

See method sections 4.5.4 and 8.6.5 for details of the model and fitting procedure.

The fit with default parameters was tested for sensitivity by altering natural mortality and growth parameter estimates above and below the default value.

Results

The model showed very great improvements in fit with lower natural mortality. Changing natural mortality from 0.09 to 0.05 reduced the negative log-likelihood by 84%. There was a continued decline but it was asymptotic with no minima above zero, hence natural mortality could not be fitted. This significant improvement suggests natural mortality estimates of around 0.1 month^{-1} are too high.

Not only was the log-likelihood reduced, but the selectivity curve seemed more realistic for trawl gears (Figure 33). This leads to a much lower F_{MSY} limit reference point, although the target remains relatively stable (Table 16; Figure 34)

Other tests indicated the model was sensitive to changes in growth parameters but too difficult to fit when parameter values were changed. This was mainly due to the lack of resolution in the size frequencies as only five size classes were defined. Growth estimates would require length frequency data.

Table 16 Target and limit reference points for trawl fishing mortality based on a yield-per-recruit analysis using the estimated selectivity with reduced natural mortality. Note that the F_{msy} limit has been greatly reduced and now the current fishing mortality exceeds it. The target fishing mortality has changed relatively little. The implication continues to be that effort should be reduced to 50% of its current level. The absolute yield-per-recruit (g) has increased because now the total mortality is much lower with the reduction in natural mortality.

	$F_{0.1}$	$F_{current}$	F_{msy}
Fishing Days	87	173	105
Yield per recruit (g)	15.97	14.78	16.23

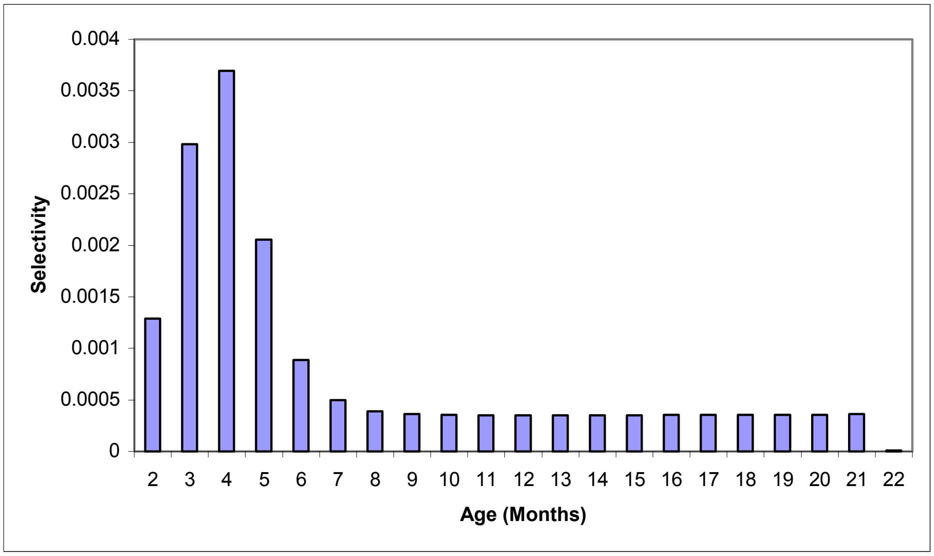


Figure 33 Selectivity for natural mortality adjusted from 0.09 month^{-1} to 0.05 month^{-1}. While it is still peaked at younger ages, selection for older individuals has not been eliminated.

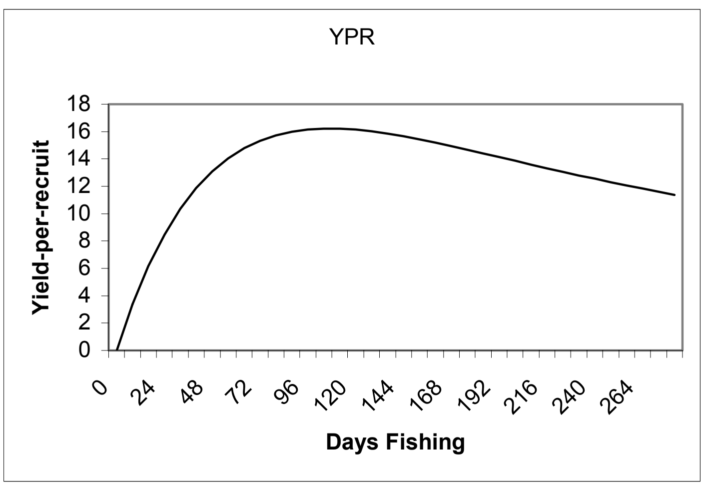


Figure 34 Yield-per-recruit for estimated selectivity with reduced natural mortality. The maximum yield is now attained at a much lower effort (F_{MSY}), suggesting that overfishing occurred in 2002.

Discussion

This improvement indicates the assessment is sensitive to these supporting parameters and models, while the default choice in parameter values has little justification. Obtaining better estimates for this species may be difficult, but nevertheless approaches must be considered, such as tagging, length composition from a lightly exploited stock or studying growth *in vitro*. The length-weight conversion model also needs to be reassessed, particularly in relation to conversion variation.

The model would be greatly improved with length frequency data (see Suriname Seabob assessment).

Given the much better fit to the data, this model with M=0.05 $month^{-1}$ should form the default until significant improvement can be found. However, given problems in growth and mortality models, it may prove more reasonable to apply a simpler biomass dynamics model and set controls on the basis of this type of model. In either case, better catch and effort data monitoring is required.

8.6.7 Management

While there are reservations with the results for each of the assessments, there was a consistent result in the optimal effort implied by each model. The optimal effort appears to be about 50% of the current effort, implying a controlled decrease in effort would benefit the fishery, even if detailed reference point estimates may change as data and models improve.

There is a clear need to improve management and data collection for this fishery. Fishing effort and number of vessels needs controlling and has exceeded the optimum level. Currently there appears to be no management control over this fishery. Management of vessels and vessel activities would not only produce greater benefits, but almost certainly produce better data on which to base the assessment.

9. Jamaica Shrimp (*Penaeus schmitti*)

9.1 Scientific Assessments

9.1.1 Background

The Jamaican shrimp fishery is artisanal. Most of the shrimp caught is marketed locally. The fleet consists of approximately 52 wooden canoes and 12 fibreglass vessels, the former propelled by oars and the latter by 40HP engines. Three types of fishing gears are used, two types of shove net, i.e. shove net and push net, and a trawl net. The main shrimp fishing area is the soft mud bottom and sea-grass areas of the Kingston Harbour.

Data is collected by bi-monthly interview trips to the landing sites. Total catch is estimated by raising catches by the number of fishing days for each landing site.

The following assessment builds on those done at the Fourth Workshop on the Assessment and Management of the Shrimp and Groundfish Fisheries on the Brazil-Guianas Shelf. 2-13 October 2000, Cumaná, Venezuela. Advice obtained from those assessments is still applicable, although it should be reviewed in the light of environmental changes in Kingston Harbour.

9.1.2 Objectives

Estimate appropriate compensation to be paid to fishers in the *Penaeus schmitti* fishery based on changes in catch rates resulting from dredging operations in Kingston Harbour.

9.1.3 Data Used

Name	Description
Catch and effort data for 1996-2003	Landings (kg) of *P. schmitti*, 1996 – 2000 from the three main gears used in the fishery in each month. Total catches are estimates raised from CPUE sampling and a total vessels.
Biological data including size frequencies sampled from landings.	This was obtained by purchasing samples from the landings. Data includes sex, weight, carapace length and tail length.

9.1.4 Assessment 13

Objective

To estimate compensation as a percentage of earnings based on the change in catch rate presumed to be due to environmental change in Kingston Harbour.

Method/Models

The available data provides estimates of catch effort sampling covering 1996-2003. However, there are many months missing data in the time series so a reliable population model is not possible. Instead, a generalized linear model was used to compare an expected catch rate in 2003 to the observed catch rate. It would be assumed that the change between the observed and expected catch rate would be due to engineering activities in Kingston Harbour.

The expected catch rate as catch weight for one day's fishing was estimated by a simple log-linear model with terms for month and gear type. Because of missing data, the generalized linear model could not fit interaction terms. Hence the model accounts for seasonality and average catch rate differences by gear type, but not interactions between gear and season. The model was fitted by minimising the Poisson log-likelihood.

The change in catch rate in 2003 was estimated by a single term comparing the 2003 values with the average 1996-2002 catch rates from data taken before the engineering activity in Kingston Harbour. Any trend in the period 1996-2002 was not accounted for (there was a slight positive trend). Instead the overall variability in this period was set against the change, if any, in 2003.

The variability was estimated using a bootstrap method. The full model was fitted to provide an expected catch rate and a standardised residual for each observation. Each bootstrap data set was obtained by adding a standardised residual selected at random with replacement from all residuals to each expected value. The standardised residual is the difference between the observed and expected day's catch divided by the expected day's catch.

Bootstrap data was calculated as:

$$Y_i = X_i + X_i R_j$$

where X_i is the i^{th} expected catch, Y_j is the new i^{th} bootstrap observation, and R_j is a randomly chosen j^{th} standardised residual. The 2003 catch adjustment estimate was obtained for each bootstrap data set fitted in the same manner as the original model.

Results

The model appears to provide a reasonable fit to the data (Figure 35; Table 17). There was an apparent drop in catch rate, with an estimated mean of 38% decline. This can be translated directly to 38% lower revenue for each fisher exploiting this fishery. Although the variation is wide (Figure 36;Figure 37;Table 18), the 95% confidence excludes zero.

The total compensation was estimated as a 15 year discounted sum as a proportion of earnings:

$$P = \sum_{j=0}^{Y-1} X e^{-\delta j}$$

where δ = discount rate, X = proportion of earnings, Y = number of years (15) and P = the compensation payment. The mean payment was around 2.5 times annual earnings from this fishery. This could be used as an appropriate one-off payment to fishers to compensate for loss in earnings.

Table 17 Analysis of variance table for the catch rate change parameter. The results indicate the parameter is significantly different from zero taking into account the underlying errors.

	SS	Change	DF	MS	F	Probability
Compensation	41574.7	443.8	1	443.8	13.68	0.000226
Residual	41130.9	41130.9	1268	32.4		

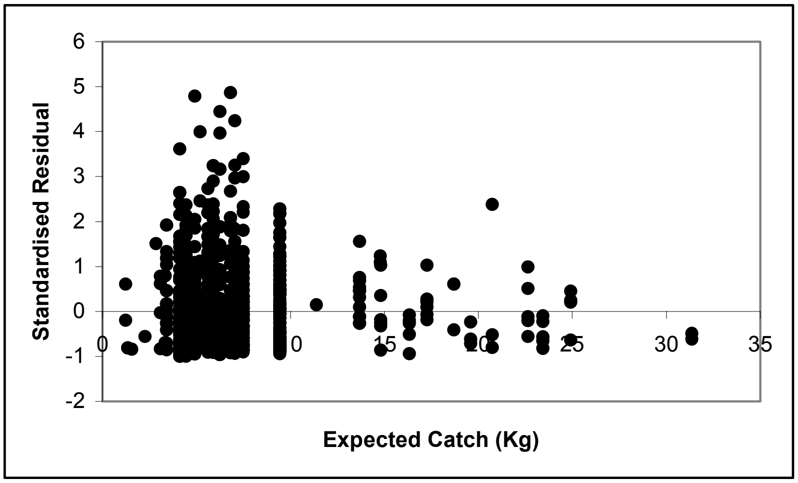


Figure 35 Standardised residuals plotted against the expected values demonstrating the heteroscedasticity has been removed.

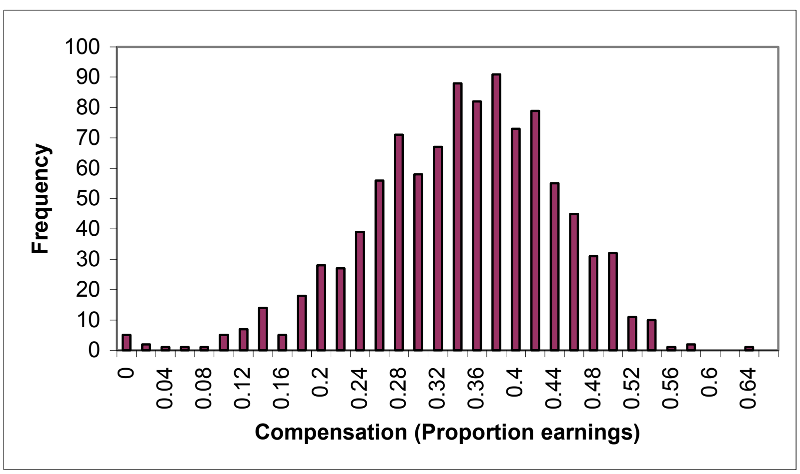


Figure 36 Frequency distribution of bootstrap estimate for the proportional change in earnings after the engineering activities in Kingston Harbour.

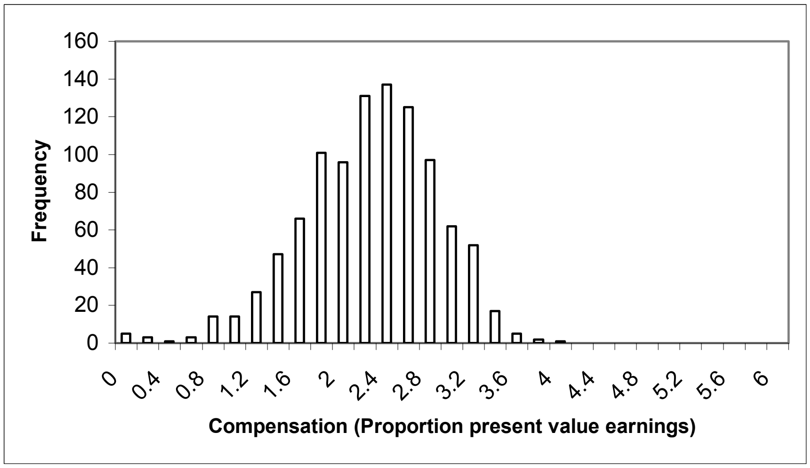


Figure 37 Frequency distribution of bootstrap estimate for the present value of earnings suitable to pay compensation for 15 years of income.

Table 18 Estimates and bootstrap results from fitting the generalized linear model to the available catch and effort data. The results indicate a average 38% decline in catch rate. The bootstrap estimates indicate that the true estimate is most likely to be between 13 – 50%.

	Parameter	Proportion Earnings	PV Payment Proportion Earnings
Best Estimate	-0.48	0.38	2.45
Average	-0.42	0.34	2.15
Bias	-0.13	-0.12	-0.12
Standard Deviation	0.14	0.10	0.62
Lower 95%	-0.69	0.13	0.81
Upper 95%	-0.13	0.50	3.20

Discussion

The results suggest that catch-per-day, even after allowing for seasonal and gear effects, have fallen by 38%. This means annual gross earnings have fallen by 38% for fishers exploiting this stock. This 38% will have a larger impact on the profits, as any costs, such as fuel, will be unaffected, which would increase the impact on net earnings.

The net present value for earnings can be calculated to allow a single compensation payment to be made to fishers. With the available official government discount rate, this indicates compensation should be paid to each fisher of 2.45 times their annual revenue earnings from the fishery. For a fair payment to be made, the gross earnings of each fisher will need to be calculated or estimated. There is some data to do this, but additional interviews should be carried out with each fisher seeking compensation to augment this and calculate an appropriate figure.

The relatively small data set makes the estimate less than certain. Further monitoring may obtain better estimates, however it is quite possible compensation estimates will increase as estimates are negatively biased. An additional interest payment may also be due on any delays.

9.1.5 Management

There is evidence that the shrimp stock has been impacted by the engineering operations in Kingston Harbour and that catch rates have fallen. This may now be compounded by overfishing as the resource has been reduced in size. There is a strong case for compensation to be paid to fishers.

Further data collection may be required to calculate the correct compensation level for fishers. This analysis demonstrates a fair calculation is possible.

Straight compensation may not be the best management result. It may be possible to develop a co-management regime based on compensation funds. For example, it may be possible to compensate some fishers if they leave the fishery, while other compensation could be used to control access to the resource and develop co-management measures. This should allow catch rates to increase back to previous levels for those remaining in the fishery, for example.

10. Suriname Seabob Fishery (*Xiphopenaeus kroyeri*)

10.1 Status of Stocks

The current state of the stock is uncertain. The catch-per-unit-effort (CPUE) has been increasing 1998-2001, suggesting the stock is recovering. This trend is similar to Guyana seabob, however Guyana has a decrease in CPUE in 2002, for which Suriname has not assembled the data yet. The yield-per-recruit assessment suggests yields could be increased by decreases in effort.

10.2 Management Advice

At present, 24 vessels are in operation. These vessels have a total production of 13 000 t year^{-1}. The fishing effort is currently averages 335 days at sea per month totalled over all vessels.

The stock assessment suggests a decrease in effort would yield higher catch if recruitment does not change. However, as the CPUE trend has been increasing, suggesting recruitment has been increasing, this fishery does not appear to be in imminent danger. Nevertheless tight control and then a reduction in effort is advised to test the stock assessment and protect the fishery against economic loss. The current assessment suggests that the fishing effort exceeds that required to obtain the maximum sustainable yield and should be lowered from 335 to 210 days at sea.

Current data collection activities should be continued or increased. A separate assessment is recommended to estimate growth parameters for improved interpretation of the routinely collected length data.

10.3 Stock Assessment Summary

A catch-at-length model was fitted to the available catch size composition data. The method assumes catch for each length class is known exactly. The selectivity estimated from the model was used to apply a yield-per-recruit, which was used to estimate reference points for the effort. Two reference points were generated. A limit reference point, F_{MSY}, defines a level of effort beyond which the total catch will fall. A target reference point defines a level of effort which will get most of the yield from the fishery, but with a much lower level of cost to the fishery.

The current effort exceeded both the limit and target reference points (Table 19). This result was consistent even when testing some of the models assumptions. However, in contradiction to this, catch-per-unit-effort has been increasing, suggesting that stock size has been increasing. Nevertheless, a precautionary action would be to reduce effort while monitoring the reaction of the stock.

Table 19 Yield-per-recruit reference points for Suriname seabob. The fishing mortality reference points use fishing effort as a proxy variable. The current effort exceeds both estimated target and limit reference points.

	$F_{0.1}$	$F_{current}$	F_{msy}
Days At Sea	131	335	210
Yield-per-recruit	115460.3	118380.8	179057

Comment: What units are these – obtained from the length-weight conversion?

10.4 Special Comments

Different sets of growth parameters produced quite different results making specific reference point estimates unreliable. Research on growth and mortality on this species is required to improve the assessment.

Catch data was not available for the artisanal Chinese seine fishery. Data on all catches needs to be assembled for a full assessment.

Available data on maturity, fecundity and sex ratios should be used to properly assess spawning stock size and relevant reference points for future assessments.

10.5 Policy Summary

Marine fisheries have been regulated in Suriname, since 1980, by the Decree C-14.

In the rural areas, the seabob fishery sustains a large number of fisher households, and is also one of the few profitable occupations in some areas. Preservation of this source of income and of living standards for the population involved is an important objective.

With the coming into being of the seabob trawl fleet in 1996, foreign exchange generation became an important component of this fishery.

Due to the lack of information on this resource, it was decided to set a maximum limit of 30 vessels. As shown in this assessment, this may be too large.

10.6 Scientific Assessments

10.6.1 Description of the Fishery

Seabob are exploited in the EEZ at the depth range from 11 – 24 m. Vessels are licensed to fish between 18m and 36m.

The sea-bob trawl fishery started in 1996 with one company, which owned 10 boats. In 1997, this company increased the numbers of vessels to 15, and a second company joined this fishery, with 3 vessels. At present, the seabob fleet is made up of 24 vessels owned by two companies, namely Guiana Seafoods N.V (GSF) and Namoona with 15 vessels and 9 vessels respectively. The catch is processed in two processing plants.

There is also an artisanal fishery for seabob with about 500 vessels using Chinese seines.

10.6.2 Objectives

- Determine the status of the seabob stock and the fishing mortality reference points.
- Determine the adequacy of the data collection programme.

10.6.3 Data Used

Name	Description
Length-frequencies	These data were collected by observers placed on board seabob vessels. Samples of seabob taken were analysed in the laboratory of the DOF. Each sample was first sorted by species, sex and maturity. Then, each seabob was measured using carapace length. The data was recorded in MS Excel and used to produce length-frequencies graphs and tables. Data were available for 1998-2001.
Catch and effort data	Catch and effort data from 1998 to 2001 were taken from the reports submitted by two companies (Namoona + GSF) involved in this fishery. The data are submitted in electronic format, which makes correcting data before analysis much easier. The data consist of catches for each vessel per fishing trip, broken down by the commercial size categories as being used in the processing plant. Effort can be expressed in days at sea, numbers of fishing trips in a month or year and number of licences. Data were available for 1998-2001.

10.6.4 Assessment 14

Objective

Complete a catch-at-length analysis using the available catch, effort and length composition data suitable to a yield-per-recruit analysis. The aim is to estimate fishing mortality (and its effort proxy) reference points for maximum sustainable yield (F_{MSY}) and a target ($F_{0.1}$).

Method/Models

The catch size classes were converted to age using an age-length key developed from a growth model with parameters supplied from previous studies. Thereafter a standard catch-at-age model was applied. It was fitted by minimising the squared difference between the population model log-fishing mortality and the expected fishing mortality using selectivity parameter for each age and the effort data. See method section 4.5.4 for details.

The growth model parameters and natural mortality were the same as those used for Guyana seabob (section 8). The weight-length conversion parameters were obtained from previous workshop reports.

Comment: Need references if possible.

Results

The assessment interprets the increasing CPUE trend as increasing recruitment. The yield-per-recruit suggests recruits are not exploited optimally. The implication is that a reduction in fishing effort would yield greater catches in the long term (Table 20).

Table 20 Yield-per-recruit reference points for Suriname seabob. The fishing mortality reference points use fishing effort as a proxy variable. The current effort exceeds both estimated target and limit reference points.

	$F_{0.1}$	$F_{current}$	F_{msy}
Days At Sea	131	335	210
Yield	115460.3	118380.8	179057

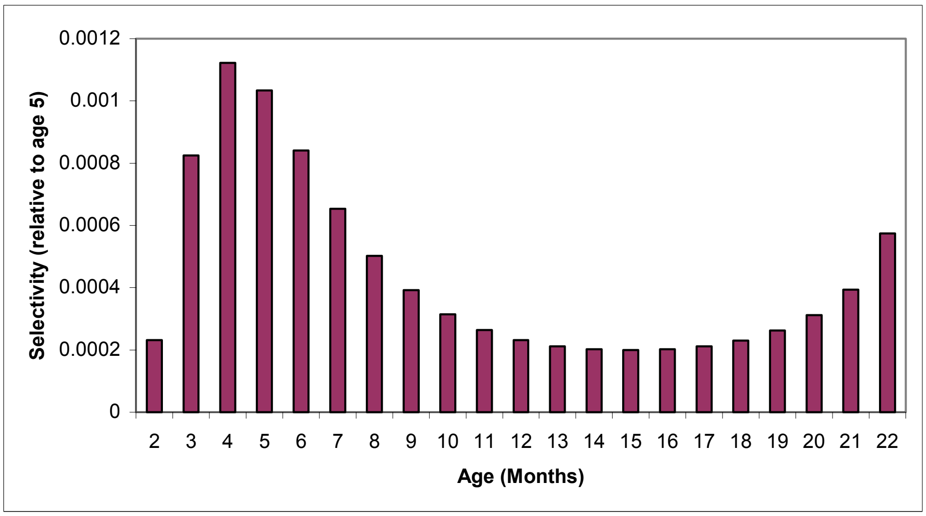


Figure 38 Trawl gear selectivity estimated using the catch-at-length model. The model suggests peak selection occurs at approximately 4 months old, thereafter fishing mortality decreases, then increases again towards the older ages. Catches in the oldest ages will be rare for this species.

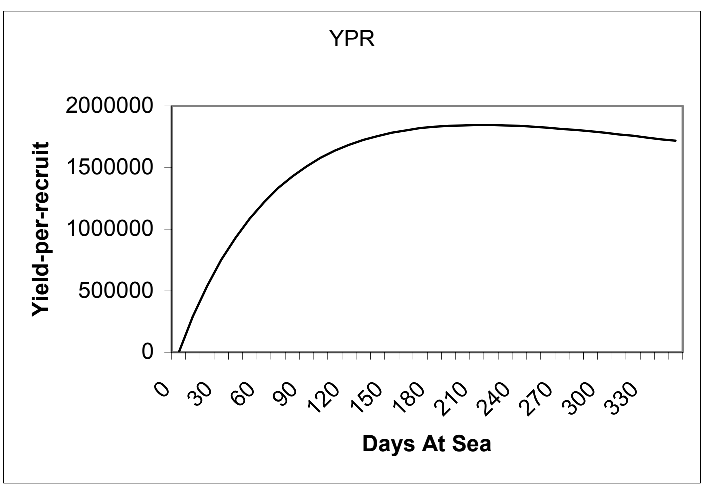


Figure 39 Yield per recruit for estimated seabob trawl selectivity.

Discussion

Good estimates of the relevant population dynamics parameters are urgently needed. All methods interpreting catch at length must be able to convert length to age. For species which cannot be aged directly, there is great reliance on the growth model and its parameters. These must be reviewed and methods sought to estimate them accurately.

For the available data, there is a common trend in CPUE with Guyana. It is possible that these fisheries and stocks are related, and therefore a common analysis is probably useful. It is necessary to obtain as up-to-date data as possible to carry out a joint assessment.

10.6.5 Assessment 15

Objective

Repeat the assessment in section 10.6.4, but fit natural mortality and growth parameter estimates instead of using default values to check the sensitivity of the results.

Method/Models

See section 10.6.4 for the basic method and section 4.5.4 for details.

In this case, natural mortality and growth parameters were fitted alongside the selectivity parameters using the same model.

Results

The model fit improves significantly when allowing the growth and natural mortality parameters to be adjusted to fit the data. The estimated values (Table 21) are not unreasonable. However, further exploration indicates quite different parameter sets can produce similar catch compositions. Even without formal analysis, this would suggest parameter estimates are heavily correlated.

As with previous estimates, selectivity peaks at an early age (Figure 40). However there is also an apparent increase in selectivity with age producing a convex function. There is no immediate justification for this shape selectivity from what is known of the trawl gear.

With the fitted parameters, yield-per-recruit reference points have been reduced compared to the default parameter values. Other sensitivity analyses also suggest lower effort will improve the state of the stock and of the fishery.

Table 21 Estimated growth and natural mortality parameters using the catch-at-length model. The model fits the data better with faster growth, smaller asymptotic size and lower natural mortality.

Growth Parameters		Natural Mortality
K	L_∞	M
0.374	29.20	0.035

Table 22 Yield-per-recruit reference points for Suriname seabob with the adjusted growth and natural mortality. The fishing mortality reference points use fishing effort as a proxy variable. The current effort exceeds both estimated target and limit reference points.

Comment: What are the yield units?

	$F_{0.1}$	$F_{current}$	F_{msy}
Days At Sea	82	335	150
Yield	2406971	2251307	2650024

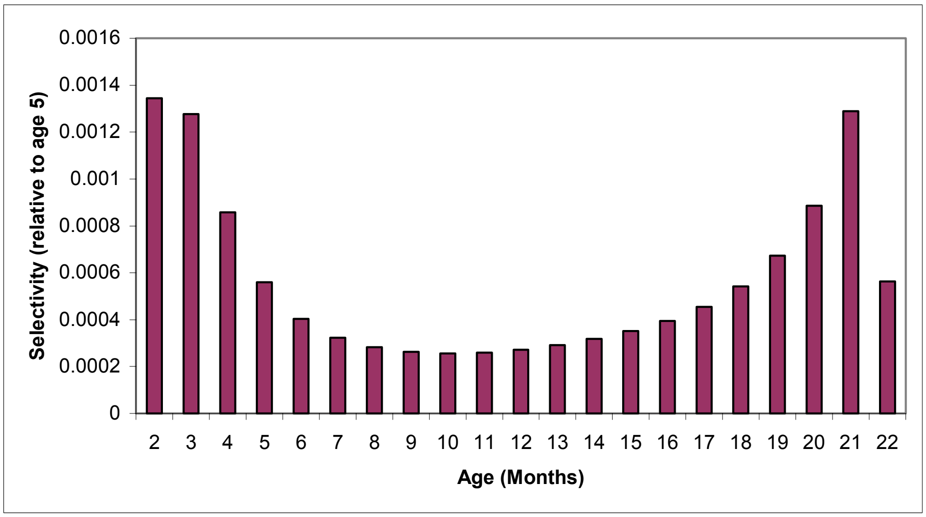


Figure 40 Trawl gear selectivity estimated using the catch-at-length model after fitting growth and natural mortality parameters.

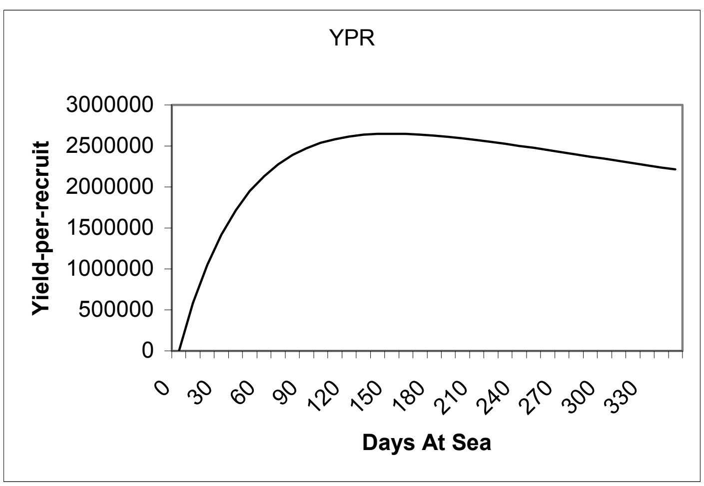


Figure 41 Yield per recruit for estimated seabob trawl selectivity.

Discussion

While the fitted growth and natural mortality parameters produce a better fit, parameter estimates are heavily correlated and the selectivity curve appears unrealistic (Figure 40). It would be better to reduce the number of parameters being fitted, for example, by exploring separate selectivity functions rather than estimate selectivity at each age independently and, most importantly, supplying accurate parameter values for stock dynamics wherever possible.

The analysis indicates the current data collection is good, but not sufficient for accurate stock assessment. The following are also required:

- Good estimates of growth parameters in particular are necessary for accurate interpretation of catch at length data.
- Contrast is required in management measures applied to the fishery. This can be achieved by varying the fishing effort and monitoring the resulting behaviour of the stock. This would also demonstrate adequate control over the fishery.
- The increasing trend in CPUE needs to be checked to ensure it is a good relative index of abundance of the stock.

10.6.6 Management

Generally, reduction in fishing effort is warranted. Given the rapid growth, it should become quickly apparent whether controlling effort is having the desired effect as long as the fishery monitoring is continued.

A reduction in effort will not only ensure sustainability in the fishery, but also improve the stock assessment advice. Ideally the time series should have a series of depletion and recovery events to provide information on the rate of exploitation and productivity of the stock. Unlike Guyana, the CPUE trend is increasing only.

11. Suriname Sea Trout (*Cynoscion virescens*)

11.1 Status of Stocks

The soft bottom demersal fish have been the main object of biomass surveys carried out during the last 30 years. Biomass estimates obtained by these surveys varied widely, however.

Because of the (presumably large) amounts discarded, it is impossible to safely assess the actual extraction, and the state of exploitation. It had been assumed that the resource was lightly exploited, until the admission of the stern trawler fleet that discarding was high. Nowadays, it is assumed to be close to full exploitation.

11.2 Management Advice

Concerning the driftnet fisheries it appears that the fishing effort is under the maximum sustainable level. Hereby it can be advised to:

- keep the mesh size at a minimum of 5 inches stretched. This measure keeps the gear selectivity for kandratiki to greater than 40 cm length and helps avoid recruitment overfishing.
- the catch per unit effort (CPUE) for the year 2000 was 19 kg day^{-1}. It has been suggested that the maximum sustainable level of exploitation should be achieved at around a CPUE of 25 kg day^{-1}. It is better not to exploit at the maximum sustainable yield, because targeting the maximum sustainable yield increases the risks of overfishing and wastes economic benefits.

Discarding and catches in other fisheries need to be addressed. These may well be a significant part of the fishery for this species and therefore controlling driftnet alone will not be enough to ensure conservation of this fishery.

11.3 Stock Assessment Summary

Various types of linearized catch curve were fitted to a length frequency sample taken from the driftnet catches to estimate fishing mortality. The models did not fit the data well, probably because gear selectivity plays a significant role in determining the length composition. It is difficult to estimate selectivity along with all other parameters necessary to explain the data.

The general results from the yield-per-recruit indicate that with the current fishing practices the fishing mortality is lower than the limit reference point, but possibly higher than the target reference point. This results from selecting older fish.

11.4 Special Comments

The fishery is prosecuted by driftnet, which selects larger fish. There is no simple way to fit selectivity models with the available data, and no model fitted the data well. Several additional types of data are required to provide an accurate stock assessment. These would include:

- Age as well as length frequency samples from the driftnet fishery.

- On-board observer information from trawlers, and in particular, sampling from discards and catches so the full exploitation can be assessed.
- Sampling catch from any other gears taking this species

11.5 Policy Summary

A draft fishery management plan forms an interim policy towards this fishery. It recognises that supplying the domestic market is the first objective of the management of this resource. A related objective has been to keep prices down, and to guarantee the availability of affordable, protein-rich food. Since a few species have started to be exported, the generation of foreign currency, though not yet a major objective, may play a significant role in the future.

The preceding considerations are compatible with the realisation of MSY. In the future, as data become available, MEY is expected to take over as the production target, especially if the production of protein at affordable (net) cost remains the main objective.

Employment plays a minor role, since the technologies used to harvest this resource are more industrial and have limited labour requirements. The njawarie fishery is labour-intensive, but includes only a small number of vessels, and therefore offers little employment. On the post-harvest side, however, there are numerous family-scale enterprises dealing primarily with small species belonging to this category. The situation of these small-scale industries (indirect employment) is an element to be considered in the management of this resource.

The current controls in the artisanal driftnet fisheries are to:

1. restrict the number of boats.
2. restrict the mesh size to a minimum of 5 inches stretched.

11.6 Scientific Assessments

11.6.1 Background

For management purposes, it is convenient to group species and categories of exploited marine organisms into assemblages with similar characteristics of fishing grounds, ecology and exploitation strategy. Categories proposed in Table 23 can be seen as management units. This classification will be refined as more detailed information becomes available. The most important species within each management unit may then be considered individually.

Many different types of fishing vessels are operating in Surinamese marine, brackish and inland waters. According to their characteristics, the type of fishing gear used and the fishing grounds they exploit, they can be grouped into a number of relatively homogeneous categories, which can be called fleets. Table 24 is a list of the fleets, divided into “industrial” and “small-scale”, currently known in Suriname.

Table 23 Classification of fishery resources into management units.

MANAGEMENT UNIT		MAIN SPECIES	OTHER SPECIES
01	Large demersal fish	*Cynoscion acoupa* *Cynoscion steindachneri* *Arius parkeri, Arius proops*	*Megalops atlanticus* *Epinephelus itajara* *Lobotes surinamensis*
02	Small soft-bottom demersal fish	*Macrodon ancylodon, Cynoscion virescens, Nebris microps,*	*Larimus breviceps* *Arius spp.* *Bagre spp.*
03	Small sandy-bottom demersal fish	*Lutjanus synagris*	*Haemulon spp.* *Calamus spp.*
04	Red snapper & deep sea fish	*Lutjanus purpureus*	*Rhomboplites aurorubens* *Serranidae*
05	Rays & sharks		
06	Large pelagic fish	*Scombridae*	*Sphyraenidae, Caranx*
07	Small pelagic fish	*Engraulidae, Clupeidae*	*Carangidae*
08	Brackish water fish	*Mugilidae, Centropomidae* *Tilapia mossambica*	*Arius passany, Arius couma, Elops saurus*
09	River fish	*Plagioscion surinamensis*	
10	Fresh water fish	*Callichthydae, Erithrinidae*	*Aequidens spp.*
11	Estuarine shrimp	*Xyphopenaeus kroyeri*	*Nematopalaemon schmitti*
12	Penaeid shrimp	*Penaeus subtilis* *Penaeus brasiliensis*	*Penaeus schmitti* *Penaeus notialis*
13	Deep sea shrimp		
14	Crabs	*Ucides cordatus*	*Other crabs*
15	Cephalopods		
16	Sea turtles	*Chelonia mydas, Dermochelys coriacea*	*Lepidochelys olivacea, Eretmochelys imbricata*

The impact of each type of fishery on each resource can be assessed through analysis of landings data over a number of years. Drifting gillnets used in the coastal zone have large mesh sizes (5 to 8 inches stretched), and belong to the most selective fishing gears. They catch almost exclusively a few large demersal fish species.

Several species belonging to the family of the sea trout (Sciaenidae), and a few smaller catfish species, constitute this resource group (see Table 23). They are distributed in shallow coastal waters and estuaries, to 25 metres depth, above soft, muddy bottom.

Table 24 Classification of fishing fleets operating in Suriname.

FLEET CATEGORY	TYPE OF VESSEL	TYPE OF GEAR
Industrial fleet	Outrigger trawlers	Shrimp trawl Fin-fish trawl Sea-bob trawl
	Stern trawlers	High-opening trawl
	Snapper boats	Hook and line
	Guyana boats	Drifting gillnet Njawarie (banknet) Longline (bottom)
	Korjaal (canoes)	Large fuiknet (chinese seine) Medium fuiknet (chinese seine) Small fuiknet (chinese seine) Drifting gillnet Longline (bottom) Kieuwnet (fixed gillnet) Haritete (river seine)
	Small or no canoes	Drag net Spannet (fixed gillnet) Chastnet

11.6.2 Objectives

The objective of the analysis was to update the current knowledge of the artisanal driftnet fishery. This was done by analyzing data of *Cynoscion virescens* caught by the artisanal driftnet fleet in 2000. From this analysis it is possible to say something about the state the fishery.

11.6.3 Data Used

Name	Description
Total catch and effort for 2000	Catch and effort was monitored for the artisanal driftnet fleet in 2000.
Bottom trawl data	Length-frequency data from the 1999 sampling program.
Landings data	Length-frequency data from several main landing sites for the artisanal driftnet fishermen during the 2000 sampling program

11.6.4 Assessment 16

Objective

The objective was to fit a length converted linearized catch curve to the available length frequency data in order to estimate current fishing mortality.

Method/Models

The methods used were:

1. A length converted catch curve model by size intervals (Ehrhardt, N.M., and C.M. Legault 1996).
2. Beverton and Holt's yield per recruit and biomass per recruit models with knife edge recruitment (see Sparre and Venema 1992, pg 225).
3. Pauly's Empirical Formula (see Sparre and Venema 1992, pg 151).

Results

A length converted catch curve was fitted to the available length frequency data (Figure 42). The model was unable to fit to most of the data (Figure 43), but estimated a total mortality based on the declining frequency to the right of the mode (Table 25). The trawl data suggests mortality between 4.5 and 12 years old is approximately equal to the natural mortality 0.3 $year^{-1}$. The drift net data suggests that after fish reach 7 years old, they are subject to a total mortality of 0.96 $year^{-1}$ with 0.66 $year^{-1}$ fishing mortality. Mortality prior to 7 years old is not known, even though the majority of the catch is taken during this period.

Table 25 Assumed parameter values used in the converting length to age and the assessment results. The growth rate (K) and natural mortality (M) values were the same as that used by the Guyana assessment. The natural mortality obtained from Pauly's empirical equation (0.46 $year^{-1}$) was much higher than that suggested by the estimated total mortality.

M ($year^{-1}$)	0.30	
K ($year^{-1}$)	0.30	
Results	**Trawl Data**	**Drift Net**
Slope	-0.305	-0.96
Intercept	8.527	14.06
R^2	0.969	0.99
F ($year^{-1}$)	0.005	0.51

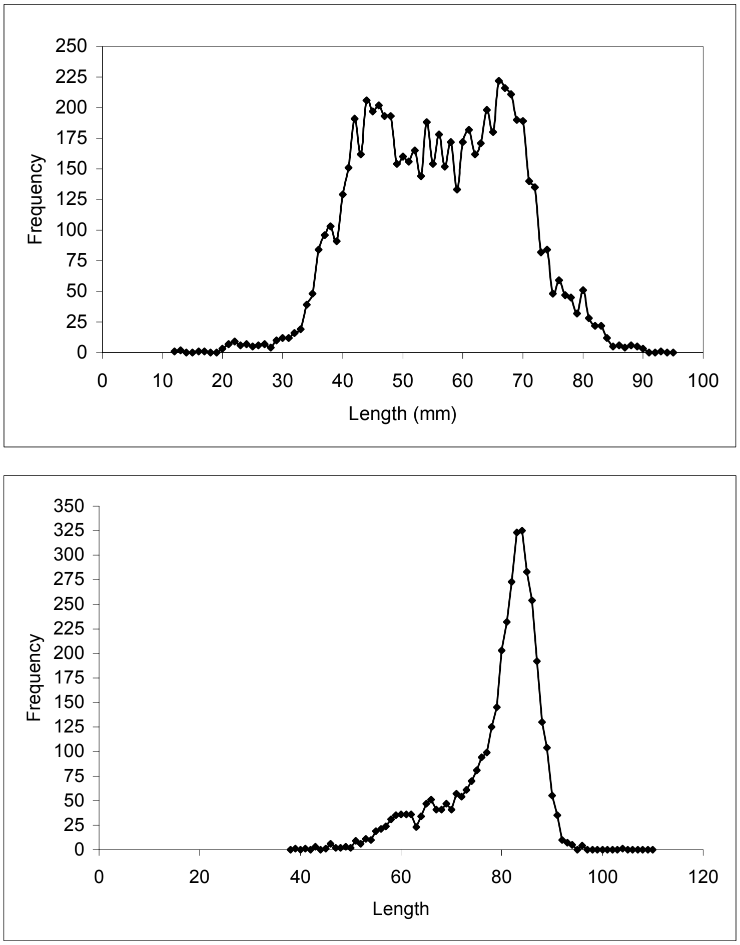


Figure 42 Length-frequency data for *Cynoscion virescens* caught by the trawl fleet in 1999 (top) and the artisanal driftnet fleet in 2000 (bottom). The downward trend to the right of the modes is assumed to be a result of mortality and implies an L_∞ of around 95cm.

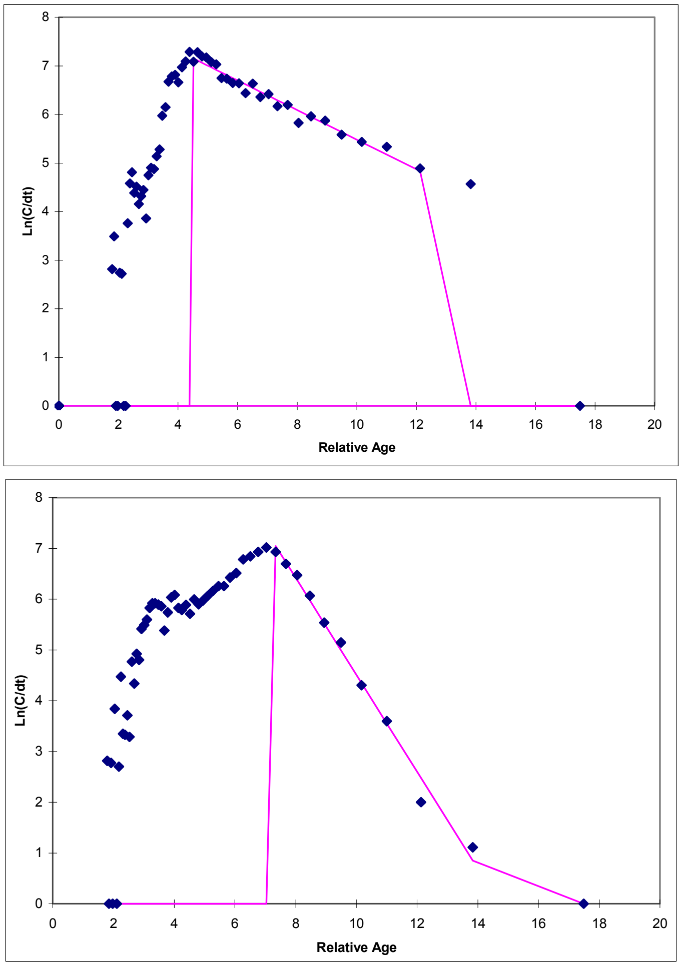


Figure 43 Length converted catch curve for *Cynoscion virescens* based on length frequency sampling for trawl in 1999 (top) and drift net in 2000 (bottom). The lengths have been converted to age based on the von Bertalanffy growth model. Data to the left of the mode are generally ignored and the slopes of the line represents the average total mortality.

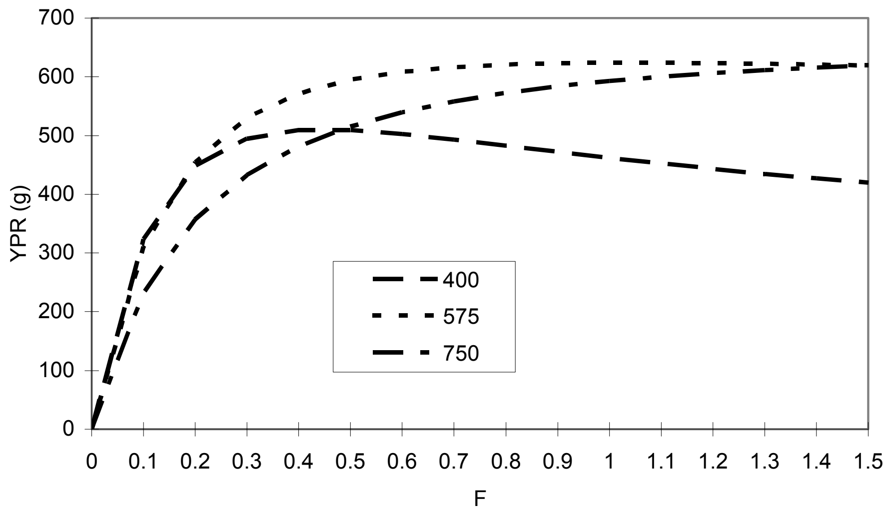


Figure 44 Yield-per-recruit for different length (mm) at first capture. The yield-per-recruit assumes knife edge selectivity, which is clearly not the case as the frequency is domed rather than declining in a linear fashion (Figure 43). However, there is probably an equivalent knife edge selection for each gear, with length at first capture at around 400mm and 750mm for trawl and drift net respectively. For 750mm, there is no F_{MSY} point, so no limit reference point can be defined based on yield-per-recruit.

Table 26 Results from the yield per recruit based on an assumed average length at first capture of 40cm and 75cm for trawl and drift net respectively. The implication of the infinite limit reference point for drift net is that yield will increase with fishing effort as long as recruitment remains unaffected. With a lower size at first capture target and limit are reasonably low values. The current mortalities for trawl and drift net do not appear to be compatible.

Length at First Capture	$F_{0.1}$	$F_{current}$	F_{MSY}
40cm (Trawl)	0.24	0.005	0.45
75cm (Drift Net)	0.46	0.66	∞

Discussion

The artisanal driftnet fleet has very selective catches. Figure 42 indicates this selectivity for species mostly 84 cm length and beginning with approximately 45 cm length. The general results suggest selection of older fish so that it is difficult for drift net to overfish this species with the current mesh size. In contrast, trawl catches smaller fish and could overfish the species, but the catch curve suggests a very low fishing mortality. There is inadequate information to assess the optimal level of fishing required by the policy.

The estimated fishing mortality relates to the period when the fish are fully selected. A proper assessment will require a selectivity curves for both gears.

11.6.5 Assessment 17

Objective

The objective was to apply a probability catch curve model to the gillnet length frequency data.

Method/Models

The method used was the same as in the assessment section 7.6.5. This is the same as a length converted catch curve with the exception that the length to age conversion was modelled using an age-length key. The model was fitted with and without a Gaussian length selectivity model. With the selectivity curve, the growth parameters used were those fitted to the Guyanese sea trout as the Guyanese model had trawl data also available which allowed an attempt to estimate growth.

Results

The catch curve was able to fit the observed frequency exactly without allowing for selectivity. However, the results were rejected as the estimated growth rate was too slow to be considered realistic.

The selectivity model provided a much poorer fit (Figure 45). It was not possible to estimate more than gillnet fishing mortality and a selectivity parameter while the growth parameters were taken from the Guyanese assessment (Table 27;Table 28). The estimated selectivity curve (Figure 46) takes predominantly older fish. As a result yield-per-recruit gives very high limit and target reference points (Figure 47;Table 29).

Table 27 Parameters used from the Guyanese assessment. These parameters could not be fitted.

K	L_∞	T_0	Sigma (CoV)
0.25	99.63	0	0.050

Table 28 Fitted parameters with the exception of the mean selectivity which was fixed as the maximum size (L_∞).

F (Other)	F Gillnet	Mean	Sigma
0.096	10.52	99.63	13.97

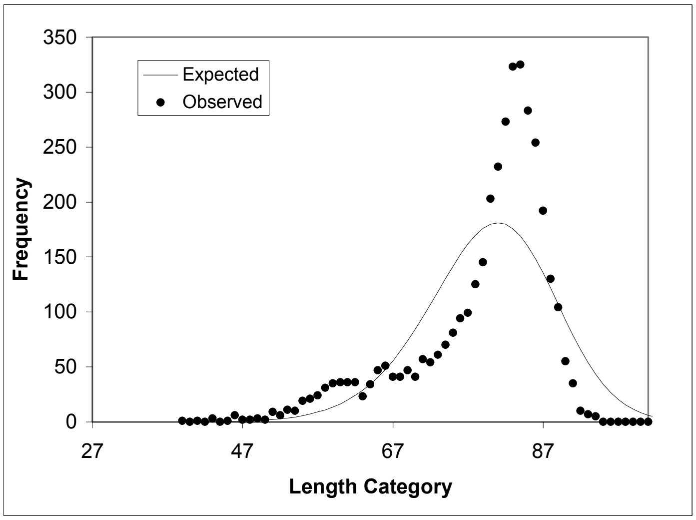


Figure 45 Probability catch curve model fitted to length composition data. The model is attempting to fit the skewed nature of the distribution, but the fit remains poor. The size distribution is more sharply peaked than the model is able to explain.

Figure 46 The estimated selectivity curve for age showing that full selection occurs beyond 10 years old.

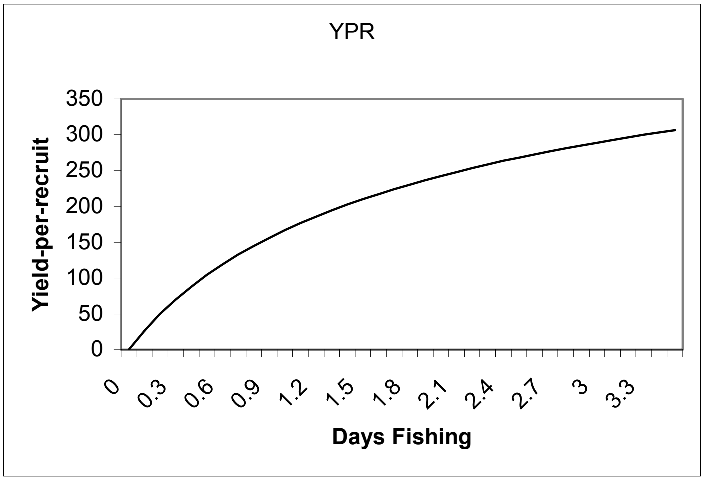


Figure 47 Yield-per-recruit for different size at first capture. There is effectively no maximum point, but a slow increase. This result is largely due to the selectivity curve.

Table 29 Results from yield per recruit analysis. The F is the fishing mortality as a proportion of the current fishing mortality. The results suggest that the stock is not heavily fished.

	$F_{0.1}$	$F_{current}$	F_{MSY}
F	4.78	1.00	540
Yield per recruit (g)	409.12	209.86	589.09

Discussion

The results are heavily dependent on the choice of selectivity function. A Gaussian function is reasonable for gillnets, but other functions could be proposed. Gillnets can show many selectivity effects, such as a bimodal frequency, depending on how they catch the fish. An alternative function could be proposed if more was known about how selectivity works.

The lack of a limit reference point is a result of the selectivity curve. Because only larger fish are selected, there is little potential growth available to improve yield for each recruit. This makes yield-per-recruit useless for developing limit reference points. Spawning stock biomass approach will have to be developed. A maturity ogive will be required for this.

Overall the assessment is unreliable. While this approach attempts to fit to all data, it does not explain the observed frequency well. This makes the assessment too unreliable to offer advice on the level of fishing effort. More data and better models are required.

Age data would be very useful for assessing gillnet catches. This species is a prime candidate for ageing a sample of the catches. Sampling length frequencies of trawl gear and total catch and effort monitoring should also lead to improved assessment.

11.6.6 Management

The analysis suggests that the current state of the stock is just below full exploitation. This has also been the case in the previous assessments. However, the total number of boats has been reduced in comparison to ten years ago. Even so, the artisanal driftnet fishery has never passed the yield MSY.

There is no evidence that the fleet sizes should be reduced. The drift net gear is targeting older animals probably beyond age at first maturity. This makes it difficult, although not impossible, to overfish this species. Trawl mortality appears low. It is quite possible that the stock can be economically overfished, however, and a target reference point needs to be developed to prevent this.

12. Trinidad Shrimp (*Farfantepenaeus notialis*)

12.1 Scientific Assessments

12.1.1 Background

The shrimp trawl fishery of Trinidad and Tobago targets: five shrimp species namely *Farfantepenaeus subtilis, F. notialis, F. brasiliensis, Lithopenaeus schmitti,* and *Xiphopenaeus kroyeri*; as well as associated groundfish namely *Micropogonias furneri and Cynoscion jamaicensis.*

This resource is exploited by artisanal, semi-industrial and industrial trawlers. The artisanal vessels are pirogues 6.7-11.6 m in length with either outboard engines (13 vessels) or an inboard diesel engine usually 137-hp (71 vessels). These vessels manually deploy one stern trawl. The semi-industrial trawlers are 10.4 -12.2 m in length with usually 176-hp inboard diesel engines. These use a single net operated by a hydraulic winch. There are currently nine of these trawlers. The industrial vessels use two nets attached to twin outriggers. The nets are set and retrieved using a hydraulic (double-drum) winch. The vessels are 17.1 -22.9 m in length and usually have 365 hp inboard diesel engines. There are currently about 25 of these vessels.

All trawlers operate in the Gulf of Paria on the west coast of Trinidad. The industrial trawlers also operate west of Saut D'eau on the north coast and in the Columbus Channel on the south coast. Trawling off the east coast is prohibited by law.

12.1.2 Objectives

The main objective was to assess different methods to analyse the available data and build a stock assessment approach able to give management advice. Data exists to estimate the total catch and effort and a biological sampling programme was conducted between 1992 and 2001. These data will allow various analyses to be carried out, the most informative but complex being a catch-at-age model. The main aim was to use one species to test whether such a model could be fitted to the data and how complex this fitting process might be. The assessment would also be used to test how scientific results could be communicated to management.

Test analyses were developed and applied to one population (female *F. notialis*) out of a possible 10 populations. The analysis would have to be extended to deal simultaneously with all species categories and gears simultaneously.

12.1.3 Data Used

Name	Description
Catch and effort data	Catch and effort data was sampled based on trips. The sample is raised using a frame survey carried out periodically.
Biological sampling	Samples were taken from landed catches separating species, sex and carapace length between 1992 and 2001.

12.1.4 Assessment 18

Objective

The objective was to estimate missing catches to prepare data for a catch-at-age model assessment.

Method/Models

The catches of female *F. notialis* were estimated based on a generalized linear model (GLM). A log-linear model was used to estimate expected catches based on the total shrimp catch including all species, year, month and gear terms for each length class. Separate models for each length class were necessary as the equivalent full interaction terms between length class and all other parameters would require too many parameters to be fitted at once. The separate models fitted were equivalent to a single model with full interaction terms except that the error was estimated separately for each model.

Otherwise, only main terms were used in the linear predictor and no interactions between total catch, year, month or gear were accounted for. There was no suggestion that any such terms were significant.

The model allowed the expected catch in any given cell to be estimated given the known variables. Where possible the original data was used, but the expected values could be used to fill in all missing data.

Results

Expected catches could be estimated for all missing observations. Original data were used where possible, but otherwise the expected catch-at-length from the GLM was used.

The models provided a reasonable fit. However, the effects that model errors have on the subsequent stock assessment were not explored. This could be done through a complex Monte Carlo simulation scheme unless an alternative approach was adopted.

Discussion

Although the GLM is adequate for the preliminary analysis, it is neither the only way to estimate missing data, nor the best way. Other ways include *ad hoc* methods of "borrowing" age composition data from adjacent cells as was done for an assessment of *F..subtilis* using these data (Die et al 2004). However, such procedures tend to be more complex and the statistical implications difficult to understand. The GLM approach is simpler, but should still take account of some local effects and therefore probably an improvement on ad hoc procedures.

Although the GLM approach is easier to understand than *ad hoc* procedures, it is not responsive to catch composition changes caused by the population dynamics. This is an important loss of information to the subsequent modelling and could well introduce bias. Alternative smoothing techniques to interpolate data, such as GAMs, could be better.

The best way would be to simply fit a model to the actual available observed data, such as would be used in a “synthesis” model. In this case, a catch-at-length model would be fitted to the raw data. This would allow the model to adjust the best fit to the observations rather than some complex estimates. Results from models fitted to the raw data could be very different than those based on processed information.

As a result of these issues, any analyses using these data should be considered preliminary.

12.1.5 Assessment 19

Objective

The objective was to fit a catch-at-length model (VPA) to the available data to see whether this would make the best assessment approach for these data.

Method/Models

Fitting the model consists of two processes. Firstly the catch-at-length data was converted to catch-at-age using an age-length key. Secondly the catch-at-age data was used in a standard VPA model where catches are assumed to be known exactly. The model was fitted by minimising the squared difference between the log-fishing mortality from the model and the expected log fishing mortality based on the available effort data.

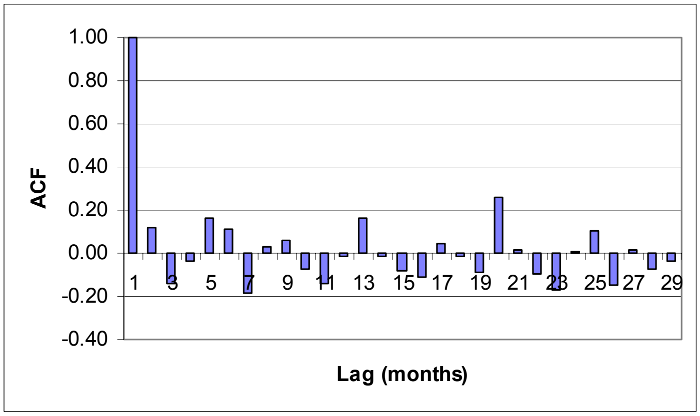
The method requires known catch-at-length. In reality, all total catches are estimated. Catches are raised from CPUE samples and estimates of total effort. Catch-at-length are obtained by breaking down total catch into length classes using length frequency samples.

Details on the model and fit are given in the methods section 4.5.4.

Results

The model provides a reasonable fit to the data, and the results are adequate to test for the problems there may be with the data. Problems may have been introduced through the use of the growth model and the calculation of catch at age.

The general results from the assessment indicate that the fleets are catching predominantly small shrimp (Figure 49; Figure 50). Recruitment appears to have been relatively stable, supported by the lack in any change in the CPUE over this period (Figure 51).



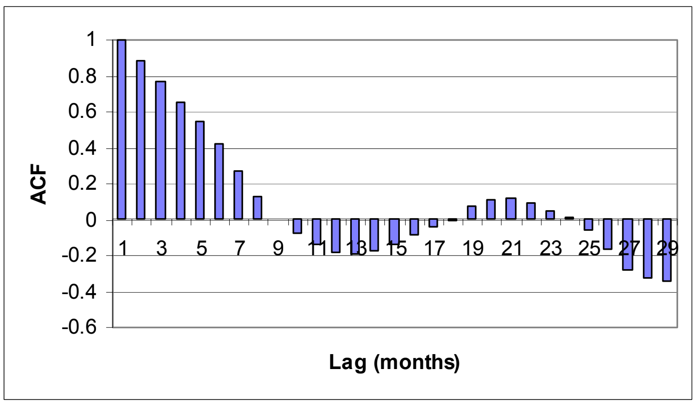


Figure 48 Autocorrelation function for sequential summed square errors associated with each month (top) and each cohort (bottom). There is no strong pattern associated with square errors between months. This suggests there is no remaining time series pattern in the data. In contrast, cohort summed square errors have a distinct residual pattern. The total error associated with each cohort is strongly correlated with the error in the next and subsequent cohorts. This pattern is the likely result of errors introduced by catch data and a failure of the population dynamics model to explain size composition changes.

The yield per recruit suggests the stock has not been overexploited with respect to yield (Figure 52). This result is due to the selectivity favouring small shrimp, as the fishery has effectively only a narrow window to exploit the stock, and a generally low catchability. Both patterns may be due to problems in the estimation of catch data.

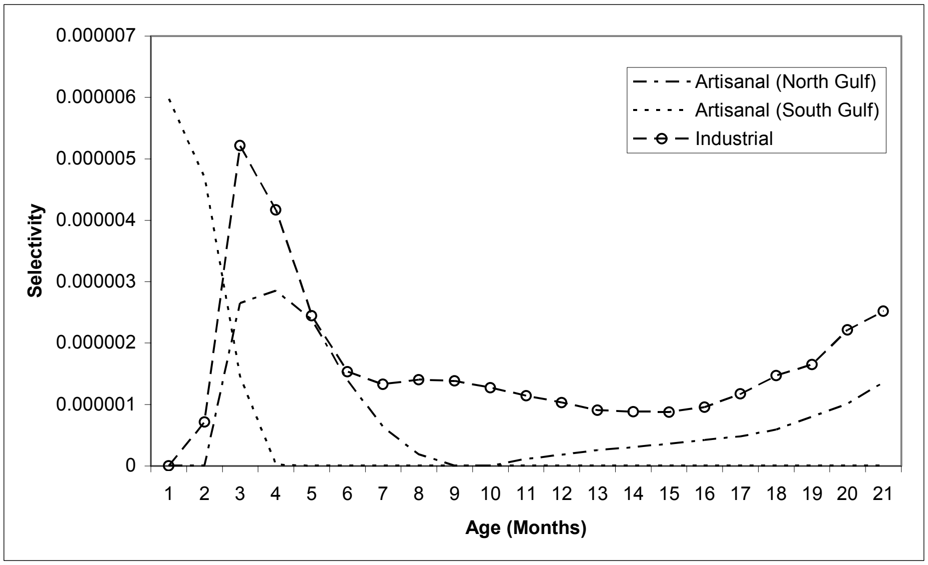


Figure 49 Selectivity of female *F. notialis* for artisanal and industrial fishery. The industrial fishery has the most even selectivity. Artisanal (South Gulf) seems to catch only small female *F. notialis*.

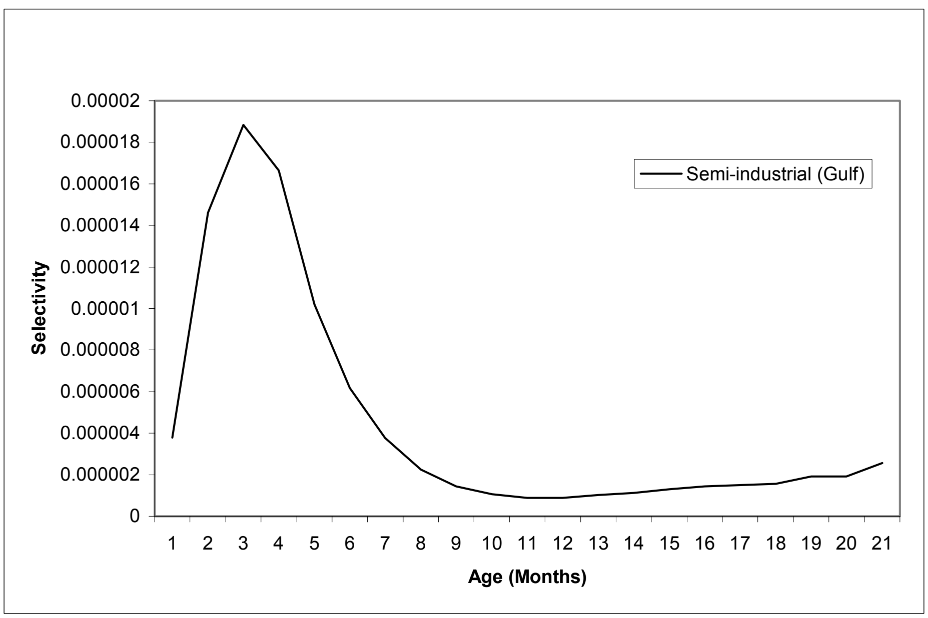


Figure 50 Selectivity of female *F. notialis* for semi-industrial fishery. The fishery seems to catch predominantly small female *F. notialis*. The selectivity (i.e. age dependent catchability) is much higher for the semi-industrial fleet reflecting its much higher catches of this species.

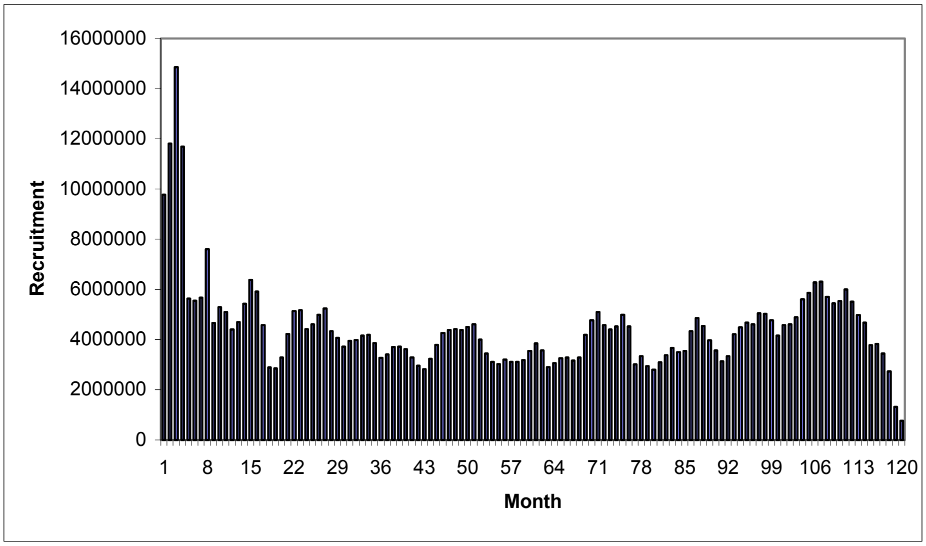


Figure 51 Recruitment in numbers of female *F. notialis* each month 1992-2001 estimated from the catch-at-length model. The initial very high recruitment at the start of the series and decline in recruitment at the end are probably artefacts of the problems in the data and model.

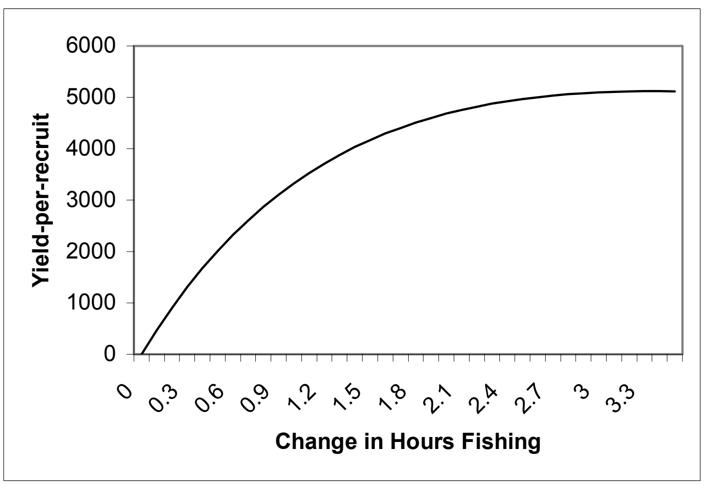


Figure 52 Yield-per-recruit as a proportional change in mean effort across all gears and months. The mean effort over the time series is set as 1.0. The maximum YPR occurs above 3.0, that is three times the average effort over the period. The shape will change with different combinations of gears.

Discussion

The model gave estimates of the fleet selectivities and recruitment. These estimates are not unreasonable and suggest that, once the key problems in the assessment have been addressed, catch-at-age models could be used as the basis for detailed advice.

The critical result is that vessels are tending to capture very young shrimp that are also very small. This is a clear indication that improved economic returns could be obtained from changing fleet selectivity towards larger shrimp and/or adjusting total fishing mortality. This general result is unlikely to change for this species.

The yield-per-recruit analysis is not reliable. Not only are other species not considered, but problems in the model make any advice on this premature. Better fitting models are likely to estimate smaller population sizes and lead to lower optimum effort levels than those indicated.

12.1.6 Management

The assessment approach should work well with the available data. It is strongly recommended that models are developed which can make use of the collected data and set appropriate reference points for the fishery. The reference points need not necessarily be complex measures, but could be estimated for simple controls which can be routinely collected easily. This may mean further length frequency sampling is not necessary, but may still be desirable for accurate assessment and monitoring.

It will be necessary to provide a clear link between the assessment and management actions. This should be addressed through discussions among all stakeholders and developed through an appropriate policy. Key issues are how the performance of the fishery will be monitored and how and what controls can be applied to affect the performance. This is often best done through control rules (Figure 53).

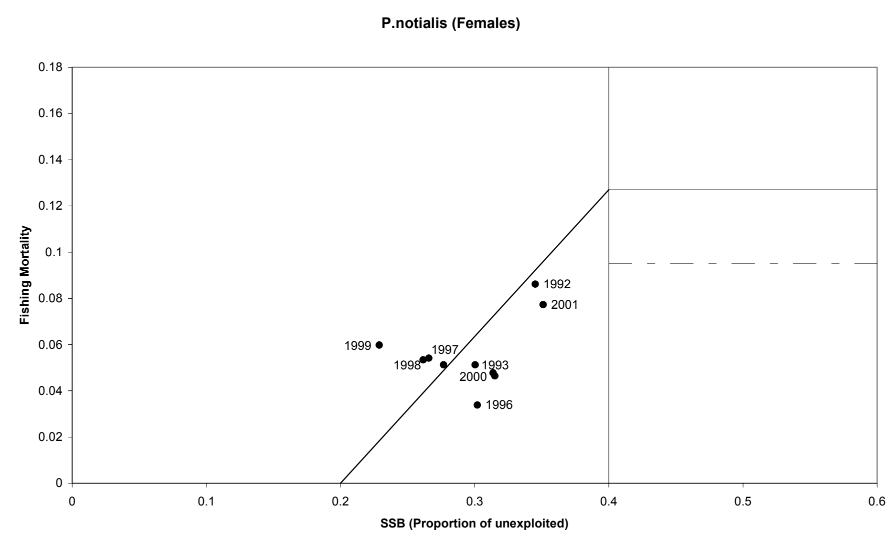


Figure 53 Possible form of decision rule based on fishing mortality and spawning stock biomass for *F.notialis*. The management should set fishery controls to maintain the fishery state below the solid line. The current state of the fishery in terms of level of exploitation (fishing mortality) and the spawning stock biomass (SSB, animals 5 months and older) was estimated through the stock assessment and plotted. The results indicate the exploitation is low enough but spawning stock needs to be increased.

13. References

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Punt, AE and Hilborn, R 1996. BIODYN: Biomass dynamic models. FAO Computerized Information Series (Fisheries). No. 10 Rome, FAO. 62 p.

Sparre, P and Venema, SC 1992. Introduction to tropical fish stock assessment. Part 1. Manual. FAO Fisheries Technical Paper No. 306.1, Rev. 1. FAO, Rome. 376p.

14. Workshops

The workshop schedule is as follows:

Countries	Dates	Location
Guyana Suriname	Nov 24 - 28, 2003	Guyana
Belize Jamaica Haiti	Dec 1 - 5, 2003	Belize
Trinidad & Tobago	Jan 26 – 30, 2004	Trinidad & Tobago

Secondary aims undertaken during the workshops were teaching fisheries science and advice on data collection. Advice on data collection was integrated with stock assessments. For example, the primary aim of the Trinidad shrimp stock assessment was to assess the available data and test a potential approach to its analysis.

The teaching was mainly conducted in Belize/Jamaica and Trinidad and Tobago workshops. It consisted of an introduction to using MS Excel and to fisheries population modelling. The following areas were covered:

- Data organisation in spreadsheets and using pivot tables for grouping data.
- An introduction to three basic population models including their derivation and assumptions: Depletion model, negative exponential and logistic models.
- Using solver to fit models through least squares and maximum likelihood.

15. Participants

Guyana and Suriname Workshop	24-28 November 2003
Guyana: Ms P Ramotar, Mr B Shury, Ms Colletta Derrell, Ms Ingrid Peters, Ms Dawn Maison, Ms Roslyn De Florinte, Ms Michelle Baptiste	
Suriname: Ms Yolanda Babb-Echteld, Mr Mario Yspol, Mr Rigillio Bansie	
Belize and Jamaica Workshop	1-5 December 2003
Belize: Mr Ramon Carcamo, Mr Jaime Villanueva, Mr Kenneth Esquivel, Mr Nathaniel Alvarado, Ms Marsha Vargas	
Jamaica: Ms June Masters	
Trinidad and Tobago Workshop	26-30 January 2004
Ms Lara Ferreira, Ms Suzuette Soomai, Ms Elizabeth Mohammed, Ms Louanna Martin, Ms Allys Forte, Ms Farahnaz Solomon	

16. Appendix 1

Visual basic routine to fit a simple cohort model (separable VPA) to catch-at-age data. The model fits to observed effort data by minimizing the squared difference between log effort and an expected effort assuming effort is proportional to mortality. The model fits the recruitment (equivalent to the terminal F). The selectivity (SaR) necessary for estimating fishing mortality is supplied externally, but can be found easily through calculation as the mean of the difference between the model's log fishing mortality and log effort for each age class.

```
Function Pop(M As Double, ByVal SaR As Range, ByVal CaR As Range,
_
             ByVal ObsR As Range) As Variant
  Const Test = 0.001
  Dim p() As Double, d() As Double, yvar() As Double
  Dim Ca() As Double, Obs() As Double, Sa() As Double
  Dim age As Integer, RelAge As Integer, Time As Integer, NAges As
Integer
  Dim StartAge As Integer, StartTime As Integer
  Dim b() As Double
  Dim MaxAge As Integer, MaxTime As Integer, agei As Integer
  Dim ExpMMI As Double, ExpMd2I As Double, ExpM As Double
  Dim ExpMM As Double, ExpMd2 As Double, ExpMMd2 As Double
  Dim P0 As Double, P0Old As Double, MinPop As Double
  Dim Tmp1 As Double, Wt As Double, Resid As Double
  Dim f1sum As Double, f2sum As Double, dmu As Double
  Dim Denom As Double, lp As Double

  MaxAge = CaR.Columns.Count
  MaxTime = CaR.Rows.Count
  If ObsR.Rows.Count <> MaxTime Then
    Pop = "Observations wrong"
    Exit Function
  End If
  If SaR.Rows.Count <> MaxAge Then
    Pop = "Selection wrong"
    Exit Function
  End If

  ReDim b(MaxAge) ', bsum(MaxAge), b2sum(MaxAge)
  ReDim p(MaxTime + 1, MaxAge + 1), Sa(MaxAge), Obs(MaxTime)
  ReDim yvar(MaxAge), d(MaxAge), Ca(MaxTime, MaxAge)

  ExpM = Exp(M):  ExpMM = Exp(-M): ExpMd2 = Exp(M / 2)
  ExpMMd2 = Exp(-M / 2)
  ExpMMI = (ExpM - 1): ExpMd2I = (Exp(M / 2) - 1)

  'Initialise variables
```

```
  b(1) = ExpMMI * ExpMM
  For Time = 1 To MaxTime
    Ca(Time, 1) = CaR(Time, 1)
  Next Time
  Sa(1) = SaR(1)
  For age = 2 To MaxAge
    b(age) = ExpMM * b(age - 1)
    For Time = 1 To MaxTime
      Ca(Time, age) = CaR(Time, age)
    Next Time
    Sa(age) = SaR(age)
  Next age
  For Time = 1 To MaxTime
    Obs(Time) = ObsR(Time)
  Next Time

  StartAge = MaxAge
  StartTime = 1

  Do
  'Initialise
    Time = StartTime
    'Calculate cumulative catches accounting for M
    d(StartAge) = Ca(StartTime, StartAge) * ExpMMd2
    For age = StartAge + 1 To MaxAge
      Time = Time + 1
      d(age) = d(age - 1) * ExpMM + Ca(Time, age) * ExpMMd2
    Next age

    'Calculate current linear predictor constant and regress P0
    MinPop = d(MaxAge) * Exp(M * (MaxAge - StartAge + 1))
    Time = StartTime: RelAge = 1
    P0 = 0: Denom = 0
    For age = StartAge To MaxAge
      d(age) = d(age) * ExpMMI - Ca(Time, age) * ExpMd2I 'Linear
predictor constant
      yvar(age) = Log(Ca(Time, age) * M) - Obs(Time) + Sa(age)
      Wt = 1 / (yvar(age) ^ 2)
      P0 = P0 + (Exp(yvar(age)) + d(age)) * b(RelAge) * Wt
'Regression coefficent
      Denom = Denom + (b(RelAge) ^ 2) * Wt
      Time = Time + 1
      RelAge = RelAge + 1
    Next age
    MinPop = MinPop + Test 'Add a smidgeon
    P0 = P0 / Denom 'weighted linear regression solution
    If P0 < MinPop Then P0 = MinPop
    'Improve estimate with Newton Raphson
    Do
      P0Old = P0
      RelAge = 1: f1sum = 0: f2sum = 0: Time = StartTime
```

```
      For age = StartAge To MaxAge
        lp = b(RelAge) * P0 - d(age)
        dmu = b(RelAge) / lp
        Resid = yvar(age) - Log(lp)
        f1sum = f1sum - Resid * dmu
        f2sum = f2sum + (Resid + 1) * dmu ^ 2
        RelAge = RelAge + 1
      Next age
      P0 = P0 - f1sum / f2sum
      If P0 < MinPop Or (P0 > 20 * MinPop) Then
         P0 = P0Old 'MinPop
         P0Old = P0
      End If
    Loop While Abs(P0 - P0Old) > Test
    'Calculate populations
    p(StartTime, StartAge) = P0
    Time = StartTime
    For age = StartAge To MaxAge
      p(Time + 1, age + 1) = p(Time, age) * ExpMM _
                     - Ca(Time, age) * ExpMMd2
      Time = Time + 1
    Next age
    If StartAge = 1 Then
      StartTime = StartTime + 1
      If StartTime + MaxAge - 1 > MaxTime Then MaxAge = MaxAge - 1
    Else
      StartAge = StartAge - 1
    End If

  Loop Until StartTime > MaxTime

  Pop = p()
End Function
```