16 APPLICATION OF A MULTISPECIES-MULTIGEAR PER-RECRUIT MODEL THAT INCORPORATES PARAMETER VARIABILITY TO THE SHRIMP AND GROUNDFISH FISHERIES OF GUYANA

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16.1 Summary

Tropical fisheries typically harvest many species by a variety of fishing gears. As a result, their stock assessment and management is complicated. Limited biological information on the harvested stocks and/or technical information available on the harvesting fishers often exacerbates this situation. Under these circumstances, the most suitable stock assessment framework is often aged-structured per-recruit modelling.

A multispecies-multigear per-recruit modelling approach was applied to the brown shrimp (*Penaeus subtilis*) and the bangamary (*Macrodon ancylodon*) in Guyana. Results from the deterministic and stochastic analyses revealed that the bangamary stock was overfished from growth and recruitment perspectives. This was in contrast to the brown shrimp that was fully fished with its spawner biomass-per-recruit at $F_{0.1}$ (marginal yield) and F_{SB40} levels. The status of the bangamary resource is of concern and immediate cognisance needs to be taken by management agencies. Management initiatives need to be adopted to reduce fishing effort on this resource so as to increase the level of spawner biomass-per-recruit that is currently estimated to be below 20% of pristine, pre-harvesting levels. This would reduce the risk associated with its recruitment-overfished status.

16.2 Introduction

The industrial fishery of Guyana is a large-scale “limited entry” fishery consisting of 127 trawlers (61 foreign-owned) of which 73 were licensed to catch penaeid shrimp, 48 to catch seabob/finfish and 6 to catch finfish. The penaeid and seabob/finfish trawlers are the standard Mexico-type trawlers ranging in length from 19-23m, with the American vessels being on average 20.4m long. The local vessels are powered by inboard Caterpillar diesel engines, while vessels of the American fleet are powered by Cummings engines. The finfish vessels are Japanese-built stern trawlers that are approximately 13.7m long and are powered by Yanmar diesel engines.

The artisanal fishery consists of approximately 1331 vessels, of which approximately 60% use gillnets, 27% use Chinese seine, 8% use cadells and 5% pin seines. These vessels range in size from 6 to 18m and are powered by sails, outboard or inboard engines. They operate from approximately 85 landing sites along the coast. A flat-bottom dory powered by sail, paddle or small outboard engine is used for Chinese seine, cadell lines and a few pin seines to give more manoeuvrability over shallow, muddy water and sandy bottom areas. These boats which operate close to shore are not equipped with ice boxes. A V-bottom boat ranging in size from 7.6-9.2m and with no cabin but with an ice box and powered by an outboard engine is used by smaller gillnet (gillnet nylon) fishermen. A larger V-bottom vessel size either 8-11m or 12.-15m, with either outboard or inboard engine and cabin are used for larger gillnet and handline operations. There is also a semi-industrial fleet of red snapper vessels, which are shared by foreign and local fishers. There are 39 vessels in this fishery which uses either traps or handline to exploit the red snapper resources (see Section 12).

There is a need to move towards objective management of these fisheries based on the best scientific information available. This is best achieved via the use of reference points (see Caddy and Mahon, 1995). These are technical values derived from analyses that estimate the state of the fishery or population and whose characteristics are therefore useful for the management of the unit stock. These management quantities allow the management agency to adjust fishing effort to ensure the stock remains at or above the reference points selected in each case.

Bangamary is one of the most important groundfish species in the Guyana fishery and is taken by several different fleets. It is particularly important in the artisanal fisheries and dominates the catches in the socially important Chinese seine fishery. *P. subtilis* is one of the most important of the penaeid shrimp species which support important commercial fisheries in Guyana. It is most commonly caught by commercial trawl vessels, which also take *M. ancylodon* as bycatch, hence providing a technological interaction between the two species. Management of either species, therefore requires consideration of the impacts of management measures on the other, so as to optimise the overall result. These two species have been the subjects of a dedicated study over the last three years (Hackett *et al.,* this volume; Shepherd *et al.,* this volume) and were therefore selected for this multispecies analysis.

The study on *M. ancylodon* has included the collection of catch and effort data from the Chinese seine fishery (Hackett *et al.*, this volume). This time series is, however, still too short for use in the estimation of population parameters and similar data are not available for the other fisheries harvesting this species. This points towards the use of a multispecies-multigear per-recruit modelling (Booth, this volume) for its assessment. Per-recruit models allow for the evaluation of the response of the yield- and spawner biomass-per-recruit of one (or more) species to changes in fishing mortality and age-at-50%-selectivity from one or more gears. Data on the size composition of *P. subtilis* landings and the total landings have been used for extensive age structured assessments of this stock and are reported elsewhere.

This paper presents a multispecies-multigear per-recruit model that incorporates biological information for two species that are harvested by a total of four gear-types.

16.3 Methods

16.3.1 Assessment framework

Unfortunately, complete directed catch and effort data are unavailable for *M. ancylodon*, principally due to it being landed in a variety of fisheries. In contrast, *P. subtilis* is only landed in the trawl fishery where it is one of the main species landed. The lack of data for *M. ancylodon* led to the decision to use a multigear-multispecies assessment model (incorporating four gears and two species) for its assessment. The methods used are outlined in Booth (this volume).

The model was found to be sensitive to the choice of the time step used in the numerical integration ($\approx dt$), affecting the functional form and magnitude of the yield-per-recruit curve. Discrete approaches typically use an annual time step (to mimic the Beverton and Holt, 1956, 1957) yield-per-recruit integral). The base case scenario of 50 000 steps yr^{-1} was used in the sensitivity analysis and compared with alternative simulations using time steps ranging between 1 step yr^{-1} and 10 000 steps yr^{-1}. An annual time step was only found to be 80% similar to the base case scenario. In contrast, the simulation results revealed convergence in the yield-per-recruit curve after 100 steps yr^{-1} with the yield-per-recruit curve being 98% similar to the base case scenario. A monthly time step (of 12 steps yr^{-1}) was considered appropriate for the study as it explained *ca.* 95% of the base case scenario, was biologically relevant for the assessment of short-lived shrimp species, was easily incorporated into existing spreadsheet models and significantly reduces computation time.

Input parameter variability was noted and included within the assessment framework. At this stage, in order to avoid the difficult problem of correlation in the population dynamics parameters, only uncertainty in natural mortality, *M*, was included as this was considered to be the most important source of uncertainty in the assessments. A uniform distribution was assumed for the natural mortality estimate, ranging between 75% and 125% of the “base case” estimate for both species. A total of 200 bootstrap iterations were conducted to construct 95% confidence parameters for the selected target reference points (TRPs). Clearly, as only a subset of the uncertainty in the input parameters was included in these analyses, these estimates of uncertainty are likely to be underestimated.

16.3.2 Reference points

Five possible target reference points (TRPs) and two limit reference points (LRPs) were estimated for the yield-per-recruit and spawner biomass-per-recruit curves. The TRPs were, F_{max} the fishing mortality which corresponds to the maximum of the yield-per-recruit curve, $F_{0.1}$ or marginal yield value (Gulland and Boerema 1973) where the slope of the yield-per-recruit curve is 10% of that at the origin and F_{SB50} and F_{SB40} which are the fishing mortalities that correspond to a reduction in the spawner biomass-per-recruit curve to 50% and 40% of its unexploited equilibrium levels, respectively. The last two of these reference points could also be considered as LRPs for some stocks (see Mace and Sissenwine, 1993). The two LRPs were F_{SB30} and F_{SB20}.

16.3.3 Input parameters

Biological and technical parameters for both *M. ancylodon* and *P. subtilis* were obtained from Hackett *et al.* (this volume) and Shepherd *et al.* (this volume). All input parameters used within the analyses are summarised in Table 16.1.

Estimation of selectivity by the various gears was problematic. The trawl and seine net gears were the simplest as both the *M. ancylodon* and *P. subtilis* were assumed to reach a size when they were susceptible to the gear, after which all available animals were retained by the gear. A temporally invariant logistic ogive, modified to reflect knife-edged selection, was therefore determined from the length-converted age frequency data. Despite the selection pattern in the gill-net fishery that appeared to be normally distributed, a logistic curve was used in these analyses, as the current version of the software did not allow for a selectivity with a normal distribution. This will be included in the future. The logistic ogive used to estimate selectivity for all gears was of the form:

$$S_a = \frac{1}{1+e^{-(a-a_{50})/\delta}}$$

where S_a is the selectivity of the gear on a fish of age a, a_{50} is the age-at-50%-selectivity and δ is the parameter that determines the width of the age-specific selectivity function. Knife-edged selectivity was mimicked by fixing δ at 0.01. The implications of this assumption on the results, necessitated by the structure of the software used for the stochastic analyses, will be examined in subsequent studies.

Table 16.1 Parameter estimates used in the per-recruit analyses for *Macrodon ancylodon* and *Penaeus subtilis* off Guyana

Parameter	Description	*M. ancylodon*	*P. subtilis*
L_∞	Predicted asymptotic length	435.7 mm (TL)	122.7 mm (CL)
K	Brody growth coefficient	0.66	1.11
α	Parameter for length/weight equation	0.00000272	0.0000319
β	Parameter for length/weight equation	3.35	2.918
M	Natural mortality rate	1.20 yr^{-1}	1.85 yr^{-1}
F	Fishing mortality rate	1.51 yr^{-1}	1.026 yr^{-1}
Max	Maximum age	7.00 years	1.33 years
a_m	Age-at-50%-maturity	1.00 year	0.5 years
δ_m	Width of maturity logistic ogive	0.10 years	0.1 years
a_{50}**: Trawl net**	Age-at-50%-selectivity	0.40 years	0.2 years
δ_{50}**: Trawl net**	Width of the selectivity logistic ogive	0.01 years	0.1years
a_{50}**: Gillnet**		1.80 years	-
δ_{50}**: Gillnet**		0.01 years	-
a_{50}**: Chinese seine**		0.18 years	-
δ_{50}**: Chinese seine**		0.10 years	-
a_{50}**: Pin seine**		0.18 years	-
δ_{50}**: Pin seine**		0.10 years	-
$F_{\text{Trawl net}}$	Gear-specific fishing mortality rate	0.62 yr^{-1}	1.026 yr^{-1}
$f_{\text{Trawl net}}$	Fishing effort	215 vessels	215 vessels
$q_{\text{Trawl net}}$	Catchability coefficient	0.002883	0.004771
F_{Gillnet}		0.53 yr^{-1}	-
f_{Gillnet}		433 vessels	-
q_{Gillnet}		0.001216	-
$F_{\text{Chinese eine}}$		0.35 yr^{-1}	-

Parameter	**Description**	***M. ancylodon***	***P. subtilis***
$f_{Chinese\ seine}$		655 vessels	-
$q_{Chinese\ seine}$		0.000541	-
$F_{Pin\ eine}$		0.01 yr^{-1}	-
$f_{Pin\ seine}$		73 vessels	-
$q_{Pin\ seine}$		0.0000996	-
Catch	Annual catch in all fishing sectors	18660 tons	4200 tons
Price	Landed price in US$	1500 kg^{-1}	5500 kg^{-1}

The proportional contribution of the trawl net ($F_{trawl\ net}$), gillnet ($F_{gillnet}$), Chinese seine net ($F_{Chinese\ seine\ net}$) and pin seine net ($F_{pin\ seine\ net}$) fisheries to the estimated instantaneous rate of fishing mortality (F) for *M. ancylodon* was estimated by multiplying the total fishing mortality, F, by the annual catch in mass for each gear as a proportion of the total annual catch. The total fishing mortality estimate for *P. subtilis* was attributed to the trawlfishery.

The coefficients of proportionality between fishing effort and fishing mortality (i.e. the catchability coefficients) will vary between species due to differences in their availability and vulnerability to the various gear (Murawski 1984).

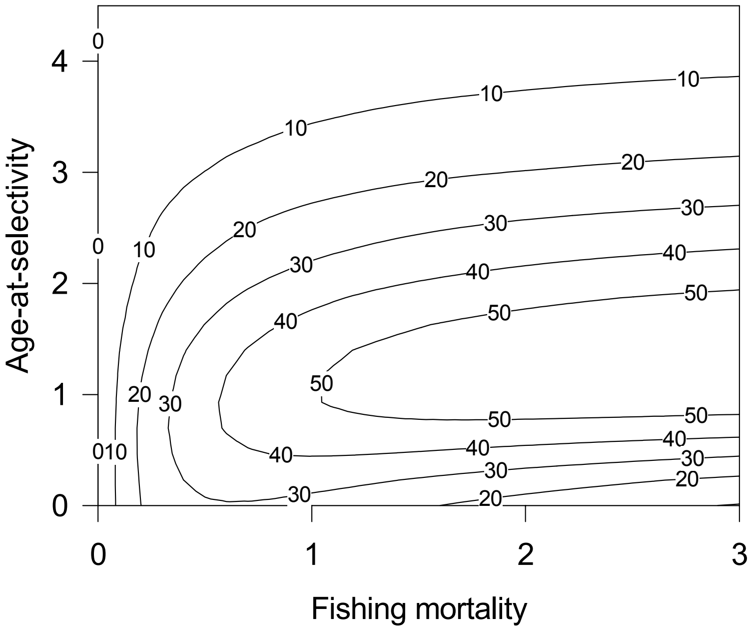
At any given level of effort, the F for each species in a multispecies fishery will be different. Catchability coefficients were estimated using the linear relationship:

$$F_{ij} = q_{ij}\ f_j$$

where q_{ij} is catchability coefficient of species *i* in fishery *j* and f_{ij} is the standardised effort for species *i* in fishery *j*. Although alternative forms of the relationship have been suggested for various species (Peterman and Steer 1981), in this study the relationship between *f* and *F* was assumed to be linear for both species.

16.4 Results

Isopleth diagrams, generated using single species-single gear per-recruit models, describing the response of yield-per-recruit to different values of fishing mortality (F) and age-at-50%-selectivity for *M. ancylodon* and *P. subtilis* are illustrated in Figures 16.1-16.4. The yield-per-recruit response isopleths showed that, in both species, yield-per-recruit increased rapidly at low values of F over most of the age range of a_{50} (equivalent, in these analyses, to the age at knife-edge recruitment). Maximum yield-per-recruit was attainable at values of a_{50} between 0.8 and 1.5 years in *M. ancylodon* and at values of a_{50} older than 1 year in *P. subtilis*. Asymptotic yield-per-recruit was attained at high values of F when the age-at- 50%-selectivity was between than 0.8 and 1.5 years in *M. ancylodon* and greater than 1 year in *P. subtilis*. The spawner biomass-per-recruit response isopleths were similar for both species. Spawner biomass-per-recruit decreased rapidly with increasing values of F, particularly at low ages-at-50%-selectivity. In *M. ancylodon*, spawner biomass-per-recruit did not drop below 50% of pristine, unharvested levels after 2 years of age, irrespective of the increase in fishing mortality exerted on the stock.



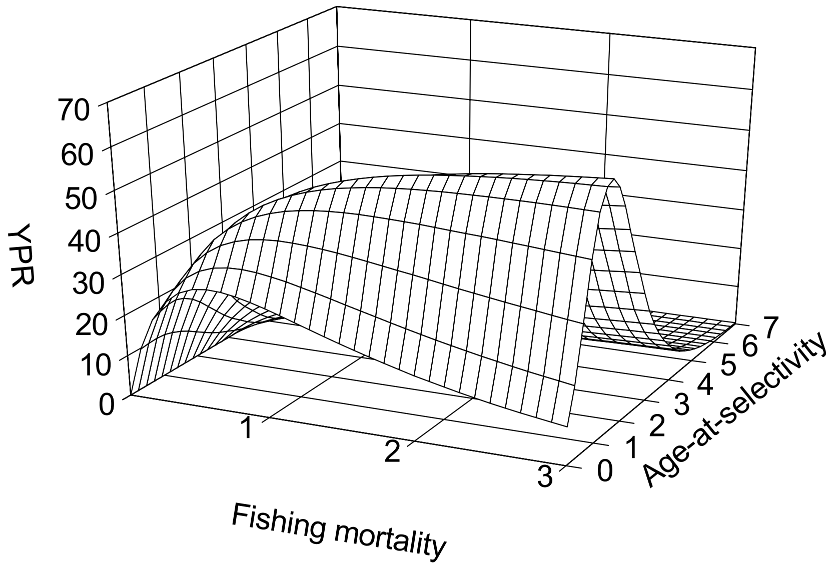


Figure 16.1 Isopleth diagrams describing the response of *M. ancylodon* yield-per-recruit to different combinations of fishing mortality and age-at-50%-selectivity. Analysis was conducted using a single-gear model with the 'base case' scenario where $M = 1.2$ year^{-1}

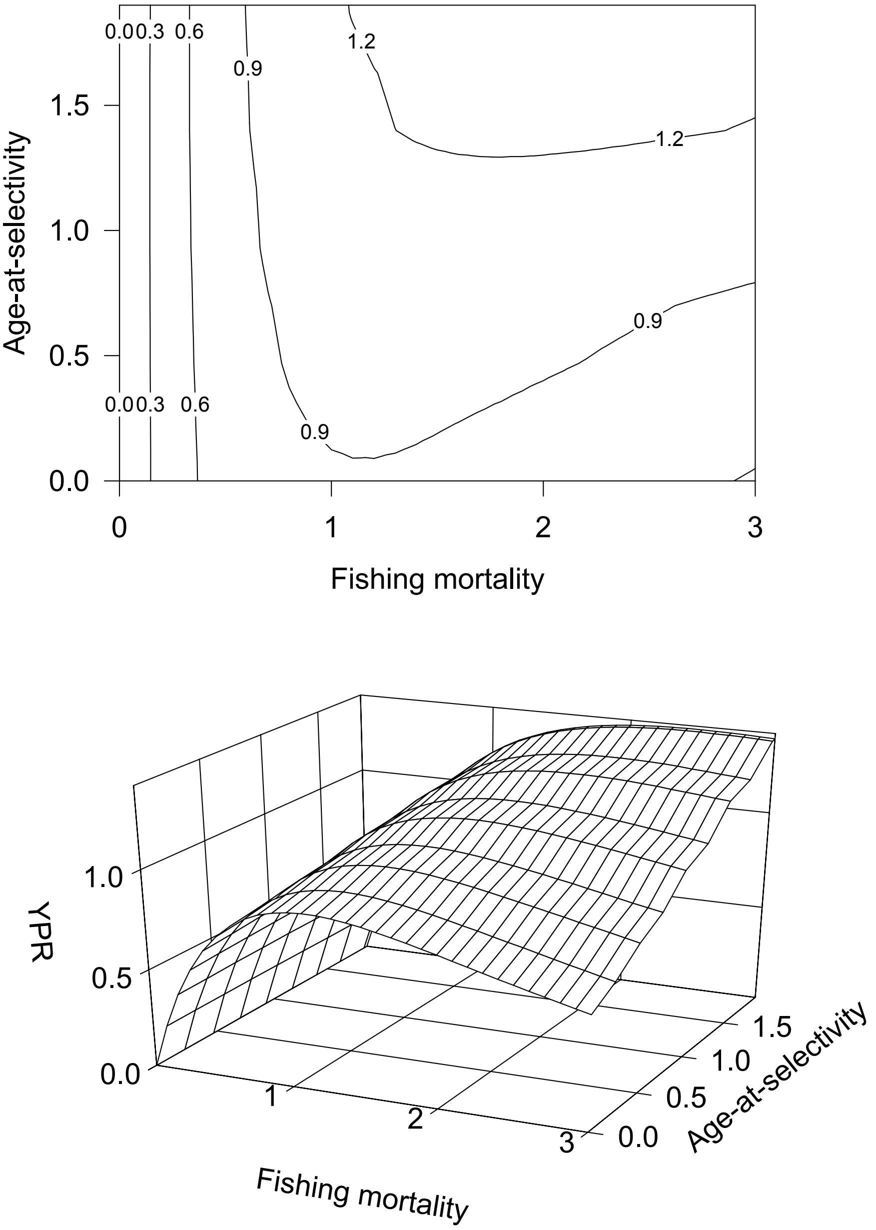


Figure 16.2 Isopleth diagrams describing the response of *P. subtilis* yield-per-recruit to different combinations of fishing mortality and age-at-50%-selectivity. Analysis was conducted using a single-gear model with the 'base case' scenario where *M* = 1.85 year^{-1}

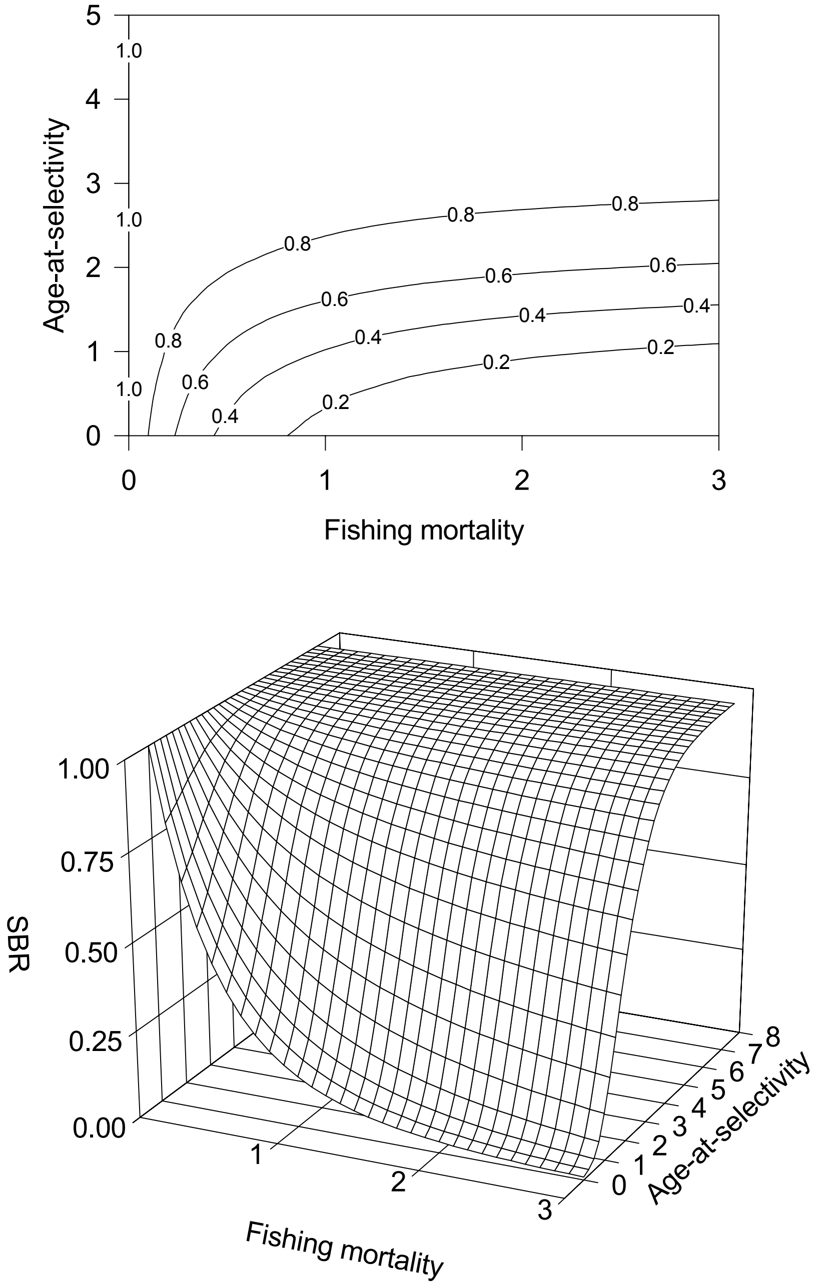


Figure 16.3 Isopleth diagrams describing the response of *M. ancylodon* spawner biomass-per-recruit to different combinations of fishing mortality and age-at-50%-selectivity (in years). Analysis was conducted using a single-gear model with the 'base case' scenario where *M* = 1.2 year^{-1}

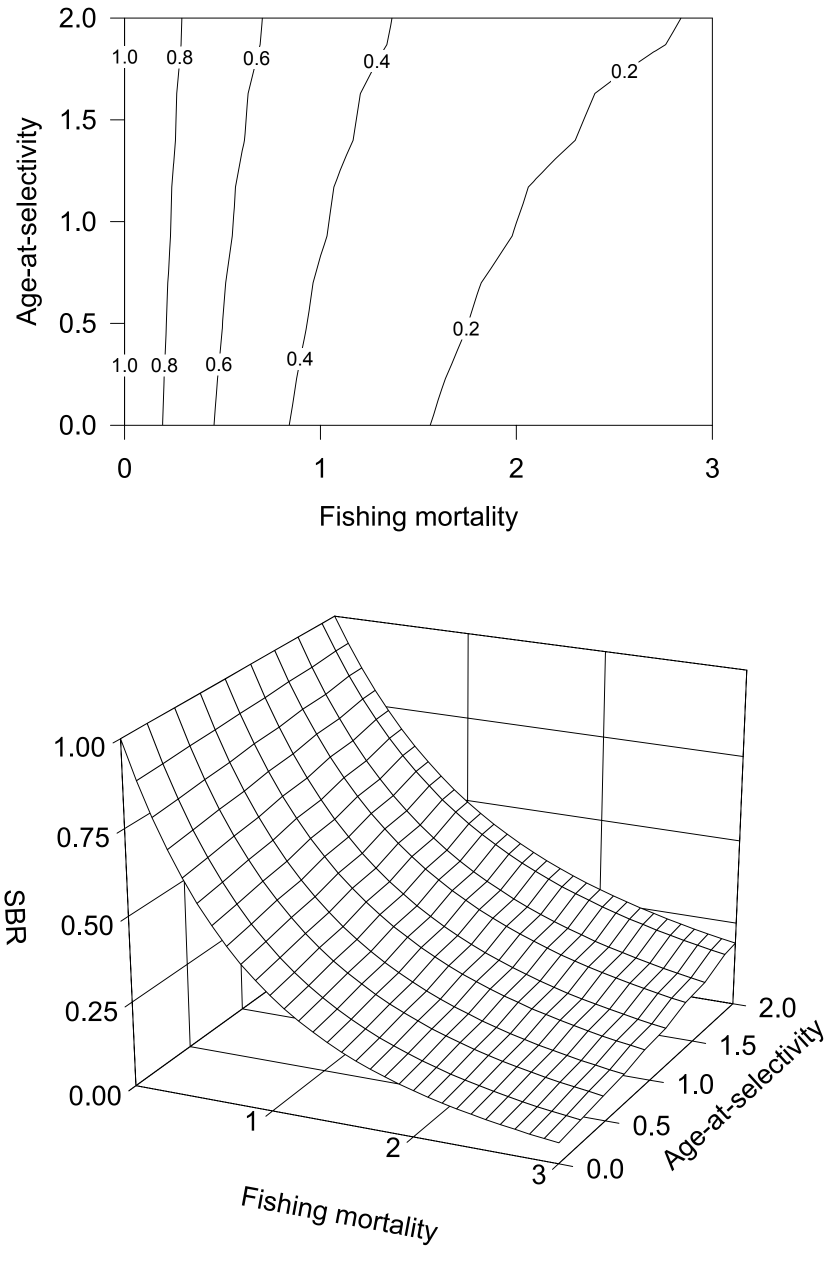


Figure 16.4 Isopleth diagrams describing the response of *P. subtilis* spawner biomass-per-recruit to different combinations of fishing mortality and age-at-50%-selectivity (in years). Analysis was conducted using a single-gear model with the 'base case' scenario where $M = 1.85$ year^{-1}

Yield- and spawner biomass-per-recruit as a function of fishing mortality (F) are illustrated in Figures 16.5 and 16.6. Since the age-at-50%-selectivity in the Chinese seine and pin seine net fisheries were identical, only the trawl, gill and Chinese seine net fishery exploitation scenarios are shown. For *M. ancylodon,* higher yield-per-recruit was obtained at higher rates of F in the gill-net fishery than in the other fisheries, reflecting its higher a_{50} (Figure 16.5). Similarly, spawner biomass was not depleted below 50% at higher fishing mortality levels (> 3 yr^{-1}) in the gill-net fishery than in the other fisheries.

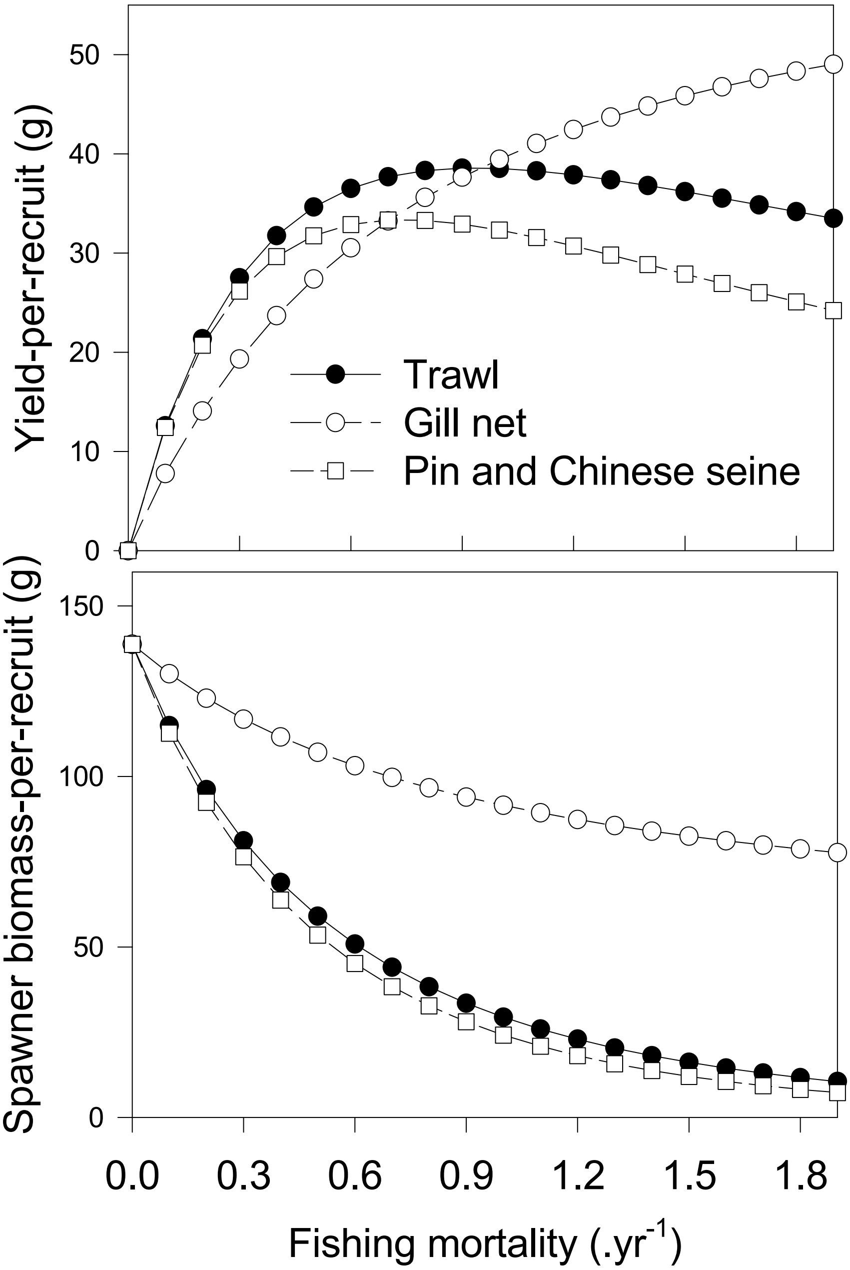


Figure 16.5 Yield-per-recruit and spawner-biomass-per-recruit of *M. ancylodon* in Guyana with 'base case' trawl net, gillnet and Chinese/pin seine net fishing. Analyses were conducted using the 'traditional' single-species models with the 'base case' scenario where *M* = 1.2 year^{-1}

The fishing mortality and fishing effort TRPs and their associated 95% bootstrap confidence intervals are summarised in Table 16.2 for the trawl net, gillnet, Chinese seine net and pin seine net fishing scenarios. Comparing the four major fisheries harvesting *M. ancylodon*, a marginal-yield fishing strategy ($F_{0.1}$) was obtained at higher fishing moralities in the gill-net fishery where a_{50} occurred after the age-at-50% maturity. In all scenarios, higher fishing pressure was necessary to obtain the marginal yield ($F_{0.1}$) than the F_{SB40} TRP. From a single-

Table 16.2 Target reference points as a function of fishing mortality and fishing effort and their 95% confidence intervals (in parenthesis) for *M. ancylodon* and *P. subtilis* using four gears from Guyana. Current *M. ancylodon* F = 1.51 year^{-1} and *P. subtilis* F = 1.03 year^{-1}. Current fishing effort 215 trawlers, 433 gillnetters, 655 Chinese seiners and 73 Pin seiners

	M. ancylodon		***P. subtilis***	
	Fishing mortality	**Fishing effort**	**Fishing mortality**	**Fishing effort**
Trawl net	a_{50} = 0.4 yrs; δ = 0.1		a_{50} = 0.2 yrs; δ = 0.1	
F_{max}	0.93 (0.72,1.16)	322 (249, 402)	1.63 (1.35, 1.95)	342 (283, 408)
$F_{0.1}$	0.59 (0.46, 0.73)	205 (160, 253)	1.06 (0.91, 1.23)	222 (190, 258)
F_{SB50}	0.39 (0.32, 0.45)	135 (111, 156)	0.77 (0.70, 0.85)	161 (147, 178)
F_{SB40}	0.54 (0.44, 0.62)	187 (153, 215)	1.05 (0.95, 1.15)	220 (199, 241)
F_{SB30}	0.73 (0.61, 0.84)	253 (211, 291)	1.44 (1.29, 1.58)	302 (270, 331)
F_{SB20}	1.04 (0.87, 1.19)	361 (302, 412)	2.03 (1.82, 2.25)	425 (381, 472)
Gillnet	a_{50} = 1.8 yrs; δ = 0.1			
F_{max}	>3	>2459		
$F_{0.1}$	1.61 (1.15, 2.08)	1324 (946, 1710)		
F_{SB40}	>3	>2459		
F_{SB30}	>3	>2459		
F_{SB20}	>3	>2459		
Chinese seine	a_{50} = 0.18 yrs; δ = 0.1			
F_{max}	0.74 (0.60, 0.87)	1368 (1109, 1608)		
$F_{0.1}$	0.50 (0.4, 0.59)	924 (739, 1091)		
F_{SB50}	0.35 (0.29, 0.39)	647 (536, 720)		
F_{SB40}	0.47 (0.4, 0.53)	869 (739, 980)		
F_{SB30}	0.64 (0.55, 0.73)	1183 (1017, 1331)		
F_{SB20}	0.90 (0.78, 1.01)	1664 (1423, 1867)		

	M. ancylodon	
	Fishing mortality	**Fishing effort**
Pin seine	**a_{50} = 0.18 yrs; δ = 0.1**	
F_{max}	0.74 (0.60, 0.87)	1368 (1109, 1608)
$F_{0.1}$	0.50 (0.4, 0.59)	924 (739, 1091)
F_{SB50}	0.35 (0.29, 0.39)	647 (536, 720)
F_{SB40}	0.47 (0.4, 0.53)	869 (739, 980)
F_{SB30}	0.64 (0.55, 0.73)	1183 (1017, 1331)
F_{SB20}	0.90 (0.78, 1.01)	1664 (1423, 1867)

gear per-recruit perspective and considering uncertainty in the assessments, the results suggest that the *M. ancylodon* stock is severely overfished. In all fisheries, except the gillnet fishery, current levels of fishing mortality exceeded the biologically least conservative TRP, F_{SB20}. The TRPs calculated for *P. subtilis* generated a less worrying result. The current fishing mortality exerted on the stock was estimated to be below the F_{max} and F_{SB40}. The stock was estimated as currently being fished at marginal yield ($F_{0.1}$) levels.

Since “traditional” single-gear/single-species yield-per-recruit and spawner biomass-per recruit models treat each fishery in isolation, the combined effect of all fisheries on the *M. ancylodon* stock cannot be determined. The various TRPs considered here, therefore, only provide information that can be used in the application of effective management action if, for example, three of the four fisheries are closed in the case of *M. ancylodon*. As the closure of any fishery is probably not a viable management option, *M. ancylodon* was assessed using multispecies-multigear yield- and spawner biomass-per-recruit models, which enables the examination of the performance of the fisheries as a whole and the impact on all of them, of changes in any one.

As a part of this assessment, a preliminary sensitivity analysis was conducted on both species by changing the assumed natural mortality “base case” estimate (Table 16.3). The results revealed that the TRPs that assessed the status of the stock from a reproductive perspective ($F_{SBx\%}$) were most robust to changes in the estimate of natural mortality. These results suggest that assessing the stocks from a spawner biomass-per-recruit perspective was more robust than setting reference points based on yield-per-recruit. As a consequence of this feature and the need to set fishing mortalities at levels which do not result in reductions in recruitment, spawner biomass-based reference points are considered the most important index for assessing the status of the *M. ancylodon* and *P. subtilis* stocks and for guiding management.

Yield- and spawner biomass-per-recruit response isopleths for the gillnet and Chinese seine net fisheries are illustrated in Figures 16.7 and 16.8. These fisheries were chosen as they represented the least (gill-net) and most (Chinese seine) destructive fisheries in terms of recruitment overfishing (by the rapid reduction of spawner biomass) and growth overfishing (harvesting of fish that are too small, before they can realise their growth potential). Figure 16.7 translates directly with Figure 16.5 in that, in the absence of one of the fisheries where F = 0, the response in both yield- and spawner biomass-per-recruit is the equivalent of the other fishery. The response surface between the two represents the trade-offs (interactions) between the two fishing mortalities. When assessing the stock from either a spawner biomass-per-recruit perspective, the optimal combination of fishing mortalities for both fisheries was attained from the relevant TRP on the isopleth contour plot.

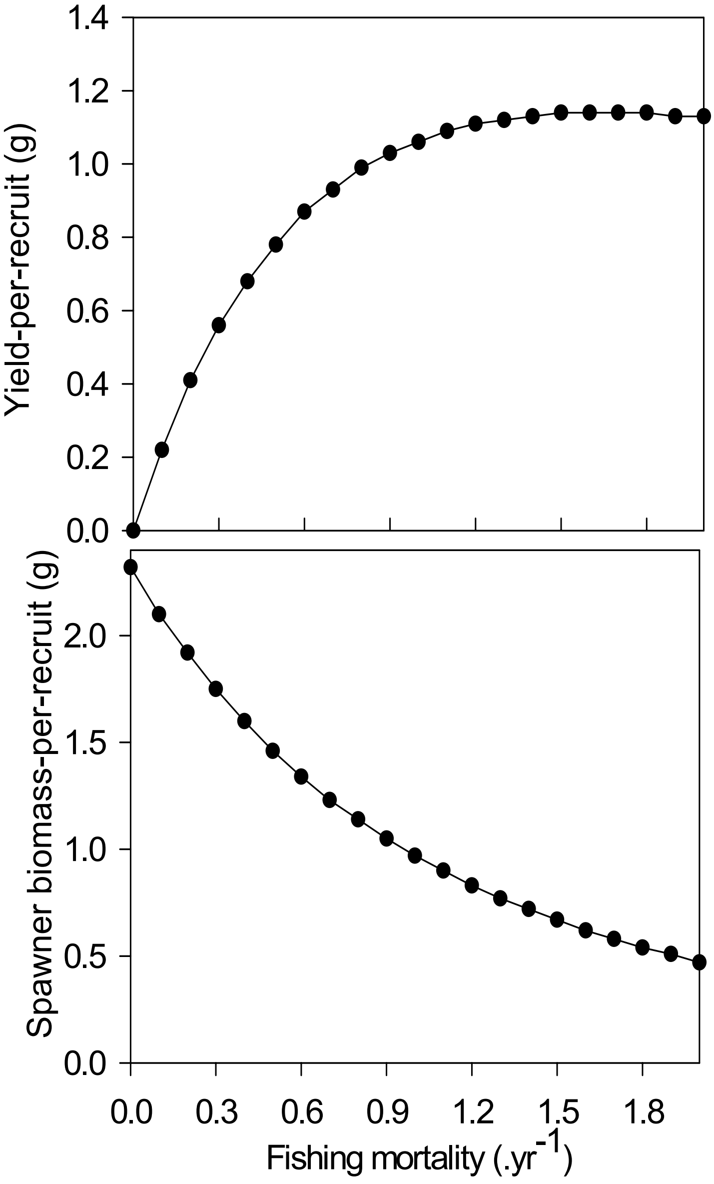


Figure 16.6 Yield-per-recruit and spawner-biomass-per-recruit of *P. subtilis* in Guyana with 'base case' trawl net fishing. Analyses were conducted using the 'traditional' single-species models with the 'base case' scenario where *M* = 1.85 yr^{-1}

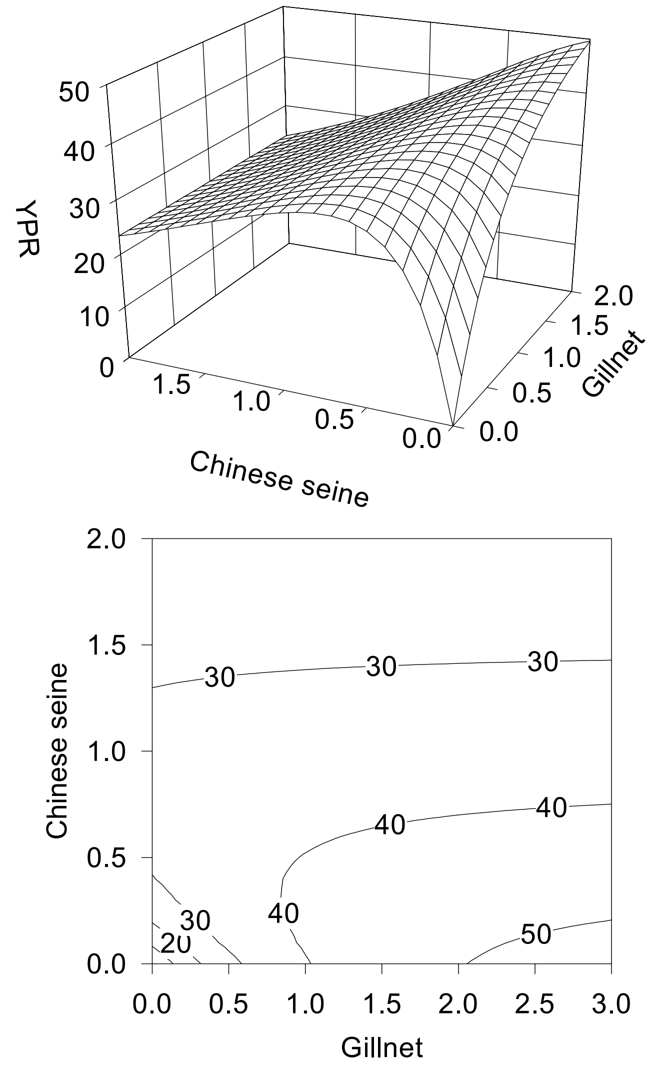


Figure 16.7 Isopleth diagrams showing the response of *M. ancylodon* yield-per-recruit (YPR) to changes in fishing mortality (*F*) in the gill-net and Chinese seine fisheries. Analyses were conducted using the multispecies-multi-fishery models and assumed that all fishing mortality was partitioned between these two gears in proportion to current landings

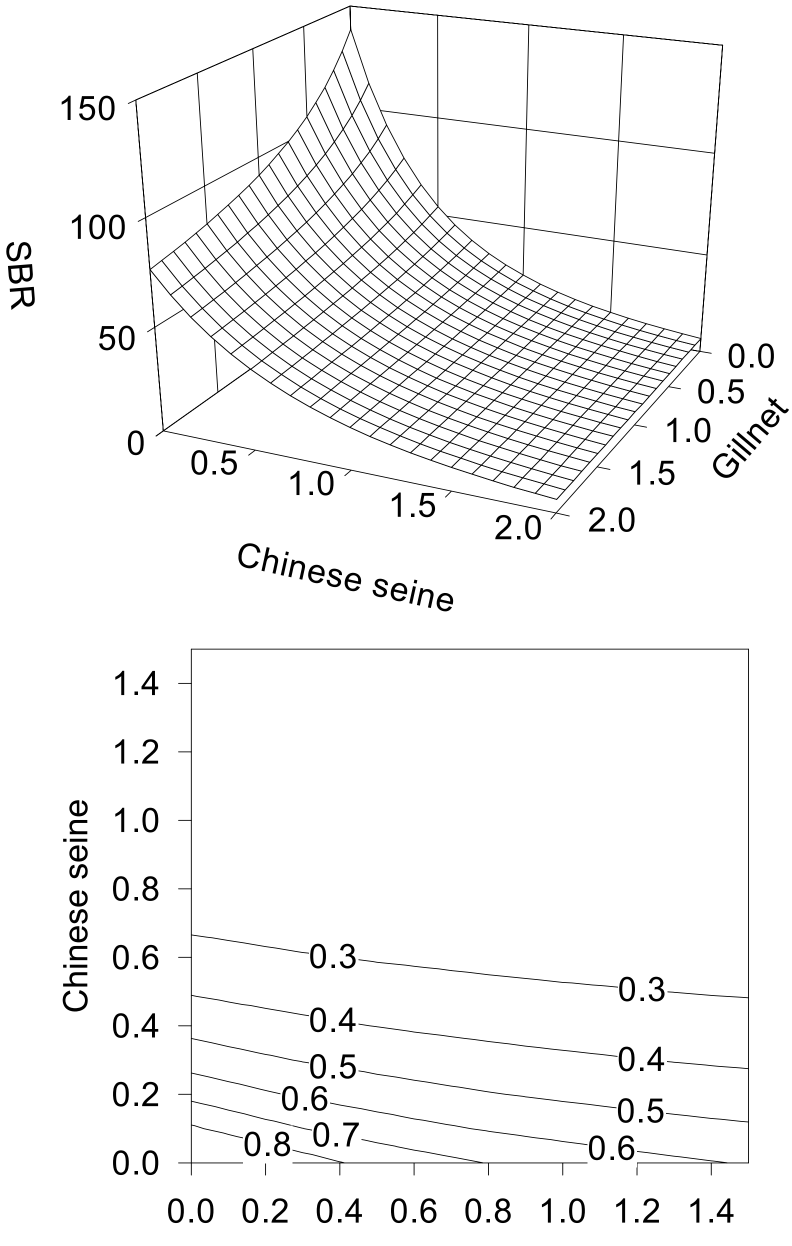


Figure 16.8 Isopleth diagrams showing the response of *M. ancylodon* spawner biomass-per-recruit (SBR) to changes in fishing mortality (*F*) in the gill-net and Chinese seine fisheries. Analyses were conducted using the multispecies-multi-fishery models and assumed that all fishing mortality was partitioned between these two gears in proportion to current catches

Results from the multispecies-multigear analysis are summarised in Table 16.3. They summarise TRPs obtained from simultaneously increasing the fishing mortalities from all four fisheries on both species, maintaining as constant the percentage contribution that each fishery makes to the total catch. Overall, the TRPs obtained for the *M. ancylodon* stock are

Table 16.3 Sensitivity of various fishing mortality-based Target Reference Points (TRPs) to variations in the "base case" estimate of natural mortality used in the per-recruit analysis for the trawlfishery

	Percentage change in the "base case" natural mortality estimate				
TRP	**-20%**	**-10%**	**0%**	**+10%**	**+20%**
***M. ancylodon* (M = 1.2 $year^{-1}$)**					
F_{MSY}	0.76 (82%)	0.85 (91%)	0.93 (100%)	1.03 (111%)	1.12 (120%)
$F_{0.1}$	0.49 (83%)	0.54 (92%)	0.59 (100%)	0.65 (110%)	0.70 (119%)
F_{SB50}	0.34 (87%)	0.36 (92%)	0.39 (100%)	0.42 (108%)	0.44 (113%)
F_{SB40}	0.46 (85%)	0.5 (93%)	0.54 (100%)	0.57 (106%)	0.60 (111%)
F_{SB30}	0.64 (88%)	0.69 (95%)	0.73 (100%)	0.78 (107%)	0.82 (112%)
***P. subtilis* (M = 1.85 $year^{-1}$)**					
F_{MSY}	1.39 (85%)	1.51 (93%)	1.63 (100%)	1.77 (109%)	1.92 (118%)
$F_{0.1}$	0.93 (88%)	1.00 (94%)	1.06 (100%)	1.14 (108%)	1.22 (115%)
F_{SB50}	0.71 (92%)	0.74 (96%)	0.77 (100%)	0.81 (105%)	0.84 (109%)
F_{SB40}	0.97 (92%)	1.01 (96%)	1.05 (100%)	1.10 (105%)	1.15 (110%)
F_{SB30}	1.32 (92%)	1.37 (95%)	1.44 (100%)	1.50 (104%)	1.57 (109%)

Table 16.4 Multigear-multispecies target reference points (TRP), estimated annual yield in metric tons (Y) and gross revenue (GR) for *M. ancylodon* and *P. subtilis* using four gears from Guyana. Current GR = US$ 51 090 and current *M. ancylodon* F = 1.51 yr^{-1} and for *P. subtilis* F = 1.03 yr^{-1}

	M. ancylodon	***P. subtilis***	
	TRP	**TRP**	**GR (US$)**
FMSY	1.13	1.63	52 575
$F_{0.1}$	0.71	1.06	48115
F_{SB50}	0.51	0.77	42430
F_{SB40}	0.71	1.05	47914
F_{SB30}	0.99	1.44	51720
F_{SB20}	1.42	2.03	52 566

less conservative than the single-gear assessments due to the positive bias caused by the gillnet fishery. As there is only one major fishery for *P. subtilis*, the multispecies TRPs obtained reflect those from the single gear assessment. The assessment still indicates serious overfishing of *M. ancylodon*, with the current level of fishing mortality being higher than all TRPs investigated.

Results from the bio-economic analysis (Table 16.4; Figure 16.9) suggested that *M. ancylodon* was a more valuable catch, both in terms of mass landed and in gross revenue generated. The maximum gross revenues are currently generated for both species are achieved at similar levels of effort, ca. 300 vessels.

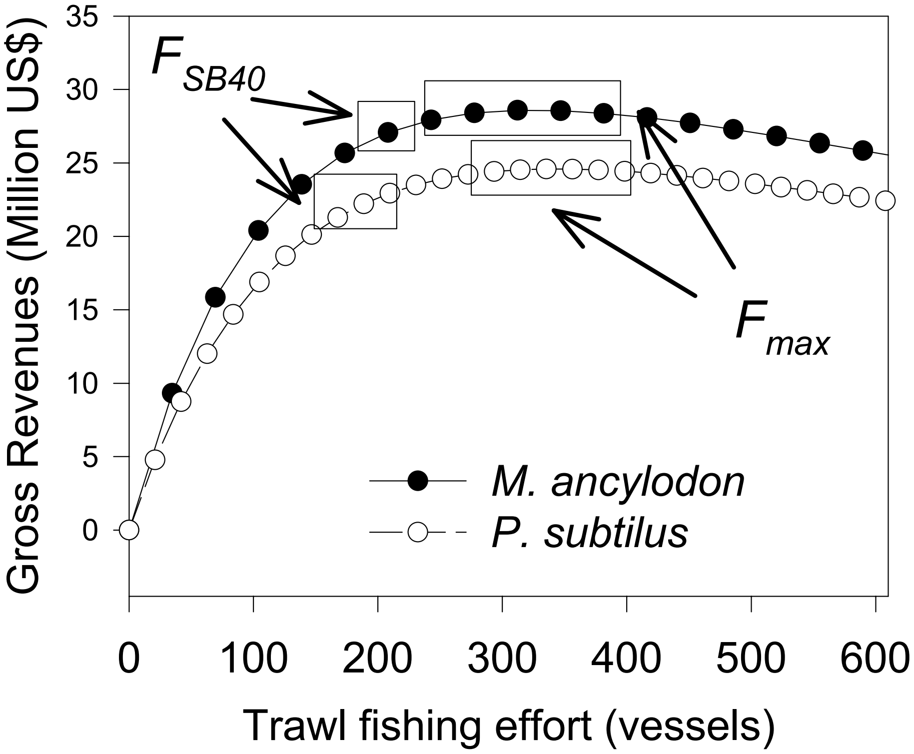


Figure 16.9 Estimated gross revenue for *M. ancylodon* and *P. subtilis* as a function of trawl fishing effort (in number of vessels). Two sets of target reference points are provided: F_{max} and F_{SB40}. Each TRP block summarises the 95% confidence intervals based on uniformly distributed variability in the estimates of natural mortality

16.5 Discussion

Results from all the analyses revealed that *M. ancylodon* is severely overfished, both from growth and recruitment perspectives. The status of the *P. subtilis* stock, in contrast, revealed that it was fully fished with the current fishing mortality similar to the $F_{0.1}$ and F_{SB40} TRPs.

Due to the dependence of recruitment on spawner stock, many scientists concerned with the management of marine species have tended to base their target reference point (TRP) recommendations on the results of spawner biomass-per-recruit models (Butterworth *et al.* 1989; Booth and Buxton 1997; Griffiths 1997a,b). The definition of a spawner-biomass TRP ($F_{SB(x\%)}$) involves setting the fishing mortality to a level at which spawner biomass-per-recruit is reduced to a percentage of its pristine level. Although there is no single widely accepted

$F_{SB(x\%)}$TRP, spawner biomass-per-recruit recommendations generally lie between 25% and 50% of unexploited levels (Deriso 1987; Sissenwine and Shepherd 1987; Butterworth *et al.* 1989; Quinn *et al.* 1990; Clark 1991; Punt 1993; Mace 1994; Booth and Buxton 1997). In the absence of information on the surplus production function or the spawner biomass-recruitment relationship, the $F_{SB(x)}$ TRPs are currently considered the most robust, allowing for the determination of a fishing mortality rate that may provide relatively high yields at lower risks (Clarke 1991; Punt 1993).

Peak yield-per-recruit is attained if an infinite fishing mortality is applied when the biomass of a cohort is at its maximum (Pereiro 1992). If this maximum is applied, only after the age-at-50%-maturity, the risk of spawning failure is reduced. However, if the age-at-50%- maturity is less than or equal to the age-at-50 % selectivity there could be an overfishing situation where the spawner biomass-per-recruit would rapidly reach levels where recruitment would fail. Thus, the maintenance of the spawner stock at levels were it can replace itself is vital. Management of the Brazil-Guianas species, where knowledge of stock dynamics is still relatively weak, should therefore focus on the maintenance of spawner biomass at a precautionary 40% of unexploited levels (F_{SB40}). Although the F_{SB40} strategy is a less conservative strategy than $F_{0.1}$ or F_{SB50}, the relationship between spawner stock size and recruitment is at present unknown and any increase in effort must be viewed with caution.

‘Traditional’ per-recruit analysis showed that both the trawl and seine-net fisheries harvested *M. ancylodon* at an age well below the age-at-50% maturity and this would lead to a rapid decrease in spawner biomass-per-recruit (and possibly spawner biomass) with small increases in fishing effort. Conversely, the gill-net fishery harvests fish above the age-at-50%-maturity. Gillnet fishing is therefore more sustainable and more robust to errors in setting limits on fishing effort, as large increases in fishing mortality would only result in a marginal drop in spawner biomass-per-recruit. Serious consideration needs to be given to reducing both fishing effort (and hence fishing mortality) and to increase the age-at-selectivity if the sustainability of the resource is to be maintained. The per-recruit indications that *P. subtilis* is fully-exploited suggests that no additional management measures are required in terms of this species, for the trawl fishery as long as fishing effort is maintained at present levels. Considering that *P. subtilis* is economically important within this fishery, if economic goals are considered the most important for the shrimp and groundfish fisheries, management measures for *M. ancylodon* should, therefore, be initiated in the Chinese and pin seine fisheries. However, if social goals are considered more important, such as maintaining the livelihoods of artisanal fishermen, this solution may not be the best option. Using techniques such as those employed here, decision makers could be advised on the implications of a range of options for reducing fishing mortality in the different fisheries, assisting them in making decisions best suited to the selected objectives. What is clear, is that there is a need for a reduction in fishing mortality, especially on the immature age classes and if this is not achieved, then both economic and social benefits will suffer in the future.

It must be noted that the per-recruit analysis of the *P. subtilis* stock should be viewed in conjunction with other non-equilibrium stock assessments. This is principally due to the inappropriateness of per-recruit modelling approach for short-lived and fast-growing species that are strongly influenced by environmental variables as the models equilibrium assumptions are violated.

The current gross revenue generated for both species was similar to the maximum gross revenue predicted by the model. While this could be interpreted as indicating that fishing effort in the trawl fishery is currently at an appropriate level from an economic perspective and that the current harvesting rate merely needs to be maintained, the detrimental impact on *M. ancylodon* spawner biomass-per-recruit at this level of effort (Table 16.2) needs to be seriously considered. Current levels of fishing mortality on the *M. ancylodon* stock are higher than those required to reduce spawner biomass-per-recruit to below 20% of pristine levels. This is clearly unacceptable as it has been shown that at these levels there is a high risk of future stock collapse (Mace and Sissenwine 1993, Caddy and Mahon 1995) and the current position is therefore clearly not sustainable. Management from a multispecies-multigear perspective therefore requires that a compromise is reached between gross revenues generated in the short-term and the maintenance of spawner biomass-per-recruit above acceptable levels (e.g. LRPs) for all species. The sensitivity of the spawner biomass of *P.subtilis* to fishing effort with the current selectivity of the trawl gear on the species also needs to be considered. With the current age-at-50%-selectivity of *P. subtilis* of 0.2 years, compared to an age-at-50%-maturity of 0.5 years, any increase in fishing effort could have a serious impact on spawner biomass (Figure 16.6). This needs to be explored by further analyses. For example, a bio-economic analysis could provide valuable information on the implications of increasing trawl mesh size to catch larger shrimp and fish. From a simple per-recruit perspective both yield- and spawner biomass-per-recruit would increase, with a likelihood of both increased net revenues and decreased risk to the stock. But this needs more investigation before any specific management action to achieve this objective could be recommended.

The multispecies and multi-fishery characteristics of Guyana are shared by many marine fisheries (Japp *et al*. 1994; Beckley and Fennessy 1996) The "traditional" single-species-per-recruit models, which ignore important species and gear interactions, provide only very incomplete information for such fisheries. However, the common lack of historical data negates the use of more comprehensive methods such as multispecies VPA (Sparre 1991; Magnusson 1995) in most fisheries. Therefore, the multispecies-multi-fishery per-recruit approach is frequently a very useful management tool for these fisheries, at least until such time as reliable long-term directed catch-at-age or catch-at-length data are available. It is recognised that the per-recruit approach has limitations, such as its assumption of constant recruitment (Pereiro 1992) and, therefore, it has to be used with caution. This problem could be addressed later within a Monte-Carlo simulation framework by incorporating long-term probabalistic forecasts using stochastic recruitment. It is crucial that relevant long-term catch-at-age or catch-at–length data are collected in all fisheries. These data, together with estimates of total catch and total effort for each fishery, will facilitate integrating the results of the per-recruit analysis with the output of other age-structured models in order to provide more accurate, comprehensive and sustainable strategies for long-term management.

Various aspects of the biology of *M. ancylodon* and *P. subtilis* need further investigation. There is an urgent need to obtain accurate age and growth estimates, by sex, as scaenids, such as *M.ancylodon*, are typically long-lived and slow growing, even in tropical environments (Beckman *et al*, 1989, 1990; Barbieri *et al*. 1994; Griffiths and Hecht, 1995, 1996; Murphy and Taylor, 1989; Ross *et al*, 1995). These growth parameters form the basis of all age-based models and, where poorly known, further reduce the inaccuracy from length-based modelling approaches. In addition, under such circumstances, length-frequency analysis induces additional bias when estimating natural and fishing mortality due the correlation between lumped parameters. With regard to the stock assessment framework used, there needs to be a move away from equilibrium based models for groundfish in Guyana. This has been achieved for the shrimp resources studied in these workshops that have been assessed, for example, using cohort analysis. This has been possible, primarily due to the availability of accurate annual estimates of age and growth and comprehensive age-structured catch statistics. Assessment of groundfish needs to take cognisance of this progress made in the shrimp assessments. The monetary value of the industrial and artisanal catches together with their importance to subsistence fishers should be sufficient motivation to collect such data for the main groundfish species as well. It is recommended that total catches and effort per fishery and suitable biological data should be collected for all the more important groundfish species, not just *M. ancylodon* and also that the economic and social value of groundfish should be studied. These data and information would contribute significantly towards their sustainable utilisation and management.