ASSESSMENT STUDIES

Caribbean LME Project

ASSESSMENT STUDIES

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
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CASE STUDY ON SHARED STOCKS OF THE SHRIMP AND GROUNDFISH FISHERY OF THE GUIANAS-BRAZIL SHELF

FAO implemented a "Case Study on Shared Stocks of the Shrimp and Groundfish Fishery of the Guianas-Brazil Shelf" (UNGF/INT/001/OPS) between July 2011 and February 2013, with six participating countries (Brazil, French Guiana (EU/France), Suriname, Guyana, Venezuela and Trinidad and Tobago). The case study was carried out within the framework of the GEF-funded Caribbean Large Marine Ecosystem (CLME) Project. The CLME Project aims at assisting Caribbean countries to improve the management of their shared living marine resources, most of which are considered to be fully or overexploited, through an ecosystem approach. A preliminary Transboundary Diagnostic Analysis identified three priority transboundary problems that affect the CLME: unsustainable exploitation of fish and other living resources, habitat degradation and community modification, and pollution.

The purpose of the case study of the Shared Stocks of the Shrimp and Groundfish Fishery of the Guianas-Brazil Shelf was to fill knowledge gaps, contribute to the final CLME Transboundary Diagnostic Analysis and to the Strategic Action Programme (SAP), with priority actions to be undertaken to ensure the sustainability of the shrimp and groundfish fisheries. Another objective was to mainstream the Ecosystem Approach to Fisheries (EAF) in the management of shrimp and groundfish fisheries. Both objectives were addressed through assessments/studies at the national and regional levels, with the participation of stakeholders and following some of the key steps of the planning process within an EAF framework.

PREPARATION OF THIS DOCUMENT

This is the compilation of the background assessment studies that were produced in support of the case study on the Shared Stocks of the Shrimp and Groundfish Fishery of the Guianas-Brazil Shelf. The assessment studies were carried out by Paul A.H. Medley, Lara Ferreira, Juan Carlos Seijo, José Augusto Negreiros Aragão, Israel Hidenburgo Aniceto Cintra, Kátia Cristina de Araújo Silva. The assessment studies were meant to provide background information currently available on the status of the main stocks, as well as an analysis of the profitability of the fisheries in the Northern Brazil Shelf Area. Elements of the background studies were taken into consideration when discussing the priorities to be included in the Caribbean Large Marine Ecosystem Strategic Action Program..

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Assessment studies
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ABSTRACT

The background assessment studies that were produced in support of the case study on the Shared Stocks of the Shrimp and Groundfish Fishery of the Guianas-Brazil Shelf were meant to compile the most recent information on the status of the main commercial species and on the profitability of the fisheries these species sustain.

In Suriname, Trinidad and Tobago and Guyana, most stocks are considered at least fully exploited and some are likely overexploited. The penaied shrimp stocks are likely to be in better conditions, but some species are at risk of overexploitation. Atlantic seabob is likely to be in good conditions in Suriname. Generally, stock status is difficult to determine in many species of shrimp and groundfish due to the lack of data and any recent stock assessment. In Northern Brazil, information is available mainly for brown shrimp (*Farfantepenaeus subtilis*). The trend over the last five years shows that the fishing effort is much lower than in the late 80’s and that population biomass seems to be recovering. Very little information is available on the status of demersal fish species.

In this context of lack of data, Productivity-Susceptibility Analysis were carried out to rate the vulnerability of a range of species. In Suriname, Trinidad and Tobago and Guyana, the most vulnerable species were found to be elasmobranchs, followed by slow-growing catfish and yellowfin river pellona. Overall data on shrimp species is of a better quality than for the other species and stocks show a lower level of vulnerability that the rest of the species that were analyzed. A similar analysis of data from Northern Brazil provided results that need to be considered preliminary because of the poor quality of the data used. The most vulnerable species was red snapper, followed by the king weakfish and brown shrimp.

Results from the bioeconomic model built for the multi-species multi-fleet shrimp fishery of Venezuela and Trinidad and Tobago indicate that effort of the fleets should not be expanded further and that effort levels should be reduced biomass and profits away from risky levels likely to result from climate change and other natural or anthropogenic effects affecting population growth. In Trinidad and Tobago, data collected in 2010 show that the value of bycatch represented 18 per cent of total catch value in the shrimp fishery. In Northern Brazil, the estimates of the bioeconomic model that was run with the data available on the shrimp fishery show a tenuous financial stability of the fishery for different levels of recruitment, and a negative profitability in case of a failure in recruitment, except for a low level of fishing effort.

Table of Contents

1 REVIEW OF THE SHRIMP AND GROUNDFISH STOCK STATUS OF GUYANA, SURINAME AND TRINIDAD

By Paul A.H. Medley

1.1 Summary

A summary of the stock status of the stocks which have been assessed is presented below (Table 1.1). Stocks by default have been defined by species and country based on management units rather than biological populations.

The method applied to determine status has been as either length-based (L) or catch-effort based (C/E) or both. Length-based methods generally estimate mortality rates, and can be used to determine exploitation risk primarily, but stock status may also be inferred. Catch and effort data can be used to fit simple population dynamics models to estimate stock and exploitation status.

The confidence in the stock assessment was indicated by the responsible scientists in each case. Although this makes a contribution to risk, it is clearly remedied by improving information on the stock and therefore is considered separately. Uncertainty may be the result of time since the assessment was carried out as well as data quality. The year of the assessment is given, and where it was greater than 10 years ago, the assessment results should be treated with caution. The other main source of uncertainty is poor data. With respect to poor quality or incomplete data, the confidence in the assessment has been classified as high (H), medium (M) or low (L).

Stock status is categorized as low (L), medium (M) or high (H) risk. Stock status is used to imply the probability that biomass is below some limit reference point, where recruitment may be reduced and recruitment overfishing becomes likely.

Exploitation status is also categorized as low (L), medium (M) or high (H) risk, and refers to the rate at which fish are being caught rather than the current biomass. This indicates whether the stock status is likely to become worse, better or remain the same. Therefore, a status at high risk and exploitation at low risk would suggest that the stock is likely to recover. Conversely, stock at low or medium risk and exploitation high risk would suggest that the stock will also become high risk over time.

Where status or exploitation is blank, the stock assessment was unsuccessful and the risk to the stock could not be determined.

Uncertainties have not necessarily been explicitly covered in all stock assessments, but it is clear that uncertainty is high in almost every assessment. The main causes of uncertainty have been the general lack of data (sample coverage and short time series), poorly estimated growth parameters and unknown gear selectivity. These can be addressed through a combination of short-term projects (to estimate growth parameters for example) and improved long term sampling that includes the fishing industry in collecting and providing data.

Table 1.1. Summary of shrimp and groundfish stock status in Guyana, Surinam and Trinidad & Tobago. The confidence in the information provided is referred to as high (H), medium (M) or low (L).

Groundfish Stock		Method	Confidence	Stock status	Exploitation status
Lane Snapper *Lutjanus synagris*	Suriname	L	1999: M	M	L
	Guyana	L	1999: L		
	Trinidad	L C/E	2006: M	M	L
Southern Red Snapper *Lutjanus purpureus*	Guyana	L C/E	2006: M	H	H
Sea Trout *Cynoscion virescens*	Guyana	L C/E	2007: M	M	H
	Suriname	L	1999: L	H	M
Whitemouth Croaker *Micropogonias furnieri*	Trinidad	L	1999: M	H	H
Bangamary *Macrodon ancylodon*	Guyana	L	2004: M	M	M
Butterfish *Nebris microps*	Guyana	L	1999: L		H
Jamaica Weakfish *Cynoscion jamaicensis*	Trinidad	L	1999: M	H	H

Penaeid Shrimp Stock		Method	Confidence	Status	Exploitation
Southern Pink Shrimp *Farfantepenaeus notialis*	Guyana	L	1999: M	M	M
	Trinidad	L C/E	2005: M	M	M
Brown Shrimp *Farfantepenaeus subtilis*	Guyana	L	1999: M	M	M
	Suriname	L	1999: L	M	M
Pink-spotted Shrimp *Farfantepenaeus brasiliensis*	Guyana	L	1999: M	M	H
	Suriname	L	1999: L	M	M
Atlantic Seabob *Xiphopenaeus kroyeri*	Suriname	C/E	2012: H	L	L
	Guyana	C/E	2012: L	L	L
	Trinidad	L C/E	2005: M	H	H
Combined Shrimp (5 species)	Trinidad and Venezuela	C/E	2011: M	M	L

1.2 Introduction

The objective of this report is to review the status of shrimp and groundfish stocks on the Brazil-Guianas shelf for Trinidad and Tobago, Suriname, and Guyana. The information presented here comes from shrimp and groundfish stock assessment meetings organised by Food and Agriculture Organization of the United Nations in 1999 and 2000, and from the annual Caribbean Regional Fisheries Mechanism Scientific Meeting which includes the Shrimp and Groundfish Working Group. This report is a brief overview only; more details including further management advice can be found in the source documents (FAO 1999, 2000; CRFM 2005, 2006, 2007, 2011, 2012).

The following review considers the main fin fish and shrimp stocks of the Brazil-Guianas shelf within the jurisdiction of Suriname, Guyana and Trinidad and Tobago, covering the stock status, management advice and the stock assessments on which this is based. The review is used to draw conclusions about the ability to manage these resources and what might be the priority actions that are needed to ensure the fisheries in the region are harvested sustainably.

Stock status is defined here both as the current biomass and the exploitation rate. The current biomass is primarily used as an indicator of whether the recruitment is put at risk. Failure in recruitment can lead to long term depletion of a stock with its incumbent economic impacts on the fishery. The exploitation rate can be used to assess whether the current fishing level is sustainable in the long term as well as whether fish are being caught before they reach their optimum size. Stock status is measured relative to reference points. Estimating appropriate reference points forms part of the stock assessment.

As well as stock status, most assessments offer advice to management. The advice suggests appropriate action or controls which management can consider. The management advice is based on stock status and other considerations, such as the need to avoid bycatch, small fish and destruction of fish habitat. In addition, advice should include the precaution required based on the confidence in the stock assessment. What has been done in only a very few assessments, but should be where data are available, is to provide an evaluation of the management actions taken.

For each stock, there is a short summary of the stock assessment from which the stock status and management advice was obtained. Two types of stock assessment form most of the analyses used for these stocks:

- Length based methods (such as length-converted catch curves) assume the stock is in a stable state and that selectivity does not change beyond some length, usually the modal length. The method converts a length sample to age, which is dependent on a growth model, and then estimates the mortality rate from the rate of decline of older fish in the sample.
- Catch and catch-per-unit-effort (CPUE) can be used separately or together to estimate abundance, where catches are assumed to be complete (all mortality due to fishing) and CPUE is a valid abundance index. CPUE has, where possible, been standardised to try to remove changes in the index which are not related to changes in abundance.

Some attempts have been made to combine catch, CPUE and length composition into a single analysis. These more sophisticated attempts at dynamic age structure models have probably not justified the additional work required to fit them, mainly because data have so far been insufficient to allow their full power to be used. Where they can be fitted, they eliminate some of the assumptions and should provide more reliable results.

For many stocks, stock status was often not precisely known or even well-defined, and there was considerable uncertainty with all determinations. All stock assessments are generally assessments of risk rather than precise estimates of stock abundance, and this is particularly the case for the stocks in this region. For this reason, a section has been added which summarises the main uncertainties.

Solutions to uncertainty are of two types. Management actions can respond to reduce risk mainly by reducing the amount of fishing, this being the precautionary approach. Unfortunately, this is very likely to result in exploitation levels well below the optimum which may be attained should information be improved. The other response is to improve information, usually through increased data collection and research. However, delaying management action while research and data collection is carried out is not precautionary. Some combination of the two is therefore probably the best response, with exploitation levels allowed to increase as more research and data are compiled. It is important that any initiative involving increased costs in monitoring a fishery is clearly connected to possible improvements in management.

1.3 Fisheries, Management Units and Stock Definition

Management units are used to define what is assessed, and are usually limited to the area over which the management has jurisdiction. Ideally, management units coincide with biological populations, which are themselves self-replenishing isolated units. In practice, marine fish populations are rarely clearly defined, and therefore what constitutes such a "stock" cannot be defined with confidence. The complications are easily demonstrated by considering shrimp. Adult shrimp do not swim far and several isolated populations may well occur with a country's management zone. However, shrimp release larvae which may well be distributed so that such populations may be linked through recruitment.

In practice, management units have been defined pragmatically, with single management units considered to exist within national boundaries. Within these boundaries the management system is harmonised, with consistent data collection, fisheries and regulation. For most management units, there have been suggestions that joint stock assessments, and by extension management harmonisation, takes place among countries. However, it remains unclear in most cases whether this would really lead to improved assessments and management in all cases, and there is a strong argument for more research and study of this issue.

Detailed descriptions of the fleets and fisheries in each country are available from national reports (CRFM, 2005-2012). Gears consist of commercial and artisanal demersal trawl for shrimp (slow moving with small mesh nets) and finfish (faster moving with larger mesh nets). Artisanal fleets contain a much wider variety of gears including, in addition to trawls, different varieties of seine nets, gillnets, pots and handline. Other gears, such as bottom-set longline, have not been used. Pelagic longlines may be used, but not on the Brazil-Guiana shelf region.

Catches in the FAO database (FAO, 2012) were reported for years back to 1950, but landings were undifferentiated from broad categories of shrimp and finfish (see Figure 1.1 to Figure 1.3). Recent reported catches have been more informative and show landings have been stable, but in some cases, such as penaeid shrimps excluding seabob, landings have been low and the resource appears to have been depleted.

The most valuable catches for export have been the penaeid shrimp resources of the region. The majority of shrimp are exported, whereas resources of finfish are more important for local consumption. Exported resources generally have much better information, since such businesses usually keep accurate information for their own business purposes as well as to report to customs their exports.

In terms of quantity of landings, Guyana exceeds most other countries in the region. Landings have been dominated by undifferentiated groundfish and Atlantic seabob (Figure 1.1), with catches remaining stable over the period 2000-2010. There was a marked change in landings of penaeid shrimps 1980 onwards, at which seabob landings were differentiated from other penaeid landings.

Both Suriname (Figure 1.2) and Trinidad (Figure 1.3) report the largest landings as undifferentiated groundfish. Suriname landings of seabob are significant, but otherwise penaeid shrimps only form a small proportion of the production in each country.

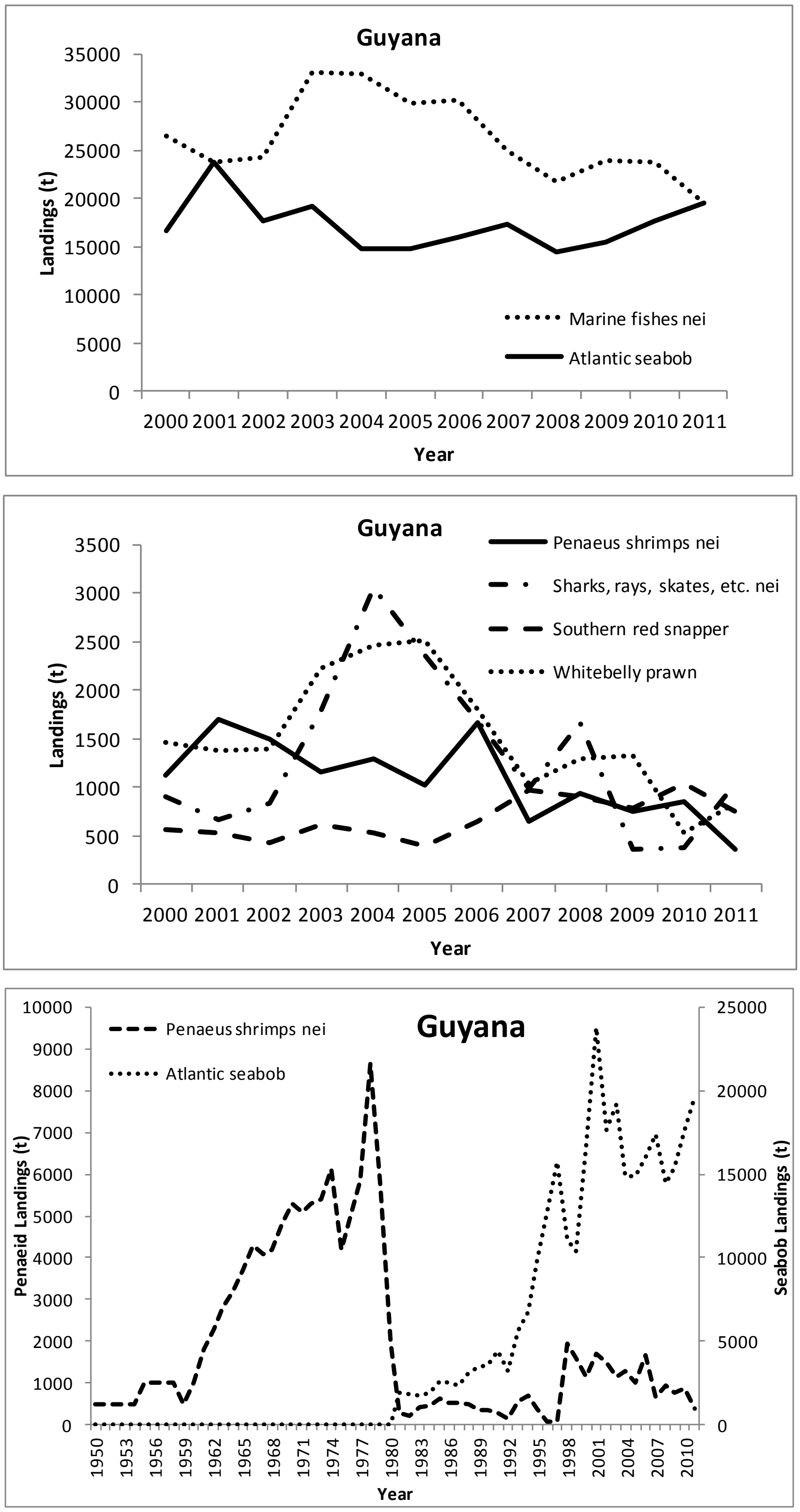
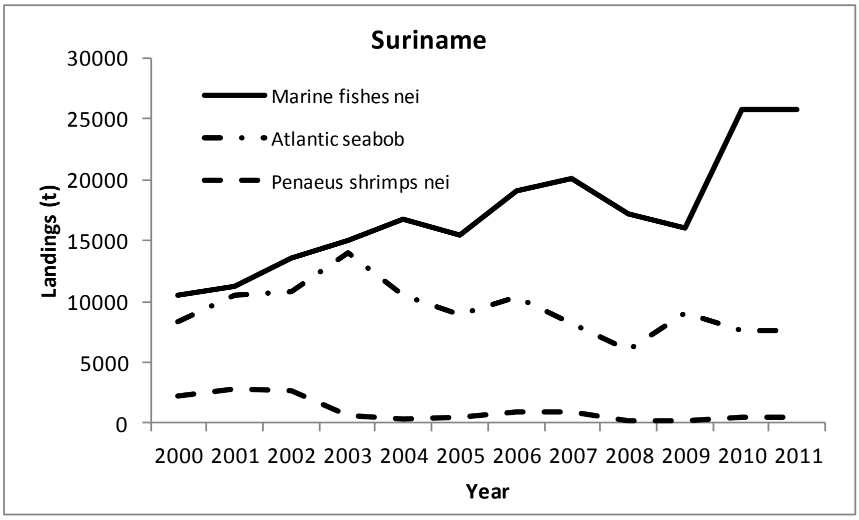


Figure 1.1. Guyana landings 2000-2010 (all stocks) and 1950-2010 (penaeid shrimps).



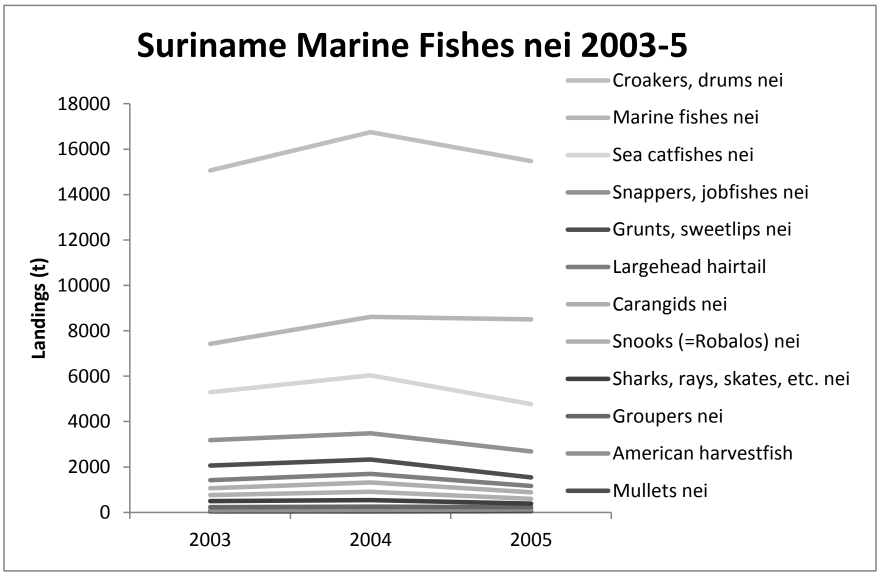


Figure 1.2. Suriname landings 2000-2010 and a breakdown to species group 2003-5.

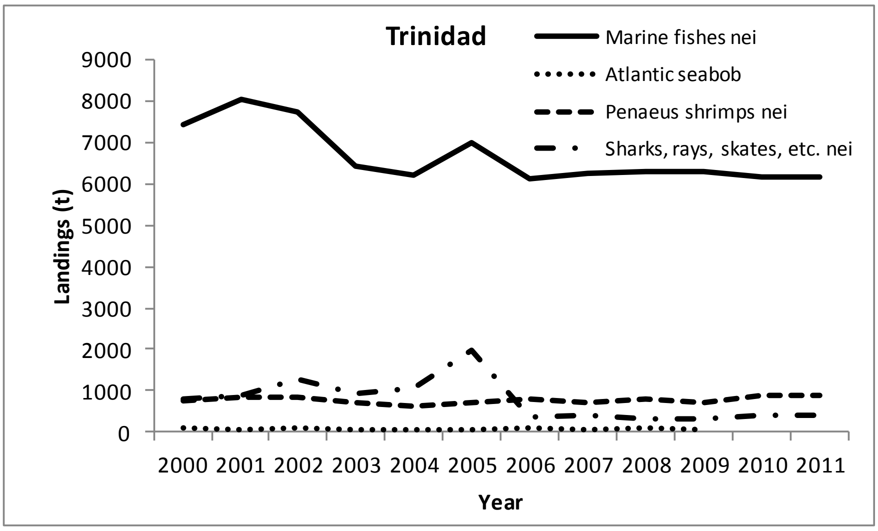


Figure 1.3. Available landings data for Trinidad 2000-2010.

1.4 Lane Snapper (*Lutjanus synagris*)

1.4.1 Suriname

- ***Stock Status***

The stock assessment carried out in 1999 suggested that the *L. synagris* stock was most likely under- to fully-exploited. It was therefore concluded that the risk to recruitment was low and that yield may be increased through increasing fishing effort directed at this species.

- Management Advice

Lane snapper is caught as bycatch in the demersal trawl fisheries which mainly target penaeid shrimp as well as those vessels that target finfish. Therefore, while yields may be increased from this stock by greater fishing effort, not all fleets would benefit, particularly vessels targeting larger fish. There are also the usual risks accompanying any increase in fishing activity and therefore any increases should be carried out with caution and appropriate levels of monitoring.

It was also found that shrimp by-catch, even though removing mainly juveniles from the fishing grounds, probably does not substantially affect the fishery since this species makes up a low proportion of the bycatch.

- Stock Assessment Summary

The fishing mortality was estimated using a length-converted catch curve and length frequency data sampled from three trawl fleets. Growth and natural mortality parameters had to be provided to the assessment. Biomass and yield per-recruit models were to estimate reference points, which could be compared to the fishing mortality estimate to define the stock status.

- Main Uncertainties

Data were only available from a short sampling period. Growth, natural mortality and selectivity parameters were assumed rather than estimated from data. However, data were considered adequate for providing management advice.

1.4.2 Guyana

Although attempted, no assessment has been successfully completed for lane snapper in Guyana. *L. synagris* is caught as bycatch in the demersal trawl fisheries which mainly target penaeid shrimp. Length data were collected and an assessment attempted in 1999. However, the data could not be explained using standard models. This may have been an issue of data quality or due to complexities in the fishery, such as changes in selectivity.

1.4.3 Trinidad and Tobago

- Stock Status

L. synagris in Trinidad and Tobago was likely to be under-exploited in 2006. Analysis of recent catch trends showed that on the west coast catches have decreased slightly (1.16% year^{-1}) as opposed to the rapid increases in south coast fishery over the same time period (35% year^{-1}).

Effort trends for both coasts were similar with a rapid decrease of more than 60% after 1993-1999. The reasons for this decline are not known. Concomitant with the decrease in fishing effort was an increase in catch-per-unit-effort (CPUE). Trends in CPUE are often used as a proxy for resource abundance and suggest that there was an apparent recovery of the stock at a rate of 23% year^{-1} on the west coast and a 34% year^{-1} on the south coast. The true magnitude of this recovery was however unknown and was probably less than that required for an economically viable fishery. Results of the

2006 assessment (CRFM 2006) updated this assessment and indicated a high fishing mortality rate, but recruitment has remained unaffected.

It was pointed out in FAO (2000) that a large proportion of the catch is immature. Results in 2006 also suggested that the landings of the lane snapper are largely comprised of fish less than 2 years old and before they can spawn.

The Caribbean Regional Fisheries Mechanism (CRFM) Shrimp and Groundfish Working Group (SGWG) has suggested that the Trinidad stock may be part of a larger population on the adjacent continental shelf that is perhaps not so heavily exploited and may supply a steady stream of recruits into Trinidad waters (CRFM 2006).

- Management Advice

In the short term fishing effort should be monitored and not allowed to increase. Otherwise, it was noted that there were data gaps that influenced the ability of the assessment to give good results. In view of the need to review the quality of the available data for the fishery there was no specific management advice in 2006.

General management objectives for the marine fisheries of Trinidad and Tobago include ensuring that the fisheries resources are not endangered by over-fishing and that the exploitation of the fisheries resources and the conduct of related activities, are consistent with ecological sustainability.

- Stock Assessment Summary

The 2006 analysis utilized recent (1995-2004), historical (1963, 1975) and reconstructed (1908 to current) annual catch per unit effort (CPUE) levels for artisanal gillnet, line and trawl fleets operating in Trinidad in addition to length data obtained from fishpot and banking (handline) in 1996-1997. Biological parameters were obtained from a previous assessment for the lane snapper in Trinidad.

The assessment was based on two different methods. A mean size model using the length frequency information (Gedamke and Hoenig, 2006) estimated the fishing mortality and a dynamic model that estimated stock abundance trends and fishing mortality from total effort and CPUE information.

Analysis of length frequencies showed that selectivity for fishpots and banking (handline) were similar after an age of two years (i.e. lengths above 30 cm) despite their very different natures. The analysis showed that there were fewer larger, older fish in the samples than might be expected if the stock was not overfished. This could also be explained also by selectivity (older fish become less likely to be caught). Selectivity can be the result of changes of size or behaviour with age.

For the analysis of CPUE, the stock was assumed to be only lightly exploited prior to 1950. Fishing mortality was estimated using the time series of reconstructed total landings as an index of relative fishing effort for the years prior to 1994.

CPUE indices for seven gears were examined. Five indices showed relatively flat trends (multifilament gillnet, monofilament gillnet, *a la vive*, semi-industrial trawl, banking). Two indices suggested recent increases in abundance (artisanal trawl, fish pot). In general, the CPUE results indicated a lightly exploited population that is well above the level that would produce the maximum sustainable yield with the current selectivity pattern.

Overall, results indicate that recruitment to the lane snapper fishery in Trinidad has not declined since the CPUE trends have been relatively constant.

- Main Uncertainties

Given the conflicting results from the analyses, the state of the stock is uncertain. However, the most likely explanation is that the length-based analysis results have been affected by selectivity. One proposal is that older fish may move away from the main fished areas so that they are less available to the gear (CRFM 2004). This may also complicate the definition of a stock in this case as well, due to the proximity of Venezuela.

Although on balance the stock is not overfished; this is not necessarily the most precautionary assumption. The presence of older fish should be confirmed if possible, through wider gear sampling and perhaps through using fishing surveys.

In better understanding stock structure, a number of biological studies might be attempted, including genetic and tagging studies, as well as more length and weight sampling of different gears among countries.

Another important source of information would be the length frequency data from the 1988 Fritdjof Nansen fish surveys in the region. These data would allow comparative assessments between areas, identifying areas where older fish may be more common, as well as improve reference point estimates.

1.5 Southern Red Snapper (*Lutjanus purpureus*)

1.5.1 Guyana

- Status of Stocks

The 2004 and 2006 assessments concluded from the preliminary results that the stock may be overfished (CRFM, 2004; CRFM, 2006).

- Management Advice

The Draft Marine Fishery Management Plan for Guyana (2006) stated that the management objectives for this fishery were to maintain the stock at above 50% of its mean unexploited level, maintain the net income per fisher above the national minimum desired income, while including as many of the existing participants in the fishery as is possible.

Given the possibility that the stock may be overfished, under the precautionary approach catch levels should be reduced from the 2006 level. However, the precise optimal levels of effort were not reliably determined and reference points are not defined for this fishery. The working group suggested improving the exploitation pattern through technical changes such as increasing the mesh size for net gears.

- Stock Assessment Summary

For the 2006 assessment, catch per unit effort (CPUE) series were generated for the hook and line fishery from 1995-2005 for all months combined and for July and August in particular (summer period). The months of July or August were the only months consistently fished, so using only July and August data accounted for possible seasonal effects. Available landings and CPUE statistics represented only a fraction of the total fishery, so the fishing mortality was estimated from the length frequency data alone using a mean-size method.

Overfishing in this case may be occurring because the estimated fishing mortality rate was greater than the assumed natural mortality rate. From a maximum yield per recruit perspective, the fishery appears to be operating near the optimum, but this assumes that future recruitment will continue at current levels.

In CRFM (2004), an attempt was made to fit a catch-at-age model 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 resulting yield-per-recruit suggested that the current effort was well above the target (optimal) effort, but below the limit reference point. The estimated recruitment increased and declined during the period, following changes in CPUE.

- Main Uncertainties

The available data for this fishery are sparse. In common with many stocks, red snapper is caught alongside other species in a variety of gears including traps and trawl and may be shared among countries along the Brazil-Guianas shelf. Catches of vermillion snapper (*Rhomboplites aurorubens*) , lane snapper (*Lutjanus synagris*), mutton snapper (*L. analis*) and silk snapper (*L. vivanus*) are landed together.

1.6 Sea Trout (*Cynoscion virescens*)

1.6.1 Guyana

- Stock Status

In 2006, the assessment found that the state of the stock could not be determined from the available data (CRFM 2006). The only data available were the size composition of the catch predominantly taken by gillnet. The size composition of gillnet catches are much more dependent on the selectivity properties of the gear than the underlying abundance of age groups. Some trawl catch data were also available, but insufficient for assessment. The assessment concluded that because the trawl mortality was low and gill net catch fish close to their maximum size, probably after their age at first maturity, the risks to stock was low.

In 2007, this conclusion was revised primarily based on the catch per day from gillnet vessels, which had declined (CRFM 2007). Based on gill net CPUE, it appeared that the adult sea trout population had been reduced to below 50% of the unexploited level. The SGWG pointed out that this condition, if allowed to continue, may also lead to a decline in recruitment.

- Management Advice

The SGWG in 2006 concluded that there was no evidence that the current fishing effort should be reduced overall, but that trawl bycatch should be minimised. The advice in 2007 revised this somewhat by suggesting that overfishing could be occurring. Therefore, the stock could be in a worse state than previously thought, and that exploitation by both trawl and gillnet should be reduced.

- 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 1.4).

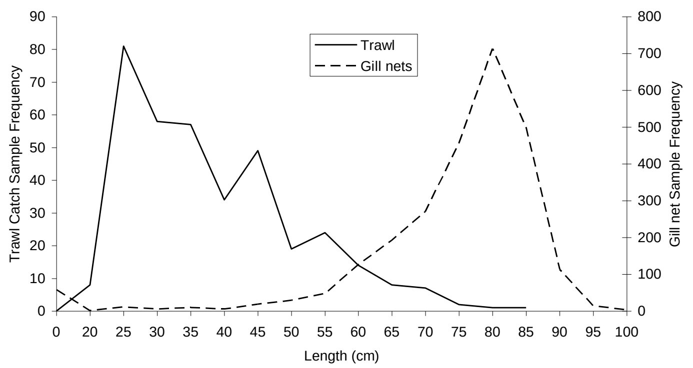


Figure 1.4. Length frequencies for the two major gear types catching sea trout in Guyana show very different selectivity. Trawl selects much younger fish than gill net.

The estimated slope of a length-converted catch curve for trawl indicated that the total mortality was around 0.47 $year^{-1}$, close to the available estimate of natural mortality (CRFM, 2006). This suggested that trawl had a low impact on this species, although the majority of the catch is taken by gill net. It was not possible to conduct a similar analysis for gillnet, because the downward slope to the right of the mode is the result of variation in asymptotic size and selectivity, not age.

Another assessment in 2007 was based on three types of analyses: (a) a mean length model that used a time series of length frequency information; (b) length-converted catch-curve analyses and (c) standardized CPUE information (CRFM, 2007). Data were available for the period 1996-2006 for artisanal gillnet, Chinese seine and trawl fleets operating in Guyana.

The mean length model and length-converted catch curves estimated similar mortality rates, and generally findings were consistent with the 2006 assessment. However, the results were heavily dependent on growth and mortality parameters used, which were noted as highly uncertain.

Catch per day was standardized to account for unbalanced and incomplete sampling across months, regions and years by use of a generalized linear model (GLM), which should reduce bias and produce a more reliable index of abundance. Trawl CPUE showed no trend, but the availability of larger fish (estimated at age 5 and older) to the gillnet fishery appears to have decreased after 1999. It is therefore likely that the adult population has decreased in size, but there is no evidence that recruitment has declined.

- Main Uncertainties

The main uncertainties in the assessment were quantity of data which was limited, and the lack information on key assumptions, notably growth parameters and selectivity. Catch and effort data quality needed to be improved.

An obvious and important source of information on growth is age data. It has been recommended on many occasions that ototliths (ear bones) and scales should be collected for a feasibility study on determining age, and if successful, further data collection to obtain a good model of growth for this species.

1.6.2 Suriname

- Stock Status

The various analyses undertaken in 1999 on the sea trout Suriname fishery all indicate extremely high fishing mortality on *C. virescens* (FAO, 1999). According to the calculations, current levels of fishing effort will have reduced spawning biomass per recruit (SBR) to 11-21% of unexploited levels. This suggested that recruitment was being put at risk in these fisheries. However, levels of effort decreased in 1999 and increased again in 2000. The effect of these changes has not been evaluated.

- Management Advice

The assessment results suggested that management intervention to reduce sea trout catches by trawlers was justified. This result was supported by an observed decrease in the lengths of *C. virescens* in landings. However, these results were not considered definitive and further research was recommended.

- Stock Assessment Summary

The available data consisted of lengths sampled from landings. The analysis consisted of a length-converted catch curve which was used to estimate monthly fishing mortality over a 2 year period. Natural mortality and growth parameters had been previously estimated and input into the model. The data showed an increasing mean size, perhaps due to the initial decrease in fishing effort in 1998 (although this would suggest a very rapid response).

- Main Uncertainties

The results depend on the assumed selectivity, growth and natural mortality rates. In addition, the data only covered a period of only two years.

1.7 Whitemouth Croaker (*Micropogonias furnieri*)

1.7.1 Trinidad and Tobago

- Stock Status

Trends in CPUE, per-recruit analysis, a biodynamic model and bio-economic analysis all indicated that *M. furnieri* was over-exploited in 1999. A joint analysis of the stock using Trinidad and Venezuelan data from the artisanal and industrial fleets showed similar results - that of low stock levels commensurate with high levels of exploitation. A biomass dynamic model of *M. furnieri* and *C. jamaicensis* combined suggested a maximum sustainable yield of approximately 1500 t (1300 to 1600 t), while fishing levels in 1999 were considerably higher than this.

- Management Advice

M. furnieri and *C. jamaicensis* are generally caught together. The intensive exploitation of *M. furnieri* and *C. jamaicensis* can be attributed to the combined effort of six gear types operating in the Gulf of Paria. The implication from the analyses suggests that there is a high risk that the stocks are overexploited. It was recommended that the fishing effort does not increase beyond 1999 levels, and with the further implication that fishing effort should be reduced, albeit gaps and limitations of the data were emphasized.

- Stock Assessment Summary

A number of analyses were carried out to assess both *M. furnieri* and *C. jamaicensis.* Fishing effort was standardised for the different gear types and for months using an analysis of variance (GLM). Then, based on standardised CPUE trends, seasonal declines in CPUE were identified and a “DeLury” depletion model was fitted to these data to obtain seasonal estimates of the fishing mortality for each species separately. Recruitment, migration and growth were assumed to be negligible within the periods defined by these subsets of data. The results from these analyses were used to further correct CPUE for seasonal changes in catchability and generate seasonal abundance and fishing mortality estimates. Finally, a per-recruit analyses based on previously estimated growth and mortality parameters were used to estimate fishing mortality reference points (maximizing yield-per-recruit, and spawning-per-recruit at a standard), defining the status of the stocks.

A joint Trinidad and Venezuela analysis was also carried out which used artisanal and industrial data from both countries. The assessment used catch and effort data for six Trinidad fleets and the Venezuelan industrial and artisanal fleets as well as biological data from the Venezuelan industrial fleet. The assessment estimated that the maximum sustainable yield for croakers was 1 500 tonnes and that this had generally been exceeded from 1987-1993 and in 1998.

- Main Uncertainties

The analysis had only CPUE for the artisanal fleet although the industrial trawl fleet and other fleets operating in the Gulf of Paria would make a considerable contribution to the exploitation. Changes in biomass and fishing mortality values may also be influenced by migration of the species and not just mortality. Various growth and mortality parameters used in the models were obtained from scientific literature, but may be another significant source of error.

1.8 Bangamary (*Macrodon ancylodon*)

1.8.1 Guyana

- Status of Stocks

Stock assessment analyses in Guyana in 1999 showed that the stock was overfished from both growth and recruitment perspectives (FAO, 2000). In contrast, the 2004 assessment which had access to a longer time series of data found no clear indication as to the state of the stock and could not confirm the findings in FAO (2000). There were no trends in CPUE and fishing mortality estimates were not large relative to likely natural mortality (CRFM, 2004). This may be partly because there is no directed fishery at this species and the species should be relatively robust to fishing.

- Management Advice

There is no policy for development of a bangamary fishery, the species being caught primarily as by-catch in several fisheries. 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.

The implication from the 1999 assessment would be to reduce fishing mortality on this species, and this would still be a precautionary action based on the 2004 assessment. With only limited information, there is a risk this species is being overfished.

Although the more recent stock assessment suggests recruitment overfishing is most likely not occurring, growth overfishing seems more likely, given the bycatch and discarding of small bangamary, which are not recorded, and the small size of the recorded catch. Reducing fishing mortality is always precautionary and some reduction may be possible without significant cost to the industry.

Given that bycatch of small bangamary is high and discards are significant, it would make sense to reduce this source of mortality as much as possible. This might be achieved by changes to mesh size and controlling where vessels fish. More information on selectivity would be required to provide more precise advice.

- Stock Assessment Summary

For the 1999 assessment, length frequency data was available from the Chinese seine, nylon gillnet and trawl fisheries during January 1996 – March 1999. Previously estimated growth parameters (K=0.66 yr^{-1} L_∞ = 43.57 cm) and natural mortality (1.20 yr^{-1}) were used to estimate an average total annual mortality of 2.7 yr^{-1}, implying fishing mortality of 1.5 yr^{-1}, which is above the natural mortality (a proxy for F_{MSY}). These results were used in the multispecies multigear yield per recruit analysis to evaluate the status of the fishery and forecast the effects of changes in the fishing pattern.

For the 2004 assessment, trends in CPUE were analysed. There was no consistent overall trend in CPUE during 1995-2003, and therefore no clear evidence that the stock size has changed over this period. In addition, length frequency data were used to estimate total mortality using length converted catch curves. Estimates from the available data were much lower than those obtained in 2000, and therefore could not confirm previous findings.

- Main Uncertainties

There were inadequate data to do full stock assessments. However, the data should be adequate to indicate general trends and status of the stock.

1.9 Butterfish (*Nebris microps*)

1.9.1 Guyana

A stock assessment was attempted in 1999 (FAO, 2000), but there were no reliable results. Unrealistic estimates of very high mortalities were obtained from length-frequency samples. As a result, no assessment has been successfully completed on this species, although the exploitation rate could be very high, putting the stock at risk.

A significant source of mortality for butterfish is as discarded bycatch in the shrimp fishery. It is therefore very likely that this resource, even if not overfished, at the very least is not being exploited optimally, and significant catches are wasted. A full stock assessment may well require monitoring of discards to understand the range mortality applied to the stock.

1.10 Jamaican Weakfish (*Cynoscion jamaicensis*)

1.10.1 Trinidad and Tobago

- Stock Status

Recent trends in CPUE, per-recruit analysis, a biodynamic model and bio-economic analysis all indicate that *C. jamaicensis* was over-exploited in 1999. A joint analysis of the stock using Trinidad and Venezuelan data from the artisanal and industrial fleets showed similar results - that of low stock levels commensurate with high levels of exploitation. A biomass dynamic model of *M. furnieri* and *C. jamaicensis* combined suggested a maximum sustainable yield of approximately 1500 t (1300 to 1600 t), while fishing levels in 1999 were considerably higher than this.

- Management Advice

The intensive exploitation of *M. furnieri* and *C. jamaicensis* can be attributed to the combined effort of six gear types operating in the Gulf of Paria. The implication from the analyses suggests that there is a high risk that the stocks are overexploited. It was recommended that the fishing effort does not increase beyond 1999 levels, and with the further implication that fishing effort should decrease, albeit gaps and limitations of the data were emphasized.

- Stock Assessment Summary

A number of analyses were carried out to assess both *M. furnieri* and *C. jamaicensis.* Fishing effort was standardised for the different gear types and months using an analysis of variance technique (GLM). Then, based on standardised CPUE trends, seasonal declines in CPUE were identified and depletion models were fitted to these data to obtain seasonal estimates of the fishing mortality for each species separately. Recruitment, migration and growth were assumed to be negligible within the periods defined by these subsets of data. The results from these analyses were used to further correct CPUE for seasonal changes in catchability and generate seasonal abundance and fishing mortality estimates. Finally, a per-recruit analyses based on previously estimated growth and mortality parameters were used to estimate fishing mortality reference points (maximizing yield-per-recruit, and spawning-per-recruit at a standard), defining the status of the stocks.

A joint Trinidad and Venezuela analysis was also carried out which used artisanal and industrial data from both countries. The assessment used catch and effort data for six Trinidad fleets and the Venezuelan industrial and artisanal fleets as well as biological data from the Venezuelan industrial fleet. The assessment estimated maximum sustainable yield for croakers was 1 500 tonnes and that this had generally been exceeded from 1987-1993 and in 1998.

- Main Uncertainties

The analysis had only CPUE for the artisanal fleet although the industrial trawl fleet and other fleets operating in the Gulf of Paria would make a considerable contribution to the exploitation. Changes in biomass and fishing mortality values may also be influenced by migration of the species and not just mortality. Various growth and mortality parameters used in the models were obtained from scientific literature, but may be another significant source of error.

1.11 Atlantic Seabob (*Xiphopenaeus kroyeri*)

1.11.1 Suriname

- Status of Stock

The assessment in 2012 indicated that the stock was not overfished ($B/B_{MSY} > 1.0$) and overfishing was not occurring ($F/F_{MSY} < 1.0$; Figure 1.5;Table 1.2). This conclusion depended, among other things, upon a reasonably accurate time series of total catch. Results for this update assessment remained broadly the same as those from the last stock assessment in 2011 and appeared robust to likely levels of artisanal landings which were not included in the total catch data (CRFM, 2012).

Table 1.2. Biomass dynamics stock assessment results from 2012 with 90% confidence intervals.

Parameter	Lower 5%	Median	Upper 95%
r	0.48	0.74	1.07
B_∞ (t)	39578	58462	91233
B 2011 (t)	0.66	0.72	0.78
MSY (t)	9753	10561	11928
Current Yield (t)		7101	
Replacement Yield (t)	7972	8492	8698
B/BMSY	1.33	1.45	1.56
F/FMSY	0.45	0.54	0.62

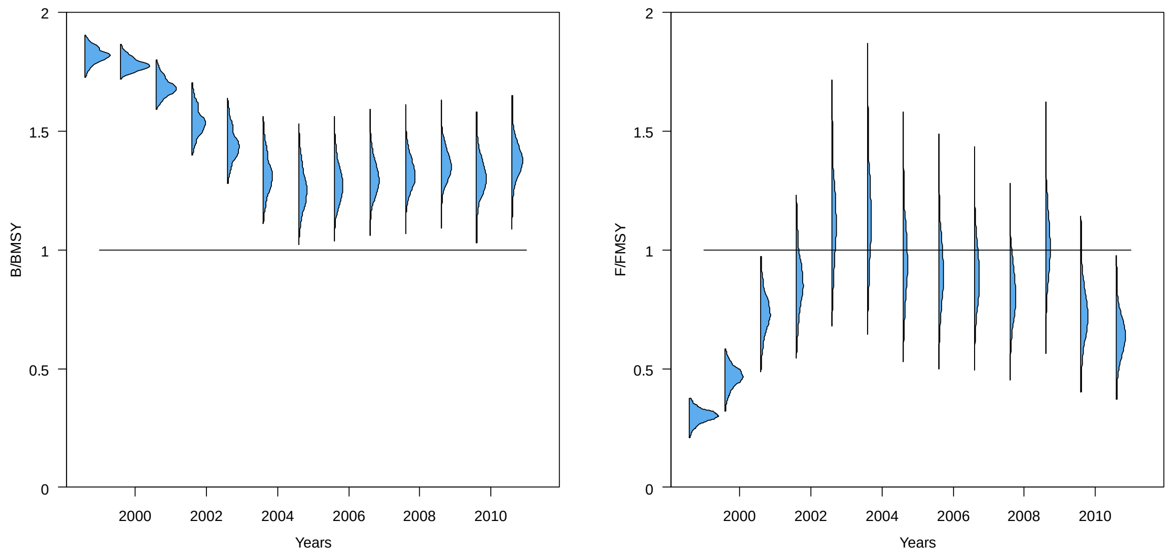


Figure 1.5. Probability estimates of the biomass and fishing mortality relative to the MSY value based on the Monte Carlo integration of the model posterior for Atlantic Seabob (*Xiphopenaeus kroyeri*) in Suriname. The range of values is shown from 5000 random draws from the posterior probability using Monte Carlo integration. More peaked distributions indicate greater certainty in estimates, whereas flatter distributions indicate greater uncertainty.

- <u>Management Advice</u>

The SGWG recommended to continue applying the harvest control rule (HCR) developed in 2010 for several more years to allow it to be evaluated. On evaluation, further scientific recommendations might be made.

Reference points and a harvest control rule were adopted in 2010 based on the maximum sustainable yield point (MSY), with the biomass limit reference point at 60% and target reference point at 120% of the MSY estimate respectively. CPUE is used as a proxy for the biomass, with reference points based upon the 2009 stock assessment (Table 1.3). Results from the current assessment suggest that these reference points are precautionary. The CPUE expected at MSY is 1.38 t day^{-1}, whereas current CPUE is 1.93 t day^{-1}.

The harvest control rule uses the proxy CPUE and days-at-sea for biomass and fishing mortality, taking into account the uncertainty with which the values of interest have been estimated (Figure 1.6 and Figure 1.7). It is applied to the industrial vessels only, which are believed to contribute the vast majority of the landings.

Reliance on CPUE as an abundance index will not provide precise estimates of stock status. However, the stock assessment approach, it is argued, does provide an empirical description of past changes in CPUE and a sound basis for a HCR which will avoid declines in CPUE in the long term. This has allowed Government and industry to agree more precise objectives for this fishery based on implicit bioeconomics.

The government policy for the fisheries sector is to provide employment, improve balance of payments through export of fish and shrimp products, contribute to investment in the country as well as the public sector through fees and tax. More recently, Suriname has successfully undertaken Marine Stewardship Council certification[1], which has more precise requirements compatible with Suriname Government policy.

A limited number of shrimp beam trawlers (18-36m in length) are licensed to fish for seabob. Seabob is exploited in the EEZ at depths of 11-24 m and is processed and exported by two processing plants.

[1] www.msc.org

There is also an artisanal fishery for seabob with about 500 vessels, which uses Chinese seines, drying the seabob for local consumption. Catches prior to 1996 are attributed to this fishery.

Table 1.3. Comparison between CPUE (t / day at sea) reference points for 2009 (current HCR) and 2012 (the most recent assessment). The trigger reference point is the expected CPUE at MSY. The 2009 values are used in the current harvest control rule, which the most recent stock assessment suggests are precautionary. The 2012 are more accurate estimates of the appropriate values, so reference point values higher than these are more precautionary.

	2009	2012
Limit	0.89	0.83
Trigger	1.48	1.38
Target	1.65	1.66

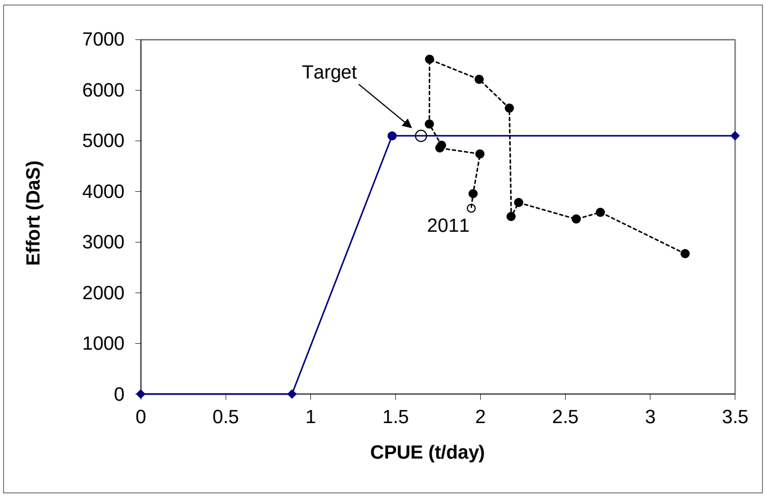


Figure 1.6. Harvest control rule (HCR) being applied to the fishery (solid line) with historical time series of HCR CPUE calculated as a moving average and effort for the corrected data (dotted line; 1998-2011). The target CPUE is shown along with the estimated HCR CPUE in 2011 (from the 2012 assessment). The HCR (blue solid line) indicates the limit on fishing effort which is applied in response to different CPUE estimates.

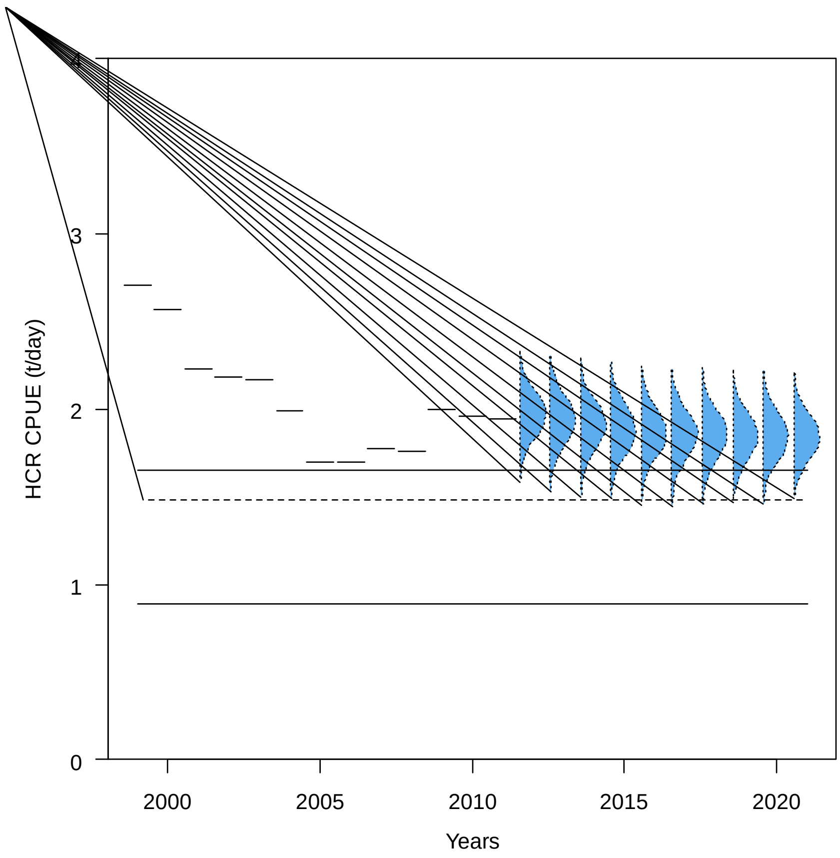


Figure 1.7. Observed historical CPUE (short horizontal line) and projected probability distribution (solid blue curve) under the harvest control rule. The full horizontal lines represent the target and limit CPUE, and the dotted line is the trigger CPUE when the HCR would require a reduction in fishing effort. The model predicts that it is highly likely that the CPUE will remain above the target level.

- Stock Assessment Summary

Bayesian statistics and the Monte Carlo (sample importance resample algorithm) methods were used to estimate probability distributions for Maximum Sustainable Yield (MSY), Replaceable Yield[2], current biomass relative to biomass at MSY, and current fishing mortality relative to fishing mortality at MSY. The assessment used the logistic biomass dynamics model fitted to the total catch 1989-2011 and catch and effort 1998-2011.

The stock assessment updated the 2011 assessment. Catch per unit effort (CPUE) was used as an index of the abundance of the stock. The measure of effort used was the number of days at sea, which would include steaming time. This was the only measure of effort available, but was thought to be strongly related to the amount of fishing carried out. The CPUE index has appeared to decline each year to 2005, but has also shown a recent increasing trend (Figure 1.8). The results indicate a reasonable fit of the model (Figure 1.9), but it should be noted that although the model largely explained the trends in the CPUE, these trends formed only a small part of the variation in CPUE. The number of data points (13) was limited and with only very shallow trends, the four parameters could only be weakly estimated.

The maximum sustainable yield was estimated to be between 9 000 and 12 000 t year^{-1} (Table 1.2). However, in absolute terms, biomass, and therefore yield is poorly estimated. Hence, the harvest control rule based on CPUE and effort rather than catch will be much more reliable.

[2] **Replacement Yield** is the yield/catch taken from a stock which keeps the stock at the current size.

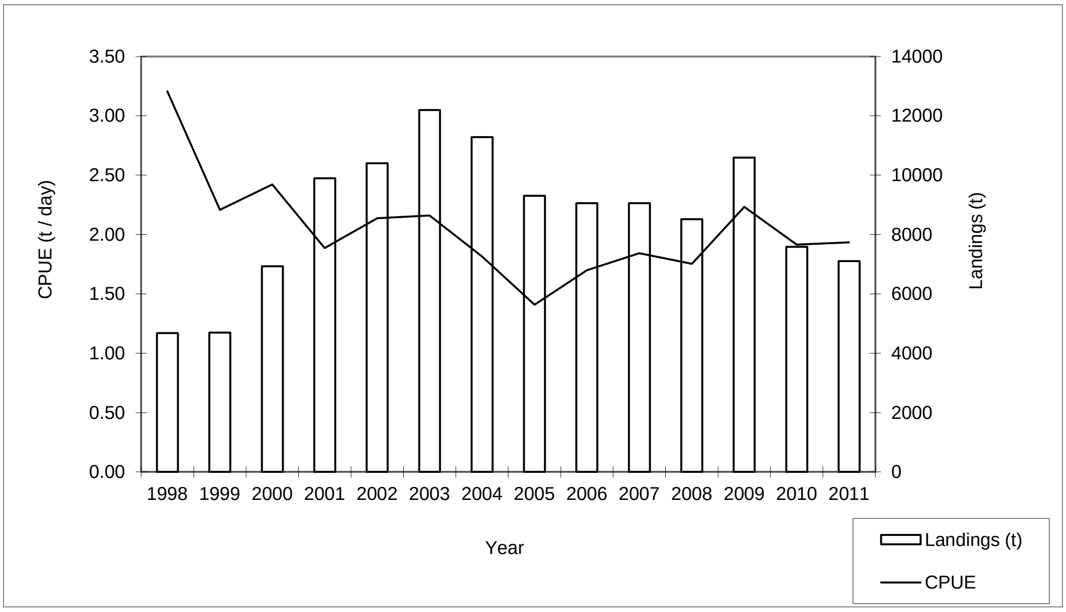


Figure 1.8. Annual catch and effort data for the period 1998-2011 for Atlantic Seabob (*Xiphopenaeus kroyeri*) in Surinam.

- <u>Main Uncertainties</u>

Annual catch and effort data were available for the period 1998-2011 (Figure 1.8). The CPUE abundance index shows a continuous decline since 1998 to 2006, suggesting that the stock abundance has declined over this period. However, there is some indication of more recent increase in catch rate following reduced catches after 2005, which are sustaining the CPUE close to 2 t day^{-1}Although there remains some doubt over data collected before 1999, no information is available to correct it. Errors so far back in time are unlikely to have a significant impact on the stock assessment unless they are very large.

The local artisanal catches for the dried seabob market had not been estimated in time for the most recent assessment. Nevertheless, information was sufficient to indicate the likely level of this catch, which was expected to be less than 800 t total landed weight. It was believed that this was sufficient to allow a sensitivity analysis to see what impact if any this level of catch might have on the stock assessment. However, this remains a sensitivity analysis until precise estimates come available.

For management purposes, the most important requirement is that the CPUE index remains valid. It has been found to be reasonably robust to various uncertainties such as poor estimates of artisanal catch, but may not be robust to all changes that occur in the fishery. The greatest risk to the index is change to the fleet, including alterations to gears, vessels or operations, so it is important that any and all changes are monitored and managed carefully.

To help deal with uncertainties, a research plan has been developed for this fishery by the Suriname seabob management working group, and this research plan forms part of the management plan. This includes new issues related to bycatch which has not been previously considered by this working group as well as potential habitat damage. In 2012, a new sampling programme is being implemented to estimate the artisanal landings.

Research is continuing on growth and mortality of seabob through the collection of detailed size frequencies. A considerable data set is already available, but analysis has been incomplete, although some preliminary analysis was completed in 2009 and 2012 (CRFM 2009, 2012). Data collection is compatible between Suriname and Guyana so direct comparisons are possible, including some assessment of the broad scale stock structure.

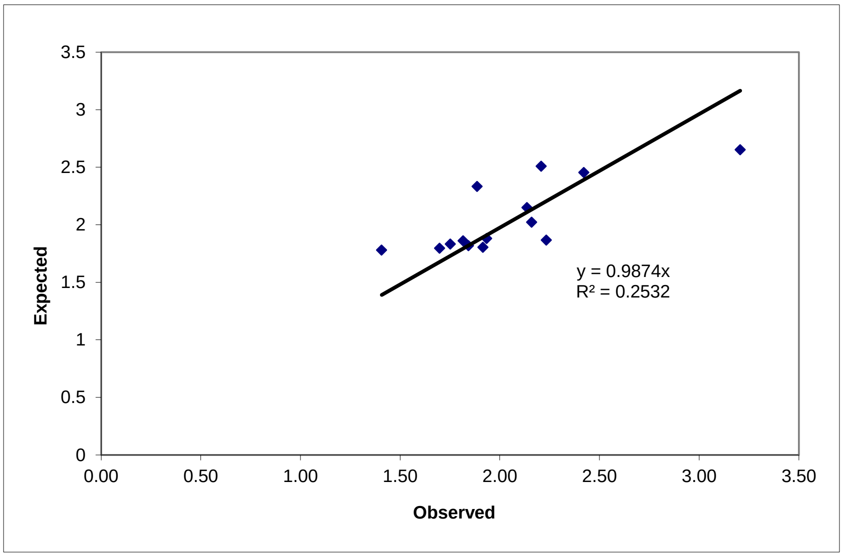


Figure 1.9. Observed and expected CPUE from the model fit. The residuals show no obvious pattern around the regression line going through the origin.

1.11.2 Guyana

- Status of Stocks

In CRFM (2006), the SGWG stated that the data were not sufficient to determine the status of the stock precisely. However, the preliminary results from the assessment indicated that the seabob fishery is fully- to over- exploited, which was based on a review of CPUE, catch and size composition data. The analyses suggested that changes to the exploitation pattern should increase the size of shrimp capture and improve yield as well as provide additional protection to the spawning stock.

A second analysis in 2012 based only on catch and effort data found that there is no evidence that the stock was overfished or that overfishing is occurring. The preliminary 2012 stock assessment suggested that the stock was well above the MSY level ($B/B_{MSY} > 1.0$) and the 2011 catch (19 433 t) was well below the MSY level ($F/F_{MSY} < 1.0$; Table 1.4; Figure 1.9). The longer CPUE time series showed a shallow decline, but still remained high relative to the start of the series.

However, the SGWG expressed reservations with the 2012 conclusion due to the quality of some of the data used and the short time series of CPUE data available. In addition, catch rates are significantly lower in Guyana (1.2 t day^{-1}) compared to Suriname (1.9 t day^{-1}) and average tail weight slightly lower. Overall, the risk of overfishing for this stock would appear to be much higher than the 2012 stock assessment would indicate.

Table 1.4. Guyana biomass dynamics stock assessment results with 90% confidence intervals.

Parameter	Lower 5%	Median	Upper 95%
R	0.37	0.61	0.96
B_∞ (t)	121513	179701	263243
B 2012	0.67	0.77	0.86
MSY (t)	20347	26501	39863
Current Yield (t)		19343	
Replacement Yield (t)	17784	19070	19170
B/B_{MSY}	1.33	1.53	1.72
F/F_{MSY}	0.32	0.51	0.73

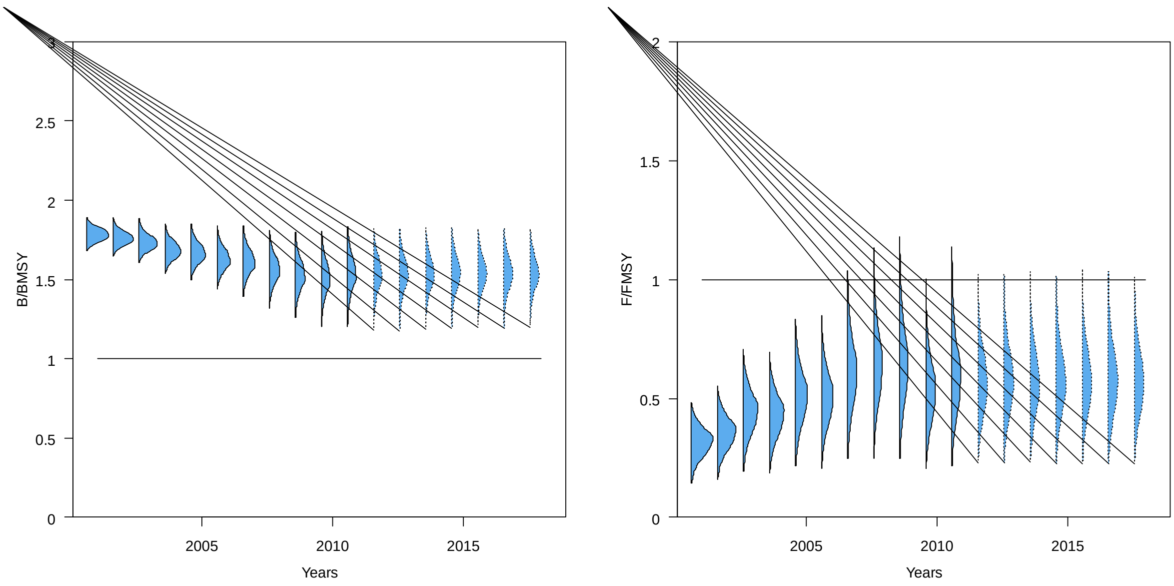


Figure 1.10. Probability estimates based on the biomass dynamics model fitted to the catch and effort data in 2012.

- Management Advice

The Draft Fisheries Management Plan of Guyana states that the objectives for the seabob management are to maintain the seabob and associated non-target stocks above 50% of its mean unexploited level (approx. MSY), and to stabilise the net incomes of the operators while including as many of the existing participants in the fishery as is possible. However, these management objectives could not be addressed because the data were not sufficient to estimate the necessary indicators.

Nevertheless, to help meet these objectives, the SGWG recommended in 2006 that the closed season be increased from 6 weeks to 8 weeks. In addition, the working group recommended that a precautionary approach to exploitation should be adopted, with limiting fishing effort at or below the levels in 2006. In 2010 and 2012, based on new data, the recommendation for changing the closed season from September to May was not necessarily supported and it was recommended that new size composition data be fully evaluated.

The lack of confidence that the SGWG has in the 2012 assessment has led to the advice that precautionary reference points and harvest control rule should be developed. This would link management controls, such as effort or catch limits, to indicators of the state of the fishery. This work is currently underway in 2012/13.

- Stock Assessment Summary

In 2006, a catch-at-size analysis was carried out using the commercial size category catch data, fitted to the available effort data. Catches were all reported in size categories by the fishing industry, but no data were available at that time to check the size distribution within these categories. Effort was measured as number of trips, but is estimated from the number of registered vessels rather than observed directly.

The catch-at-size data were converted from size to age using a growth model. No growth model parameters were available for this species in Guyana, but reasonable parameter estimates were available from the scientific literature. Nevertheless, without an accurate growth model, the indicators would not be accurate, but relative trends should still be valid.

The catch-at-age data were used in a standard assessment method (virtual population analysis) to obtain fishing mortality (approximately the proportion of the stock being removed by fishing) and selectivity. These results were used in a yield-per-recruit to generate reference points.

A yield-per-recruit (YPR) accounts for the effective weight each new shrimp recruited to the stock contributes to the catch. It allows for the fact that shrimp are growing, so they contribute increased weight as they are older, but that they are also dying from natural causes, so that as they get older there are also fewer of them. As the stock is fished harder, the catch tends to consist of larger numbers of younger smaller shrimp (Figure 1.11). This will may increase the yield but with diminishing returns.

Yield-per-recruit was used to advise on the length and timing of the closed season. Increasing the closed season delays fishing allowing the shrimp to grow. The yield-per-recruit was maximised with a closed season between 2 and 3 months. A greater proportion of small shrimp are landed in May. As a result, it was found that yield-per-recruit from a closure in May would provide the greatest benefit to the fishery (Figure 1.12).

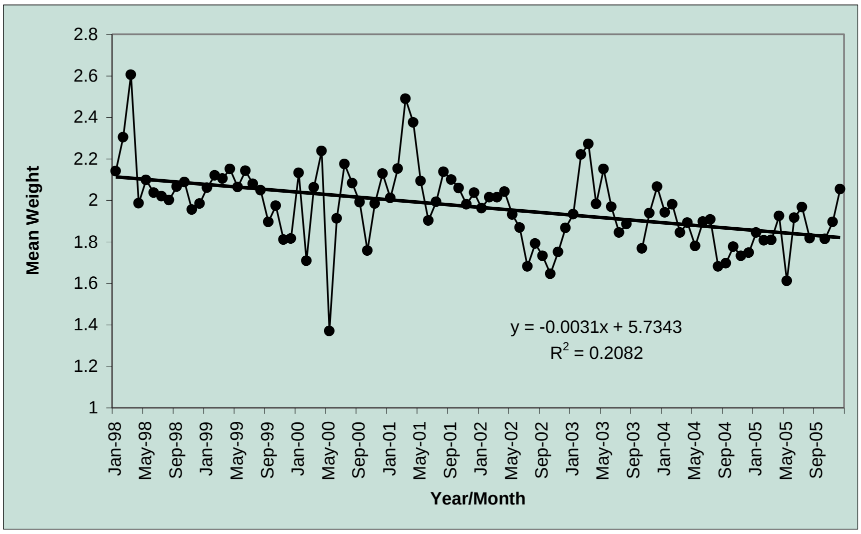


Figure 1.11. Mean size of shrimp estimated from the commercial size composition data. The linear trend line indicates a decline in average size over the seven year period consistent with increasing fishing mortality.

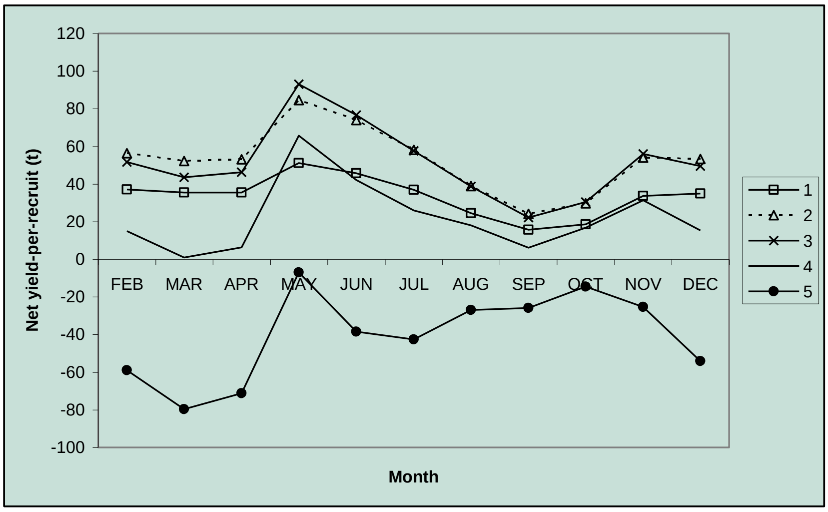


Figure 1.12. Yield-per-recruit "score" for season closure in each month (from CRFM 2006). A closure of 2 or 3 months gives maximum benefit, close to the current closed season in September / October of 1.5 months. It is apparent, however, that most benefit would be obtained from a closure in May and June, when the majority of the smallest shrimp are landed.

In 2012, a simple biomass dynamics model was fitted to the catch and effort data. Bayesian Statistics and the Monte Carlo (Sample importance resample algorithm) methods were used to estimate maximum sustainable yield (MSY), replacement yield[3], current biomass relative to biomass at MSY, and current fishing mortality relative to fishing mortality at MSY. The assessment used the logistic surplus-yield model fitted to the total catch 1985-2011 and catch and effort 2001-2011.

Catch per unit effort (CPUE) was used as an index of stock abundance. The measure of effort used was the number of days at sea, which would include steaming time. The CPUE data were constructed from two series: processor data reported to government 2005-2011 and other data obtained directly from a processor for the period 2001-08. The CPUE index appears to be declining each year indicating a small decline in stock size since the start of the series.

The results indicate some problems with the fit of the model (Figure 1.13), and therefore this model is likely to predict CPUE changes poorly. The number of CPUE data points was limited and with only a slight decreasing trend (Figure 1.14). The CPUE does not cover the period when catches changed significantly, which is the period that would be informative on stock assessment parameters.

The results suggested that the maximum sustainable yield would be between 20000-40000 t $year^{-1}$. However, the assessment entirely depends upon the accuracy of the available data and is likely to be heavily influenced by the high catches in 2004 and 2005. If these are overestimates, the state of the stock may well be re-evaluated downwards.

The assessment indicates that the stock is not overfished ($B/B_{MSY} > 1.0$) and overfishing is not occurring ($F/F_{MSY} < 1.0$). The SGWG could not endorse this conclusion without verification of the data, improvement in the stock assessment and/or evidence from other sources.

Assuming that the stock status is correctly estimated, the current level of fishing can be sustained. However, the current catch per unit effort is significantly lower than Suriname (Figure 1.15). A better understanding of the relative fisheries and seabob populations in Suriname and Guyana would produce significant improvements in management advice.

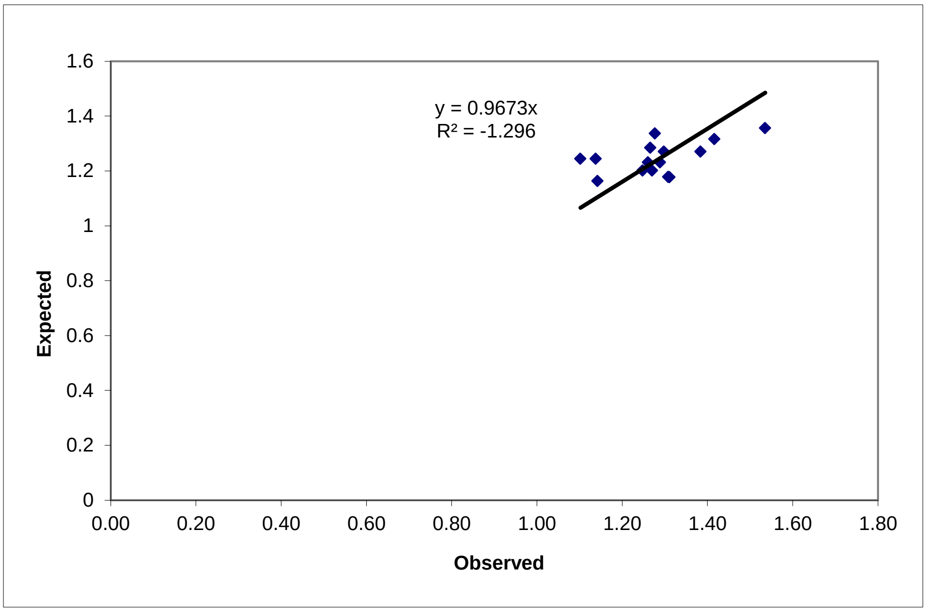


Figure 1.13. Observed and expected CPUE from the model fit. The residuals show some bias around the regression line going through the origin, with expected values being relatively high compared to the observed CPUE at lower values.

[3] **Replacement Yield** is the yield/catch taken from a stock which keeps the stock at the current size.

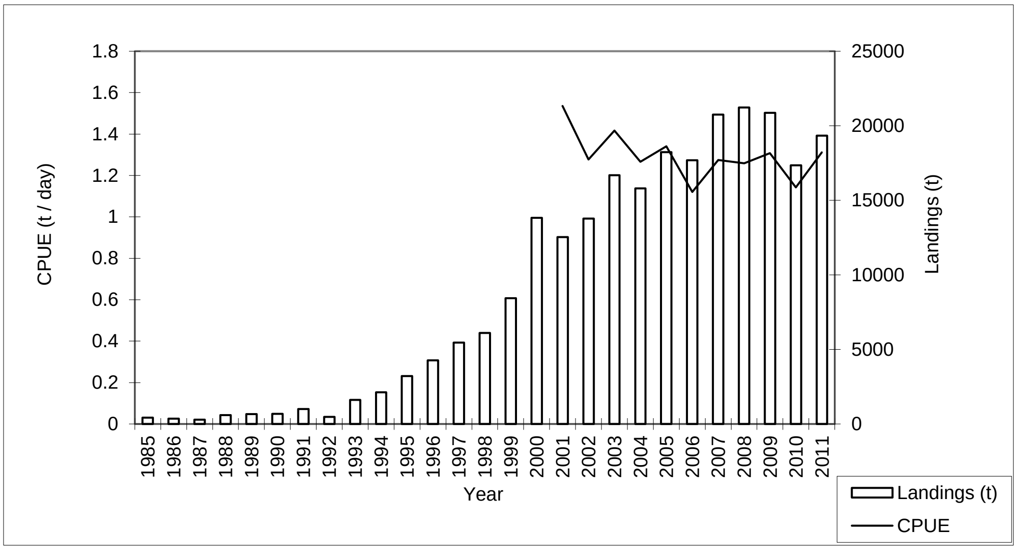


Figure 1.14. The CPUE abundance index and landings of seabob 1985-2011.

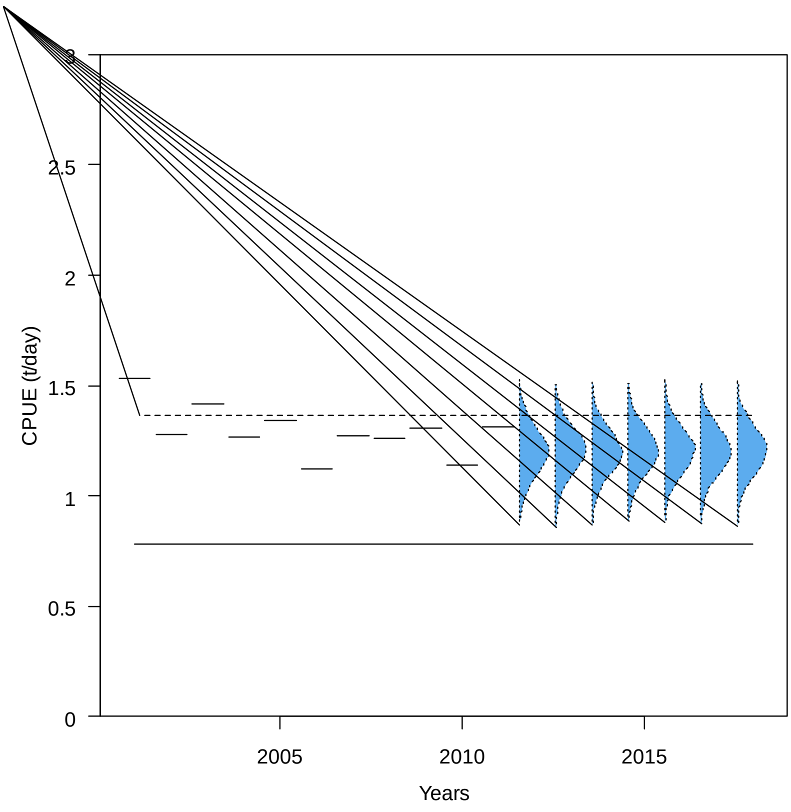


Figure 1.15. Observed mean CPUE (horizontal lines) and projected CPUE (probability) assuming total fishing effort is maintained as the mean observed 2008-2011. The lower solid line represents the median estimate of the CPUE expected at MSY for the Guyana fishery. The upper dotted line represents the median estimate of the CPUE expected at MSY for the Suriname fishery.

- Main Uncertainties

This fishery has received conflicting scientific advice over a number of years, emphasizing the uncertainties with the data in particular.

An appropriate growth model has not been estimated for this species, making any size based assessment highly uncertain. In addition, the commercial size categories are very broad and not very informative on size composition. This last problem has been addressed over the last few years by a landings sampling programme that is yielding significant size composition and maturity data from one of the processors.

Because this species is more associated with estuaries and brackish water, it is likely that there is some link with productivity and the local environment, specifically river flow. Any such link has not yet been found, however.

Annual total catch data were available for the period 1985-2011 and monthly catch and effort data available for 2001-2011, but there remains considerable uncertainty over the data accuracy. There have been very significant increases in catch during the time series but unfortunately during the period when catch per unit effort was unavailable.

It is likely with improvements in the catch and effort data and other information that the state of the stock will be revised downward. This is based on the view of the working group that the biomass estimate in this model may well be too high.

1.11.3 Trinidad and Tobago

- Stock Status

The biomass per recruit for the *X. kroyeri* females suggested that this stock was overexploited in 2002, in the sense that recruitment was being put at risk. Based on a yield per recruit analysis for *F. notialis* and *X. kroyeri* combined, the 2002 fishing effort of the trawl fleets directed at these species is estimated to be about 71% of the effort required to obtain the maximum yield from the fishery. This indicates close to full exploitation.

- Management Advice

The main recommendation from CRFM (2005) assessment was to control the fishing effort and gear types to improve selectivity and exploitation rates for both *F. notialis* and *X. kroyeri*.

Effort should be controlled by limiting the numbers of trawlers with a view to a reduction in fleet size. This would require the implementation of a licensing system for trawlers.

The results obtained also indicate poor exploitation patterns, where some trawlers tend to capture very young, small shrimp, especially the artisanal fleet operating in the southern Gulf of Paria, and the semi-industrial fleet. It was recommended that methods for controlling gear selectivity be investigated. This might be done through the implementation of closed areas and seasons to protect young and spawning shrimp, as well as increased mesh sizes to target larger shrimp.

- Stock Assessment Summary

The stock assessment applied the same method for both *F. notialis* and *X. kroyeri* using available data for the period 1992 to 2002. Missing catches by length for months when shrimp lengths were not sampled were estimated using generalized linear models. Catch-at-length data were converted to catch-at-age using an age-length key constructed as a probability matrix from the Von Bertalanffy growth model. Catch-at-age data were used in a separable Virtual Population Analysis (VPA) model to obtain estimates of gear selectivity, fishing mortality, and recruitment. Outputs from the VPA model were used in Beverton and Holt’s yield per recruit and biomass per recruit models to determine the current state of the fishery.

- Main Uncertainties

These results on the current state of the fishery in terms of level of exploitation and the spawning stock biomass are considered preliminary due to the limitations of the data and the models. Sample sizes were small and therefore estimates of values input as data to the model (catch-at-length) uncertain. This uncertainty was not fully accounted for in the model. Growth and natural mortality parameters could not be estimated and had to be assumed.

The shrimp stocks of Trinidad and Tobago have been assumed to be shared with neighbouring Venezuela and hence it was recommended that joint assessments may be carried out with Venezuela. However *F. notialis* and *X. kroyeri* are not important species in the landings of Venezuela, hence the reason these species could be analysed in the absence of data from Venezuela.

1.12 Brown Shrimp (*Farfantepenaeus subtilis*)

1.12.1 Guyana

- Stock Status

The assessment in 1999 suggested that the stock was fully exploited at this time. There was a downward trend in the abundance of *F. subtilis, F. notialis* and *F. brasiliensis* mainly during the late 1980s and throughout the 1990s. While some of this has been attributed to sustained environmental changes, exploitation rates in any case have been too high relative to the productivity of the resources.

- Management Advice

The main shrimp resources in the Guyana fishery require management intervention to achieve the Government goal of maximising revenue and employment. The implications of the assessment in 1999 was that the Guyana shrimp fisheries required reduced fishing effort and reduced fishing capacity to meet these objectives.

The assessment also raised the risk of the impact of the fishery on fish and shrimp habitat (FAO, 1999) which had not been assessed. It was noted that the implication of the precautionary approach would be to consider measures to reduce such impact, such as closure of environmentally sensitive areas to demersal trawl.

- Stock Assessment Summary

The same methods were applied to the main Guyana shrimp species. Two different methods were used to generate estimates of the exploitation rates: length converted catch curves and tuned length-based cohort analysis. Both used an assumed growth model to convert length to age. The tuned length-based cohort analysis also estimated abundance by tuning fishing mortality to the length converted catch curve fishing mortality and scaling the abundance to the total catch.

- Main Uncertainties

The results were dependent upon assumed selectivity, immigration and growth. These assumptions remained untested, but were not unreasonable. Shrimp are not likely to swim long distances, but the stocks may be shared at the national boundaries with Venezuela and Suriname. Growth parameters chosen were reasonable, and shrimp are not likely to escape trawls at larger size unless they are moving to areas of lower density where trawls are less likely to operate. Nevertheless, these assumptions remain a major source of uncertainty until testing, such as scientific surveys or tagging experiments, are carried out.

Another major source of uncertainty was changes in the environment, which might lead to changes in productivity and therefore shifts in appropriate reference points. This would need to be better understood before it could be accounted for in this sort of stock assessment.

1.12.2 Suriname

- Stock Status

Between 1985 and 2000, brown shrimp fishing mortality has increased and abundance decreased. The trends in abundance, catch and CPUE were similar, but the catch appeared to reflect abundance more closely than the catch per unit effort did. In 2000, the fishery was determined as having low recruitment and low yields for all shrimp stocks. Causes identified include high fishing mortality, increasing selectivity on small shrimp, environmental effects on recruitment and natural mortality. It was noticeable that penaeid shrimp landings further declined in 2003 and that no recovery in yield has been observed.

- Management Advice

The stock status indicates that management should look at reducing fishing effort on shrimp stocks to increase abundance and therefore catch rates. In addition, the increased proportion of small size shrimp and concern over shrimp habitat suggests spatial management should be introduced to control where the fleet operates and therefore protect nursery areas and habitat to aid recruitment. If successful, productivity in the fishery could be rebuilt.

It was agreed with industry that no single cause of low recruitment could be identified with certainty and that more investigation was necessary. It was also felt that the increasing harvest of small shrimp by the shrimp companies themselves probably has an adverse effect and that it should be possible for the industry to try to control this impact.

Bycatch of small shrimp by trawlers targeting seabob was not considered to be a significant factor in stock decline.

- Stock Assessment Summary

Length-based cohort analysis and length converted catch curve analysis for the available range of lengths was used to estimate fishing mortality and abundance. The analyses made use of length composition data and assumed growth and natural mortality rates. Results for all analyses indicated an increasing fishing mortality and decreasing abundance. This is supported by decreasing CPUE over the same period.

- Main Uncertainties

As with other assessments using this type of data and model, the results will be dependent upon assumed selectivity, immigration and growth. Changes in the environment were also identified as being a potential source of changes in productivity. None of these issues have been investigated.

1.13 Southern Pink Shrimp (*Farfantepenaeus notialis*)

1.13.1 Guyana

- Stock Status

As for Guyana brown shrimp, the assessment in 1999 suggested that the stock was fully exploited at this time. There was a downward trend in the abundance of *F. subtilis, F. notialis* and *F. brasiliensis* mainly during the late 1980s and throughout the 1990s. While some of this has been attributed to sustained environmental changes, exploitation rates in any case have been too high relative to the productivity of the resources.

- Management Advice

The main shrimp resources in the Guyana fishery require management intervention to achieve the Government goal of maximising revenue and employment. The implications of the assessment in

1999 was that the Guyana shrimp fisheries required reduced fishing effort and reduced fishing capacity to meet these objectives.

The assessment also raised the risk of impact of the fishery on fish and shrimp habitat (FAO, 1999) which had not been assessed. It was noted that the implication of the precautionary approach would be to consider measures to reduce such impact, such as closure of environmentally sensitive areas to demersal trawl.

- Stock Assessment Summary

The same methods were applied to all the main Guyana shrimp species. Two different methods were used to generate estimates of the exploitation rate: length converted catch curves and tuned length-based cohort analysis. Both use an assumed growth model to convert length to age. The tuned length-based cohort analysis also estimates abundance by tuning fishing mortality to the length converted catch curve fishing mortality and scaling the abundance to the total catch.

- Main Uncertainties

The results were dependent upon assumed selectivity, immigration and growth. These remained untested, but were not unreasonable. Shrimp are not likely to swim long distances, but the stocks may be shared at national boundaries with Venezuela and Suriname. Growth parameters chosen were reasonable, and shrimp are not likely to escape trawls at larger size unless they were moving to areas of lower density where trawls are less likely to operate. Nevertheless, these assumptions are a major source of uncertainty until testing, such as scientific surveys or tagging experiments, are carried out.

Another major source of uncertainty was changes in the environment, which might lead to changes in productivity and therefore shifts in appropriate reference points. This would need to be better understood before it could be accounted for in this sort of stock assessment.

1.13.2 Trinidad and Tobago

- Stock Status

The biomass per recruit for the *F. notialis* females suggested that the stock was fully exploited in 2002, and therefore increased exploitation could put recruitment at risk. Based on a yield per recruit analysis for *F. notialis* and *X. kroyeri* combined, the 2002 fishing effort of the trawl fleets directed at these species was estimated to be about 71% of the effort required to obtain the maximum yield from the fishery. This indicated full exploitation.

- Management Advice

The main recommendation from CRFM (2005) assessment was to control the fishing effort and gear types to improve selectivity and exploitation rates for both *F. notialis* and *X. kroyeri*.

Effort should be controlled by limiting the numbers of trawlers with a view to reducing fleet size. This would require the implementation of a licensing system for trawlers.

The results obtained also indicated poor exploitation patterns, where some trawlers tended to capture very young, small shrimp, especially the artisanal fleet operating in the southern Gulf of Paria, and the semi-industrial fleet. It was recommended that methods for controlling gear selectivity be investigated. This might be done through the implementation of closed areas / seasons to protect young and spawning shrimp, as well as increased mesh sizes to target larger shrimp.

- Stock Assessment Summary

The stock assessment applied the same method for both *F. notialis* and *X. kroyeri* using available data for the period 1992 to 2002. Missing catches by length for months when shrimp lengths were not sampled were estimated using generalized linear models. Catch-at-length data were converted to catch-at-age using an age-length key constructed as a probability matrix from the Von Bertalanffy growth model. Catch-at-age data were used in a separable Virtual Population Analysis (VPA) model to obtain estimates of gear selectivity, fishing mortality, and recruitment. Outputs from the VPA model were used in Beverton and Holt's yield per recruit and biomass per recruit models to determine the current state of the fishery.

- Main Uncertainties

The results on the current state of the fishery in terms of level of exploitation and the spawning stock biomass were considered preliminary due to the limitations of the data and the models. Sample sizes were small and therefore estimates of values input as data to the model (catch-at-length) uncertain. This uncertainty was not fully accounted for in the model. Growth and natural mortality parameters could not be estimated and had to be assumed.

The shrimp stocks of Trinidad and Tobago have been assumed to be shared with neighbouring Venezuela and hence it was recommended that joint assessments may be carried out with Venezuela. However *F. notialis* and *X. kroyeri* are not important species in the landings of Venezuela, hence the reason these species could be analysed in the absence of data from Venezuela.

1.14 Spotted Shrimp (*Farfantepenaeus brasiliensis*)

1.14.1 Guyana

- Stock Status

The stock was last assessed in 1999. There was a generally stable trend in fishing mortality rates to 1989, but starting in the 1990s, there is a general increase in fishing mortality for both females and males. The average estimate of fishing mortality for the last year of the study is 0.3 $month^{-1}$ (3.6 $year^{-1}$), while the natural mortality rate (M) is 0.2 $month^{-1}$ (2.4 $year^{-1}$). This suggests that the stock was being overfished in 1998.

- Management Advice

The advice in 2000 (FAO, 2000) was to stop the downward trend in abundance of shrimp generally, and in the case of *F. brasiliensis*, promote recovery of the stock.

The main shrimp resources in the Guyana fishery require management intervention to achieve the Government goal of maximising revenue and employment. The implications of the assessment in 1999 was that the Guyana shrimp fisheries required reduced fishing effort and reduced fishing capacity to meet these objectives.

The assessment also raised the risk of impact of the fishery on fish and shrimp habitat (FAO, 1999) which had not been assessed. It was noted that the implication of the precautionary approach would be to consider measures to reduce such impact, such as closure of environmentally sensitive areas to demersal trawl.

- Stock Assessment Summary

The same methods were applied to all the main Guyana shrimp species. Two different methods were used to generate estimates of the exploitation rate: length converted catch curves and tuned length-based cohort analysis. Both use an assumed growth model to convert length to age. The tuned length-based cohort analysis also estimated abundance by tuning fishing mortality to the length converted catch curve fishing mortality and scaling the abundance to the total catch.

- Main Uncertainties

The results were dependent upon assumed selectivity, immigration and growth. These remained untested, but were not unreasonable. Shrimp are not likely to swim long distances, but the stocks may be shared at national boundaries with Venezuela and Suriname. Growth parameters chosen were reasonable, and shrimp are not likely to escape trawls at larger size unless they are moving to areas of lower density where trawls are less likely to operate. Nevertheless, these assumptions remain a major source of uncertainty until testing, such as surveys or tagging experiments, are carried out.

Another major source of uncertainty was changes in the environment, which might lead to changes in productivity and therefore shifts in appropriate reference points. This would need to be better understood before it could be accounted for in this sort of stock assessment.

1.14.2 Suriname

- Stock Status

The status of *F. brasiliensis* is similar to that determined for *F. subtilis*, but declines in abundance were not as great. Between 1985 and 2000, fishing mortality has been stable, but abundance decreased. The trends in abundance, catch and CPUE were similar, but the catch appeared to reflect abundance more closely than the catch per unit of effort did. In 2000, the fishery was determined as having low recruitment and low yields for all shrimp stocks. Causes identified include high fishing mortality, increasing selectivity on small shrimp, environmental effects on recruitment and natural mortality. It was noticeable that penaeid shrimp landings further declined in 2003 and that no recovery in yield has been observed.

- Management Advice

The stock status indicated that management should look at reducing fishing effort on shrimp stocks to increase abundance and therefore catch rates. In addition, the increased proportion of small size shrimp and concern over shrimp habitat suggested spatial management should be introduced to control where the fleet operates and therefore protect nursery areas and habitat to aid recruitment. If successful, productivity in the fishery could be rebuilt.

It was agreed with industry that no single cause for low productivity could be identified with certainty and that more investigation was necessary. It was also felt that the increasing harvest of small shrimp by the shrimp companies themselves probably has an adverse effect and that it should be possible to reduce this impact.

Bycatch of small shrimp by trawlers targeting seabob was not considered to be a significant factor in stock decline.

- Stock Assessment Summary

Length-based cohort analysis and length converted catch curve analysis for the available range of lengths was used to estimate fishing mortality and abundance. The analyses made use of length composition data and assumed growth and natural mortality rates. Results for all analyses indicated stable fishing mortality, but decreasing abundance.

- Main Uncertainties

As with other assessments using this type of data and model, the results will be dependent upon assumed selectivity, immigration and growth. Changes in the environment were also identified as being a potential source of changes in productivity. None of these issues have been investigated. *F. brasiliensis* data were thought to be worse than *F. subtilis* data due to incomplete sampling. The *F. brasiliensis* stock was also thought to be shared with Guyana and French Guyana.

1.15 Assessment of Combined Shrimp Resources

1.15.1 Trinidad & Tobago and Venezuela

- <u>Status of Stocks</u>

The overall shrimp stock was determined in 2010 (CRFM, 2011) as not overfished relative to the MSY having recovered from overfishing likely to have occurred in the 1990s (Figure 1.16). The stock biomass is probably increasing, mainly as a result of catches being considerably reduced in Venezuela.

However, with the cessation of the Venezuelan industrial trawl fleet, an important abundance index has been lost, resulting in greater uncertainty as to the recovery of the stock. Furthermore, it is unclear how connected different areas are. Therefore, it is not possible to provide an accurate prediction of the status of shrimp populations in areas specific to Trinidad or how reductions in Venezuelan catches will affect the Trinidad fleet.

The evidence from an age-structured stock assessment (CRFM, 2005) suggested that the two shrimp stocks *Farfantepenaeus notialis* and *Xiphopenaeus kroyeri* in Trinidad were fully to over-exploited in 2002. In addition, some trawlers tend to capture very young, small shrimp, especially the artisanal fleet operating in the southern Gulf of Paria, and the semi-industrial fleet. With the recent reduction in Venezuelan fishing effort, it is unclear what the status is of these species in 2012, but it may have improved with a likely decrease in the capture overall.

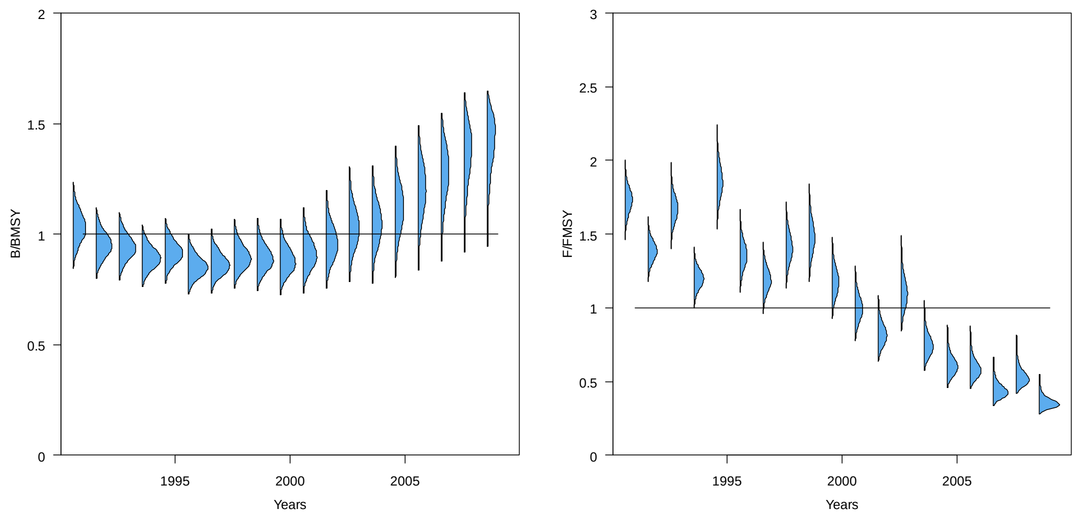


Figure 1.16. Estimates of the change in overall biomass and fishing mortality status in the combined Venezuela-Trinidad penaeid shrimp fishery. The graph shows probability distributions by year for total biomass and fishing mortality relative to the MSY levels (horizontal line). The probability distributions become flatter as uncertainty increases, and conversely more peaked as uncertainty decreases.

- <u>Management Advice</u>

The SGWG advised that new fishing controls be introduced (in both Trinidad and Venezuela) to decrease the total number of days at sea permanently in order to prevent overexploitation. Although catches overall decreased, this was the result of action taken in Venezuela only. This sole action will be inadequate to achieve economic and conservation objectives of the Trinidad fishery. To prevent a re-expansion of the fishery to unsustainable levels and prevent likely on-going local depletion, it was recommended that Trinidad should implement its own management controls. It has been suggested to:

(1) <u>Implement a closed season for trawling.</u> It appears that Trinidad fishers would find a seasonal closure acceptable, but only if they understand that it results from a stock assessment. Note

that the real objective of the closure would be to limit effort to desirable levels, which might be achieved more effectively in other ways.

(2) Limit the numbers of trawlers with a view to a reduction in fleet size:

- Update fisheries legislation to facilitate a limited entry fishery
- Implement a licensing system for trawlers

(3) Strictly enforce the current regulations for the trawl fishery as this will contribute to the sustainability of the stocks. The Trinidad Fisheries Regulations (2001) specify a minimum cod-end mesh size as well as areas of operation including a zoning regime in the Gulf of Paria according to trawler type.

(4) Set appropriate and specific reference points for the fishery, defining constraints within which the fishery must operate. This would make operational the management objectives for this fishery outlined in the policy document and management plan, which otherwise are imprecise.

These proposals were consistent with the Government policy. The management objective for the shrimp trawl fishery of the Government of the Republic of Trinidad and Tobago is "full utilisation of the resource consistent with adequate conservation, and minimal conflict between the artisanal and non-artisanal components of the fishery" (Fisheries Division and FAO, 1992).

- Stock Assessment Summary

The trawl fleet catches mainly five shrimp species namely *Farfantepenaeus subtilis*, *F. notialis*, *F. brasiliensis*, *Litopenaeus schmitti*, and *Xiphopenaeus kroyeri*; as well as associated groundfish, mainly *Micropogonias furneri* and *Cynoscion jamaicensis*. Shrimp landings are undifferentiated and sampling of the catches ceased in 2002, so it has become necessary to assess the management as a single group of five species.

The assessment in 2011 used a simple biomass dynamics model to assess the biomass for all species as a single unit, which provides advice based on the joint MSY reference point. This reference point can be used to restrict the risk of unsustainable fishing to an acceptable level. All shrimp catches from the Trinidad and Tobago and Venezuela trawl fleets were treated as a single stock in the model since the group felt unable to disaggregate Trinidad catches by species accurately. In addition, the assessment used interview information obtained from fishers as a "prior" for model parameters and to evaluate socio-economic preferences among the possible results from management actions.

The model requires a complete series of catch data and as long a series of catch-per-unit effort (CPUE) data as possible. Total catches for the period 1988 to 2009 had to be reconstructed from various sources. CPUE data were provided for four Trinidad trawl fleets and two Venezuela trawl fleets. However, only three Trinidad CPUE series and one Venezuela series was used due to concerns with data quality. In addition, the Venezuela series and one Trinidad series was truncated due to these vessels no longer operating in this fishery. This severely limited the assessment's ability to monitor the presumed recovery of the stock due to the reduction in catch.

Additional information was necessary to determine the state of the stock in 1988 when the population model was started. It is known that the stock was relatively lightly fished in 1975, with an approximate total catch around 600 t. This was used to estimate the approximate stock state in 1975, which helps to provide a useful reference point, the expected CPUE when the stock was only lightly fished.

A reasonable fit for the model was obtained with relatively stable results. The general results indicate the state of the stock is now above MSY and the current fishing mortality is allowing a sustained recovery.

The model shows a recovery in stock size to above the MSY level, implying the stock is no longer overfished (Figure 1.17). This result is inferred from the reduced catch, but was not supported by CPUE indices. CPUE should have increased, but relevant indices are now either unavailable or are too noisy to support this presumed increase in biomass. Therefore, while this general result remains highly likely, its benefit to Trinidad is equivocal because the driving force behind the increase in stock size is derived almost entirely from Venezuela.

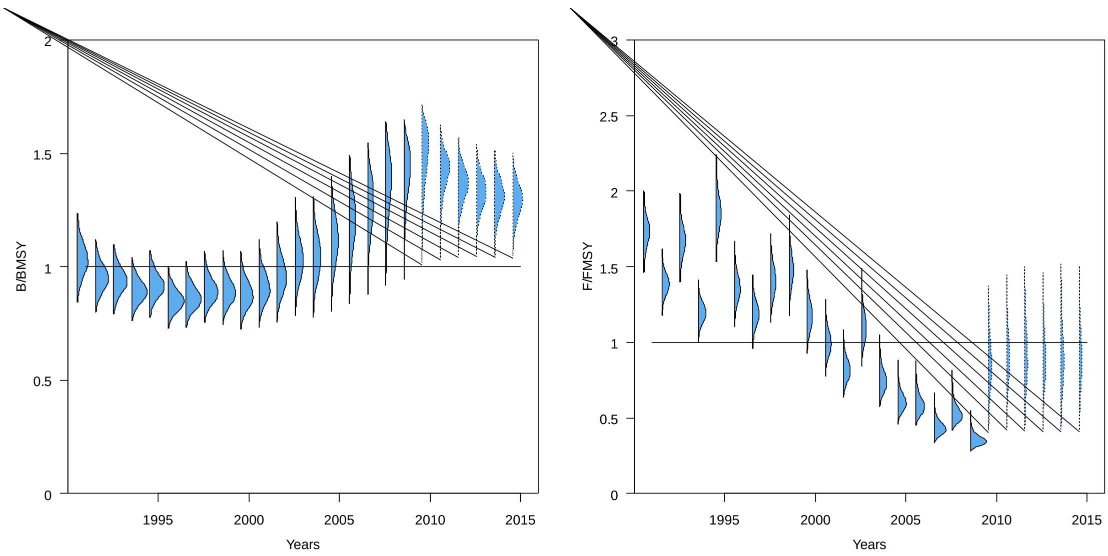


Figure 1.17. Biomass and fishing mortality relative to reference points under closed season harvest control rule affecting fishing effort with effort at MSY and minimum 10000 Type II boat days or equivalent.

This assessment was an update of that conducted at the CRFM Scientific Meeting in 2006 (CRFM 2006) and developed at an FAO workshop in 2005 (Medley *et al.* 2005). Joint assessments using shrimp data from both Venezuela and Trinidad have been conducted several times in the past (Die *et al.* 2004, FAO 2000) with management recommendations being applicable to all fleets.

- <u>Main Uncertainties</u>

Catches before 1988 were unavailable, which greatly contributes to uncertainty and makes the single 1975 base year, for which a catch estimate was available, important in estimating the unexploited state and hence MSY and the current state of the management unit.

Stakeholders believed that pollution was a contributing factor in negatively affecting productivity. Pollution could cause shift in the reference points.

Perhaps the greatest problem facing this assessment is the loss of the Venezuelan industrial trawl fishery index, which makes the assessment much more uncertain than the model would suggest.

Combining all species, which clearly cannot be a single stock, gives imprecise estimates of status. The assessment describes CPUE rather than stock size. This should also maintain overall biomass at high levels, but might allow depletion of some species within the complex. Biological sampling within the catches across all areas and accurate reporting of total landings and effort by the industry would be required to allow improvements on this model.

As well as consideration of separate species as separate stocks, combining areas across Trinidad and Venezuela may well combine several shrimp populations and fisheries into a single assessment. It may be better to separate areas rather than species, so Trinidad and Venezuela need not conduct joint assessments on all fisheries and management controls can be implemented more precisely. While recruitment might be shared among areas, adult shrimp do not migrate across the area exploited by these fisheries, suggesting that they could be managed on a finer spatial scale. This could also help develop local participatory management.

1.16 References

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2 TRIAL OF PRODUCTIVITY AND SUSCEPTIBILITY INDICES TO DETERMINE STOCK VULNERABILITY IN GUYANA, SURINAME AND TRINIDAD

By Paul A.H. Medley

2.1 Introduction

Stock assessment through quantitative modelling of fishery data remains the most rigorous method for determining whether a stock is vulnerable to becoming overfished at different levels of exploitation. However, most populations have insufficient data to carry out such assessments. In these cases, a flexible semi-quantitative methodology is required which is able to make use of the available information, but can still deal with data poor stocks.

Patrick *et al*. (2009) recommended using the Productivity and Susceptibility Assessment (PSA) as the best approach for determining the vulnerability of data-poor stocks. They developed a PSA methodology suitable for use in stocks under the jurisdiction of the United States of America. PSA has become part of the set of United States National Marine Fisheries Service standard methodologies (National Fisheries Toolbox, NFT: http://nft.nefsc.noaa.gov/PSA.html). This methodology, with a few adaptations, has been used here to assess stocks which are caught using seabob trawl in Suriname.

The vulnerability of a stock to becoming overfished can be defined as a function of its productivity (the capacity of the stock to produce MSY and to recover if the population is depleted) and its susceptibility to the fishery (the potential for the stock to be impacted by the fishery, which includes direct captures, as well as indirect impacts to the fishery).

The PSA evaluates an array of productivity and susceptibility attributes for a stock, from which index scores for productivity and susceptibility are computed and graphically displayed. The PSA methodology scores attributes on a three-point scale (i.e., 1 = low, 2 = moderate, 3 = high). The weighted average of each factor's attribute scores is plotted in an x-y scatter plot and the vulnerability score of the stock is calculated by measuring the Euclidean distance of the datum point from the origin of the plot. Stocks that receive a low productivity score and a high susceptibility score are considered to be the most vulnerable, while stocks with a high productivity score and low susceptibility score are considered to be the least vulnerable.

Compared to previously published PSA methods, Patrick et al. (2009) have expanded the number of attributes scored from 13 to 22 considering both direct and indirect impacts; aligned scoring reference points to life history characteristics of fish species found in U.S. waters; introduced a weighting system that allows customization, included a data quality index to provide an estimate of information uncertainty; and developed a protocol for dealing with multiple gear types. For this trial use, the U.S. methodology is used, although there has been some adaptation of the attributes to better reflect available information. These changes, outlined and justified below, have not undergone any rigorous review and therefore this application of PSA remains a trial.

2.2 Method

2.2.1 Weights

The default weight for each attribute is 2. The methodology allows for alternative weights where attributes may be considered more important in a fishery. No such argument was available for the attributes used here and therefore all weights were set to the default.

For this preliminary analysis, some attributes used by Patrick *et al.* (2009) were given a weighting of zero, removing them from the analysis. Because no information was available on these attributes in this case, they could not be used to distinguish between stocks. This is not entirely satisfactory, but might only be address by using expert judgement and further literature review and research.

2.2.2 Information Sources

The species considered were those reported as caught in the Suriname seabob trawl (Willems, Pers. Comm.). This list is relatively complete. In addition, there was quantitative data which is being used for a PhD. Thesis

The PSA was used specifically because information is available from the internet on species encountered on the Brazil-Guianas shelf, primarily from Fishbase (Froese and Pauly 2000; www.fishbase.org). While use of this information directly from Fishbase is not entirely satisfactory, it is quick and for most species attributes should be accurate enough to place them in the correct PSA categories. However, there is clearly a need to review the information obtained using local expertise and scientific work.

Remaining information was obtained for the main target shrimp and finfish stocks from stock assessment reports (Ferreira, 2012; Soomai *et al.*, 2012; CRFM, 2005; FAO, 1999; FAO, 2000).

2.2.3 Productivity Attributes

The following productivity attributes were used.

Population growth (*r*): This is the intrinsic rate of population growth or maximum population growth that would be expected to occur in a population under natural conditions (i.e., no fishing), and thus directly reflects stock productivity. While this attribute combines many of the other attributes (i.e. it is a direct measure of productivity), it is rarely estimated and therefore no greater weight than the default 2 is attributed to it.

The approximate expected population doubling time is reported in Fishbase for most species under "resilience". This estimate is usually based on the broad category defined by the likely parameter estimates for growth and reproduction. The "doubling time" (t) is related to r as: $r=Log_e(2)/t$.

Maximum size (*L_{max}*): Maximum size is also correlated with productivity, with larger species tending to have lower levels of productivity. The scoring definitions were based on the ANOVA applied to the observed fish stocks considered to be representative of U.S. fisheries. The L_{max} for a majority of these fish ranges between 60 to 150 cm TL.

Growth coefficient (*k*): The von Bertalanffy growth coefficient measures how rapidly a fish reaches its maximum size, where long-lived, low-productivity stocks tend to have low values of *k* (Froese and Binohlan, 2000). The attribute scoring definitions based upon the ANOVA applied to the fish stocks considered to be representative of U.S. fisheries was 0.15 to 0.25 year^{-1}. This is roughly consistent with the values obtained from Froese and Binohlan's (2000) empirical relationship $k = 3/ t_{max}$ of 0.1 to 0.3, based upon maximum ages of 10 and 30.

Natural mortality (*M*): Natural mortality rate directly reflects population productivity, as stocks with high rates of natural mortality will require high levels of production in order to maintain population levels. Several methods for estimating *M* rely upon the negative relationship between *M* and maximum age (Hoenig, 1983). The attribute scoring thresholds from the ANOVA applied to the fish stocks considered to be representative of U.S. fisheries was 0.2 to 0.4, and were roughly consistent with those produced from Hoenig's (1983) empirical regression of 0.14 to 0.4, based on t_{max} values of 10 and 30.

Fecundity: Fecundity (i.e., the number of eggs produced by a female for a given spawning event or period) varies with size and age of the spawner, so Patrick *et al.* (2009) suggested that fecundity should be measured at the age of first maturity. However, low values of fecundity imply low population productivity, but high values of fecundity do not necessarily imply high population productivity; thus, this attribute may be more useful at the lower fecundity values. In reality, estimates of fecundity are rare, and certainly have not been reported specific to age-at-maturity. Nevertheless, low-fecund species could be easily identified and the attribute scores made to reflect this.

Breeding strategy: The breeding strategy of a stock provides an indication of the level of mortality that might be expected for the offspring in the first stages of life. Patrick *et al*. (2009) used a well-justified index of parental investment. This information was not available for the Brazil-Guianas, and therefore a simpler category was used to capture the same effect: Viviparous (low), brooders or demersal eggs (medium) and egg-scatterers (high).

Length at maturity (*L_{mat}*): Patrick *et al*. (2009) used age at maturity, where lower productivity stocks will have higher length at maturity relative to stocks. Age at maturity was not reported for any species, but length at first maturity. Equivalent approximate breaks in size maturity were defined for total lengths of 40cm and 100cm.

Mean trophic level: Lower-trophic-level stocks are generally more productive than higher-trophic-level stocks. The trophic level of a stock can be computed as a function of the trophic levels of the organisms in its diet. For this attribute, stocks with trophic levels higher than 3.5 were categorized as low productivity stocks and stocks with trophic levels less than 2.5 were categorized as high-productivity stocks, with moderate productivity stocks falling between these bounds. These attribute threshold roughly categorize piscivores to higher trophic levels, omnivores to intermediate trophic levels, and planktivores to lower trophic levels (Pauly *et al.* 1998).

The following attributes were **not** used.

Maximum age (*t_{max}*): Maximum age is a direct indication of the natural mortality rate (*M)*, where low levels of *M* are negatively correlated with high maximum ages (Hoenig 1983). Stocks have not been aged routinely in the Brazil-Guianas shelf, so this information was not available for this analysis.

Recruitment pattern: Stocks with sporadic and infrequent recruitment success often are long-lived and thus might be expected to have lower levels of productivity. However, no information was available for these species on this attribute, and therefore it was not used in this analysis.

2.2.4 Susceptibility Attributes

The following attributes were used.

Management Strategy: This attribute was present to allow the effect of management measures to be incorporated into PSA as an attribute. In practice, all scores were set to 3 for all stocks with the exception of seabob itself. It is likely that this scoring could be improved with local knowledge, where the impact of various technical measures or effort control could be considered for each stock. This information was not available for this preliminary analysis. Note that the possible effects of Turtle Excluder Devices (TEDs) and Bycatch Reduction Devices (BRDs) were considered under morphology below.

Areal overlap: This attribute pertains to the extent of geographic overlap between the known distribution of a stock and the distribution of the fishery. Greater overlap implies greater susceptibility, as some degree of geographical overlap is necessary for a fishery to impact a stock. The USA has scientific surveys to estimate overlap, whereas the distributions of the Brazil-Guianas stocks were not known, so the precise overlap with the fishery was unknown. Therefore, this attribute made use of habitat information on each species, and how this is likely to overlap with the demersal seabob trawl. Pelagic or reef associated species were considered to have low susceptibility, and brackish soft-bottom habitat had highest susceptibility.

Geographic concentration: Geographical concentration is the extent to which the stock is concentrated into small areas, where a relatively even distribution across its range may be less susceptible than a highly aggregated stock. Again in contrast to the USA, the distribution of the stocks is not known in the Brazil-Guianas shelf region, but the distribution of the species overall is available. Therefore, this attribute was changed to represent the distribution of the species. This indicates the possibility that the local stock is supported by populations outside the area. The highest susceptibility was allocated to species only found within the Brazil-Guianas shelf, medium susceptibility for Brazil-Guianas and Caribbean. Judgement was used for allocating the lowest susceptibility on this attribute, but low susceptibility was generally allocated to Atlantic-wide populations.

Vertical overlap: Similar to geographical overlap, this attribute concerns the depth of the stock relative to the fishing gear. In contrast to Patrick et al. (2009), only overlap of depth was used, not the position in the water column which was considered as part of a real overlap (i.e. habitat). For example, the depth that the industrial seabob trawl gear operates is between 18m and 70m depth, but with additional artisanal gears used in shallower water, a 0-70m depth range for the whole seabob fishery was used. A species overlapping with less than 50% of this range was considered low, greater than 50 but less than 100% medium risk and a species entirely within this range (100% overlap) would be high risk.

Morphology affecting capture: This attribute accounts for the fishing gear’s suitability to capture fish based on their morphological characteristics. Because gear selectivity varies with size and age, this measure should be based on the age or size classes most representative of the entire stock. Very little direct information is available on this attribute, but the most relevant characteristics of the gear that is a low-speed (for finfish) demersal trawl with small mesh size that is most suitable for shrimp. In addition, TEDs with a distance of 4 inches (10cm) between the bars are fitted, which should exclude all larger fish, and more recently BRDs have been fitted, which should reduce the incidental capture of small to medium sized fish. Information on the evaluation of these gear modifications should become available, making the scores for this attribute more accurate. In the meantime, very large fish excluded by the TEDs or able to avoid the trawl altogether are scored at medium susceptibility and all other fish are high susceptibility. Evaluation of BRDs and TEDs could lower the scores for many species.

Desirability/value of the fishery: This attribute assumes that highly valued fish stocks are more susceptible to overfishing or becoming overfished due to increased effort directed at that stock. Fishbase gives a market value which was used in this analysis. However, this takes no account of the size of the fish caught or the local value, so these preliminary scores should be reviewed with local information.

Survival after capture and release: Fish survival after capture and release varies by species, region, and gear type or even market conditions, and thus can affect the susceptibility of the stock. Information on this is lacking and therefore all scores were set to high (high mortality before or immediately after release). Better information could lower or increase the scores for many species.

Fishery impact on habitat: A fishery may have an indirect effect on a species via adverse impacts on habitat. Demersal trawl has a reputation for damaging benthic habitat. However, there are mitigating factors associated with shrimp trawl, notably the light gear and trawled areas which are predominantly dynamic substrate (mud and sand deposited and moved by currents). Although research is being undertaken on this issue, there is no direct information that habitat is not impacted so all stocks are scored high. Nevertheless, this attribute was included. The scores for some species could be reduced as more information on habitat impacts becomes available.

The following attributes were **not** used.

Fishing mortality rate (relative to *M*): The conservative rule of thumb is that natural mortality (*M*) should be an upper limit of *F*, and therefore *F*/*M* should not exceed 1. Having information to score this attribute implies a full stock assessment has been conducted which would suggest the PSA is unnecessary or that a score for all the susceptibility attributes can be made based on this information. Furthermore, the F/M ratio is arguably a measure of vulnerability (i.e. includes productivity) rather than of susceptibility alone.

Biomass of Spawners: Analogous to fishing mortality rate, the extent to which fishing has depleted the biomass of a stock relative to expected unfished levels offers information on realized susceptibility. However, information on this attribute was not available for these species and it was not clear that this was an appropriate attribute (see Fishing Mortality above).

Seasonal migrations: Seasonal migrations either to or from the fishery area (i.e. spawning or feeding migrations) could affect the overlap between the stock and the fishery. This attribute also pertains to cases where the location of the fishery changes seasonally, which may be relevant for stocks captured as bycatch. The lack of knowledge and seasonality in the fishery implied that this attribute was not useful in this case.

Schooling, aggregation, and other behaviours: This attribute encompasses behavioural responses of both individual fish and the stock in response to fishing. Individual responses may include, for example, herding or gear avoidance behaviour that would affect catchability. The most likely information relevant here is where spawning aggregations are fished, which has not been identified as an issue in any fishery as yet. Information on other more subtle behaviours are not available and therefore this attribute was not scored.

2.2.5 Data Quality Index

As a precautionary measure, ecological risk assessments should provide higher-level risk scores when data are missing. A lack of information can lead to an incorrect management response and therefore is associated with higher risk. While this approach is appropriate, it also confounds the issues of data quality with other sources of risk. For example, under this approach a data-poor stock may receive a high-risk evaluation either because of missing data or the risk assessment of the available data (Hobday *et al*. 2004). To separate this issue, a data quality score was applied to each attribute as well as the susceptibility/productivity score. Poor data quality implies that risks may be decreased specifically by more scientific investigation, including literature review and expert consultation, which may be less onerous than alternative management actions.

Patrick *et al*. (2009) developed a data quality index that provided an estimate of uncertainty for individual vulnerability scores based on five tiers ranging from best data or high belief in the score to no data or little belief in the score (Table 2.1). The data quality score is computed for the productivity and susceptibility scores as a weighted average of the data quality scores for the individual attributes, and denotes the overall quality of the data or belief in the score rather than the actual type of data used in the analysis.

Patrick et al. (2009) suggested dividing the data quality scores into three groupings (low > 3.5; moderate 2.0 to 3.5; and high < 2.0) for display purposes. Data quality index scores are also provided in the appropriate tables.

Table 2.1. The five tiers of data quality used when evaluating the productivity and susceptibility of an individual stock (Patrick *et al*., 2009).

Data quality score	Description	Specific Reason
1 **Best data**	Information is based on collected data for the stock and area of interest that is established and substantial. The attribute score is based on directed scientific observations and research with strong confidence in the score.	Attribute can be scored based on published report, data and/or research which has undergone some level of scientific review.
2 **Adequate data**	Information with limited coverage and corroboration, or for some other reason deemed not as reliable as Tier 1 data, such as more limited temporal or spatial data, or relatively old information.	The source of information is indirect, such as Fishbase, but where there is still some confidence in the Fishbase information.
3 **Limited data**	Estimates with high variation and limited confidence and may be based on similar taxa or life history strategy. Similar genus or family, etc.	Indirect source of information such as Fishbase, but with some inference from similar species and/or with lower confidence in the accuracy or relevance of the Fishbase information
4 **Very limited data**	Expert opinion or based on general literature review from wide range of species, or outside of region. General data – not referenced.	Score based on subjective guesswork and therefore needs to be evaluated.
5 **No data**	No information to base score on – not included in the PSA, but included in the DQI score.	There was no basis on which to suggest a score.

2.3 Results

A table of the full analysis results are in Appendix 1. Figure 2.1 provides a summary plot, and the twenty most vulnerable species are listed in Table 2.2.

The first seven and the eleventh most vulnerable stocks are elasmobranchs (rays and sharks), which have a low reproductive output with significant investment in each egg produced. This, together with slow growth, makes these stocks have low productivity. These species also appear to be found in locations likely to be taken as bycatch. Larger animals should be excluded by the TEDs, which after evaluation, may be adequate to reduce the risks to acceptable levels for these stocks.

After the elasmobranchs, are two species of large, slow-growing catfish and the yellowfin river pellona, which are also “high risk”. These stocks may be less susceptible to the gear than this analysis suggests, since if they are found in fresh water extending into the lower river, they are not likely to be available to seabob trawl in these areas. In the analysis, it is assumed that a large proportion of these populations overlap with the trawled areas.

Stocks ranked 12 and 17 are also catfish. Catfish brood their young, males often protecting larvae until they are juveniles and mortality has decreased. Sea trout (green weakfish), also ranked 12, has the same vulnerability as softhead and coco sea catfish, but it is by far the greatest commercial value of the stocks listed. Sea trout has some limited stock assessment information, but no reliable growth model and its status remains uncertain.

The variation with respect to susceptibility is low compared to productivity. This might be because all these species are susceptible to shrimp trawl gear, but also may indicate that the susceptibility attributes need to be reviewed so that they reflect real risks in the fishery.

Table 2.2. Scores allocated to the twenty most vulnerable species identified based on the Productivity-Susceptibility Assessment. Stocks ranked 11 and above are, based on the US reference levels, considered at high risk of depletion.

Rank	ID	Stock	Scientific Name	Productivity Score	Susceptibility Score	Vulne-rability	Quality Score
1	47	Cownose ray	*Rhinoptera bonasus*	1.12	2.62	2.48	3.25
2	24	Southern stingray	*Dasyatis americana*	1.12	2.50	2.40	3.25
2	26	Longnose stingray	*Dasyatis guttata*	1.12	2.50	2.40	3.25
4	25	Sharpsnout stingray	*Dasyatis geijskesi*	1.25	2.62	2.39	3.25
5	96	Smalleyed round stingray	*Urotrygon microphthalmum*	1.62	2.88	2.33	3.25
6	34	Smooth butterfly ray	*Gymnura micrura*	1.25	2.50	2.30	3.25
6	62	Chola guitarfish	*Rhinobatos percellens*	1.38	2.62	2.30	3.25
8	10	Thomas sea catfish	*Notarius grandicassis*	1.75	2.88	2.25	3.25
9	61	Yellowfin river pellona	*Pellona flavipinnis*	2.12	3.00	2.18	3.50
10	6	Gillbacker sea catfish	*Sciades parkeri*	1.75	2.75	2.15	3.25
10	93	Smalleye smooth-hound	*Mustelus higmani*	1.75	2.75	2.15	3.25
12	5	Softhead sea catfish	*Amphiarius rugispinis*	2.00	2.88	2.12	3.38
12	8	Coco sea catfish	*Bagre bagre*	2.00	2.88	2.12	3.25
12	**67**	**Sea trout**	***Cynoscion virescens***	**2.00**	**2.88**	**2.12**	**3.25**
15	19	Swordspine snook	*Centropomus ensiferus*	2.38	3.00	2.10	3.25
15	90	Banded puffer	*Colomesus psittacus*	2.38	3.00	2.10	3.25
17	7	Bressou sea catfish	*Aspistor quadriscutis*	2.12	2.88	2.07	3.38
17	86	Pond perch	*Diplectrum radiale*	2.12	2.88	2.07	3.25
19	2	Longtail sole	*Apionichthys dumerili*	2.62	3.00	2.03	3.38
19	3	Slipper sole	*Trinectes paulistanu*	2.62	3.00	2.03	3.25

Data quality scores indicate most information needs to be verified. The best information is available for shrimp (stocks 97-101). Despite there being considerable uncertainty due to the difficulties in studying these species (specifically, there are no reliable techniques to age shrimp and studies based on fishery science techniques such as tagging remain difficult), the many studies that have been carried out provide information reliable enough for this sort of risk assessment. In most cases, information for the purposes of risk assessment can be considered to be medium quality. That is, basic information exists which is able to categorize stocks for most, but not all, attributes reasonably well. Information is usually missing on parameter estimates for growth rate, fecundity, natural mortality as well as characteristics of the stocks relative to susceptibility to the fishing gear. Only one species, the dusky snake eel (57: *Ophichthus cylindroideus*), was considered to have very poor information, and was reliant on guesswork for almost all attributes. Note that because attributes were excluded where no information exist for any species, this assessment over-estimates data quality overall.

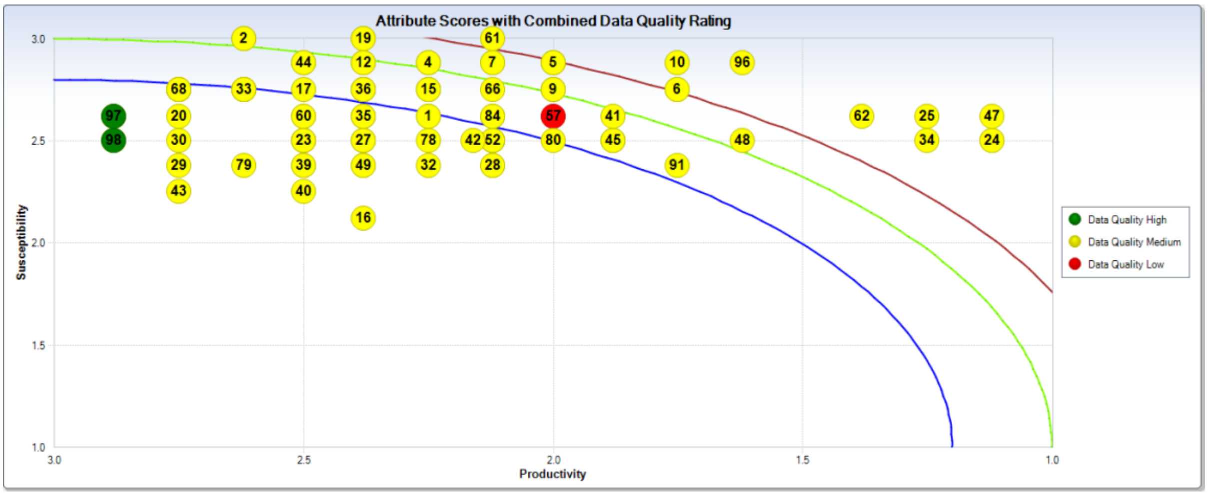

Figure 2.1. Plot of productivity (x-axis) susceptibility (y-axis) scores for the 101 species considered in the analysis. The vulnerability reference levels are indicated by the red, green and blue lines representing high, medium and low risk as estimated for the United States fisheries (Patrick *et al*. 2009). Data quality is indicated by the dot colours, with most species of medium quality (yellow). Stocks are indicated by numbers (see Appendix 1 for a complete list).

2.4 Conclusion

This analysis remains preliminary because some of the scores may be biased or incorrect. Attributes were not scored based on collaborative effort among experts, but was based primarily upon internet resources and one person's expert judgement. It therefore remains more a test of the potential use of this approach rather than any final analysis of stock vulnerability.

An important consideration is how this type of analysis might be used. It should make a contribution to the ecosystem approach to fisheries management by considering all mortality caused by fishing, not just mortality on the target species. However, the scientific advice that results from this type of analysis still needs to be developed.

Fisheries management can respond to the analysis in two ways:

1. Commission research on stocks for which there is little information and data quality is poor. Such research should try to identify appropriate management actions that might reduce risk for a stock, but have minimum impact on the economic and social performance of the fishery. Research might include the evaluation of management actions to see whether they reduce the susceptibility of the stock to the gear. In extreme cases, research might be to collect data and conduct a full stock assessment.

2. Implement management actions that reduce risk to the stock. Actions include reducing susceptibility scores for the stock, so that the effects of the action on the risk score is clear. For example, limiting the depths where trawling is allowed could reduce the vertical overlap of the fishery with the stock, altering the risk score.

Results from the analysis should be linked to management action and resources allocated for this purpose as part of the risk assessment. Unless this is done, it is unclear whether this analysis is worth carrying out. Although the analysis can cover large number of species, more work is required than was applied for this preliminary assessment. Not only should further scientific articles be reviewed to obtain more and better estimates of species productivity parameters, but Vessel Monitoring System (VMS) data, survey data (e.g. R/V Fridtjof Nansen survey), salinity levels, depth profiles and habitat maps can be used to better characterise susceptibility.

Although the PSA covers large numbers of species relatively rapidly, it is still costly and time consuming to carry out correctly. The analysis carried out here was on a single gear, and clearly a combined analysis of all gears is required. In addition, information should be obtained from improved sources, particularly local biologists in the countries which share the Brazil-Guianas shelf.

The methodology itself needs to be adapted for use in these fisheries, with a review of the appropriate attributes which might be applied locally, and reference points for the vulnerability score for these fisheries. This particularly applies to the susceptibility attributes, which did not discriminate well among the different species. The NFT software is based on the Microsoft Access database, which is not particularly easy to use or adapt to alternative attributes. The methodology is simple enough to set up in a spreadsheet, which should make it easier to maintain the information. In addition, the spreadsheet could be linked to R to provide high-quality graphics and further analysis.

2.5 References

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Willems, T. (Pers. Comm.) Tomas Willems is conducting research which will lead to a PhD Thesis. The species list was kindly sent to allow the PSA to be carried out. Institute for Agricultural and Fisheries Research, Animal Sciences Unit – Fisheries, Ankerstraat 1, 8400 Oostende, BELGIUM. Tomas.Willems@ilvo.vlaanderen.be http://tomaswillems.wordpress.com/

2.6 Appendix 1- Table of scores and derived indices

Table of scores and derived indices for all species considered in this analysis. The scores of individual attributes have not been reviewed, so these results are preliminary. Species are arranged in order of family and then species. Penaeid shrimps have added to the end of the table, and all other species are finfish, either sharks and rays (Chondrichthyes) or bony fish (Osteichthyes).

						Productivity				Susceptibility			
Rec No.	Stock / Common Name	Scientific Name	Productivity Score	Susceptibility Score	Vulnerability	Score Standard Deviation	No. of Attributes Scored	Quality Score	Quality Standard Deviation	Attribute Standard Deviation	No. of Attributes Scored	Quality Score	Quality Standard Deviation
1	Drab sole	Achirus achirus	2.25	2.62	1.79	0.707	8	3.38	1.061	0.744	8	3.25	0.707
2	Longtail sole	Apionichthys dumerili	2.62	3	2.03	0.518	8	3.5	1.069	0.000	8	3.38	0.744
3	Slipper sole	Trinectes paulistanu	2.62	3	2.03	0.518	8	3.5	1.069	0.000	8	3.25	0.707
4	Kukwari sea catfish	Amphiarius phrygiatus	2.25	2.88	2.02	0.707	8	2.88	1.126	0.354	8	3.38	0.744
5	Softhead sea catfish	Amphiarius rugispinis	2	2.88	2.12	0.756	8	2.75	1.165	0.354	8	3.38	0.744
6	Gillbacker sea catfish	Sciades parkeri	1.75	2.75	2.15	0.707	8	2.62	1.061	0.463	8	3.25	0.707
7	Bressou sea catfish	Aspistor quadriscutis	2.12	2.88	2.07	0.641	8	2.88	1.126	0.354	8	3.38	0.744
8	Coco sea catfish	Bagre bagre	2	2.88	2.12	0.756	8	2.75	1.035	0.354	8	3.25	0.707
9	Crucifix sea catfish	Sciades proops	2	2.75	2.02	0.756	8	2.62	1.061	0.463	8	3.38	0.744
10	Thomas sea catfish	Notarius grandicassis	1.75	2.88	2.25	0.707	8	3	1.195	0.354	8	3.25	0.707
11	Banjo	Aspredo aspredo	2.25	2.88	2.02	0.707	8	2.75	1.165	0.354	8	3.38	0.744
12	Cocosoda catfish	Pseudauchenipterus nodosus	2.38	2.88	1.98	0.744	8	3.38	1.061	0.354	8	3.25	0.707
13	Pacuma toadfish	Batrachoides surinamensis	2	2.75	2.02	0.756	8	2.75	1.165	0.707	8	3.25	0.707
14	Atlantic midshipman	Porichthys plectrodon	2.25	2.62	1.79	0.707	8	3.12	1.126	0.744	8	3.25	0.707
15	Eyed flounder	Bothus ocellatus	2.25	2.75	1.9	0.707	8	3.12	1.126	0.463	8	3.25	0.707
16	Crevalle jack	Caranx hippos	2.38	2.12	1.29	0.744	8	2.62	1.061	0.835	8	3.25	0.707
17	Caribean moonfish	Selene browni	2.5	2.75	1.82	0.756	8	3.12	1.126	0.463	8	3.38	0.744
18	Lookdown	Selene vomer	2.25	2.75	1.9	0.707	8	3.12	1.126	0.463	8	3.25	0.707
19	Swordspine snook	Centropomus ensiferus	2.38	3	2.1	0.744	8	2.75	1.165	0.000	8	3.25	0.707
20	Scaled herring	Harengula jaguana	2.75	2.62	1.64	0.463	8	2.5	1.069	0.744	8	3.25	0.707
21	Guiana longfin herring	Odontognathus mucronatus	2.88	2.5	1.51	0.354	8	3	1.069	0.926	8	3.25	0.707

Rec No.	Stock / Common Name	Scientific Name	Productivity Score	Susceptibility Score	Vulnerability	Productivity				Susceptibility			
						Score Standard Deviation	No. of Attributes Scored	Quality Score	Quality Standard Deviation	Attribute Standard Deviation	No. of Attributes Scored	Quality Score	Quality Standard Deviation
22	Duskycheek tonguefish	Symphurus plagusia	2.38	2.88	1.98	0.518	8	3	1.195	0.354	8	3.25	0.707
23	Flying gurnard	Dactylopterus volitans	2.5	2.5	1.58	0.756	8	3.12	1.126	0.926	8	3.25	0.707
24	Southern stingray	Dasyatis americana	1.12	2.5	2.4	0.354	8	3	1.195	0.756	8	3.25	0.707
25	Sharpsnout stingray	Dasyatis geijskesi	1.25	2.62	2.39	0.463	8	3	1.195	0.744	8	3.25	0.707
26	Longnose stingray	Dasyatis guttata	1.12	2.5	2.4	0.354	8	3	1.195	0.756	8	3.25	0.707
27	Web burrfish	Chilomycterus antillarum	2.38	2.5	1.62	0.518	8	3.12	1.126	0.756	8	3.25	0.707
28	Live sharksucker	Echeneis naucrates	2.12	2.38	1.63	0.354	8	3.12	1.126	0.916	8	3.25	0.707
29	Broad-striped anchovy	Anchoa hepsetus	2.75	2.38	1.4	0.463	8	2.88	1.126	0.744	8	3.25	0.707
30	Spicule anchovy	Anchoa spinifer	2.75	2.5	1.52	0.707	8	3.12	1.126	0.756	8	3.25	0.707
31	Broadband anchovy	Anchoviella lepidentostole	2.88	2.5	1.51	0.354	8	3.12	1.126	0.756	8	3.25	0.707
32	Atlantic spadefish	Chaetodipterus faber	2.25	2.38	1.57	0.707	8	3	1.195	0.744	8	3.25	0.707
33	Caitipa mojarra	Diapterus rhombeus	2.62	2.75	1.79	0.518	8	3	1.195	0.463	8	3.25	0.707
34	Smooth butterfly ray	Gymnura micrura	1.25	2.5	2.3	0.463	8	3	1.195	0.756	8	3.25	0.707
35	Barred grunt	Conodon nobilis	2.38	2.62	1.74	0.518	8	3	1.195	0.518	8	3.25	0.707
36	Torroto grunt	Genyatremus luteus	2.38	2.75	1.86	0.518	8	3.12	1.126	0.463	8	3.25	0.707
37	Bronzestripe grunt	Haemulon boschmae	2.5	2.5	1.58	0.535	8	3.12	1.126	0.756	8	3.25	0.707
38	Corocoro grunt	Orthopristis ruber	2.38	2.62	1.74	0.744	8	2.88	1.126	0.518	8	3.25	0.707
39	Slender halfbeak	Hyporhamphus roberti roberti	2.5	2.38	1.46	0.535	8	3.12	1.126	0.744	8	3.25	0.707
40	Squirrelfish	Holocentrus adscensionis	2.5	2.25	1.35	0.535	8	2.5	0.756	0.886	8	3.25	0.707
41	Southern red snapper	Lutjanus purpureus	1.88	2.62	1.98	0.835	8	2.75	1.165	0.744	8	3.25	0.707
42	Lane snapper	Lutjanus synagris	2.16	2.5	1.72	0.627	8	2.26	0.471	0.756	8	3.25	0.707
43	Planehead filefish	Stephanolepis hispidus	2.75	2.25	1.27	0.463	8	2.75	1.165	0.886	8	3.25	0.707
44	Dwarf goatfish	Upeneus parvus	2.5	2.88	1.94	0.756	8	3.12	1.126	0.354	8	3.25	0.707
45	Guyana pike-conger	Cynoponticus savanna	1.88	2.5	1.88	0.641	8	3.5	1.069	0.756	8	3.25	0.707
46	Caribbean ocellated moray	Gymnothorax ocellatus	1.88	2.5	1.88	0.641	8	3.38	1.188	0.535	8	3.25	0.707

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47	Cownose ray	Rhinoptera bonasus	1.12	2.62	2.48	0.354	8	3.12	1.126	0.518	8	3.25	0.707
48	Brazilian electric ray	Narcine brasiliensis	1.62	2.5	2.03	0.916	8	2.88	1.126	0.756	8	3.25	0.707
49	Slantbrow batfish	Ogcocephalus declivirostris	2.38	2.38	1.51	0.518	8	3.5	1.069	0.744	8	3.38	0.744
50	Shortnose batfish	Ogcocephalus nasutus	2.12	2.38	1.63	0.835	8	3.5	1.069	0.744	8	3.25	0.707
51	Batfish	Ogcocephalus notatus	2.38	2.38	1.51	0.518	8	3.5	1.069	0.744	8	3.38	0.744
52	Spotted batfish	Ogcocephalus pantostictus	2.12	2.5	1.74	0.835	8	3.5	1.069	0.756	8	3.38	0.744
53	Roughback batfish	Ogcocephalus parvus	2.38	2.5	1.62	0.518	8	3.5	1.069	0.756	8	3.12	0.835
54	Dwarf batfish	Ogcocephalus pumilus	2.5	2.38	1.46	0.535	8	3.5	1.069	0.744	8	3.38	0.744
55	Polka-dot batfish	Ogcocephalus radiatus	2.12	2.5	1.74	0.835	8	3.5	1.069	0.756	8	3.38	0.744
56	Seadevil	Ogcocephalus vespertilio	2.12	2.5	1.74	0.835	8	3.5	1.069	0.756	8	3.38	0.744
57	Dusky snake eel	Ophichthus cylindroideus	2	2.62	1.91	0.756	8	3.75	1.282	0.744	8	3.5	0.756
58	Scrawled cowfish	Acanthostracion quadricornis	2.38	2.75	1.86	0.518	8	3.12	1.126	0.463	8	3.25	0.707
59	Dusky flounder	Syacium papillosum	2.38	2.75	1.86	0.744	8	3.25	1.165	0.463	8	3.25	0.707
60	Atlantic bigeye	Priacanthus arenatus	2.5	2.62	1.7	0.756	8	3	1.195	0.518	8	3.25	0.707
61	Yellowfin river pellona	Pellona flavipinnis	2.12	3	2.18	0.641	8	3.5	1.069	0.000	8	3.5	0.756
62	Chola guitarfish	Rhinobatos percellens	1.38	2.62	2.3	0.518	8	3.12	1.126	0.744	8	3.25	0.707
63	Barbel drum	Ctenosciaena gracilicirrhus	2.62	2.75	1.79	0.744	8	3.12	1.126	0.463	8	3.25	0.707
64	Acoupa weakfish	Cynoscion acoupa	2.25	2.75	1.9	0.707	8	3.12	1.126	0.463	8	3.25	0.707
65	Jamaica weakfish	Cynoscion jamaicensis	2.62	2.75	1.79	0.744	8	2.62	1.061	0.463	8	3.25	0.707
66	Smallscale weakfish	Cynoscion microlepidotus	2.12	2.75	1.96	0.641	8	3.12	1.126	0.463	8	3.25	0.707
67	Green weakfish	Cynoscion virescens	2	2.88	2.12	0.756	8	3.38	1.061	0.354	8	3.25	0.707
68	Rockhead / Shorthead Drum	Larimus breviceps	2.75	2.75	1.77	0.463	8	3.12	1.126	0.463	8	3.25	0.707
69	Longtail croaker	Lonchurus lanceolatus	2.75	2.75	1.77	0.463	8	3.12	1.126	0.463	8	3.25	0.707
70	Bangamary / weakfish	Macrodon ancylodon	2.62	2.75	1.79	0.744	8	2.38	0.518	0.463	8	3.25	0.707
71	Southern kingcroaker	Menticirrhus americanus	2.62	2.75	1.79	0.518	8	2.88	1.126	0.463	8	3.25	0.707

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72	Whitemouth croaker	Micropogonias furnieri	2.38	2.75	1.86	0.518	8	2.38	0.518	0.463	8	3.25	0.707
73	Smalleye croaker	Nebris microps	2.5	2.88	1.94	0.756	8	3.12	1.126	0.354	8	3.25	0.707
74	Banded croaker	Paralonchurus brasiliensis	2.75	2.75	1.77	0.463	8	3.12	1.126	0.463	8	3.25	0.707
75	Blackfin croaker	Paralonchurus elegans	2.62	2.75	1.79	0.518	8	3.25	1.282	0.463	8	3.25	0.707
76	Smalleye stardrum	Stellifer microps	2.75	2.75	1.77	0.463	8	3.12	1.126	0.463	8	3.25	0.707
77	Rake stardrum	Stellifer rastrifer	2.75	2.75	1.77	0.463	8	3.12	1.126	0.463	8	3.25	0.707
78	Longfin scorpionfish	Scorpaena agassizii	2.25	2.5	1.68	0.707	8	3.5	1.069	0.756	8	3.25	0.707
79	Shortfin scorpionfish	Scorpaena brachyptera	2.62	2.38	1.43	0.518	8	3.5	1.069	0.744	8	3.25	0.707
80	Barbfish	Scorpaena brasiliensis	2	2.5	1.8	0.926	8	3.5	1.069	0.756	8	3.25	0.707
81	Smooth-head scorpionfish	Scorpaena calcarata	2.5	2.5	1.58	0.535	8	3.5	1.069	0.756	8	3.25	0.707
82	Plumed scorpionfish	Scorpaena grandicornis	2.12	2.5	1.74	0.835	8	3.5	1.069	0.756	8	3.25	0.707
83	Smooth-cheek scorpionfish	Scorpaena isthmensis	2.38	2.5	1.62	0.744	8	3.5	1.069	0.756	8	3.38	0.744
84	Scorpionfish 1	Scorpaena melasma	2.12	2.62	1.85	0.835	8	3.5	1.069	0.744	8	3.38	0.744
85	Scorpionfish 2	Scorpaena petricola	2.12	2.62	1.85	0.835	8	3.5	1.069	0.744	8	3.38	0.744
86	Pond perch	Diplectrum radiale	2.12	2.88	2.07	0.641	8	3.5	1.069	0.354	8	3.25	0.707
87	American harvestfish	Peprilus paru	2.38	2.75	1.86	0.744	8	3.38	1.061	0.463	8	3.25	0.707
88	Smallscale lizardfish	Saurida caribbaea	2.5	2.5	1.58	0.756	8	3.25	1.165	0.535	8	3.38	0.744
89	Inshore lizardfish	Synodus foetens	2.5	2.62	1.7	0.756	8	3.25	1.165	0.518	8	3.25	0.707
90	Banded puffer	Colomesus psittacus	2.38	3	2.1	0.744	8	3.12	0.991	0.000	8	3.25	0.707
91	Smooth puffer	Lagocephalus laevigatus	1.75	2.38	1.86	0.707	8	3.12	0.991	0.916	8	3.25	0.707
92	Checkered puffer	Sphoeroides testudineus	2.38	2.62	1.74	0.744	8	2.62	1.061	0.744	8	3.25	0.707
93	Smalleye smooth-hound	Mustelus higmani	1.75	2.75	2.15	0.886	8	2.88	1.126	0.463	8	3.25	0.707
94	Largehead hairtail	Trichiurus lepturus	1.88	2.5	1.88	0.641	8	2.88	1.126	0.926	8	3.25	0.707
95	Bluewing searobin	Prionotus punctatus	2	2.75	2.02	0.926	8	3.12	1.126	0.463	8	3.25	0.707
96	Smalleyed round stingray	Urotrygon microphthalmum	1.62	2.88	2.33	0.916	8	3.25	1.165	0.354	8	3.25	0.707

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97	White shrimp	Farfantepenaeus schmitti	2.88	2.62	1.63	0.354	8	1.62	1.061	0.518	8	2.12	0.835
98	Pink shrimp	Farfantepenaeus notialis	2.88	2.5	1.51	0.354	8	1.62	1.061	0.756	8	2.12	0.835
99	Pink spotted shrimp	Farfantepenaeus brasiliensis	2.88	2.62	1.63	0.354	8	2.25	1.165	0.518	8	2.25	0.707
100	Brown shrimp	Farfantepenaeus subtilis	2.88	2.62	1.63	0.354	8	2.25	1.165	0.518	8	2.12	0.835
101	Seabob	Xiphopenaeus kroyeri	2.88	2.5	1.51	0.354	8	2	1.069	0.926	8	2.38	1.408

3 BIOECONOMICS OF SHRIMP AND GROUNDFISH FISHERIES OF THE BRAZIL-GUIANAS SHELF

3.1 Introduction

The shrimp and groundfish valuable resources of the study region are found within the highly productive North Brazil Shelf Large Marine Ecosystem (NBSLME) and the adjacent Gulf of Paria. The NBSLME extends along northeastern South America from the Parnaíba River estuary in Brazil to the boundary with the Caribbean Sea and has a surface area of about 1.1 million km^2.. The Gulf of Paria, is a 7800 km^2 inlet of the Caribbean Sea lying between the Venezuelan coast and Trinidad; it hosts complex fisheries operated by heterogeneous fleets harvesting shared stocks of a diversity of species (Chakalall, Cochrane and Phillips, 2002; Phillips, Chakalall and Romahlo, 2009). One of the main fisheries in the area is the multi-species and multi-fleet shrimp fishery of the Gulf of Paria and Orinoco river delta. Trinidad and Tobago and Venezuela share the stocks. This study reviews the existing contributions to bioeconomic analysis of the shrimp and groundfish fisheries of the Brazil-Guianas shelf, and reports an update of economic performance of fleets operating in the Gulf of Paria and Orinoco river delta. Three management questions were addressed in this study: (i) what is the current economic performance of fleets targeting shrimp resources in the study region?, (ii) what is the bioeconomic status of the shared shrimp stock fishery?, and (iii) what is a bioeconomically sustainable level of effort for each vessel type in the shared stock fishery?

To answer the above- mentioned questions the following steps were undertaken: (i) a characterization of the shared stock fishery in terms of fleets, area of operation and species harvested, (ii) a review of available data to estimate biologic and economic parameters for the shared stock fishery, (iii) a calculation of the economic performance of fleets targeting the shrimp stock in the study region, (iv) a calculation of the open access performance of biomass of the main species harvested (i.e. brown shrimp *Farfantepenaeus subtilis*) and profits of artisanal and industrial fleets, considering also revenues from harvesting other shrimp species and corresponding bycatch value, and (v) building a multi-fleet and multispecies Schaefer-Gordon model to undertake a bioeconomic analysis for calculating sustainable effort levels for artisanal and industrial fleets in the study region.

3.2 Review of existing bioeconomic studies

Trinidad and Tobago and Venezuela have participated in four workshops since 1986 on the Biological and Economic Modelling of the Shrimp Resources of the Guiana-Brazil Shelf organized by the Food and Agriculture Organization of the United Nations (FAO) under the Western Central Atlantic Fishery Commission (WECAFC), as well as the four annual Stock Assessment Workshops on the Shrimp and Groundfish Resources of the Guianas-Brazil Shelf organized by FAO, DANIDA, NORAD and CFRAMP since 1997. The initial focus was on biological assessments of the shrimp and groundfish fisheries and at the 1999 and 2000 workshops bio-economic analyses were conducted to address specific management issues regarding the fisheries.

The following management issues were highlighted at the National Workshops on Shrimp and Groundfish Fisheries of the Guianas-Brazil Shelf held in Belém, Brazil, in 2009 and in Cumaná, Venezuela in 2000 (FAO, 2000):

a. Studies conducted up to 2000, including those completed under the FAO/WECAFC Shrimp and Groundfish Working Group, indicate full or over-exploitation of targeted as well as incidental capture stocks (Booth *et al.* 2001, Ehrhardt, 2001; Alió *et al.*, 1999a and 1999b; Soomai *et al.*, 1999; Lum Young, Ferreira and Maharaj, 1992b; Manickchand-Heileman and Kenny, 1990). Over-capitalization is also evident in the trawl fishery (Ferreira, 1998; Ferreira and Maharaj, 1993; Seijo *et al.* 2000; and Soomai and Seijo 2000).

b. The artisanal fisheries provide stability to rural coastal communities where it is estimated that some 195 fishermen are directly employed in the trawl fishery and 464 fishermen in the gillnet and line fisheries. Hence, although over-exploitation must be avoided to foster sustainable sources of food and employment, the socio-economic importance of the artisanal fisheries must be a major consideration in decision-making.

c. The interdependence of fleets due to the sequential nature of the shrimp fishery (i.e. artisanal boats harvesting juveniles, and semi-industrial and industrial vessels harvesting adults, create sequential externalities among fleets affecting different components of the population structure over time) represents a source of conflict and indicates the need to restructure the fishing effort and operations among the fleets to optimally utilize the resources.

d. Previous studies show that the majority of species captured incidentally by the trawl fleets is discarded (Maharaj, 1989; Kuruvilla, Ferreira and Soomai, 2001). A major proportion of the discards comprise juveniles of commercially important species targeted by other gears. This results in conflict among trawlers and other gear users.

e. Fisheries resources are shared among neighboring countries. It is thus imperative that assessments are done in collaboration with these countries and that the resources are jointly managed.

Information coming from the assessment groups that were held so far is summarized in the paragraphs below.

3.2.1 The multi-species and multi-fleet shared stocks shrimp fishery

The shrimp trawl fishery of Trinidad and Tobago and Venezuela is considered to be one of the most valuable fisheries in the Guianas-Brazil region. Five species of penaeid shrimp are of commercial importance, namely *Penaeus subtilis, P. notialis, P. schmitti, P. brasiliensis,* and *Xiphopenaeus kroyeri.* One of the dominant species exploited by the fleets is *Penaeus subtilis* (brown shrimp). An assessment of the *P. subtilis* stocks in the Orinoco-Gulf of Paria region was conducted during the 1997 meeting of the Working Group using landings and trip information for the period 1973 to 1996 for Trinidad’s artisanal, semi-industrial, and industrial trawl fleets, and Venezuela’s industrial fleet (Alió *et al.*, 1999a). The results of the study indicate that the maximum sustainable yield (MSY) is approximately 1 300 metric tonnes, and the fishing effort at which this yield can be obtained (f_{MSY}) is in the region of 13,000 days at sea for both fleets combined. The study suggested that the shrimp resources were over-exploited during the period 1990 to 1993, and recommended that the fishing effort be maintained sufficiently below f_{MSY} for several years and should not be allowed to increase beyond the 1996 level i.e., approximately 11,000 days (4,500 for Trinidad, and 6,700 for Venezuela). Landings and catch rate should be monitored for evidence of stock rebuilding so that fishing effort can be adjusted accordingly. The need to fill the gaps in the dataset was highlighted especially in the case of landings and trip information for the industrial fleet of Trinidad.

An assessment was also conducted for the *P. subtilis* and *P. schmitti* stock exploited by the Trinidad artisanal fleet in the Orinoco Delta of Venezuela for the 1990/1991 fishing season (Lum Young, Ferreira and Maharaj, 1992b). These results indicated that the shrimp stocks were fully to over-exploited.

3.2.1.1 Economic performance of the trawl fleet

Costs and earnings studies have been conducted in 1993 and 1997 for the trawl fishery of Trinidad by Ferreira and Maharaj (1993), and Ferreira (1998). The latter was based on interviews conducted with nine artisanal, four semi-industrial, and five industrial trawler owners. The average vessel revenues, costs and profits for 1997 were estimated for each trawler category, with net profits to owner being estimated at approximately TT$17,500 for an artisanal trawler, TT$16,600 for a semi-industrial, and a loss of TT$79,000 for an industrial trawler. Of the vessels surveyed, 33% of the artisanal, 50% of the semi-industrial, and 60% of the industrial were found to be operating at a loss. Several indicators of vessel performance were also presented for each of the trawler categories. The results suggest that the small trawlers are more efficient than the large trawlers such that for every dollar spent in operating the vessel, a dollar is earned by an industrial trawler, TT$1.40 is earned by a semi-industrial trawler, and TT$1.60 is earned by an artisanal trawler. The annual return on investment was estimated to be approximately 33% for an artisanal trawler, 6% for a semi-industrial trawler, and –13% for an industrial trawler.

3.2.1.2 Bio-economic analysis of shrimp trawl fishery

A bio-economic analysis was conducted at the 1999 and 2000 meetings of the Working Group which used data from the above economic study and biological data collected from the trawl fishery in Trinidad, as well as data on the Venezuelan industrial trawl fishery (Seijo *et al.* 2000). This analysis covered four shrimp species, namely, *P. subtilis* (brown shrimp), *P. schmitti* (white, cock or cork shrimp), *P. notialis* (pink shrimp), and *Xiphopenaeus kroyeri* (seabob, honey or jinga shrimp). The latter two species are caught in negligible quantities by the Venezuelan fleet and hence data were not included for these species for this fleet. Landings and trip data were included for the period 1995 to 1998 for Venezuela, and 1995 to mid- 1996 for Trinidad since data beyond this date were not available at the time.

The results indicated that as the fishing effort increases, the final biomass of *P. subtilis* at the end of the four-year period decreases and the probability of the biomass falling below the limit reference point of 0.25 of the virgin biomass (481 tonnes) increases, with the probability being 39% at the 1999 level of effort (8,175 days (in industrial fleet units) for the Trinidad fleet, and 9,348 days for the Venezuelan fleet). The optimum effort at which the Maximum Economic Yield of US$46.1 million (US$28.5 million for Venezuela and US$17.6 million for Trinidad) for the shared fishery is attained is calculated to be 5,000 days for the Trinidad fleet and 7,697 days for the Venezuelan fleet. The analysis therefore recommended that the fishing effort of both the Trinidad and Venezuelan fleets should not be increased beyond the level at that time. In addition, the optimum allocation of fishing effort between the two fleets which would yield maximum profits to this shared fishery was 61% of the 1999 effort of the Trinidad fleet and 82% of the effort of the Venezuelan fleet.

Decision tables for alternative management strategies under varying states of nature were derived from the model. The net present value of the joint Trinidad and Tobago/Venezuela fleet over the four-year period was estimated for three levels of fishing effort (current level, 90% and 80% of current level) at recruitment levels of 120% and 80% of the 1999 level. The most favorable management strategy was found to be 80% of the current level of effort (6,540 days at sea for the Trinidad fleet and 7,478 days at sea for the Venezuelan fleet). Using precautionary management criteria, this strategy maximized the minimum net present value and minimizes the expected value of loss of opportunities (See decision tables under Maximin and Bayesian precautionary criteria in Seijo, Defeo and Salas, 1998, and Anderson and Seijo, 2010).

3.2.2 The multi-species and multi-gear groundfish fishery

Groundfish is predominantly landed as bycatch from the demersal shrimp trawl fleet as well as the gillnet and line fisheries which target the mackerels (Scomberomorus spp) and other coastal pelagic species. The main species of commercial importance in the groundfish fishery are the sciaenids, *Micropogonias furnieri* (whitemouth croaker) and *Cynoscion jamaicensis* (Jamaica weakfish) locally known as cro-cro and salmon respectively. These species are generally landed by vessels operating on the west coast (Gulf of Paria) and on the south coast (Columbus Channel) of Trinidad. Apart from trawling, the main gear used in catching these species are demersal-set monofilament and multifilament gillnets, hand lines (banking and a-la-vive), and demersal-set long lines (palangue). From the 1998 census of fishing vessels (Chan A Shing, 1999) it is estimated that there were 464 vessels using gillnets and lines.

3.2.2.1 Stock assessment of groundfish

Stock assessments were conducted at the 1998 and 1999 meetings of the Working Group for the croaker (*M. furnieri*) and salmon (*C. jamaicensis*) using catch and effort data obtained from artisanal and semi-industrial trawlers, gillnets, palangue, banking and a-la-vive gear operating in the Gulf of Paria from 1989 to 1997. Results show that the levels of fishing effort exceeded the levels at which Maximum Sustainable Yield (MSY) for both species would be obtained (Soomai *et al*. 1999). The results of this assessment clearly indicated a very intensive exploitation of these resources. This may be attributed to the combined effort of six gear types operating in the Gulf of Paria. The analysis, however, used CPUE for the Trinidad and Tobago artisanal fleet only. Data from the Trinidad and Tobago industrial trawl fleet and other fleets operating in the Gulf of Paria were not available and hence the biomass and fishing mortality values can be considered to be approximate.

At the 1999 workshop, a joint analysis was also carried out with Venezuela for *M. furnieri* which used artisanal and industrial data from both countries (Alió *et al.*, 1999b). The assessment used catch and effort data for these six fleets and the Venezuelan industrial and artisanal fleets as well as biological data from the Venezuelan industrial fleet. Results show that the MSY for croaker is 1,500 tonnes and this has generally been exceeded from 1987-1993 and in 1998.

The results of both studies are consistent and it was recommended that the fishing effort should not be increased beyond current levels. The need to fill the gaps in the data- set was highlighted, especially in the case of catch and effort information for the industrial fleet of Trinidad. It was therefore recommended that catch and effort data for groundfish be collected from the industrial trawl fleet, and a biological sampling programme be implemented for the groundfish species so that data on the size structure of both species can be collected from the trawl, gillnet and line fleets to provide an improved assessment of the current state of the fishery.

3.2.2.2 Economic performance of artisanal fleets landing groundfish

A cost and earnings study was conducted in 2000 for the artisanal gillnet and line fisheries of Trinidad. The study was based on interviews conducted with ten monofilament gillnet operators, four multifilament gillnet, eight banking, four a-la-vive and six palangue operators. The format of the interviews was consistent with that used for the trawl fishery (Ferreira, 1998). The average vessel revenues, costs and profits for 1999 were estimated for each of the gillnet and line fleets. Annual net profits to monofilament gillnet operators were estimated at TT$65,943, TT$5,716 for the multifilament gillnet, TT$57,552 for the banking, TT$69,809 for the a-la-vive and TT$67,313 for palangue. Of the vessels surveyed, 20% of the monofilament gillnet operators were operating at a loss, compared with 25% of the multifilament gillnet, 25% of the banking, and 17% of the palangue operators.

3.2.2.3 Bioeconomic analysis of artisanal groundfish fishery

A preliminary bio-economic analysis was carried out for the croaker (*M. furnieri*) and salmon (*C. jamaicensis*) at the 1999 meeting of the Working Group based on biological and economic data collected from the artisanal fleets landing groundfish. This analysis was completed at the 2000 workshop of Cumana (Soomai and Seijo, 2000). A multispecies, multigear dynamic bio-economic model was used to examine the performance of the five artisanal fleets over a twenty (20) year period. The model used observed catch and effort data obtained from the trawl (artisanal and semi-industrial), monofilament gillnet, multi-filament gillnet, hand line (banking and a-la-vive) and artisanal long line (palangue) fleets from 1984 to 1997.

This model was used to test several management strategies to observe the temporal fluctuations in performance variables (e.g. profits, yield, and biomass) over a twenty (20) year simulation, from 1989 to 2009, under open access and limited effort conditions. Results show that in an "Open Access Fishery" yield and net revenues decrease along with biomass of both species. Initial biomass levels *for M. furnieri* and *C. jamaicensis* were estimated at 6,322 and 602 tonnes respectively and forecasted at 198 and 109 tonnes respectively at the end of the twenty -year period. Under a "Limited Entry Fishery" fishing effort was fixed for trawling and monofilament gillnets at the level of effort that optimizes net present value for the five fleets while the other fleets were allowed to operate under open access. Under these conditions, biomass, yield and rent improve.

Decision tables were constructed to investigate the performance of the fishery, in terms of the net present value and the biomass of *M. furnieri,* under alternative management options based on limiting effort of the different fleets. The catchability for the monofilament gillnets was higher than the other gears and its limitation or reduction in the fishery would result in greater net present values of resource rent to society. The recommended management option was however to limit effort for all fleets since this option maximizes the minimum final biomass attainable and minimizes the expected value of loss of opportunity to the fishery.

3.3 Management recommendations of the 1999 and 2000 bioeconomic assessments

The recommendations for management of the shrimp and groundfish fisheries based on the results of the shrimp and groundfish bioeconomic assessments conducted in 1999 and 2000 were the following (Seijo *et al.* 2000; FAO, 2001; Ferreira and Soomai, 2001):

(i) Limit number of trawlers with a view to a reduction in fleet size. In 1988 a Cabinet decision established a ceiling on the total number of artisanal, semi-industrial and industrial trawlers. As proposed in the Management Plan for the Trawl fishery designed by the Fisheries Division and FAO in 1992, owners of trawlers should be required to hold entitlements to the fishery and these entitlements should be transferable provided the replacement vessel does not have a greater horsepower or fishing power, and provided that replacement of the vessel is in keeping with the level of fishing effort approved in the Plan. In addition, as recommended in the bio-economic assessment of the shrimp trawl fishery, the fishing effort should be reduced to 80% of the current level in order to increase the economic yield to this fishery.

(ii) Limit level of fishing effort on groundfish resources. The combined effort of all fleets impacting on groundfish resources, namely trawl, monofilament and multifilament gillnet, hand line (banking and a-la-vive), and palangue, should not be allowed to exceed current levels.

(iii) Implement a biological and economic data collection programme for the groundfish fishery. This programme would facilitate the conduct of age-structured biological and bio-economic analyses which would provide more refined assessments of the status of the fishery.

(iv) Government support for the shrimp and groundfish data collection programme**.** Availability of financial and human resources is critical to the success of the following activities:

a. Logbook and observer programmes for the semi-industrial and industrial trawl fleets

b. On-going shrimp biological sampling programme

c. Establishment of the groundfish biological sampling programme

d. Economic data collection from the trawl, gillnet and line fisheries.

(v) Stakeholder participation in the management and development of the fishing sector. This is essential for the successful implementation of any fishery management plan and would be achieved through the formalization of the consultation process between the Government and the fishing industry.

(vi) Activate the existing 1989 Protocol on co-operation in fisheries research between Trinidad and Tobago and Venezuela. The FAO should be approached to provide technical assistance in the following:

a. Harmonization of data collection and analysis methods.

b. Joint length-based assessments for shrimp and groundfish species.

c. Joint bio-economic analyses by fleet for shrimp and groundfish species.

Bilateral meetings are considered essential in the inter-sessional periods between regional assessment meetings.

3.4 Current status of the shrimp fishery

Some of the main characteristics of the fleets operating in this shared ecosystem and the target and bycatch species harvested by these two countries are summarized as follows (Fabres, Maharaj and Ferreira, 1995; Seijo *et al*. 2000; Die *et al*. 2004; Ferreira and Medley, 2007:

3.4.1 The Trinidad and Tobago shrimp fishing fleets

Trinidad and Tobago operate four fleet types: (i) Artisanal type I fleet comprised of vessels (7 to 10 m with outboard engines), (ii) Artisanal Type II vessels (8 to 12 m with inboard diesel engines), (iii) Semi-industrial Type III vessels (10 to 12 m with inboard diesel engines), and (iv) Industrial Type IV vessels (17 to 22 m Gulf of Mexico double-rigged vessels). All trawlers operate in the Gulf of Paria. The industrial fleet also operates in the Columbus Channel, as well as on the north coast of Trinidad (west of Saut D’eau). Up until 1995, 70 artisanal vessels were also permitted to trawl in the Orinoco Delta of Venezuela under an agreement between the two countries.

3.4.2 The Venezuela shrimp fleet

The Venezuelan fleet currently comprises only an artisanal fleet, but prior to 2009 also comprised an industrial fleet. This industrial trawl fleet was mostly metal vessels 24 to 30 m in length and operated in the southern Gulf of Paria and in front of the Orinoco river delta. This fleet targeted shrimp (*P. subtilis* and *P. schmitti*) and finfish of the families: Sciaenidae, Carangidae, Haemulidae, Trichiuridae, Lutjanidae, Arridae and Mustelidae. On the other hand, the Venezuelan artisanal fleet is composed of trawlers: 8 m in length with outboard engines essentially operating in the northern area of the Orinoco river delta. This fleet targets only juvenile *P. schmitti*, as artisanal fishing takes place in estuaries and coastal lagoons where only juveniles occur .

3.4.3 Proportion of shrimp species harvested by the Trinidad and Tobago and Venezuela fleets

Five species of shrimp are harvested by the Trinidad and Tobago trawlers: *Penaeus subtilis*; *P. schmitti*; *P. notialis*; *P. brasiliensis*; and *Xiphopenaeus kroyeri*. Several species of demersal finfish from families such as *Sciaenidae*, *Serranidae*, *Haemulidae* and *Lutjanidae* are caught incidentally or may be targeted. The artisanal Venezuelan fleet harvests *Farfantepenaeus subtilis* and *Litopenaeus schmitti*. The industrial and semi-industrial fleets of Trinidad harvest mostly *Farfantepenaeus subtilis* and *Farfantepenaeus notialis.* The Trinidad artisanal fleet harvest *Xiphopenaeus kroyeri, Litopenaeus schmitti, Farfantepenaeus notialis, F. subtilis.* The proportion of species caught by the different fleets targeting shrimp species in the Gulf of Paria and Orinoco river delta is presented in Figure 3.1.

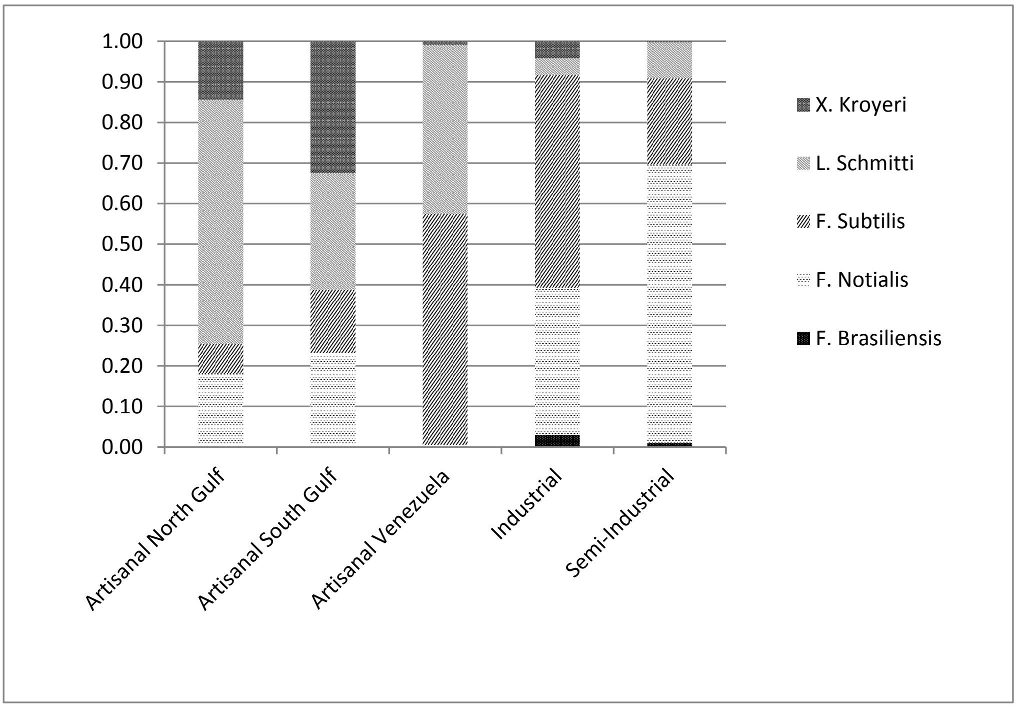

Figure 3.1. Proportion of shrimp species caught by different fleets in the study region (Ferreira and Medley, 2007).

3.5 A comparison of fleets operating in the study region in 2000 and 2010

The number of vessels of fleets targeting shrimp species in the Gulf of Paria and Orinoco Delta is summarized in Figure 3.2. The following can be observed:

a. The Trinidad and Tobago artisanal fleets (Type I and II) decreased slightly during the decade under consideration to 86 vessels
b. The Venezuelan artisanal fleet increased substantially over this period from 28 to 155.
c. The Trinidad and Tobago semi-industrial fleet (Type III) decreased from 11 to 8 vessels,
d. The Trinidad and Tobago industrial fleet increased from 19 to 27 over the period, and
e. The Venezuelan industrial fleet which had 88 in 2000 ceased to operate in 2009.

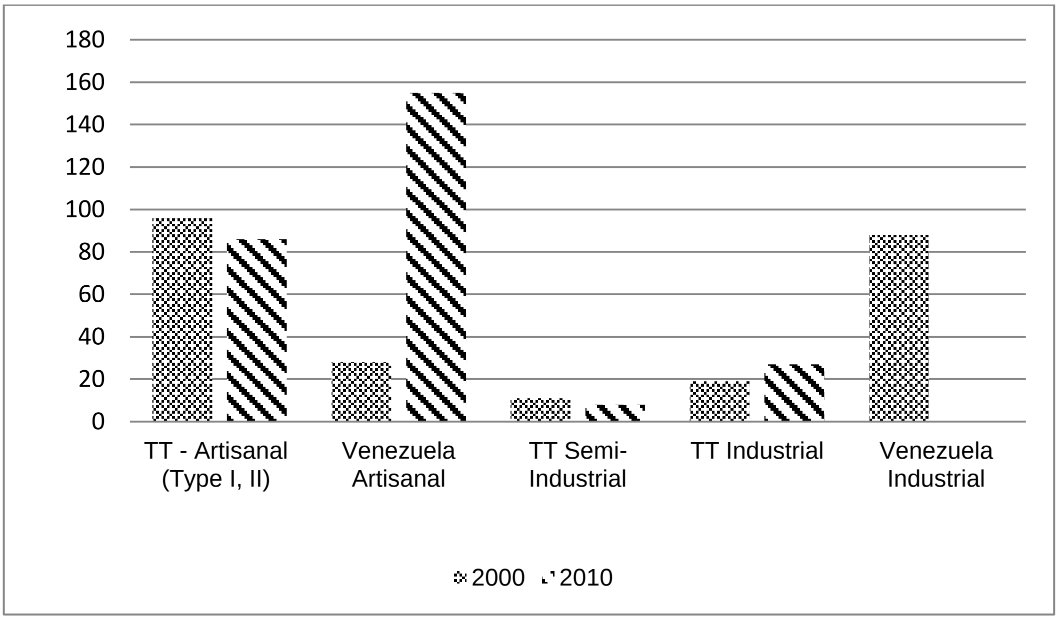

Figure 3.2. Number of vessels of artisanal, semi-industrial and industrial fleets operating in the Gulf of Paria and Orinoco river delta in 2000 and 2010.

3.6 Economic performance of the fleets

As part of the cooperation of this FAO project with national fisheries institutions, a survey of current costs and revenues of artisanal, semi-industrial, and industrial fleets was undertaken by the Fisheries Division of Trinidad and Tobago. Monthly catch and effort data for 2010 for the artisanal, semi-industrial and industrial fleet, and updated costs from the survey mentioned above were used to assess the performance of the three fleets

3.6.1 Value of shrimp catch and bycatch of artisanal, semi-industrial and industrial fleets.

The values of shrimp catch and bycatch of artisanal, semi-industrial and industrial fleets of Trinidad and Tobago harvested in the Gulf of Paria and Orinoco river delta are presented in Figure 3.3.

In 2010, the value of bycatch represented 18% of total catch value of the three fleets. It should be pointed out, however, that the contribution of bycatch to total revenues varies among fleets. For the artisanal fleet, by-catch represented 11% of their total revenues, while it contributed between 27 and 21 percent to total revenues of semi-industrial and industrial fleets respectively. In 2010, calculated total value of shrimp catch and bycatch of the artisanal, semi-industrial and industrial fleets of Trinidad and Tobago was 5.7 million US$.

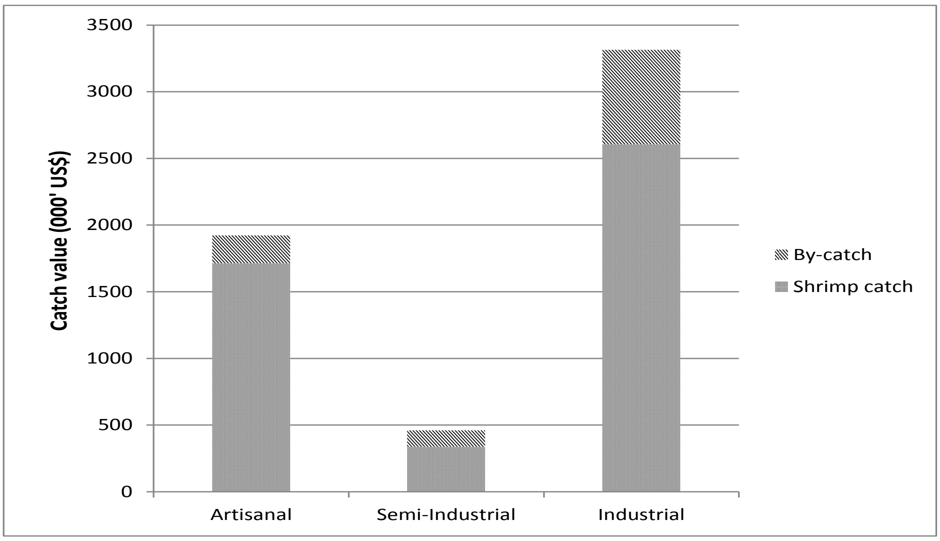

Figure 3.3. Fleet-specific values of shrimp catch and by-catch of the Trinidad and Tobago shrimp fishery of the Gulf of Paria and Orinoco river delta in 2010.

3.6.2 Seasonal and annual profits of fleets

Associated with the above is the comparative economic performance of the artisanal, semi-industrial and industrial economic seasonal and annual economic performance. Seasonal and annual profits of the three fleets are presented in Figure 3.4. A significant difference is observed between the month where highest profits are obtained by the artisanal fleet (mode: August) against the month of highest profits of the semi-industrial and indistrial fleets (mode: March). The distributions tend to express the sequential nature of artisanal/industrial shrimp fisheries.

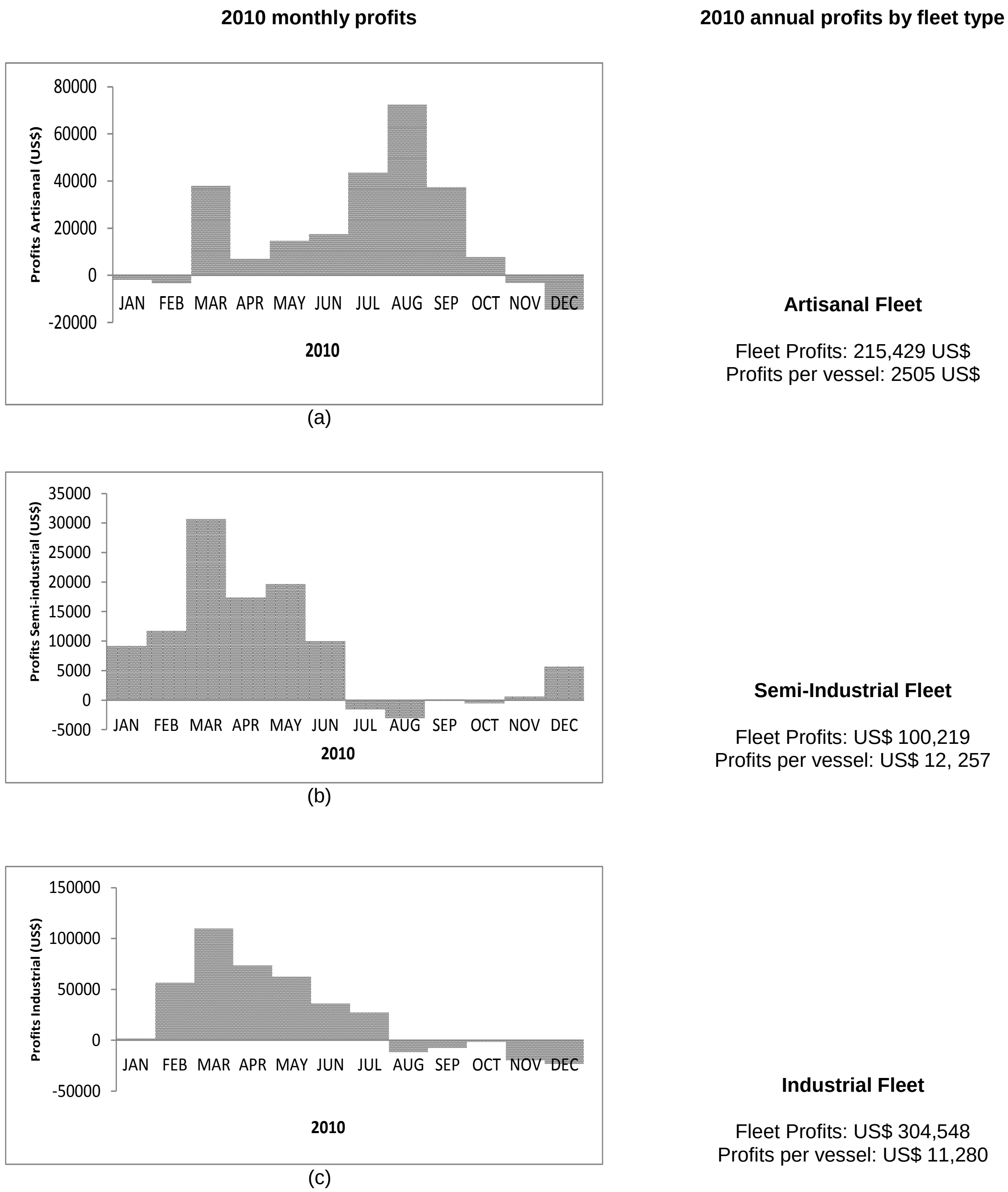

Figure 3.4. Calculated seasonal and annual profits of artisanal, semi-industrial and industrial fleets of Trinidad and Tobago for 2010, based on catch and effort data and revenues and costs survey.

Total costs, total revenues and profits of the three types of vessels are summarized in Table 3.1.

Table 3.1 Calculated annual costs, revenues and profits of the artisanal, semi-industrial and industrial shrimp fleets of Trinidad and Tobago operating in the Gulf of Paria and Orinoco river delta for 2010.

Fleet type	Total costs (USD/vessel)	Total revenues (USD/vessel)	Profits (USD/vessel)	Number vessels
Artisanal	19846	22351	2505	86
Semi-Industrial	44983	57510	12527	8
Industrial	111440	122719	11280	27

3.7 Bioeconomic analysis of the multispecies shrimp fishery of the Gulf of Paria and Orinoco river basin

3.7.1 Procedure to undertake the bioeconomic analysis

Bioeconomic models are useful for estimation of reference points for biologic and economic indicators, and for exploring the effect of alternative management strategies. Applied to the shrimp fishery of the Gulf of Paria and Orinoco river delta, models can provide analytical and numerical estimates of bio-ecologic and socio-economic target reference points (TRPs), and the corresponding input and output controls needed to achieve them. They are also useful to determine Limit Reference Points (LRP´s), beyond which the main stock and the fishery as a whole are compromised. In their dynamic versions, they can estimate the potential impacts of alternative management strategies and regulations on bio-economic indicators. A summarized procedure for applying the bioeconomic approach for defining and using indicators and reference points in the Brazil-Guianas shrimp fisheries is presented as follows:

1. Identify fishery management questions for the transboundary shrimp fishery of the Gulf of Paria and Orinoco river delta:
   a) In the absence of the Venezuelan industrial fleet and with the increasing number of artisanal vessels in the study region, which is the level of artisanal effort that corresponds to MSY (maximum sustainable yield of the main species harvested *F. subtilis*)?
   b) Which is corresponding effort level for the shared stock fishery to operate in maximum economic yield (MEY)?
2. Estimate biologic and economic parameters for the fishery, needed to apply an appropriate bioeconomic model of the fishery.
3. Calculate analytically and/or numerically the level of effort for achieving target reference points such as maximum economic yield (MEY) or maximum sustainable yield (MSY).
4. Build decision-tables with and/or without mathematical probabilities to acknowledge uncertainty in critical biologic and/or economic parameters, likely to be exacerbated by the effect of climate change on marine fisheries (Cochrane *et al.,* 2009). In this case, decision tables were built considering possible states of nature of intrinsic growth rate of shrimp populations in the study area. Apply different precautionary systematic criteria to deal with uncertainty.

3.7.2 Bioeconomic model used to calculate reference points

For the management questions identified above and data available for the fishery (i.e. catch and effort data), a simple multi-species, and multi-fleet Schaefer-Gordon dynamic model was developed for the fishery. Model equations are presented in Table 3.2.

Table 3.2. Equations of bioeconomic model used to calculate the target reference values under different management criteria.

Description	Equation	Unit of measurement
Dynamic biomass function	$X_{t+1} = X_t + r \cdot X \cdot \left(1 - \frac{X_t}{K}\right) - \sum_v y_{v,t}$	tonne
Fleet specific dynamic catch	$y_{v,t} = q_v E_{v,t} X_t$	tonne
Fleet specific dynamic total revenues	$TR_{v,t} = p(y_{v,t} + yb_v) + p_b Ob_{v,t}$	US$
Fleet specific total costs	$TC_{v,t} = c_v E_{v,t}$	US$
Fleet specific profits	$\pi_{v,t} = TR_{v,t} - TC_{v,t}$	US$

Where:

- **v**:vessel type (i.e. artisanal or industrial)
- **X**: biomass of *P. subtilis*
- **r**: *P. subtilis* population instrinsic growth rate
- **K**: shrimp (*P. subtilis)* species carrying capacity
- **y**: catch of *P. subtilis*
- q_v: fleet specific catchability coefficient
- TR_v: fleet specific total revenue
- E_v: fleet specific fishing effort
- **p**: weighted average price of other shrimp species
- yb_v: fleet specific average catch of other shrimp species
- Ob_v: fleet specific bycatch
- TC_v: fleet specifc total cost
- c_v: unit cost of efort
- π_v: fleet specifc profits

3.7.3 Bioeconomic parameter set

The biologic and economic parameters used to undertake the bioeconomic analysis and determine alternative target reference point and corresponding effort levels of artisanal and industrial fleets are presented in Table 3.3.

Table 3.3. Bioeconomic parameters used to calculate fleet -specific effort at MSY and MEY.

Parameter	Symbol	Value	Unit of measurement	Source
Carrying capacity of *F. subtilis*	K	10000	ton	Die *et al.* 2004
Intrinsic growth rate	r	0.4	1/year	Die *et al.* 2004
Catchability coeficient small-scale vessel	q_1	0.0005	CPUE/vessel/year	This study
Catchability coeficient industrial vessel	q_2	0.0021	CPUE/vessel/year	This study
Prop. of other shrimp caught by artisanal vessels	Ysa	0.41	Proportion	This study
Prop. of other shrimp caught by industrial vessel	Ysi	0.47	Proportion	This study
Average bycatch per artisanal vessel	Yba	2.854	ton/vessel/year	Fisheries Division T & T
Average bycatch per industrial vessel	Ybi	22.13	ton/vessel/year	Fisheries Division T & T
Price of bycatch	Pb	1300	US$/ton	Fisheries Division T & T
Price of shrimp caught by artisanal vessel	Pa	5200	US$/ton	Fisheries Division T & T
Price of shrimp caught by industrial vessel	Pi	6000	US$/ton	Fisheries Division T & T
Unit cost of effort of artisanal vessel	c_1	19846	US$/vessel/year	This study
Unit cost of effort of industrial vessel	c_2	111440	US$/vessel/year	This study
Initial biomass	X_0	4971	ton	Die *et al.* 2004

3.7.4 Indicators and possible reference points to analyze alternative management options

The biologic and economic reference points calculated for this shared stock fishery are presented in Table 3.4.

Table 3.4. Target reference point and corresponding sizes of artisanal and industrial fleets targeting shrimp species in the Gulf of Paria and Orinoco river delta.

Management Decision	Artisanal vessels	Industrial vessels
f_{2010} current effort	241	27
f_{MSY} with constant industrial vessels	295	27
f_{MSY} with constant artisanal vessels	241	39
$f_{MEY,}$ with constant industrial vessels	122	27

Optimizing effort to operate at biomass producing maximum sustainable yield B_{MSY} indicates that in the absence of the Venezuelan fleet, effort could be expanded as follows: (i) If the total number of industrial vessels of 2010 remains constant, i.e. 27 industrial vessels, the artisanal vessels could increase by 22%, *i.e.* from the current 241 to 295 vessels. If the current number of artisanal vessels is kept constant over time, the industrial vessels could increase from 27 to 39.

To operate in a way that biomass is kept at the level that produces maximum economic yield (MEY) the analysis indicates that, keeping constant the industrial fleet, the effort of the artisanal fleet should not be greater than that of 121 vessels (close to 50% of the current artisanal fleet size including the Venezuelan fleet).

3.8 Management of the shrimp fishery under uncertainty conditions

Bioeconomic models can be used to aid decision -making under uncertainty by calculating the possible performance values for indicators resulting from alternative management decisions, and introducing them in a decision table that considers possible states of nature. Climate change will tend to increase uncertainties associated with future biomass availability of shrimp and groundfish species in the study region. Such uncertainties impose new challenges to risk assessments which are usually based on knowledge of probabilities of occurrence of past events. Data to determine effects of previous climate changes in the best of cases cover some decades and would not be an appropriate guide for future expectations.

Uncertainties associated with future intrinsic growth rate parameters and possible changes in carrying capacity of the Brazil-Guianas ecosystem should be accounted for in the decision-making process. In this analysis decision tables are built to consider the alternative effect of managing the growing artisanal fleet under three possible states of nature associated with shrimp population growth parameters in the Gulf of Paria and Orinoco river delta.

With the fishery context described in previous sections, an application of the decision theory for systematic choice under uncertainty considering different risk attitude criteria, with and without mathematical probabilities is suggested. Under this approach, decision-makers in the multi-species multi-fleet shared-stock shrimp fishery are expected to select one management strategy, ***d***, out of a set of ***D*** alternative options. When selecting a strategy, the fishery manager should be aware of the corresponding consequences. These consequences are likely to be a function of the cause-effect relationships specified in the fishery bioeconomic model, the estimated bio-ecologic and economic parameters, and the possible states of nature.

In decision analysis, it is important to be able to estimate a loss of opportunities function, $L(d,\theta)$, also called *regret matrix* in the decision theory literature (Parmigiani and Inoue, 2009), which reflects the resulting losses of having selected strategy ***d*** when the state of nature occurring is $\boldsymbol{\theta}$.

If *prior* or *posterior* probabilities are available to build decision tables for fishery managers, the expected values (*EV*) and their corresponding variance (*VAR*) should be estimated for the selected fishery performance variable (*FPV)*, (e.g. stock biomass, yield, profits). There are, however, different degrees of risk aversion, and therefore the decision theory provides alternative criteria for increasing degrees of caution in decision making (Shotton and Francis, 1997; Seijo, Defeo and Salas, 1998). Applying these concepts to the multi-species and multi-fleet shrimp fishery, the criteria *with* and *without* mathematical probabilities are presented as follows.

3.8.1 Bayesian criterion

The Bayesian criterion is a procedure that uses *prior* or *posterior* probabilities to aid the selection of a management strategy (i.e. shrimp fishery fishing effort of different fleets). It helps the fishery manager to select the decision that minimizes the expected loss of opportunities. Decisions without experimentation use *prior* distributions estimated out of experiences that are translated subjectively into numerical probabilities. Fishery decisions that are based on experimentation can use *posterior* probabilities. Posterior probabilities are the conditional probability of state of nature θ, given the experimental data. The criterion proceeds to select the fishery management option with the lowest expected value of loss of opportunities. For this, we need to build a loss of opportunities matrix or regret matrix as mentioned above. Because of current absence of probabilities of occurrence of alternative states of nature this decision criterion was not applied to the shrimp fishery of the Gulf of Paria and Orinoco river delta. This criterion was not applied in this study because of lack of probabilities of occurrence of states of nature considered.

3.8.2 Decision criteria without mathematical probabilities: Minimax and Maximin criteria

In the absence of sufficient observations to assign probabilities to possible states of nature in shrimp and groundfish fisheries of the Brazil-Guiana shelf, there are two decision criteria reflecting different degrees of precaution concerning selection of fishery management strategies: Minimax and Maximin (Anderson and Seijo, 2010; Seijo, Pérez and Caddy, 2004; Seijo and Caddy, 2000). The Minimax criterion uses the regret or loss of opportunity matrix to calculate the maximum loss of opportunities of each management strategy and selects the one that provides the minimum of the maximum losses. This criterion proceeds as if nature would select the probability distribution, defined for all possible states of nature, which is least favourable for the decision-maker of the shrimp fishery. Maximin, uses the performance variable decision table (payoff table) that estimates the resulting values for a set of combinations of alternative decisions and states of nature. The criterion calculates a vector of the minimum values for the performance variable (e.g. F. *subtilis* stock biomass, fishery profits) resulting from each alternative management decision. Then, the fishery manager proceeds to select the maximum of the minimum of those values. This is the most cautious of the decision theory criteria.

3.8.3 Decision Tables for the multi-species and multi-fleet fishery of the Gulf of Paria and Orinoco river delta.

Decision tables were built for a set of alternative decisions and a set of states of nature associated, as mentioned above, with possible values of the intrinsic growth rate of brown shrimp (*F. subtilis*), the main species captured in this fishery. Concerning alternative decisions under consideration to answer the management questions expressed in sub-section 1.7.1, the following ones were treated in the analysis: (i) limiting entry of artisanal and industrial vessels so that effort is not expanded beyond current levels (ii) limiting entry at maximum sustainable yield, $f_{v,MSY}$, by fixing the number of industrial vessels according to current effort, and determining the number of artisanal vessels to operate in MSY, and (iii)) limiting entry at maximum economic yield, $f_{v,MEY}$, by fixing the number of industrial vessels according to current effort, and determining the number of artisanal vessels to operate at MEY. Decision tables with alternative degrees of caution using the Maximin and Minimax criteria were built for biomass and profits as performance variables.

Applying the Maximin criterion to the shrimp fishery requires determining a vector of minimum performance values for each of the management decisions under consideration when alternative states of nature θ_i (i.e. alternative intrinsic growth rates r=0.3, r=0.4, and r=0.6) occur (Table 3.5). Once the vector is determined, then the maximum of the minimum values is identified as corresponding to the cautious management decision, d_3 in this case.

Table 3.5. Application of the Maximin criterion to the shrimp fishery of Gulf of Paria and Orinoco river delta, using biomass of brown shrimp (*F. subtilis*) as the performance variable.

	Alternative States of Nature under climate change			Maximin Criteria
Alternative Decisions	θ_1 (r=0.3)	θ_2 (r=0.4)	θ_3 (r=0.6)	Min
d_1: limiting entry to current f_v (industrial=27; artisanal=241)	4206	5654	7103	4206
d_2: $f_{v\,msy}$, industrial (27 vessels); artisanal (295 vessels)	3331	4998	6665	3331
d_3: $f_{v\,mey}$, industrial (27 vessels); artisanal (122 vessels)	6134	7100	8067	**6134**
Performance indicator: Biomass of brown shrimp (F. subtilis), ton.				
Maximin Criteria:	Select the maximum of the minimum performance vector			

The results of applying the Maximin criterion with fishery profits as the performance variable are presented in Table 3.6. Along with profits, the Maximin criterion also selects decision d_3 of operating the fishery with levels of effort corresponding to maximum economic yield.

Table 3.6. Application of the Maximin criterion to the shrimp fishery of Gulf of Paria and Orinoco river delta, using shrimp fishery profits as the performance variable.

	Alternative States of Nature under climate change			Maximin Criteria
Alternative Decisions	θ_1 (r=0.3)	θ_2 (r=0.4)	θ_3 (r=0.6)	Min
d1: limiting entry to current f_v (industrial=27; artisanal=241)	-0.17	1.73	3.63	-0.17
d_2: $f_{v\,msy}$, industrial (27 vessels); artisanal (295 vessels)	-1.46	1.05	3.56	-1.46
d_3: $f_{v\,mey}$, industrial (27 vessels); artisanal (122 vessels)	1.48	2.34	3.20	**1.48**
Performance indicator: Profits of brown shrimp (*F. subtilis*) fishery (million US$)				
Maximin Criteria:	Select the maximum of the minimum performance vector			

3.8.4 The loss of opportunity matrix

To apply the Minimax criterion, a loss opportunity matrix for the performance variable needs to be calculated. This is done for each alternative decision being considered, by identifying the maximum performance value associated with one specific state of nature (e.g θ_1 (r=0.3)) with and subtracting from this value each of the performance values that could occur with each alternative decision when this specific state of nature is present. The loss of opportunity matrices for biomass and fishery profits as performance variables are calculated in Table 3.7 and Table 3.8 for the shrimp fishery under consideration.

Table 3.7. Application of the Minimax criterion to the shrimp fishery of Gulf of Paria and Orinoco river delta, using biomass of brown shrimp (*F. subtilis*) as the performance variable.

	Loss of Opportunity Matrix			
	Alternative States of Nature under climate change			Minimax Criteria
Alternative Decisions	θ_1 (r=0.3)	θ_2 (r=0.4)	θ_3 (r=0.6)	Max
				Loss of Opportunities
d1: limiting entry to current f_v (industrial=27; artisanal=241)	1928	1446	964	1928
d_2: $f_{v\,msy}$, industrial (27 vessels); artisanal (295 vessels)	2803	2102	1402	2803
d_3: $f_{v\,mey}$, industrial (27 vessels); artisanal (122 vessels)	0	0	0	0
Performance indicator: Biomass of brown shrimp (F. subtilis), ton.				
Minimax Criteria:	Select the decision that generates the minimum of the maximum losses vector			

Table 3.8. Application of the Minimax criterion to the shrimp fishery of Gulf of Paria and Orinoco river delta, using fishery profits as the performance variable.

	Loss of Opportunity Matrix			
	Alternative States of Nature under climate change			Minimax Criteria
Alternative Decisions	θ_1 (r=0.3)	θ_2 (r=0.4)	θ_3 (r=0.6)	Max
				Loss of Opportunities
d1: limiting entry to current f_v (industrial=27; artisanal=241)	1.65	0.61	0.00	1.65
d_2: $f_{v\,msy}$, industrial (27 vessels); artisanal (295 vessels)	2.94	1.29	0.07	2.94
d_3: $f_{v\,mey}$, industrial (27 vessels); artisanal (122 vessels)	0.00	0.00	0.43	**0.43**
Performance indicator: Profits of brown shrimp (*F. subtilis*) fishery (million US$)				
Minimax Criteria:	Select the decision that generates the minimum of the maximum losses vector			

In consistency with the more cautious criterion Maximin, applying the Minimax criterion also identified, for both performance variables, decision d_3 as the adequate one.

3.9 Synthesis and recommendations

Some of the main conclusions and recommendations of this study are the following:

i. The shrimp trawl fishery of Trinidad and Tobago and Venezuela is considered to be one of the more valuable fishery in the Brazil-Guianas region. Five species of penaeid shrimp are of commercial importance namely *Penaeus subtilis, P. notialis, P. schmitti, P. brasiliensis,* and *Xiphopenaeus kroyeri*. One of the more dominant species exploited by the fleets is *Farfantepenaeus subtilis* (brown shrimp).

ii. Catch and effort data was available for the multi-species multi-fleet shrimp fishery of the Gulf of Paria and Orinoco river delta.

iii. There is no current length frequency data catch data on different shrimp species harvested by artisanal, semi-industrial and industrial fleets in the Gulf of Paria and Orinoco river delta needed for to reflect current effects on different components of the population age structures.

iv. For exploring optimal closed seasons, it is essential to seasonally monitor the length frequency distribution of the species harvested by artisanal and industrial fleets.

v. A comparison of the 2000 and 2010 number of vessels Venezuela and Trinidad and Tobago fleets targeting shrimp species in the Gulf of Paria and Orinoco Delta indicate that:

    a. The Trinidad and Tobago artisanal fleets (Type I and II) decreased 10.4 % during the decade under consideration from 96 to 86 vessels,

    b. The Venezuelan artisanal fleet increased substantially over this period from 28 to 155,

    c. The Trinidad and Tobago semi-industrial fleet (Type III) decreased from 11 to 8 vessels,

    d. The Trinidad and Tobago industrial fleet increased from 19 to 27 over the period, and

    e. The Venezuelan industrial fleet which had 88 vessels in 2000 ceased to operate in 2009.

vi. There are considerable information gaps of monthly catch and effort data of the Venezuelan artisanal fleet.

vii. The fraction of the stock not taken by the Venezuela industrial fleet since 2009, is reflected in recent stock recovery. On the other hand, the artisanal Venezuelan fleet has increased substantially in the last 10 years.

viii. In 2010 the value of by-catch represented 18% of total catch value of the three fleets. It should be pointed out however that the contribution of by-catch to total revenues vary among fleets. For the Artisanal fleet, by-catch represented 11% of their total revenues, while it contributed to 27 and 21 percent to total revenues of semi-industrial and industrial fleets respectively. In 2010, calculated total value of shrimp catch and by-catch of the artisanal, semi-industrial and industrial fleets of Trinidad and Tobago was 5.7 million US$.

ix. Concerning seasonal and annual profits of the Trinidad and Tobago fleets, a significant difference is observed between the month where highest profits are obtained by the artisanal fleet (mode: August) against the month of highest profits of the semi-industrial and indistrial fleets (mode: March). The intra-annual profits distributions tend express the sequential nature of artisana/industrial shrimp fisheries.

x. Results from the bioeconomic model built for the multi-species multi-fleet shrimp fishery of Venezuela and Trinidad and Tobago and the decision table analysis indicate that effort of each the fleets should not be expanded further.

xi. With the absence of the Venezuela industrial fleet, the fishery seems to be operating in the neighborhood of $B_{msy.}$

xii. Decision tables applying risk averse criteria indicate that to cope with climate change, effort levels of artisanal fleets should be reduced towards maximum economic yield levels to maintain biomass and profits away from risky levels which could result from the effects of climate change and other possible natural and anthropogenic activities, affecting population growth parameters.

xiii. Concerning groundfish fisheries of the study area, there is a need to update catch and effort data as well the corresponding costs and revenues to undertake meaningful and updated bioeconomic analysis.

3.10 References

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4 SHRIMP FISHERY ON THE AMAZON CONTINENTAL SHELF: PRESENT SITUATION AND LEVEL OF EXPLOITATION OF THE STOCKS

By: José Augusto Negreiros Aragão[4], Israel Hidenburgo Aniceto Cintra[5], Kátia Cristina de Araújo Silva[6]

4.1 Introduction

The shrimp fishery on the Amazon continental shelf occurs along the entire coast off the northern region of Brazil. The fisheries are conducted in shallow waters and estuarine inlets by artisanal vessels and in the coastal zone by small- and medium- scale boats. Landings occur in many communities throughout the coast of the region and are important as a source of income for a large number of fishermen, as well from the point of view of food security.

There is scant information on the small- and medium- scale fishery in the region and even reliable statistics of landings in general are not available due to the dispersion of landings sites. Thus, it is not possible to properly assess the effect of this activity on the target resource or the impact on the environment. The catches in these fisheries are mainly composed of seabob shrimp *Xiphopenaeus kroyeri* (C. Heller, 1862), white shrimp *Litopenaeus schmitti* (Burkenroad, 1936) and also of juveniles of brown shrimp *Farfantepenaeus subtilis* (Pérez Farfante, 1967). Besides, a large number of species are taken as bycatch (IBAMA, 1994).

The offshore fisheries in the region are carried out by industrial boats and the operations are concentrated mainly on the continental shelf of the states of Pará and Amapá and the main species caught, commercially called brown shrimp, are *F. subtilis* and *Farfantepenaeus brasiliensis* Latreille, 1817, with an absolute predominance of the former. Other species such as seabob shrimp (*X. kroyeri*) and a great diversity of fish and other aquatic organisms taken as bycatch also make up the catches of these fisheries (Aragão; Cintra & Silva, 2004).

The industrial fishery constitutes one of the most important activities in the fishing industry at regional and national levels, as they generate foreign exchange. Belém is the main landing port and the base of the shrimp processing industry. Some vessels used to operate from Fortaleza, State of Ceará, where there are also processing industries. Until 1998, there were a few boats and a processing company based in Macapá, State of Amapá.

The industrial landings in the region grew until 1987/1988 when they attained the historical record of 6,900 tonnes of tails, but have fallen since then, to only 2,400 tonnes of tails in 2005. The decline in landings was mainly due to the reduction in the number of boats of the fleet, owing to economic reasons. A significant recovery was however observed in 2006, when landings reached 4,600 tonnes of tails. But in subsequent years, the level of fishing effort was continuously reduced and landings fell again, oscillating between 1,990 tonnes and 1,081 tonnes, in 2008 and 2010, respectively (Aragão, 2012).

The downward trend in the levels of fishing effort in recent years, coupled probably with favourable environmental conditions, contributed to the recovery of the relative abundance index (CPUE), suggesting that nowadays there is no evidence of overfishing of the brown shrimp stock on the northern Brazilian coast. But this also generated an economic crisis in the activity, a situation that needs to be better understood and assessed, so that appropriate management measures can be instituted (Aragão, 2012).

Until mid-2000, the product of the industrial fishery was oriented almost entirely towards the international market, with the main importers being the United States and Japan. In the period from 1989 to 2002 the activity generated an average revenue of US$ 31.5 million, with a peak of US$ 49.8 million in 1993/94 (6,348 tonnes and 5,383 tonnes respectively) and a minimum of

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US$ 21.7 million in 2002 (2,195 t). In 2006, following the recovery of the landings, exports reached US$ 32.9 million. Thereafter, exports fell sharply again to only US$ 6.9 million in 2011 (MDIC/Aliceweb, 2013).

4.2 The Amazon Continental Shelf

The Amazon continental shelf is situated between the mouth of the Oiapoque river (05°N, 051°W), border of Brazil and French Guiana, and São Marcos Bay (02°S, 044°W), in the State of Maranhão. Its meteorological and oceanographic characteristics are quite peculiar when compared to other coastal regions of the country, featuring, among others, high annual rainfall (up to 3,300 mm), high temperatures (> 20 ° C) with low annual thermal variation, wide continental shelf (reaching ~ 330 km), strong macrotides or macrotidal regime (with maximum of 8 m in Maranhão, 6 m in Pará and 12 m in Amapá), discharge of tens of estuaries and of the world's largest river, the Amazon River (Pereira *et. al.*, 2009).

This area is characterized by a low physiographic relief (0 to 80 m) wide coastal plain (up to 70 km wide) and continental shelf (~ 200 km wide) and is extremely irregular, jagged and indented by several estuaries. On such an extensive coastline, a large number of draining rivers are found and the area is subject to active erosion and sedimentation. It features several environments, such as beaches, tidal plains, saline and sweet marshes, estuaries, mangroves, floodplain forest, tropical forests, lakes, lagoons, islands, rivers, deltas and dunes, etc. It covers the largest continuous extension of mangroves in the world, with a total area of 7,591 km^2, between the Bay of Marajó (PA) and the Ponta do Tubarão, in the Bay of São José (MA), plus about 1,800 km^2 along the coast of the State of Amapá. Inundated mangroves cover an area of 30 km wide and the estuaries extend over more than 80 km inland (Souza-Filho, 2005).

The climate in the region is hot and humid, with a well- defined dry season (July to December) and a rainy season (January-May), with average annual rainfall ranging from 2,500 to 3,000 mm and the annual average temperature around 26ºC. It is directly influenced by the regional hydrological cycle, characterized by two typical periods: "drought" between October and November; and "flood", between May-June (Filizola *et al*. 2006). This clear seasonal pattern of the regional climatology has long been indicated as the main factor governing the life cycle of aquatic species (Bates, 1869).

Many authors acknowledge that El Niño Southern Oscillation (ENSO) is a key stimulus to the environmental variability in the tropics and its impact is widespread, with strong influence on temperature and rainfall patterns around the globe. It is considered that the El Niño and La Niña phases of the ENSO cycle affect, at least partially, the cycle of "flood" and "drought" in the Amazon region. In general, periods dominated by "El Niño" are drier and warmer than normal in the Amazon, while under the influence of "La Niña" are more humid and cold (Foley *et al.*, 2002; Poveda & Mesa, 1997).

4.3 Biological Characteristics of the Species

Shrimps are crustaceans that support important fisheries in tropical and subtropical regions worldwide. On the north coast of Brazil, the commercially important species belong to the family Penaeidae (Rafinesque, 1815) and three distinct genera: gender *Farfantepenaeus* Burukovsky, 1997, represented by the *F. subtilis* and *F. brasiliensis* known as brown shrimp; gender *Litopenaeus* Pérez Farfante, 1969, represented by the *L. schmitti* called white shrimp; and gender *Xiphopenaeus* Smith, 1869, represented by the *X. kroyeri*, the seabob shrimp.

In the northern region of Brazil juveniles of the three species are found in the extensive mangrove system that dominates the coast from the state of Piauí up to the state of Amapá, while adults are concentrated, mature, mate and spawn in the sea, where they are captured. The brown shrimp reaches depths of over 100 m at the adult stage. On the other hand, the white shrimp is found in a more coastal zone and can reach ocean areas, but at lower depths compared to the brown shrimp. At some time of the life cycle of the species they inhabit common depths (Aragão, 2012).

4.3.1 Brown shrimp (Farfantepeaneus subtilis)

The brown shrimp *F. subtilis* is distributed in tropical waters of the eastern Atlantic, stretching from Cuba to the State of Rio de Janeiro, Brazil (Pérez-Farfante, 1969). On the north coast, juveniles are found in mangroves along the entire coastline and, as they develop, migrate to deeper waters in the northwest direction, in greater numbers since November. This cycle is evidenced by higher catches of juveniles in the coastal region of the state of Pará, from October to January, while larger individuals are caught in the ocean waters of the state of Amapá, mainly from July to September (Aragão, 2012).

4.3.2 Brow shrimp (Farfantepeaneus brasiliensis)

The brown shrimp *F. brasiliensis* is distributed in the western Atlantic, from North Carolina, USA, to the coast of Rio Grande do Sul, and Patos Lagoon, Brazil. They occur at depths ranging from 3 to 335 m, but catches are more frequent between depths of 45 and 65 m, in muddy and sandy-muddy grounds (Takeda, 1983). Juveniles are estuarine and adults are marine (Pérez-Farfante, 1978).

4.3.3 White shrimp (Litopenaeus schmitti)

The white shrimp is present in the western Atlantic from the Bay of Matanzas (Cuba) to the state of Rio Grande do Sul (Brazil), including the Caribbean and Central America (Pérez-Farfante, 1969). In Brazil it is found along the entire coast from the Amapá to Rio Grande do Sul states (IBAMA, 2011).

4.3.4 Seabob shrimp (Xiphopenaeus kroyeri)

The distribution of the seabob shrimp includes the American Pacific coast, from Mexico to Peru, as well as a wide area in the western Atlantic, from North Carolina, United States, to Rio Grande do Sul, Brazil, including the Caribbean and Central America (Pérez-Farfante, 1969). In Brazil the presence of the species has been observed in all states, from Amapá to Rio Grande do Sul, although occurrences in this latter state are only occasional.

4.3.5 Shrimp bycatch

In the industrial shrimp fishery, a large proportion of other living aquatic organisms are also captured, including a wide variety of fishes, mollusks and crustaceans. Part of these catches is composed of species of commercial value, but only a relatively small proportion is utilized and the majority is discarded. This catch is known in the literature as bycatch and constitutes one of the major environmental impacts of this fishery. The bycatch is also an issue in the small- and medium- scale fisheries, further worsened by the catch of a large proportion of juveniles of the species. This topic will be discussed in more detail during the course of this work.

4.4 Fishing Grounds

The industrial fisheries are carried out in the open seas between the mouth of the Parnaíba River (02°53'S), in the state of Piauí, and the mouth of the Oiapoque River (04°23'N), on the border between Brazil and French Guiana, comprising the coast of the states of Maranhão, Pará and Amapá, and catches occur mainly at depths between 40 and 80 metres (Figure 1). This area is part of an extensive shrimp fishing ground which extends to the mouth of the Orinoco River in Venezuela, covering about 223,000 km² (IBAMA, 1994).

Along the coastline, the fisheries are conducted in shallow waters, estuaries and inlets by artisanal vessels and small- scale boats. Motorized wooden boats, ranging from 6 to 12 m in length (medium-scale fleet), operate at lower depths (Aragão et al., 2001). The two main areas of activity of the industrial fleet are known as "Amazon" and "Amapá", and are located off the coast of the state of Pará and off the state of Amapá, respectively (Figure 4.1).

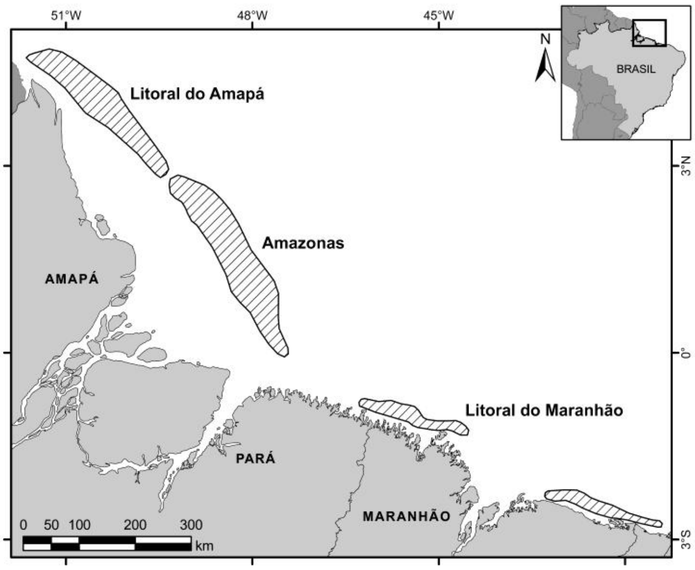

Figure 4.1. Fishing grounds for *Farfantepenaeus subtilis* on the Amazon continental shelf of Brazil.

4.5 Description of the Fisheries

The following description of the fisheries is found in Aragão *et al.* (2001):

4.5.1 Artisanal and small -scale fisheries

The information on artisanal fisheries and small- scale fisheries in the region is scarce and often outdated. There are no reliable statistics on landings or even on the amount of units in operation. Thus, it is only possible to present some descriptive information on the fisheries carried out in the states of Maranhão and Pará.

The artisanal and small- scale shrimp fisheries are conducted in estuaries, bays, inlets and shallow waters near the coastline. Fishing operations are carried out with fixed fishing gear ("zangaria"), passively influenced by the tides, with small fixed opening trawls ("puçá-de-arrasto" and "puçá-de-muruada") and seine nets ("redes de lance") operated manually and assisted by a small boat, as well as cast nets ("tarrafas") (SUDAM/UFMA, 1981).

The main species caught, in order of importance, are the white shrimp and seabob shrimp, along with some juveniles of brown shrimp. The intensity of occurrence of the species depends on the location, the season and the level of salinity (SUDAM/UFMA, 1981). In the state of Pará there is also a fishery directed at the “canela” shrimp, *Macrobrachium amazonicum* (Heller, 1862), along the rivers, with the use of wooden traps, known as "matapi" (IBAMA, 1998).

A fleet of medium- scale trawlers operates throughout the year on the eastern coast of Maranhão, near the mouth of the Parnaíba River, in the so called “Tutóia area”, with a high concentration of the white shrimp. The most recently available data indicate that between 1979 and 1991 the fleet was composed of a minimum of 11 vessels in 1979 and a maximum of 23 vessels in 1981. In 1991, the last year for which information is available, there were 16 boats. In the second quarter, some industrial boats, mainly from Ceará, eventually used to operate in this area, undertaking night trawls of 6 hours, at depths of 20 to 40 metres.

4.5.2 Industrial fisheries

The industrial vessels are typical double rig shrimp trawlers with steel hull and length between 17 and 23 metres, 6.5 m of mouth opening, main engine power ranging from 375 to 425 Hp, and a crew of five fishermen. They are equipped with modern navigation and communication equipment and freezing system on board. The fleet used to carry out between 4 and 6 trips during the year, lasting 40 to 50 days, at depths ranging mainly from 40 to 80 m.

The best yields of the fishery are obtained from February/March to July/August, the high season, when fishing operations are conducted during the day and night and generally four trawls, lasting 5-6 hours, are carried out. During the low season only two trawls, lasting a little longer, are carried out at night. In recent years the boats have operated only during the high season due to the high operational costs.

The vast majority of the industrial boats are based in Belém, the state of Pará, but some are in Fortaleza, the state of Ceará. The total number of units of the fleet was over 250 vessels by the end of the eighties, but only 123 units remained in operation in 2006, with 108 based in Belém and 15 based in Fortaleza. Today the fleet is composed of only 101 licensed boats, all based in Belém, but only around 70 of these boats have been in operation over the last five years.

F. subitlis is the main targeted species and operations are carried out basically in the "Amazon" and "Amapá" areas. A small number of *F. brasiliensis* has been reported in the catches, but, in recent years, the proportion of *F. subtilis* represents almost all of the landings, according to the Project CEPNOR / IBAMA "Shrimp Bioecology and Fishery on the North Coast of Brazil." As already indicated, apart from the shrimp dozens of tonnes of fish and aquatic organisms of various species are also taken daily as bycatch. .

4.6 Trend of the catch and effort in the industrial fishery

From 1978, the volume of landings of the national fleet increased and reached the highest levels in 1987 and 1988, with about 6,400 tonnes of tails. During this time the fleet was made up of 250 boats, the maximum number of boats allowed. Since then, the fleet showed a decreasing trend and the annual volume of landings has also decreased, totaling just 3,919 tonnes of tails in 1990. But, in subsequent years, annual landings increased again, reaching a peak of 5,747 tonnes in 1993. They then started to fall sharply again, attaining the lowest value in 2001, with only 2,156 tonnes of tails (Figure 4.2). From 2002 a gradual recovery is observed and landings reached the expressive (significant) and surprising level of 4,607 tonnes of tails in 2006. In the following years, the level of fishing effort declined sharply and the landings ranged from 1,990 to 1,081 tonnes, in 2008 and 2010, respectively (Aragão, 2012).

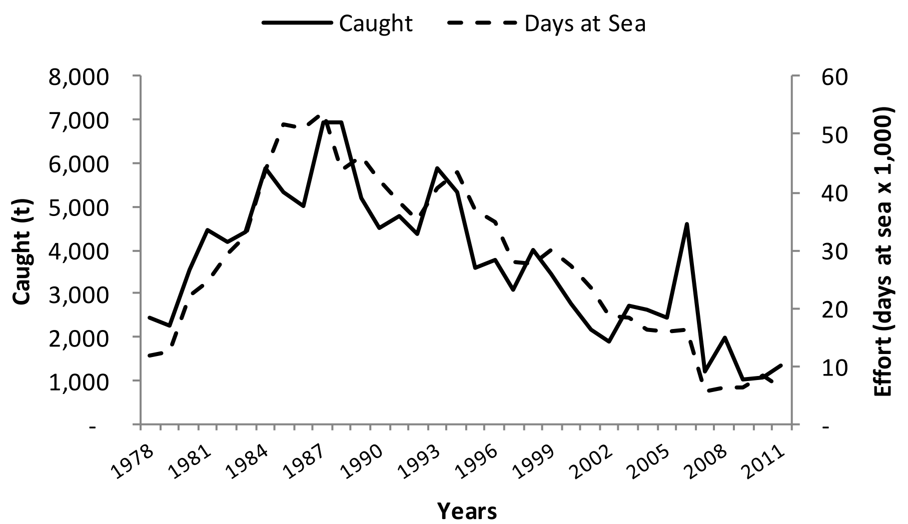

Figure 4.2. Catch (t) and fishing effort (days at sea x 1,000) of the industrial fishery of *Farfantepenaeus subtilis* on the Amazon continental shelf of Brazil (Source: Cepnor/Ibama)

The fishing effort in terms of number of days at sea (days/sea) presents a trend somehow similar to the landings. It grows continuously until 1985, when it reached 49,677 days/sea and then decreased gradually, to 36,015 days/sea in 1992. In 1993-1994 the effort increased again, reaching 41,500 days/sea. From then on, a continuous decline is observed, attaining a total of only 15,529 days/sea in 2006, similar to the effort observed at the beginning of the fishery in the late 70s. In 2007, the level of fishing effort dropped to 5,783 days/sea and has been oscillating around 7,000 days/sea since then.

The catch per unit of fishing effort (CPUE), defined here in kilogrammes per day at sea (kg/DS) shows an oscillating trend, with peaks around 150 kg per day at sea in the years 1988, 1993, 1998 and 2003 and lower values, around 95 kg per day at sea, in the years 1986, 1990, 1995, 1999 to 2001 (Figure 4.3). A quick look at the plot indicates a cyclical pattern with a difference of about 5 years between each peak. In the cycle which began in 1999 the CPUE declines again, but soon recovers and reaches 150.6 kg per day at sea in 2003.

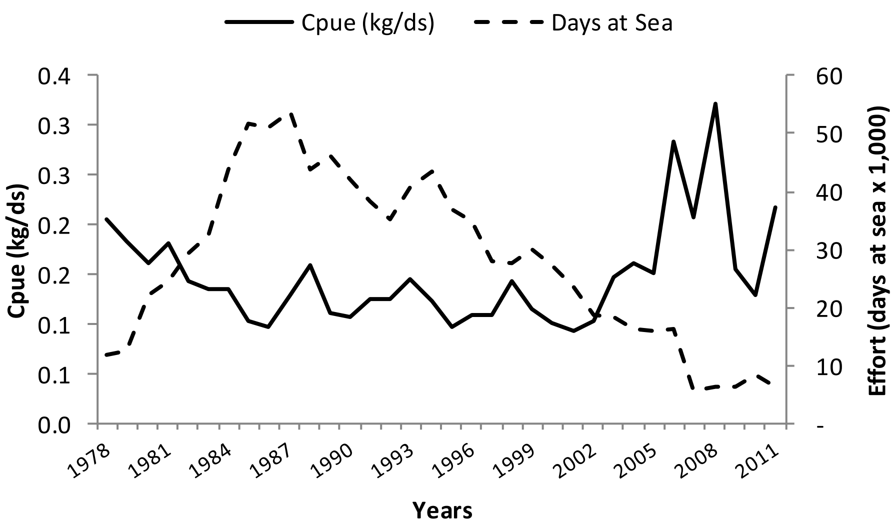

Figure 4.3. Catch (t) and CPUE (kg/day at sea) in the industrial shrimp fishery on the Amazon continental shelf of Brazil (Source: Cepnor/Ibama)

From 2004, there is evidence of the beginning of a new cycle, with a marked recovery in CPUE, reaching the extraordinary peaks of 265.2 kg per day at sea, in 2006, and 322.5 kg per day at sea, in 2008. Such a level of CPUE is only comparable to that obtained at the beginning of the fishery in the late 1970s and early 1980s. Thus, a preliminary conclusion is that low levels of fishing effort applied in recent years had an important effect or impact on the recovery of the stock.

4.7 Biological Parameters and Population Dynamics

The following information refers basically to *F. subtilis*, a species which, due to its absolute predominance in industrial catches, has been studied more intensively on the northern coast of Brazil. Among the main studies on the fishery, biology, population dynamics and stock assessment of the species in the region are those of: SUDEPE (1981); SUDEPE (1985); Isaac, Dias Neto & Damasceno (1992); Vieira et al. (1997); Ehrhardt, Aragão & Silva (1998); Aragão *et al.* (2001); Aragão, Silva & Cintra (2004); Cintra, Aragão & Silva (2004), Aragão, Silva & Cintra (2005). Recently, a comprehensive and detailed study was conducted by Aragão (2012) and the main results of this and previous studies are presented and discussed briefly below.

4.7.1 Reproduction

Although most tropical penaeid spawn throughout the year, periods of higher intensity have been indicated (Garcia & Le Reste, 1981). On the north coast of Brazil, Isaac, Dias Neto & Damasceno (1992) suggest that the spawning of *F. subtilis* occurs with more intensity in two periods of the year, one from March to July and another from September to October. SUDEPE (1985) indicates that the highest proportion of immature individuals occurs in March and the highest proportion of individuals at the maturation stage IV is observed from July to September, concluding that the latter is the higher intensity spawning period. Cintra, Aragão & Silva (2004) indicate the months of February/April and July/August as those of greater occurrence of mature females. However, Aragão (2012) makes a detailed analysis of the reproductive aspects of *F. subtilis* and presents strong evidence that the higher intensity period of spawning is from May to September.

Porto & Santos (1996) estimated the onset size of ripening of *F. subtilis* at 117.5 mm for females and at 91.2 mm for males. The average size (total length) where 50% of females are mature was estimated by Isaac, Dias-Neto & Damasceno (1992) at 140 mm. and by Cintra, Aragão & Silva (2004) at 135.5 mm. Aragão (2012) using monthly data on gonad maturation stages from samples obtained aboard commercial vessels, from 2000 to 2004, estimated the average size at first maturity of *F. subtilis* on the Amazon continental shelf at 142.6 mm while the size at the onset of ripening was estimated at 89.8 mm (Figure 4.4).

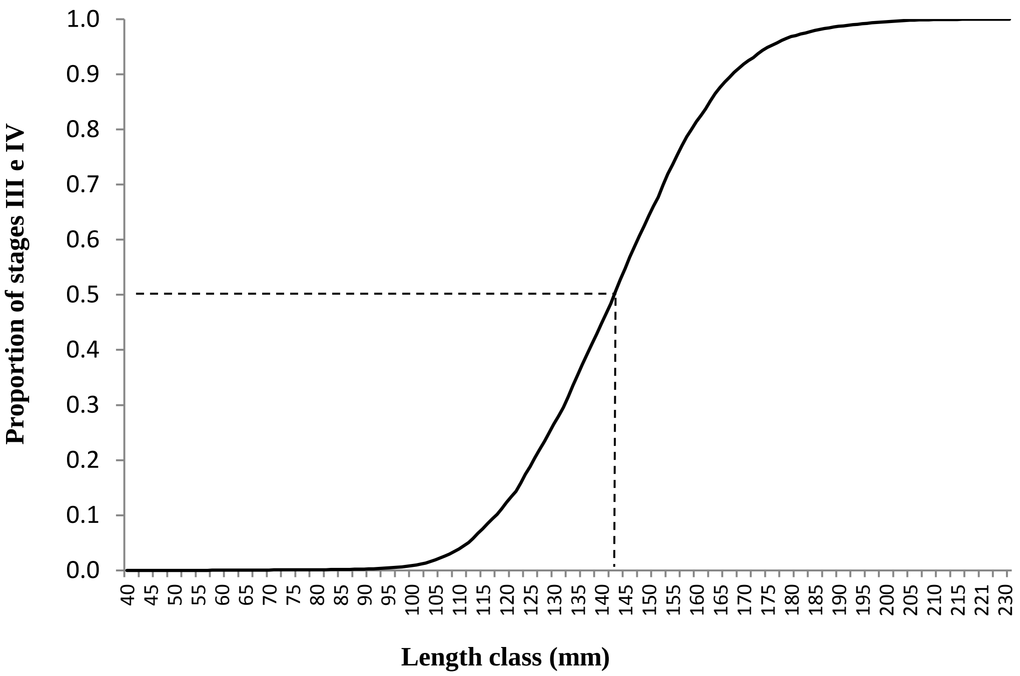

Figure 4.4. Proportion of individuals at maturation stage III and IV per length class in the samples of the industrial fishery on the Amazon continental shelf of Brazil, from 2000 to 2004, highlighting the length at first sexual maturation of *Farfantepenaeus subtilis* (Aragão, 2012)

4.7.2 Recruitment

According to Isaac, Dias-Neto & Damasceno (1992), the recruitment of *F. subtilis* in areas of open sea occurs more intensely in the period from December to May, with evidence of a second period between July and August. They suggest, however, that the first period is markedly more evident considering the high catch rates of small shrimp recorded and estimated in two to three months of the time between the departure from estuaries and the arrival of recruits in the growth areas.

Ehrhardt, Aragão & Silva (1999) suggest that recruitment, defined as those individuals who enter the phase of exploitation between 53 and 71 mm of tail length, presents a different pattern for females and males. Females show a clear and more intense peak that corresponds to the period of most intense rainfall in the region between December and May, while males show some stability with a slight increase in recent months.

More recently, the results obtained by Aragão (2012) show clearly that the most intense period of recruitment of *F. subtilis* in fishing grounds occurs from September to January, showing consistency with the period of highest intensity of reproduction already indicated. The period of greater intensity of each phase of the life cycle of the species proposed by the author is presented in the Figure 4.5 below.

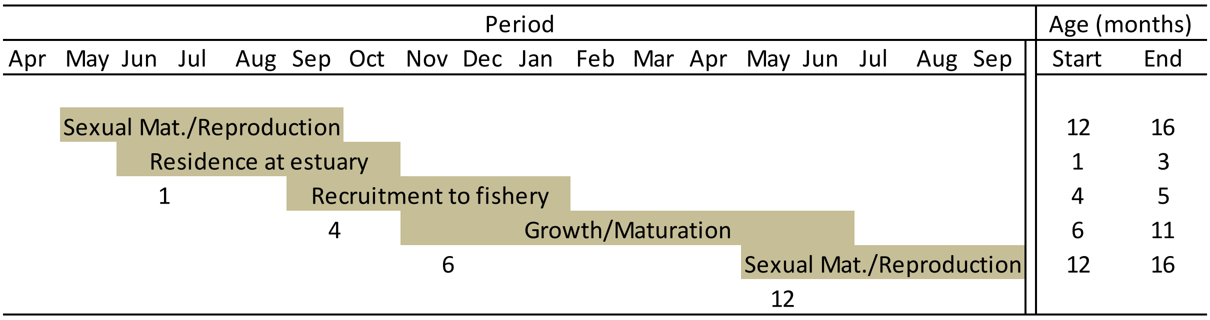

Figure 4.5. Periods of higher intensity of each phase of the life cycle of *Farfantepenaeus subtilis* in the Amazon continental shelf of Brazil (Aragão, 2012).

4.7.3 Growth parameters and natural mortality

The growth parameters and natural mortality of *F. subtilis* shown in Table 4.1. Estimated growth parameters and natural mortality of *Farfantepenaeus subtilis* in the Amazon continental shelf of Brazilwere estimated by Isaac, Dias-Neto & Damasceno (1992) and Aragão (2012). The estimated values for the parameters by Aragão (2012) are within the range of values presented by other authors, but the asymptotic lengths for males and females are higher than those found by Isaac, Dias-Neto & Damasceno (1992). The growth constant and natural mortality values are also much higher for females.

Table 4.1. Estimated growth parameters and natural mortality of *Farfantepenaeus subtilis* in the Amazon continental shelf of Brazil

Author	Females			Males		
	M (year^{-1})	L_∞	K (year^{-1})	M (year^{-1})	L_∞	K (year^{-1})
Isaac, Dias-Neto & Damanesco (1992)	2.11	225	1.00	1.90	187	1.08
Aragão (2012)	2.53	236	1.60	1.83	215	0.94

The reasons for the differences still need to be investigated, but it should be noted that the latter study analyzed a large number of monthly samples representative of the catches in the two main areas of capture, obtained aboard commercial vessels in the period from 2000 to 2004. The total number of individuals sampled was nearly 300,000 and the ranges of sizes in these samples are much broader than those previously analyzed.

4.7.4 Stock assessment

Estimates of maximum sustainable yield of the stock of brown shrimp were obtained in the past by applying surplus production models. The estimate of the annual maximum sustainable yield (MSY) varies from 7,300 tonnes to 9,016 tonnes of round weight for a fishing effort between 32,000 and 72,298 days at sea (Sudepe, 1985, Isaac, Dias-Neto & Damasceno, 1992). The results in all evaluations seem clearly overestimated and were obtained using models that consider the equilibrium of the population, a simply unrealistic assumption.

The results obtained by Aragão (2012) using the biomass dynamics model (Hilborn & Walters, 1992) are more consistent and coherent with the history of the fishery. The main conclusions of this study are presented below:

- The recovery of the CPUE levels in recent years coincides with the expressive reduction of the fishing effort and probably favourable environmental conditions in the period from 2003 to 2006. The movement of the biomass of *F. subtilis* over the period of the study resembles the movement of the CPUE with a reversal of the declining trend and a recovery from 2002;
- The estimated value of the maximum sustainable yield (MSY=4,032 t of tail) was compatible with the yields that have been obtained by the fishery, although the estimation of the maximum sustainable effort (MSE=19,370 days at sea) was below the levels applied historically to the stock.
- Changes in fishing power, expressed by the catchability coefficient (q), show an annual increase since the nineties that can be attributed in large part to the continuing decline in fishing effort, especially after 1994, leading the remaining boats to operate with greater intensity in areas of higher concentration of biomass;
- The projection of the stock for the coming years, considering the optimal parameters estimated by the model for the current fishing pattern, shows the recovery of biomass to levels consistent with the estimated maximum sustainable yield.

Another two comprehensive studies on the level of exploitation of the stocks of brown shrimp using estimates of catches and monthly samples of length were carried out by Ehrhardt, Aragão & Silva (1999) and Aragão (2012). In the first study the method of cohort analysis (Jones, 1981) was applied, using a process of "calibration" and the most recent study used a method of sequential population analysis fully length-based, which incorporates a stochastic growth function (Sullivan, Lai & Gallucci, 1990). Some key findings of this study are presented below:

- The analysis used a large data base composed of different types of data and applied a method of stock assessment with an algorithm whose assumptions seem more realistic, considering the behaviour expected to be observed in natural populations;
- The pattern of intra-annual variation in abundance, for both sexes, is quite clear. At the beginning of the season the abundance is high, declining continuously throughout the year, and the abundance of females is much higher than that of males;
- The high inter-annual variability of abundance, for both sexes, could be related not only to the intensity of fishing effort, but mainly to environmental factors;
- The recruitment in the fishery also presents a well-defined intra-annual pattern, with a peak between the last and first quarters of the year. Along with mortality, it is the main factor responsible for the pattern of the abundance;
- The CPUE and the catchability coefficient (q) show intra-annual and inter-annual variations, the latter being determined by the combination of variation in the abundance and in the distribution pattern of the fishing effort;
- The catches in this fishery appear to be primarily governed by the level of seasonal abundance that usually determines the level of the fishing effort. It follows that the catch per unit of fishing effort (CPUE) does not fully reflect a proportional relation with the abundance of the stock;
- The catchability coefficient presents a growth trend due to two factors: a) gradual increase in the efficiency of the fleet in the development phase of the fisheries; b) concentration of the fleet operations in more productive areas in the period of decline of the intensity of the fishing effort and the recovery of the abundance;
- The stock is at a somewhat moderate level of exploitation during the period analyzed with an exploitation rate of 0.557, slightly higher than the value considered as optimum ($F/Z = 0.5$). It

must be emphasized that the reduction of fishing effort in recent years points to a decrease in the exploitation rate after 2006.

4.8 Influence of environmental factors

On the Amazon continental shelf, the Amazon River plume is the main factor influencing the environmental conditions. It can reach 300 km away from the mouth and is responsible for extensive coverage of the substrate composed of sediments of mud and sand in the coastal zone. The strength of the plume depends directly on the intensity of the river flow that varies with rainfall across the Amazon basin, characterized by two markedly peculiar climatic periods. The “rainy season”, from December to May, when we observe increased intensity of rainfall, and the “dry season”, between July and November, when the rains, the flow of the rivers and the level of lakes diminish markedly (Filizola *et al.*, 2006, Silva, 2010).

During the “dry season”, temperatures and the rate of evaporation are higher and there is an increase in salinity in the coastal zone. As in other regions of the world, this probably has a great influence on the intensity of settlement and the survival rate of post-larvae of *F. subtilis* in the estuarine and coastal zone. It could also affect the development of juveniles, and hence the abundance of adults in subsequent months (Aragão, 2012). In fact, annual fluctuations in total biomass of brown shrimp on the northern coast are often observed, affecting the total catch and the catch per unit of fishing effort (CPUE), which experience significant seasonal and inter-annual variations.

In recent years, there has been a notable recovery of the catch rates in the *F. subtilis* fishery in the northern region suggesting a recovery of the population abundance. Although this recovery had occurred along with a sharp decline in the intensity of the fishing effort, it should be noted that marked fluctuations in the stock abundance had already been detected in previous periods and are probably related to environmental factors. Ehrhardt, Aragão and Silva (1999) suggested a negative relationship between the index of relative abundance (CPUE) and the intensity of fishing effort in the fishery, but also highlighted evidence of the influence of the environment on fluctuations in the biomass of the resource.

Thus, considering that the environmental conditions on the northern coast are affected largely by variations in the intensity of the Amazon River flow, Aragão (2012) attempted to establish links between the river flow and the fluctuations in abundance of the brown shrimp. The main results of these analyses are presented below:

- The high landings observed in 2006 and the fluctuations in the CPUE around a higher level in subsequent years may be evidence of the recovery of the abundance of the population, as a consequence of the low levels of fishing effort and favourable environmental conditions, strongly influenced by the Amazon River flow, but also reflects changes in the behaviour of the fleet in these circumstances, which concentrates its activities in the most productive areas;
- The decrease in the Amazon River flow coincides with the beginning of the most intense period of larval migration, settlement of post-larvae in estuaries and development of juveniles in the coastal zone. It can be said that, in general, the early life stages and juveniles of *F. subtilis* are associated with phases of decreasing and minimum flow of the Amazon River, while the population of sub-adults and adults is related mainly to the phases of increase and peak of the river flow;
- There is a good correlation between the intensity of the monthly Amazon River flow, with a delay of four months, and the CPUE. The negative anomalies of the average flow of the river, in the period from June to November, usually related to El Niño episodes, are associated with positive anomalies of CPUE and better yields of the fishery in subsequent years;
- The statistical models used in the analysis confirmed the good correlation between the yield of the fisheries with the fishing effort and intensity of the average Amazon River flow in the period from June to November of the previous year, which corresponds to the period of migration and development of the early life stages in estuaries.

4.9 Shrimp bycatch

A significant proportion of other living aquatic organisms is also captured as bycatch by the industrial brown shrimp fishery, including a considerable diversity of fishes, mollusks and crustaceans. Part of these catches is composed of species of commercial value, but only a relatively small proportion is utilized and the majority is discarded. These catches, known in the literature as “bycatch“, constitute one of the major environmental impacts of this fishery.

Studies conducted in the 1980s by Damasceno (1986, 1988) indicated that for every kilogramme of shrimp tail 7.2 kg of fish and other aquatic organisms were captured, of which 4.4 kg could be destined for human consumption. The annual bycatch was estimated at between 19 and 24 thousand tonnes, but only a small proportion of these catches was not discarded.

Damasceno and Evangelista (1991) estimated the production of the total bycatch in the northern pink shrimp industrial fisheries at 20.6 thousand tonnes and a volume of 17.4 thousand tonnes could be retained for marketing. They identified about 150 species of aquatic organisms in the composition of this bycatch, being 90% of fish, 7.5% of crustaceans and 2.5% of molluscs.

Recent studies indicate a lower proportion of bycatch in the northern brown shrimp industrial fishery. Paiva *et al*. (2009) reported that 4.28 kilogrammes of bycatch is caught for every kilogramme of shrimp, being 43% of finfish, 5% of elasmobranches, 3% of crustaceans and 49% of a "mix" consisting of fishes, crustaceans and small shellfishes. They estimate that 17.2 thousand tonnes of bycatch were captured in these fisheries in 2003, in the states of Pará and Amapá,

Several commercially important species are included in the composition of the bycatch of the northern brown shrimp industrial fishery. Among the most common we find: weakfish (pescada gó - *Macrodon ancylodon* Bloch & Schneider, 1801), croaker (corvina - *Cynoscion jamaicensis* Bocourt & Vaillant, 1883), red snapper (pargo - *Lutjamus purpureus*), dwarf goatfish (trilha - *Upeneus parvus* Poey, 1853), seabob shrimp (camarão sete barbas - *Xiphopenaeus kroyeri*), lobsters (lagostas - *Panulirus* spp), sharks and stingrays, and catfish of the Ariidae family.

Some of the main barriers to increasing the utilization of the bycatch species are: the limited space available on board the vessels for handling the catch; the low market prices; the crew’s size; and the possible impairment of the shrimp’s quality due to the common use of refrigeration and freezing rooms. It should be noted that today the market prices of some species have increased and a higher proportion has been retained for human consumption and also, during the last and first quarters of the year, some boats are orienting their activities towards the capture of some of these species, mainly the weakfish (Paiva *et al.*, 2009).

Although there has been an increase in the proportion of bycatch retention in recent years, the discarding of so much fish is still unacceptable. Solutions to the reduction and better use of bycatch are being developed, mainly in tropical countries, including the handling of the fish and processing of the final product aboard the vessels or the collection and transportation of the production for onshore processing (Morais, 1981; Paiva, 1997, Pinheiro & Cintra, 1999; Eayrs, 2007).

4.10 Processing and commercialization

4.10.1 Processing and products

The processing of the brown shrimp starts on board the vessels as soon as the nets are raised and opened on the deck. The shrimp is then separated from the bycatch and, generally, headless, washed and frozen. After landing, the production is processed by commercial categories, taking into account the size and quality of the shrimp. Initially, the sorting is carried out based on the number of pieces of tail per pound or, sometimes, number of individuals (head on) per kilogramme and then separated according to the quality: the "first class"; and the "broken" (damaged parts).

The traditional commercial size categories for the headless shrimp intended for the international market are: M/71, 61/70, 51/60, 41/50, 31/40, 26/30, 21/25, 16/20 and 10/15 tails per pound. After processing the product is packaged in cardboard boxes, with a net weight of 2 kg, and frozen. For the shrimp occasionally processed as “head on” the categories are U/6, 6/8, 8/12, 13/15, 16/20, 21/25 and 26/30 individuals per kilogramme.

4.10.2 Commercialization

Most of the industrial production of shrimps in northern Brazil is traditionally destined for foreign markets as frozen tails. A small portion is processed and exported as a whole product, primarily for the Japanese market. A relatively small share of industrial production is sold in the local market and in other states. In recent years, the number of shrimp processing plants has decreased and currently only three large capacity companies are in operation in Belém, state of Pará (Aragão, Silva & Cintra, 2005).

Exports reached higher values in the years 1987/1988, at 73.2 and 75.4 million dollars, respectively. Since then they have maintained the same downward trend observed in the landings, with a peak in 1993/1994, when they totaled US$ 49.8 million, and the lowest in 2003, with just US$ 18.0 million. In 2006, with the recovery of landings, exports went up to US$ 32.9 million, but since then exports have been dropping sharply, reaching only US$ 6.9 million in 2011 (MDIC/Aliceweb, 2013).

Prices vary according to the commercial category and, in the Japanese market are generally higher than those prevailing in the U.S. market, but the quality requirements are more stringent. According to the Association of the Fishery Industry of Pará/Amapá (SINPESCA), the average price (FOB, Fret on Board) per kilogramme of tail exported through the port of Belém, in the period from 1991 to 1998, varied between US$ 7.0 and US$ 24.8 per kilogramme, with an average of US$ 14.2, in the Japanese market, and between US$ 6.16 to US$ 17.05 per kilogramme, with an average of US$ 10.45, in the U.S. market (Vieira *et al*., 1997).

Since 1999, the average export prices began to fall steadily, reaching only US$ 8.8 per kilogramme in 2007 (MDIC/Aliceweb, 2011). This fall has caused a proportionally higher rise in the costs of the activity in relation to the revenues and led to the diversion of part of the production to the domestic market. Nevertheless, a market recovery is being observed in recent years and prices by commercial category range between US$ 5.6 and US$ 21.3 per kilogramme, with the average price attaining US$ 14.4 in 2011. This increase can also be due to the fact that today exports are somewhat dominated by commercial categories of larger sizes.

4.11 Economic aspects

There are few studies on the economic aspects of the industrial shrimp fishery on the northern coast of Brazil and a more detailed economic analysis is not possible. It is only possible to highlight the work of Vieira *et al.* (1997) and a bioeconomic analysis (Aragão *et al*., 2000) undertaken during the workshop “Assessment and Management Workshop on the Shrimp and Groundfish Fisheries on the Brazil-Guianas Shelf”, held in Cumana, Venezuela, in October 2000.

The work of Vieira *et al.* (1997) analyzed the results of the industrial processing by commercial category and presents some conclusions on the revenue of the fisheries and the relative share of the large (between 11 and 25 pieces per pound), medium (between 26 and 50 pieces per pound), and small (over 51 pieces per pound) size class of shrimp, processed in the period from 1982 to 1994.

Between 1982 and 1986, the period before the establishment of fishing closure, the proportion of small shrimps in the bulk of the commercial categories was 44%. From 1987 to 1990, when the closed season was from December 20 to February 19, this percentage was 37%. From 1991 to 1994, when the fishery was closed from December 01 to January 31, the percentage increased to 48%.

The total revenue of the fishery was 18.5% higher in the period when the closed season included part of February, suggesting that this is the best period to close the fishery. Aragão *et al.* (2001) observed, since 1994, however, a marked downward trend in the relative share of large shrimps and an increase in the relative proportion of small shrimps, even with closed seasons.

The bio-economic analysis of the brown shrimp fishery on the northern coast (Aragão *et al*., 2000) was carried out aiming at determining the best scenarios for obtaining larger catches and positive financial results of the activity. The conclusion was that the fleet was operating close to the bio-economic equilibrium at that time, considering the estimated level of recruitment. This meant that for the level of biomass and fishing effort at that time, there was loss of income. The level of fishing effort that would maximize the net profit of the fishery was estimated at 23,000 days of fishing.

An analysis of costs and profitability of some industrial vessels involved in the capture of brown shrimp, on the northern coast of Brazil, conducted in 2002, concluded that the average margin of profit was approximately 16% of net profit and 30% of gross profit. This implies that 70% of the actual revenues were sufficient to cover operating expenses and expenditure for insurance and licensing, leaving the remaining 30% as gross margin return. According to these results, the economic scenario of the fishery at that time seemed very comfortable (Carvalho, Chaves & Cintra, 2003).

A new bio-economic assessment of the industrial fishery for *F. subtilis* in the northern region was now carried out in the light of new data and use of a more sophisticated model of population dynamics previously mentioned. Detailed results are presented in another document of this series but the general conclusion is that the levels of fishing effort should be kept around 18 thousand days at sea, to ensure the economic viability of the fisheries, considering a scenario of moderate recruitment. This is consistent with the results presented earlier in the stock assessment studies.

4.12 . Fisheries management

The management measures put in place for the industrial shrimp fishery in northern Brazil are oriented primarily towards the control of the fishing effort and the protection of juveniles' recruitment in the growth and fishing areas. The closure of the fishery in the region has been established between the last and first quarters of the year, when the intensity of recruitment at the fishery is higher. The main management measures adopted are the following:

- Limit of 101 on the number of boats allowed to operate in the industrial fishery in the region (Ordinance N^o 117 of May 14, 2008);
- Closure of the shrimp fishery to motorized vessels in the area between the border of the states of Piauí and Ceará and the border of Brazil and French Guiana from October 15 to February 15 (Ordinance N^o 09/04, September 3, 2004).
- Prohibition on the use of any type of trawling by motorized vessels at less than 3 miles from the coastline in the State of Piauí (Ordinance N^o 15, June 15, 1981);
- Prohibition on the use of any type of trawling by motorized vessels at less than 10 nautical miles (nm) from the coastline, between the border of the states of Maranhão and Pará and the border of Brazil and French Guiana (Ordinance N^o 11, May 13, 1987);
- Prohibition on the use of trawling by motorized vessels at less than 10 nm from the coastline in the state of Maranhão and permission to be sought for trawling for seabob shrimp by motorized vessels of less than 10 TBA (gross tonnage) between 3 and 10 nm of the coast (Ordinance N^o 96, August 31, 1993);
- Mandatory use of sea turtles excluding devices (TED) in fishing trawl nets by the industrial vessels along the Brazilian coast (Ordinance N^o 36, April 7, 1994).

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5 PRODUCTIVITY, SUSCEPTIBILITY AND VULNERABILITY INDICES OF BYCATCH IN THE BROWN SHRIMP INDUSTRIAL FISHERY ON THE AMAZON CONTINENTAL SHELF OF BRAZIL

By José Augusto Negreiros Aragão

5.1 Introduction

Quantitative methodologies are the most appropriate methods to assess whether a stock of aquatic organisms is vulnerable to becoming overfished or is currently experiencing overfishing. However, in many cases, there is insufficient data to apply this type of methodology, indicating the need to develop a flexible semi-quantitative methodology that could be applied broadly to assess the level of exploitation of the stocks in many fisheries and regions (Patrick *et al.*, 2009).

Semi-quantitative methods are based on the concept of "productivity", i.e. the ability of the stock to produce MSY and to recover in the event of depletion of the population, and "susceptibility", the potential for the stock to be impacted by the fishery, which includes direct captures, as well as indirect impacts on the fishery. Milton (2001) and Stobutzki *et al.* (2001) were among the first in the development and application of such methodology for classifying differences in bycatch sustainability in the Australian prawn fishery.

The Productivity and Susceptibility Analysis (PSA) has been recognized as an appropriate methodology when there is not sufficient data for application of quantitative methods. The PSA assesses an array of productivity and susceptibility attributes of a stock for which scores of indexes of productivity and susceptibility are computed and graphically displayed.

In the methodology used by the U.S. National Oceanography and Atmosphere Agency (NOAA) a scale of three levels is used to assign values to the scores: 1 - low, 2 - moderate, 3 - high. The weighted average of the values of the attribute scores for each factor ("productivity" and "susceptibility") is plotted on a scatter plot and the vulnerability score of the stock is determined by measuring the Euclidean distance of the datum point from the origin of the plot. A stock with a low score of productivity and high susceptibility score is considered more vulnerable, while a stock with a high score of productivity and low score of susceptibility is considered less vulnerable.

In fisheries where incidental catches occur, the analysis should be applied to both the target stocks and the stocks that make up the bycatch of the fishery. The importance of using the methodology for non-target species is highlighted by Patrick *et al.* (2009) who found that in some fisheries the vulnerability of the target species was not significantly different from the non target species. These authors also recommend that in situations where the quality and/or availability of data are inadequate, the precautionary approach criteria should be applied. The brown shrimp (*Farfantepenaeus subtilis*) industrial fishery on the Amazon continental shelf of Brazil is an example of fisheries where many species are part of the bycatch of the target species.

5.2 Application of PSA

In this paper we tried to apply the PSA analysis to the bycatch of the *F. subtilis* industrial fishery on the Amazon continental shelf of Brazil. Although the biology of the target species has been systematically studied and the level of exploitation of the resource assessed by quantitative methods, there is very little information concerning the species that compose the bycatch and for a large number of these species there is not even sufficient information for applying a semi-quantitative methodology.

It was possible to apply the PSA only to the king weakfish (*Macrodon ancylodon*) and to the red snapper (*Lutjanus purpureus*) and yet superficially since many of the biological parameters as well as information on the responses of the species with regard to the fishing effort are unknown. Even data on the total catch of the species is not available. Many of the parameters and information were obtained from the literature available for similar species in other areas of the Western Atlantic and Caribbean.

The analysis was carried out using the PSA Software that is part of the NOAA Fisheries Tools box (NOAA/NFT) available at the site: http://nft.nefsc.noaa.gov/. The attributes and range of values used for each productivity and susceptibility score in this analysis were the same as that of the methodology proposed by the NOAA and are presented in the following Tables (Table 55.1, Table 555.2 and Table 5).

Table 55.1. Productivity and susceptibility attributes and scores for king weakfish (*Macrodon ancylodon*)

Productivity attribute	Species Value	Attribute Score	DQI	Reference
Population growth rate (r)	0.4	2	5	No data
Maximum age	7 anos	3	2	Fishbase
Maximum size	45.5	3	1	(Camargo, 1999)
v. B. growth coefficient (k)	0.491	3	1	(Camargo, 1999)
Estimated natural mortality	0.78	3	1	(Souza & Fonseca, 2008)
Measured fecundity	1.00E+05	2	4	Fishbase
Breeding strategy	>4	1	4	Fishbase
Recruitment pattern	50%	2	5	No data
Age at maturity	22 cm - 1,5 ano	3	3	Fishbase
Mean trophic level	2.8	2	3	Fishbase
Susceptibility attribute				
Areal overlap	50%	2	5	No data
Geographic concentration	> 50%	1	5	No data
Vertical overlap	50%	2	3	Fishbase
Seasonal migrations	Fair	2	5	No data
Schooling/Aggregation and other behavioral responses	Fair	2	5	No data
Morphology affecting capture Species shows low selectivity to the fishing gear	Fair	2	5	No data
Desirability/Value of the fishery	Fair	2	1	Ibama
Management strategy	Bad	3	1	Ibama
Fishing rate relative to M	0.5	2	1	(Souza & Fonseca, 2008)
Biomass of spawners (SSB) or other proxies	Fair	2	5	No data
Survival after capture and release	Low	3	5	No data
Fishery impact to EFH or habitat in general for nontargets	Fair	2	5	No data

Table 555.2. Productivity and susceptibility attributes and scores for red snapper (*Lutjanus purpureus*)

Productivity attribute	Species Value	Attribute Score	DQI	Reference
Population growth rate (r)	0.24	2	3	(Mendozaa; Larez, 2004)
Maximum age	12	2	3	Fishbase
Maximum size	92.6	2	1	(Sarmento 2012)
v. B. growth coefficient (k)	0.12	1	1	(Sarmento 2012)
Estimated natural mortality	0.366	2	1	(Sarmento 2012)
Measured fecundity	2.90E+05	3	1	(Souza, 2002)
Breeding strategy	>4	1	3	Fishbase
Recruitment pattern	Fair	2	5	No data
Age at maturity	5 anos	1	1	(Souza, 2002)
Mean trophic level	3.5	2	3	Fishbase
Susceptibility attribute				
Areal overlap	> 50%	3	5	No data
Geographic concentration	> 50%	1	5	No data
Vertical overlap	> 50%	3	5	No data
Seasonal migrations	Fair	2	5	No data
Schooling/Aggregation and other behavioral responses	Fair	2	5	No data
Morphology affecting capture Species shows low selectivity to the fishing gear	Fair	2	1	(Souza, 2002)
Desirability/Value of the fishery	High	3	1	Ibama
Management strategy	Low	3	1	Ibama
Fishing rate relative to M	0.58	2	1	(Sarmento 2012)
Biomass of spawners (SSB) or other proxies	Fair	2	5	No data
Survival after capture and release	< 25	3	1	Ibama
Fishery impact to EFH or habitat in general for nontargets	Fair	2	5	No data

Table 55.3. Productivity and susceptibility attributes and scores for camarão (*Penaeus subtilis*)

Productivity attribute	Species Value	Attribute Score	DQI	Reference
Population growth rate (r)	0.342	2	1	Aragão, 2012
Maximum age	1.5	3	1	Aragão, 2012
Maximum size	23.6	3	1	Aragão, 2012
v. B. growth coefficient (k)	1.6	3	2	Aragão, 2012
Estimated natural mortality	2.53	3	2	Aragão, 2012
Measured fecundity	1.00E+05	3	3	Gillett, 2008
Breeding strategy	> 4	1	1	Gillett, 2008
Recruitment pattern	Fair	2	1	Aragão, 2012
Age at maturity	< 1 year	3	1	Aragão, 2012
Mean trophic level	>3	1	3	Zimmerman, 1991
Susceptibility attribute				
Areal overlap	> 50%	3	1	Aragão, 2012
Geographic concentration	> 50%	1	2	Aragão, 2012
Vertical overlap	> 50%	3	3	Gillett, 2008
Seasonal migrations	Increase	3	2	Aragão, 2012
Schooling/Aggregation and other behavioral responses	Fair	2	3	Gillett, 2008
Morphology affecting capture Species shows low selectivity to the fishing gear	Fair	2	5	No data
Desirability/Value of the fishery	High	3	1	Aragão, 2012
Management strategy	Fair	2	1	Aragão, 2012
Fishing rate relative to M	< 0.5	1	1	Aragão, 2012
Biomass of spawners (SSB) or other proxies	> 40%	1	1	Aragão, 2012
Survival after capture and release	< 33%	3	5	No data
Fishery impact to EFH or habitat in general for nontargets	Fair	2	5	No data

5.3 Results and discussion

This analysis should be seen more as a preliminary exercise or just an example of application of the methodology and its results should not be considered realistic. In general, the data and information available are limited, except for the brown shrimp (*F. subtilis*) to which quantitative models have been applied. Besides, the methodology could be roughly applied only to two of the species that make up the bycatch. Anyway the results obtained were somewhat consistent with the biology of the species.

The brown shrimp (*Farfantepenaeus subtilis*) is a small-sized, short life cycle and fast growth species and in view of the current exploitation pattern has a low level of vulnerability, mainly due to the high productivity index. This can be considered a reliable result, because the information available is of good quality and numerical methods have been applied to assess the level of exploitation of stocks also indicating the low vulnerability of the species.

The king weakfish (*Macrodon ancylodon*) also showed a high level of productivity. It is also a *relatively* small-sized species, with a life cycle of about eight years and relatively high growth rate. However, the available information is insufficient and the reliability of the analysis indicating a low level of susceptibility is low. Much of the biological information used refers to similar species in other regions and little is known about the current pattern of exploitation.

Regarding the red snapper (*Lutjanus purpureus*), a higher vulnerability is evident. It is a species with a long life cycle, of slow growth and large size and pattern of fishing relatively well known. Much of the available information is of good quality and the high susceptibility assessment can be considered reliable. One aspect that makes the high susceptibility more critical is the high proportion of juveniles in the catch, reported by Souza (2002).

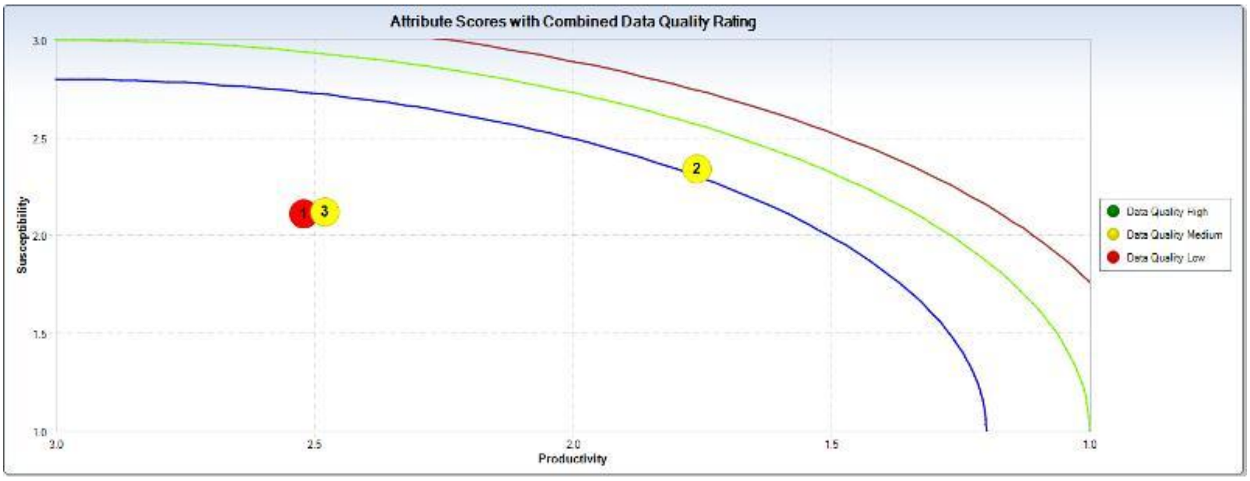

Figure 5.1. Attribute scores combined with data quality rating

Table 5.4. Summary of attribute scores for productivity and susceptibility of some species of Brown shrimp (*F. subtilis*) industrial fishery on the Amazonian continental shelf of Brazil

Stock	King Weakfish	Red Snapper	Brown Shrimp
CommonName	Pescada gó	Pargo	Camarão rosa
ScientificName	Macrodon ancylodon	Lutjanus purpureus	Farfantepenaeus subtilis
Productivity score	2.52	1.76	2.48
Productivity quality score	4.64	2.04	1.56
Suscecibility score	2.11	2.34	2.12
Suscecibility quality score	5	3.34	2.92
Vulnerability	1.21	1.83	1.23

Table 5.5. Attribute scores for productivity and susceptibility of some species of Brown shrimp (*F. subtilis*) industrial fishery on the Amazon continental shelf of Brazil

Stock	King Weakfish	Red Snapper	Brown Shrimp
CommonName	Pescada gó	Pargo	Camarão rosa
ScientificName	Macrodon ancylodon	Lutjanus purpureus	Farfantepenaeus subtilis
Productivity score	2.52	1.76	2.48
Suscecibility score	2.11	2.34	2.12
Vulnerability	1.21	1.83	1.23
Produtivity StDev	0.796	0.617	0.796
Number of produtivity attributes	10	10	10
Productivity quality score	4.64	2.04	1.56
Productivity quality StDev	1.028	1.349	0.793
Suscecibility StDev	0.770	0.630	0.787
Number of suscecibility attributes	12	12	11
Suscecibility quality score	5	3.34	2.92
Suscecibility quality StDev	0	2.06	1.74

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6 BIO-ECONOMIC MODEL APPLIED TO INDUSTRIAL FISHING OF FARFANTEPEANEUS SUBTILIS ON THE AMAZON CONTINENTAL SHELF OF BRAZIL

By José Augusto Negreiros Aragão

6.1 Material and methods

A dynamic bio-economic model structured by length, composed of a biological sub-model, based on the work of Sullivan, Lai & Gallucci (1990) and an economical sub-model based on the work of Seijo, Defeo & Sallas (1997), was used to carry out this analysis and explore the impacts of alternative state of nature and the fisheries management strategy. A short- and medium- term analysis was conducted taking into account the pattern of recruitment for the fisheries and the observed temporal distribution of the fishing effort in the *Farfantepenaeus subtilis* fishery on the Amazon continental shelf of Brazil.

From an initial monthly composition of the population by length, several scenarios were simulated considering different levels of recruitment and fishing effort, and the monthly yield of the fisheries (catches) for the next three years was estimated. It was used as reference for the composition of the population by length in the year 2000, because it was the last year when the fleet operated the whole year (12 months) and the level of exploitation of the population was relatively high, which also made it possible to assess the effects of the closed season. The biological parameters determined in the previous section were used in the application of the models.

From the monthly data on capture in weight and fishing effort and the biological parameters, the model helps to estimate the monthly recruitment, survival rate, length composition, as well as the monthly population biomass that should be present at sea in order to obtain those catch and exploitation rates. Once the status of the population, the pattern of recruitment and exploitation rates were determined, simulations are made for different scenarios. Several scenarios were simulated and evaluated considering alternative combinations of recruitment and levels of fishing effort according to the Table 6.1 below.

Table 6.1. Scenarios considered in the bio-economic analysis of *F. subtilis* industrial fisheries

Initial recruitment levels (milions of individuals)			
R_50	R_80	R_110	R_140

Fishing effort levels (thousands of days at sea)													
E_8	E_12	E_16	E_18	E_20	E_22	E_24	E_26	E_28	E_30	E_32	E_34	E_38	E_42

Fisheries revenue for each month and year was estimated from the conversion of prices per commercial category for pricing by length class. In this regard the length ranges of each commercial category were determined from the weight ranges, using the tails weight and length relationship. Estimated catches corresponding to each class of length were then multiplied by the respective prices and added up.

The operational cost for one unit of fishing effort and the annual fixed costs of a vessel were estimated from the results presented in the work of Carvalho, Chaves & Cintra (2003). The following Table 6.2 presents the relative composition of annual costs of a typical boat used in this fishery:

Table 6.2. Relative composition of costs of the industrial shrimp fishery for *F. subtilis*

Relative composition		%
Total cost		100%
Fixed cost		7%
Variable cost		93%
	Fuel	60%
	Others	40%

As there is no recent data, the fishing operational cost was updated from the annual variable costs estimated for a typical vessel obtained FROM Carvalho, Chaves & Cintra (2003) presented in the above Table 2. The value of the diesel consumed by a boat during a fishing day (980 litres) was simply calculated at today's prices (R$ 1.90), and the total operational cost was estimated from this value, which corresponds to 60% of the variable costs. This cost was divided by the number of days at sea by vessel, thus giving the operating cost of a unit of fishing effort (days at sea). The total cost for each vessel has been estimated, knowing that the operating cost corresponds to 93% and that the fixed cost per vessel corresponds to 7% of total costs.

It should be emphasized that the fixed costs considered here include only the monetary (financial) return of the capital invested in the activity when, in general, the boats are more than 20 years old. It was assumed, therefore, that the depreciation of the hull, engines and equipment is already included in the annual maintenance costs and other minor fixed costs like licenses and taxes were not considered.

The monthly operational profit (or loss) of the activity was obtained by subtracting the variable costs from the revenue and the final profit of the activity was obtained by deducting the annual fixed costs of the fleet corresponding to that level of fishing effort. The projected values over time were corrected using a monthly average rate of discount of 0.0045 (Aragão and Silva, 2000). The annual operational profit (or loss) thus obtained represents the “present value” or “net operational profit” of the fishery.

The following Table 6.3 presents a summary of the biological and economical parameters used in the analysis.

Table 6.3. Biological and economic parameters of the F. subtilis industrial fisheries on the Amazon continental shelf of Brazil

Economic Parameters	
Rate of discount:	0.0045
Dolar exchange rate	R$ 2.05
Diesel price (l)	R$ 1.90

Biological Parameters (ARAGÃO, 2012)	Female	Male
Assimptotic length	236.3	215.3
Growth curvature parameter, k (1/year)	1.60	0.94
Natural mortality coeficient, M (1/year:	2.53	1.83
Parameter t0 of growth equation:	0.0	0.0
Length 50% retention tail (mm)	85.2	65.8
Length 75% retention tail (mm)	92.3	71.6
Parameter **a** of length-weight relationship	40.820	41.845
Parameter **b** of length-weight relationship	0.318	0.313

Commercial categories prices				
Class	Mean (#)	Weight	Length	US$/kg
91/120	90	5.0	68.3	5.60
71/90	71	6.4	73.6	8.69
61/70	61	7.4	77.3	9.46
51/60	51	8.9	81.8	9.90
41/50	41	11.0	87.7	11.40
31/40	31	14.6	95.8	12.90
26/30	26	17.4	101.4	14.90
21/25	21	21.6	108.5	18.10
16/20	16	28.3	118.3	21.30
11/15	11	41.2	133.3	21.30

6.2 Results and Discussion

The following tables and graphs show the results of the evaluation of different scenarios on the "status" of the population estimated from the length composition of the population in the year 2000. The results refer to the yield in weight (catches) and "present value" of the fishery (net income) in the three years following the year of reference (second, third and fourth years).

The results of the projections for a recruitment of 50 million are shown in

Table 6.4 and Figure 6.1. Yield (t) and present value (profit US$) for a recruitment level of 50 million, The results of the projections for a recruitment of 80 million are shown in Table 6.5 and Figure 6.2. The results of the projections for a recruitment of 110 million are shown in Table 6.6 and Figure 6.3 and the results of the projections for a recruitment of 140 million are shown in Table 6.7 and Figure 6.4.

It is clear that the yield increases in weight of the fishery are more related to higher level of recruitment than to increases in the level of fishing effort. For the same level of recruitment, expressive (significant) increases of the yield of the fishery in weight are not observed for levels of fishing effort beyond 18 thousand days at sea.

The tenuous financial stability of the fishery is very clear, with a tendency for losses to be incurred at moderate or high levels of fishing effort at all levels of recruitment. In fact, the profitability of the fishery is negative for any level of fishing effort in case of a failure in recruitment (R-50), except for a level of fishing effort of only 8 thousand days at sea per year.

Results described in the tables show that profits are obtained in the fishery, even if small, for the three years, for any level of recruitment, only for a level of fishing effort corresponding to 8 thousand days at sea. For moderate recruitment levels (R-80 and R-110) the profitability of the fishery is positive up to the level of fishing effort of 18 to 20 thousand days at sea. However, even for very high recruitment levels (R-140) fishery income becomes negative in the case of fishing effort levels above 28 thousand days at sea.

For low and moderate levels of recruitment the frequency of losses incurred in the activity for high levels of fishing effort is very high, increasing continuously as the level of fishing effort increases. Financial losses are also frequent in the activity for high levels of fishing effort scenarios, even though the level of recruitment is also high.

The results obtained here are somewhat consistent with the estimated maximum sustainable effort obtained by the biomass dynamic model. It is, therefore, recommended that the maximum fishing effort being applied should not exceed 18,000 days at sea, therefore lower than the level estimated in the previous bio-economic analysis carried out by Aragão and Silva (2000).

6.3 Scenarios for the industrial fishery of *F. subtilis* in the Amazon Continental Shelf of Brazil

Table 6.4. Yield (t) and present value (profit US$) of the fishery for a recruitment level of 50 millions

	Yield (t)			Present value (US$)		
	R50			**R50**		
Effort	2nd Year	3rd Year	4th Year	2nd Year	3rd Year	4th Year
E08	1,112	1,107	1,094	$2,679	$3,249	$2,779
E12	1,391	1,295	1,284	-$611	-$1,338	-$1,562
E16	1,569	1,391	1,384	-$5,508	-$7,277	-$7,162
E18	1,631	1,420	1,415	-$8,349	-$10,500	-$10,206
E20	1,680	1,441	1,436	-$11,374	-$13,817	-$13,344
E22	1,719	1,454	1,451	-$14,536	-$17,195	-$16,543
E24	1,750	1,464	1,462	-$17,803	-$20,608	-$19,781
E26	1,771	1,446	1,468	-$21,167	-$24,310	-$23,044
E28	1,793	1,473	1,471	-$24,543	-$27,484	-$26,313
E30	1,807	1,474	1,473	-$27,979	-$30,928	-$29,587
E34	1,828	1,472	1,471	-$34,922	-$37,800	-$36,127
E36	1,839	1,466	1,466	-$41,905	-$44,636	-$42,637
E42	1,846	1,458	1,458	-$48,893	-$51,428	-$49,106

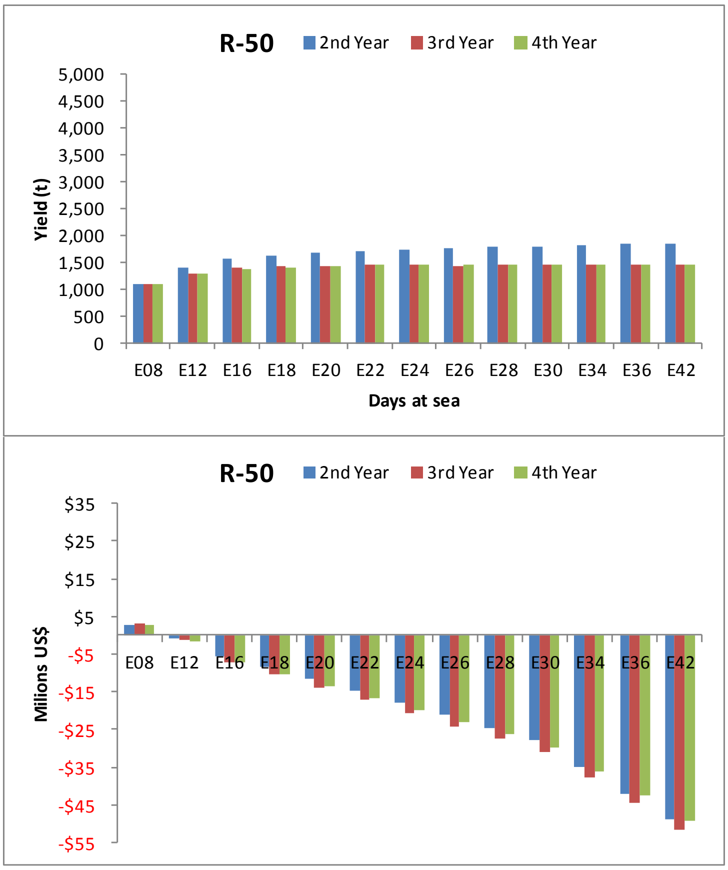

Figure 6.1. Yield (t) and present value (profit US$) for a recruitment level of 50 million

Table 6.5. Yield (t) and present value (profit US$) of the fishery for a recruitment level of 80 million

	Yield (t)			Present value (US$)		
	R80			R80		
Effort	2nd Year	3rd Year	4th Year	2nd Year	3rd Year	4th Year
E08	1,507	1,855	1,867	$7,852	$13,783	$13,204
E12	1,895	2,187	2,192	$5,741	$10,608	$10,041
E16	2,146	2,361	2,363	$1,493	$5,096	$4,722
E18	2,235	2,414	2,415	-$1,160	$1,884	$1,645
E20	2,306	2,451	2,452	-$4,062	-$1,504	-$1,592
E22	2,362	2,477	2,477	-$7,155	-$5,007	-$4,934
E24	2,407	2,495	2,495	-$10,391	-$8,581	-$8,342
E26	2,442	2,506	2,506	-$13,734	-$12,198	-$11,788
E28	2,470	2,512	2,512	-$17,155	-$15,835	-$15,253
E30	2,493	2,514	2,514	-$20,632	-$19,479	-$18,725
E34	2,524	2,511	2,511	-$27,688	-$26,751	-$25,651
E36	2,542	2,502	2,502	-$34,808	-$33,968	-$32,525
E42	2,553	2,489	2,489	-$41,938	-$41,113	-$39,331

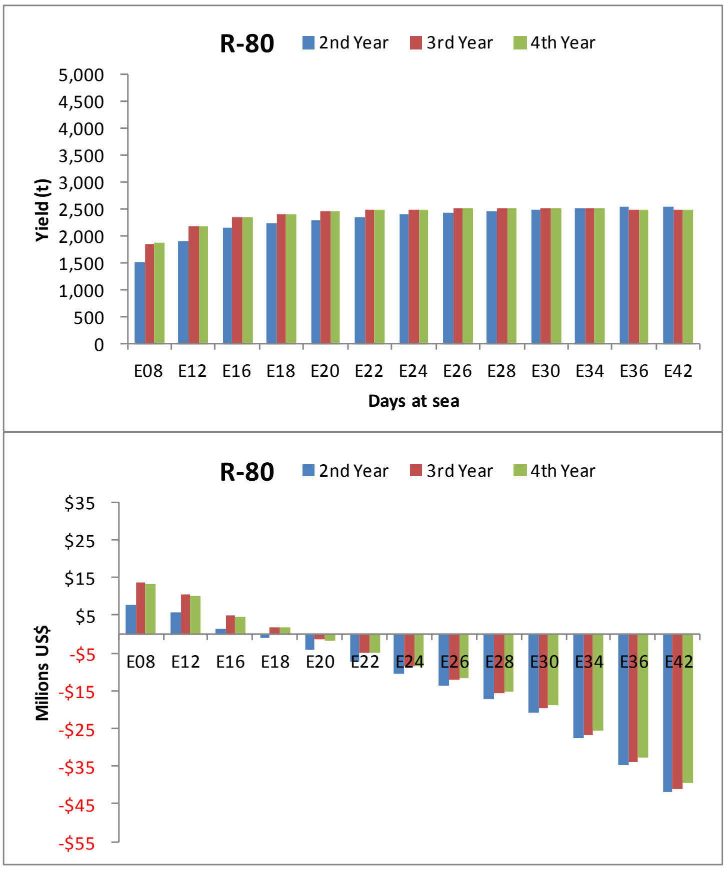

Figure 6.2. Yield (t) and present value (profit US$) for a recruitment level of 80 million

Table 6.6. Yield (t) and present value (profit US$) of the fishery for a recruitment level of 110 million

	Yield (t)			Present value (US$)		
	R110			R110		
Effort	2nd Year	3rd Year	4th Year	2nd Year	3rd Year	4th Year
E08	1,783	2,378	2,406	$11,460	$21,130	$20,475
E12	2,247	2,809	2,825	$10,172	$18,939	$18,133
E16	2,548	3,038	3,046	$6,376	$13,725	$13,010
E18	2,655	3,107	3,113	$3,854	$10,520	$9,911
E20	2,742	3,156	3,160	$1,037	$7,083	$6,605
E22	2,810	3,190	3,193	-$2,007	$3,494	$3,163
E24	2,865	3,213	3,215	-$5,222	-$193	-$364
E26	2,909	3,228	3,229	-$8,566	-$3,937	-$3,940
E28	2,943	3,236	3,237	-$12,003	-$7,711	-$7,540
E30	2,971	3,240	3,240	-$15,508	-$11,495	-$11,149
E34	3,009	3,236	3,237	-$22,644	-$19,046	-$18,345
E36	3,032	3,224	3,225	-$29,858	-$26,529	-$25,473
E42	3,046	3,208	3,208	-$37,088	-$33,919	-$32,513

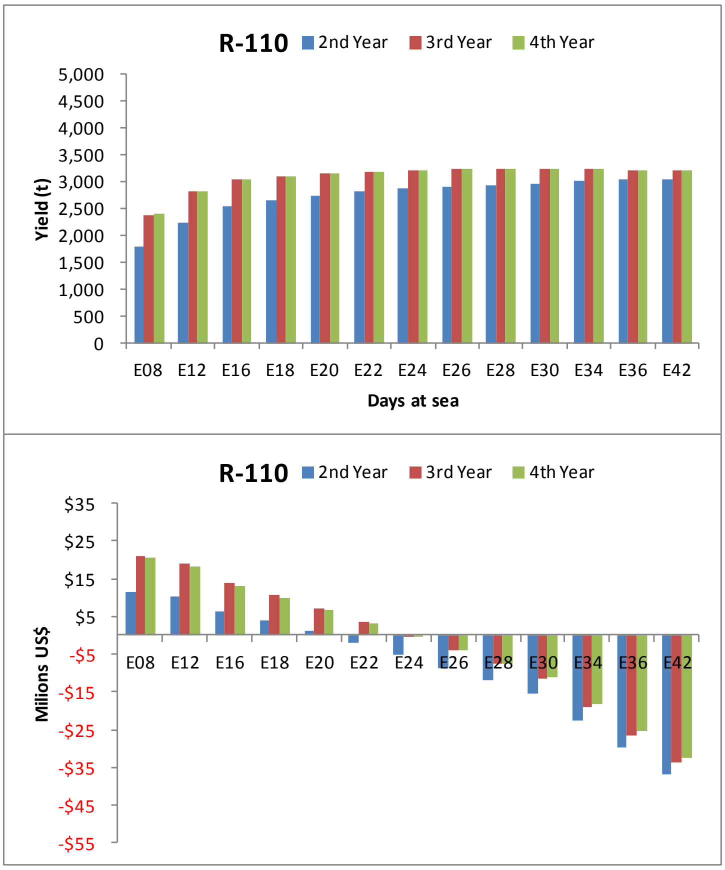

Figure 6.3. Yield (t) and present value (profit US$) for a recruitment level of 110 million

Table 6.7. Yield (t) and present value (profit US$) of the fishery for a recruitment level of 140 million

	Yield (t)			Present value (US$)		
	R140			R140		
Effort	2nd Year	3rd Year	4th Year	2nd Year	3rd Year	4th Year
E08	2,119	3,013	3,062	$15,851	$30,071	$29,323
E12	2,675	3,566	3,595	$15,563	$29,078	$27,980
E16	3,038	3,861	3,876	$12,319	$24,225	$23,097
E18	3,168	3,950	3,961	$9,956	$21,030	$19,970
E20	3,272	4,014	4,022	$7,242	$17,534	$16,579
E22	3,356	4,058	4,064	$4,258	$13,838	$13,016
E24	3,423	4,088	4,092	$1,068	$10,014	$9,345
E26	3,476	4,107	4,110	-$2,276	$6,115	$5,611
E28	3,518	4,118	4,120	-$5,734	$2,176	$1,846
E30	3,552	4,123	4,124	-$9,273	-$1,779	-$1,929
E34	3,600	4,119	4,119	-$16,505	-$9,669	-$9,453
E36	3,629	4,104	4,104	-$23,835	-$17,475	-$16,891
E42	3,646	4,083	4,083	-$31,186	-$25,165	-$24,216

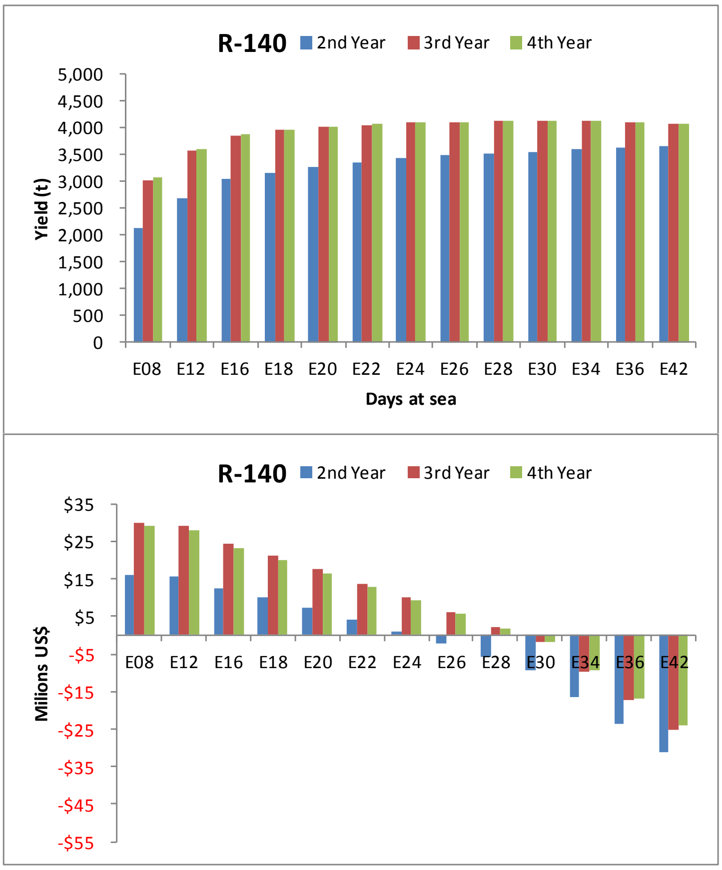

Figure 6.4. Yield (t) and present value (profit US$) for a recruitment level of 140 million

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This document is the compilation of the assessemtn studies that were carried out in support to the Case Study on the Shared Stocks of the Shrimp and Groundfish Fishery of the Guianas-Brazil Shelf of the Caribbean Large Marine Ecosystem Project (CLME). It is the ninth of ten reports that were produced as a result of the case study activities. These documents summarize the outputs of the different steps undertaken to mainstream the Ecosystem Approach to Fisheries (EAF) in the management of the shrimp and ground fish resources of the Northern Brazil Shelf Ecosystem.