INTERMEDIATE REPORT

ASSESSMENT OF STOCK STATUS AND INTENSITY OF EXPLOITATION FOR THE CAVALA PRETA, CHICHARRO AND DOBRADA, SMALL PELAGIC FISHERY RESOURCES IN THE WATERS SURROUNDING CAPE VERDE

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Submitted to:

West Africa Regional Fisheries Project-Cape Verde (WARFP-CV)
Praia, Santiago, Cape Verde

31 March 2012

EXECUTIVE SUMMARY

Cavala preta

Landings of cavala preta in the last two decades have ranged from less than 500 to almost 3000 metric tons (mt), with an average of 2000 mt in the last decade. Previous assessments of stock status of cavala preta in Cape Verdean waters have stated that this species was moderately exploited, and that there was potential for additional yield. The results of all the analyses conducted, and in particular the equilibrium surplus production and the biomass dynamic models analyzing data over a 20 year period from 1989 to 2009, indicate that *MSY* for cavala preta is about 2500 mt. However it must be noted that to achieve this production the stock must be rebuilt to B_{MSY}. According to this analysis, overfishing has occurred, and as a result the resource has been depressed and overfished for almost all of the period investigated. Overfishing is defined here to be when F/F_{MSY} is >1.0. When B/B_{MSY} is <1.0, the stock is considered depressed, and when B/B_{MSY} is <0.5 the stock is considered overfished. In 2009 the stock is overfished as B_{2009} is estimated to be well below 0.5 B_{MSY} and overfishing is occurring as

F_{2009} is estimated to well above F_{MSY}. This analysis and the management advice resulting from it assume that the fishery has covered the same area over the history of the data series, and that the catch and effort data from the artisanal and industrial circle net fisheries, and the resulting Catch per Unit Effort CPUE) is representative of the relative abundance of the stock.

The results of the Yield per Recruit (YPR) and Spawning Stock Biomass per Recruit (SSBPR) analyses indicate that the current minimum fish length should be observed and enforced, if necessary, so as to allow for as many fish as possible to mature and contribute to spawning stock biomass and stock rebuilding. In fact, if the minimum legal length of the fish that was permitted to be landed was increased to 22 cm, both the yield and the spawning stock remaining after fishing would increase significantly. Most importantly, based on the projection of the Fox non-equilibrium surplus production model, it is recommended that for the next 3 years landings be limited to 1000 mt. Then as the stock rebuilds, the landings can be slowly increased, ultimately reaching the estimated *MSY* or 2700 mt annually. Finally, it should be noted that without a restriction on landings, the stock is in jeopardy, and not taking additional management action beyond the current minimum landing size of 18 cm and a 2 month closed season, is not consistent with a precautionary approach.

<u>Chicharro</u>

Landings of chicharro in the last two decades have ranged from less than 500 mt in the 1980s and 1990s, to almost 1400 mt in the 2004 and 2005, and have since declined to about 1000 mt in 2009. Previous assessments of stock status of chicharro in Cape Verdean waters have stated that this species was moderately exploited, and that there was potential for additional yield.

The results of the qualitative analysis of the CPUE data suggest a sustainable catch at the current biomass level of 1000 mt. The results of the trend analysis for the mode of the length frequency distribution indicate an almost significant positive trend in the size of the fish landed, suggesting that the intensity of fishing has reduced slightly during the observation period, as fish are growing larger due to being in the stock a longer time before being harvested, unless the fishery has expanded into areas where the stock has been less heavily exploited. The results of the YRP and SSBPR analyses suggest that there is minimal benefit to enforcement of the minimum landed length regulations, and that this is due to the very different life history characteristics of the species, as compared to cavala. The results of the equilibrium surplus production model estimate MSY at 1000 mt, but this method is believed to produce generally optimistic results.

So, in contrast to previous assessments, the results of this work suggest that chicharro is fully exploited, and that landings should restricted to about 1000 mt, so as to maintain the stock at productive levels.

Dobrada

Landings of dobrada in the last two decades have ranged from less than 200-400 mt in the 1980s and until 1998, then increased to almost 1200 mt in the 2000, and more recently declined to an average of 300 mt. There have been no previous assessments of dobrada, and there is limited life history information available for this species.

The results of the qualitative analysis of the CPUE data suggest a sustainable catch at the current biomass level of 300 mt. The results of the trend analysis for the mode of the length frequency distribution indicate a trend in the size of the fish landed that was not significantly different from 0. The YPR and SSBPR analyses could not be conducted due to a lack of life history information, and a surplus production model could not be fit, because the CPUE does not decline with increasing effort. The most convincing analysis is the decrease in gillnet fishery CPUE by one half in the last decade, and this suggests that the stock abundance is in decline.

Given the lack of information on this resource, and the decrease in the fishery dependent CPUE, it is suggested that the management of this resource proceed with caution, and that no further expansion of the fishery be considered, until more data is available on the life history characteristics of the resource, and there are clearer trends in the CPUE index as a function of effort and time.

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PREFACE

This report is the first in a series of reports on the stock status and intensity of fishing on the fishery resources of Cape Verde. This report addresses small pelagics fishery resources, and subsequent reports will be directed to the demersals and lobster fishery resources. The analyses and management advice are described by species: cavala, chicharro, and dobrada. The most recent data available in 2012 from the Instituto Nacional de Desenvolvimento das Pescas (INDP) on landings and effort is 2009, so the analyses are limited to that date.

INTRODUCTION

The small pelagic fishery resources in the waters surrounding the Cape Verde islands (Figure 1) consist of primarily three species: the mackerel scad or cavala preta (*Decapterus macarellus*), big eye scad or chicharro (*Selar crumenophthalmus*), and the black spot picarel or dobrada (*Spicara melanurus*) (Figure 2). Cavala and chicharro are harvested primarily with circle seine nets by both artisanal boats and industrial vessels, whereas dobrada are harvest primarily with gillnets set by artisanal fishermen. The Instituto Nacional de Desenvolvimento das Pescas (INDP) is the government agency responsible for the collection of landings and effort data on the fisheries of Cape Verde, and there exist comprehensive summaries (Statistical Bulletins) of catch statistics dating to 1988 for most of the Cape Verdean fisheries. The most recent data available is for 2009. In 2011 Dr. Joseph DeAlteris was contracted by West Africa Regional Fisheries Project-Cape Verde (WARFP-CV) to assist INDP with the development of stock assessments and management advice based on current data for the key fishery resources of Cape Verde. The scope of the contract includes small pelagic, demersals, and crustacean fishery resources.

The purpose of this assessment and report is to review the stock status of cavala preta, chicharro and dobrada, and the levels of fishing intensity through 2009. The report also provides biological advice on the management of these fishery resources for sustainability into the future.

Figure 1. Bathymatric map of the Cape Verde Islands and the surrounding waters.

a.

b.

c.

Figure 2. Pictures of the Cape Verdean small pelagic species: a. mackerel scad or cavala preta (*Decapterus macarellus*), b. big eye scad or chicharro (*Selar crumenophthalmus*), and c. the black spot picarel or dobrada (*Spicara melanurus*)

DESCRIPTIONS OF THE FISHERIES AND THEIR LANDINGS

Fisheries

The artisanal fisheries Cape Verde in 2011 include 1221 outboard powered boats and 3084 fishermen spread over 73 communities. This compares to 1036 boats reported in the statistical bulletin for 2008, an 18% increase over three years. The median age of boats is 8 years, and the median length of boat 5 m. The price of fuel (gasoline) to artisanal fishermen is not subsidized, and is $170 CVE per liter. The semi-industrial and industrial fisheries include 90 inboard powered vessels of various sizes up to 30 m in length, of which 20 are semi-industrial vessels at 11 m. The price of fuel (diesel) to the semi-industrial and industrial fisheries is government subsidized, and is $94.4 CVE per liter, compared to a pump price of $111 CVE[1].

Cape Verde small pelagic fisheries are all open access fisheries, that is, anyone can fish and fishing effort is not limited. The small pelagic fisheries harvest three principal fish species. Cavala preta is harvested primarily by seine nets: purse seines and other seines set in a circle. Other gears including hand lines, gillnets and beach seines produce a small portion of the landings. The seines have a minimum mesh size of 24 mm stretch mesh size. The artisanal fishermen fish from the shore to seaward; industrial vessels must fish beyond 3 nm from shore; and the semi-industrial vessels (11 m) can fish within 3 nm of shore, but not in semi-enclosed bays as these areas are reserved for artisanal fishermen. There is a two month closed season (August and September) during spawning season, and there is a minimum size for landings of 18 cm. It is reported however that there are landings of cavala during the closed season by artisanal fishermen, and that there is little compliance with the minimum fish length regulations (INDP, per. comm.) The price of cavala in 2011 at Frescomar, a cannery, is $40 CVE per kg dockside and $40-60 CVE per kg for fishermen selling catch in the open market.

Chicharro are harvested by many gears including seine nets set in a circle, other seines, hand lines, and gillnets. These various gears are used by artisanal fishermen, while the semi-industrial and industrial vessels primarily use encircling seine nets. There is a directed night fishery using encircling seine nets where the chicharro are attracted to a fishing area with lights then surrounded with the seine. There is no closed season for chicharro, but there is a minimum size for landings of 12 cm. The price of chicharro in 2011 is $40-60 CVE per kg to fishermen in open market.

[1] http://data.worldbank.org/indicator/EP.PMP.DESL.CD

Dobrada is primarily harvested in a directed, bottom set, gillnet fishery operated by the artisanal fishermen. The gillnet has a minimum mesh size of 40 mm. There is no closed season, but there is a minimum size for landed fish of 17 cm.

Landings

Landings by species for the artisanal and industrial sectors of the small pelagic fisheries of Cape Verde (cavala, chicharro, and dobrada) for the period 1986 to 2009 are summarized in Table 1 and plotted as time series in Figures 3, 4, and 5. The terms landings and catch are used interchangeably in this report as all catch is landed. Landings of cavala by the artisanal sector have slowly declined from the late 1980s when they peaked at almost 1500 mt to the present where they are less than 400 mt. In contrast the landings of the industrial sector have slowly risen from less than 200 mt in the late 1980s to an average of 1500 mt at present. Superimposed on these trends are cycles with a period of 3 to 5 years that are presumably related to a strong year class or cohort working its way through the fishery stock. Long term average landings of chicharro by the artisanal sector has remained constant from the late 1980s to the present at about 400 mt, but again there are cyclic patterns in the data, and in the last five years landings have decreased from a high of more than 700 mt to a low of less than 300 mt. In contrast the landings of the industrial sector have slowly risen from less than 50 mt in the late 1980s to an average of 750 mt at present. Long term average landings of dobrada by the artisanal sector increased from the late 1980s to 1999 when they peaked at almost 1200 mt, but since then they have declined to about 400 mt. In contrast the landings of the industrial sector have remained at less than 50 metric tons annually for the entire period form in the late 1980s to the present.

Comparing the total landings by both the artisanal and industrial sectors for the period from the late 1980s to the present (Figure 6), the total landings of cavala have steadily risen over the period, with the previously mentioned cycles superimposed. The total landings of chicharro have steadily risen over the period, but not at the rate of cavala. The total landings of dobrada steadily rose from the late 1980s to the year 2000, then slowly declined to the present. Over the last decade, average landings of cavala have been about 2000 metric tons or a little less than 60% of the total landings of all small pelagics; landings of chicharro have averaged about 1000 mt; and landings of dobrada have averaged a little less than 500 mt. Combined total landings of small pelagics have averaged about 3500 mt in the last decade, and peaked in 1998 at a little more than 4000 mt. There appear to be no clear patterns of increased landings of one species alternating with decreased landings of another species.

Total catch of small pelagic fishes slowly rose from about 1500 mt in the mid-1980s to about 4200 mt the late 1990s, and since then has remained at an average of about 3800 metric tons

(Figure 7). Following the record landings in 2000, the catch declined markedly in 2001, then rose again. Interestingly, landings remained reasonably steady in the 2004-2006 period, despite the dramatic decrease in industrial effort in that period.

Fishing effort for small pelagics is reported in the INDP Statistical Bulletins in trips by small outboard boats for the artisanal fleet and by days at sea for the industrial fleet. Each trip on an artisanal vessel is most often a single day at sea of fishing. Interestingly, the industrial vessels are generally small vessels that also make day trips, and therefore each day is equivalent to a trip. In other words, the reported units of effort generally have the same duration for both the industrial and the artisanal fleets, but because the industrial vessels are so much more efficient due to size and level of mechanization, they have greater landings for a single unit effort. The landings and effort data used to develop Landings per Unit Effort (LPUE) indices for the analyses reported on herein were specific to the species harvested and the gears used. The LPUE indices are referred to as Catch per Unit Effort (CPUE), so as to be consistent with the scientific literature. It must also be noted that a single unit of effort (fishing day) could result in catches and landings of multiple species of fish. These CPUE indices are used and reported in the results of each particular analysis by species.

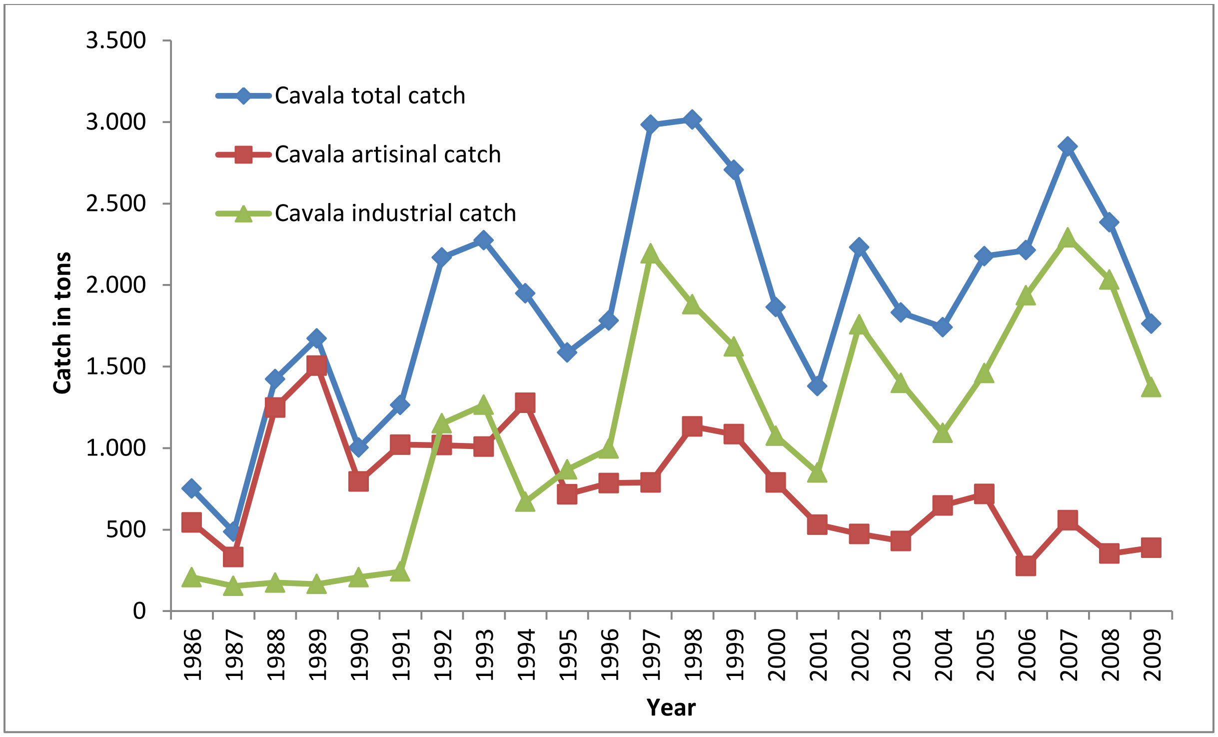

Figure 3. Total, artisanal, and industrial catch (mt) of cavala preta (mackerel scad), *Decapterus macarellus* in Cape Verde from 1986 to 2009.

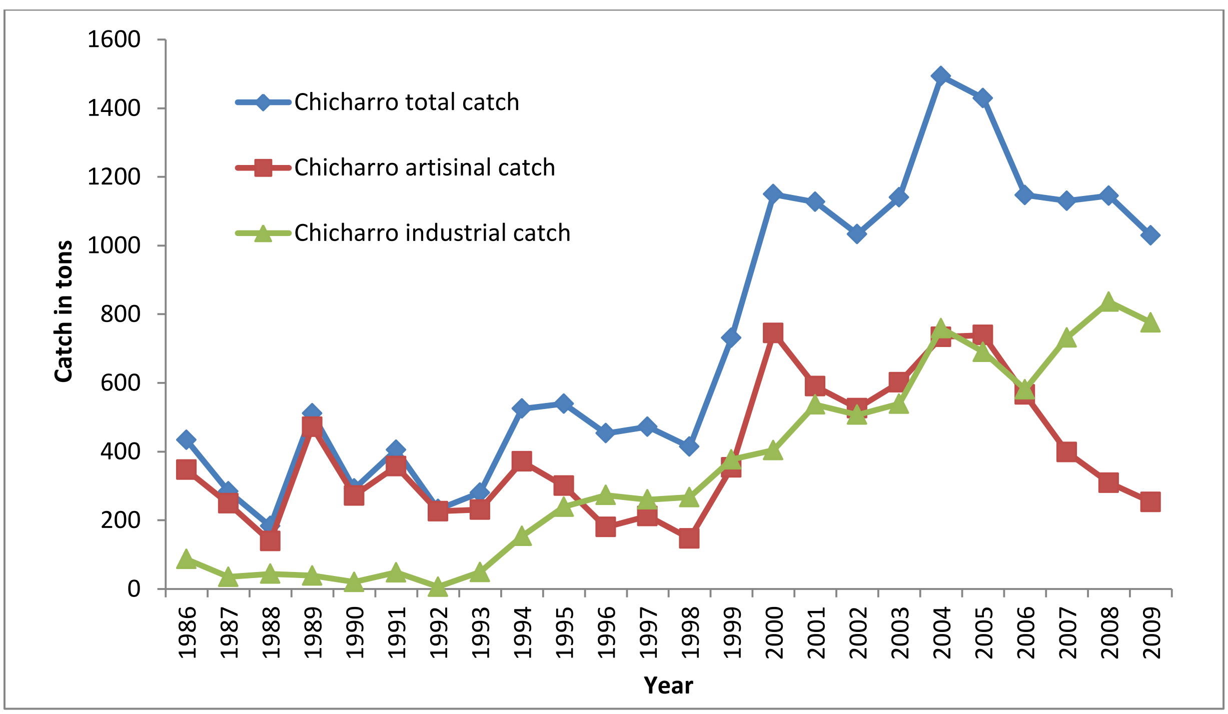

Figure 4. Total, artisanal, and industrial catch (mt) of Chicharro, (Big eyed scad) *Selar crumenophthalmus*, in Cape Verde from 1986 to 2009.

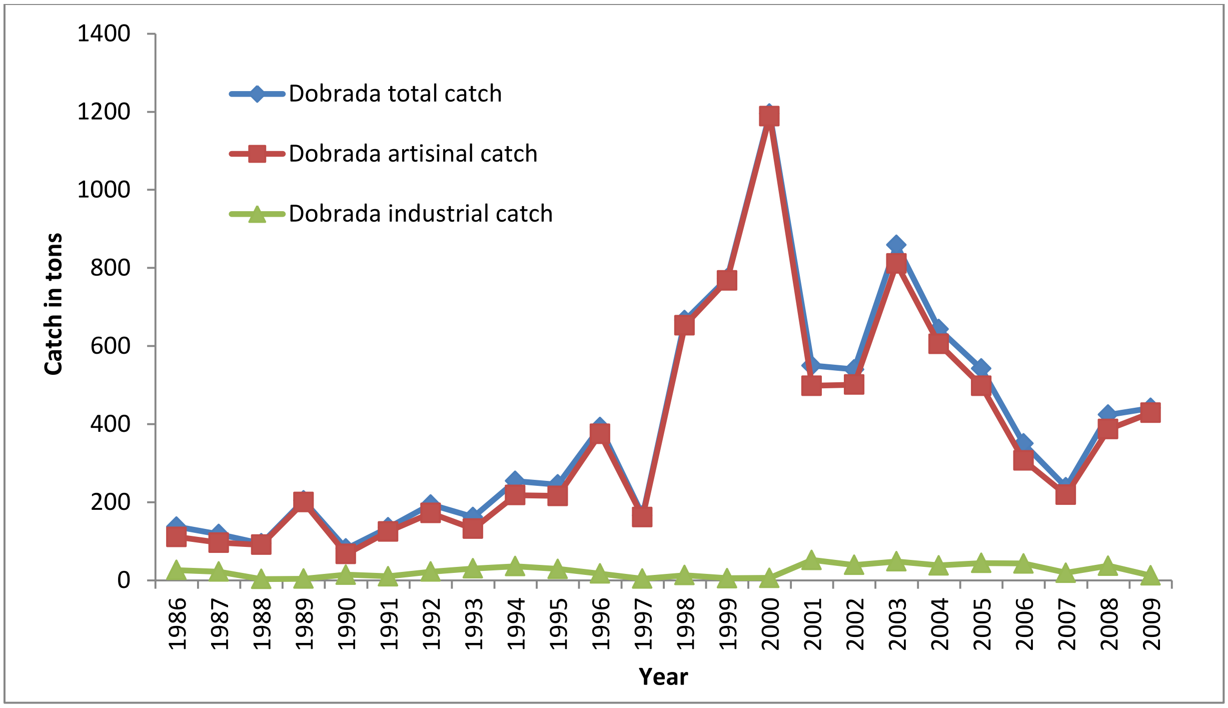

Figure 5. Total, artisanal, and industrial catch (mt) of Dobrada (*Spicara melanurus*) in Cape Verde from 1986 to 2009.

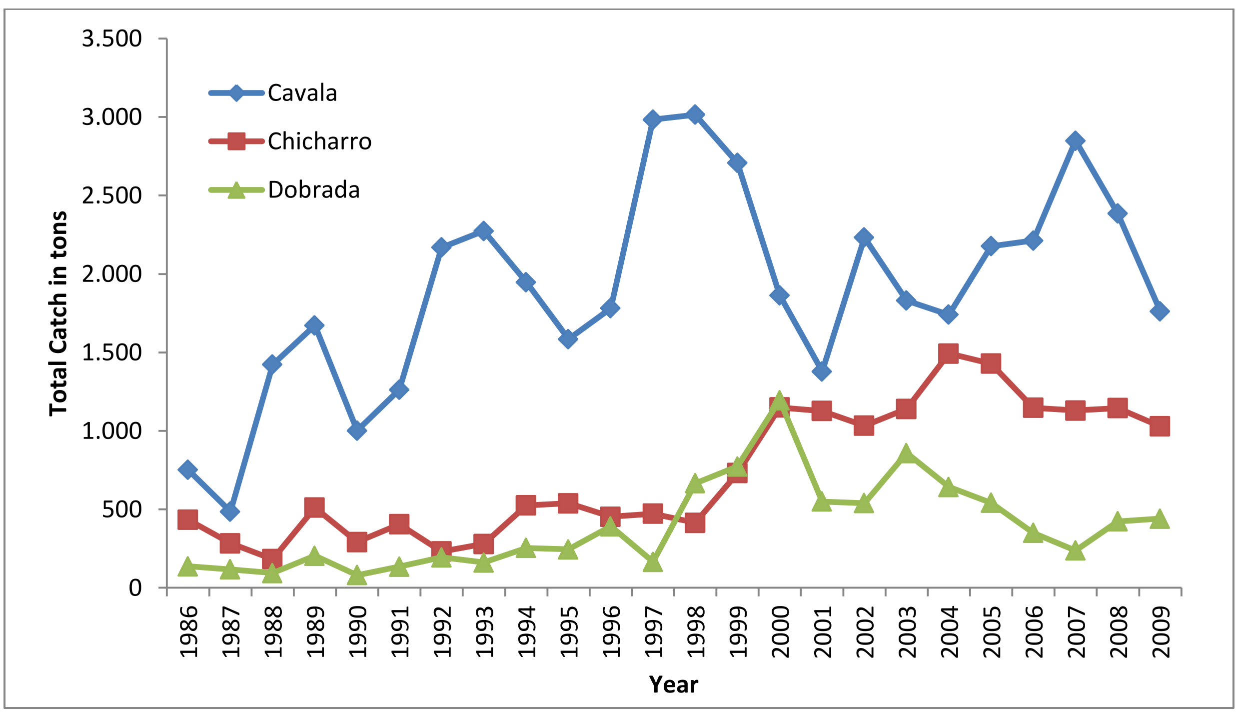

Figure 6. Total, artisanal, and industrial catch (mt) by species for all small pelagics in Cape Verde from 1986 to 2009.

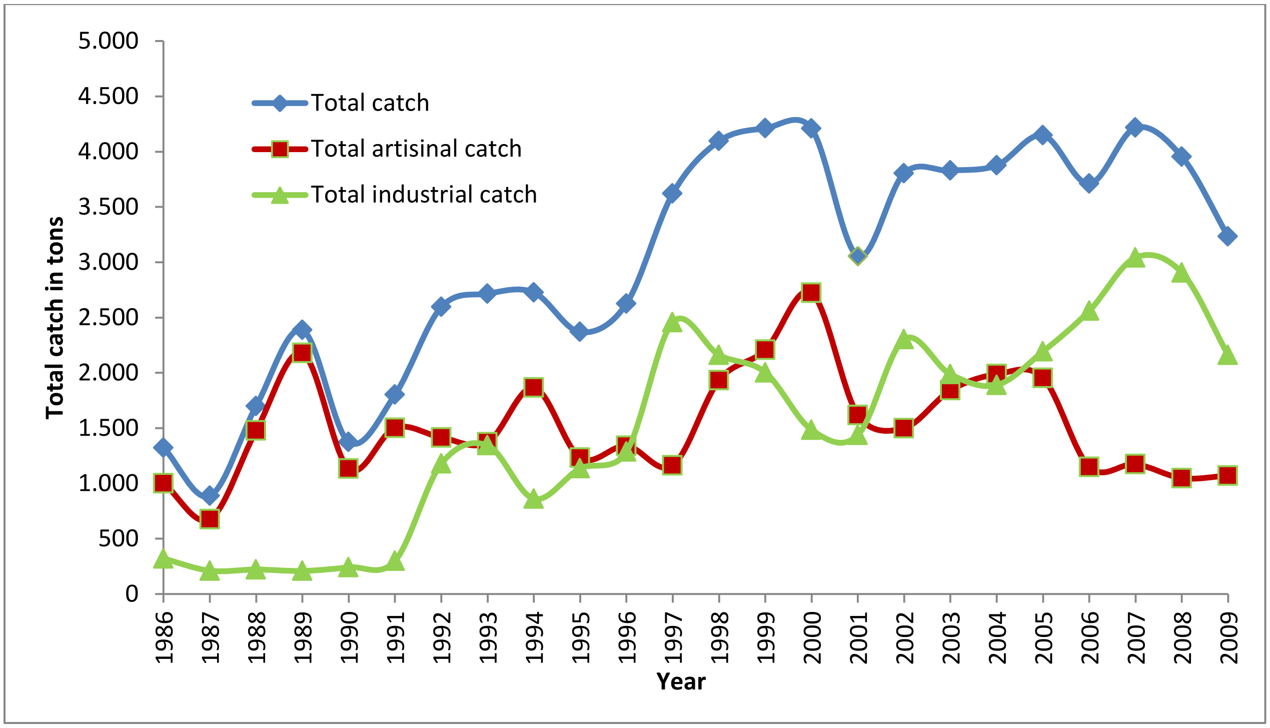

Figure 7. Total, artisanal, and industrial catch (mt) for all small pelagic species combined.

Table 1. Landings (mt) of small pelagic species in Cape Verde in artisanal and industrial fisheries in metric tons by species, Cavala (*Decapterus macarellus*), Chicharro (*Selar crumenophthalmus*) and Dobrada (*Spicara melanurus*), as provided by INDP.

Year	Cavala Artisinal Catch	Cavala Industrial Catch	Cavala Total Catch	Chicharro Artisinal Catch	Chicharro Industrial Catch	Chicharro Total Catch	Dobrada Artisinal Catch	Dobrada Industrial Catch	Dobrada Total Catch
1986	544	208	752	347	87	434	111	26	137
1987	332	154	486	249	35	284	96	22	118
1988	1,248	175	1,423	139	44	183	91	3	94
1989	1,506	166	1,672	472	39	511	200	4	204
1990	794	208	1,002	272	20	292	67	14	81
1991	1,021	242	1,263	357	48	405	125	10	135
1992	1,018	1,151	2,169	226	6	232	172	22	194
1993	1,009	1,265	2,274	231	49	280	132	30	162
1994	1,277	671	1,948	371	154	525	218	36	254
1995	716	869	1,585	300	239	539	216	29	245
1996	785	996	1,781	180	273	453	375	17	392
1997	789	2,194	2,983	212	260	472	162	4	166
1998	1,133	1,882	3,015	147	267	414	653	13	666
1999	1,085	1,622	2,707	354	377	731	768	5	773
2000	789	1,075	1,864	745	404	1149	1189	6	1195
2001	530	849	1,379	590	537	1127	498	52	550
2002	473	1,759	2,232	526	507	1033	501	39	540
2003	430	1,400	1,830	601	539	1140	811	48	859
2004	648	1,093	1,741	734	759	1493	605	38	643
2005	717	1,460	2,177	739	690	1429	498	44	542
2006	276	1,937	2,213	566	581	1147	307	43	350
2007	557	2,292	2,849	398	732	1130	219	19	238
2008	352	2,033	2,385	309	836	1145	387	37	424
2009	389	1,373	1,762	253	776	1029	429	12	441

PREVIOUS SCIENTIFIC WORK

Cavala preta

Previous investigations of the biology and the fisheries for the small pelagic fish resources of Cape Verde have been primarily directed to cavala preta, most abundant of the three dominant species in the landings. In the early 1990s, Carvalho (1993) reported on the results of his studies of growth, mortality and taxonomy of cavala preta. He estimated growth parameters for the von Bertalanffy individual growth equation[2] for cavala for L_{inf} and K of 32-36 cm and 0.44-0.54 yr^{-1}. Almada (1997) reported on the life history of cavala preta, and included an estimate of the stock abundance for the resource based on a length structured model. Almada estimated cavala preta to have a life span of 7 years, and this resulted in an estimate of natural mortality of M=0.42. He compared this estimate to others for the same species using an alternative method and reported that a M=0.65 would be appropriate based on the Pauly method (1983) that accounts for water temperatures. Almada determined the length at 50% maturity at 20.0-21.5 cm. He also investigated the growth of cavala preta using a method previously described by Macdonald and Pitcher (1979), that analyzed the observed length frequency distributions from the landings, and his best estimates of L_{inf}, K and t_o were 30.1 cm, 0.34 yr^{-1} and -0.11 years. Almada's assessment of the status of the mackerel scad stock based on a yield per recruit model integrated into a stock-recruitment relationship suggested that maximum sustainable yield would be 5,500 metric tons and given that the landings at the time were only about 3,000 metric tons, he cautiously suggested that the landings could be increased. Jardim (1999) estimated the MSY for cavala preta using two alternative methods. Based on a Jones length cohort analysis he estimated MSY at 1868 mt, but alternatively considered a Fox equilibrium model for the industrial and artisanal sectors individually and estimated MSY to be 5358 and 1548 mt, respectively. Clearly, the Fox equilibrium surplus production model over-estimated the equilibrium yields.

More recently, Stobberup (2005) investigated the coastal ecosystem of the Cape Verdean waters, and more specifically he studied the small pelagic resources by fitting a Schaefer biomass dynamic model to the landings and effort data. He estimated that for all three species the MSY may range from 3,000 to 4,000 metric tons, as a function of two alternative methods of fitting the model, frequentist vs. Bayesian. He also noted that the equilibrium surplus

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[2] The version of the von Bertalanfy growth equation used here is:

$$L_t = L_\infty\left(1 - e^{-K(t-t_0)}\right)$$

Where

. L_t is the expected or average length at time (or age) t,

. L_∞ is the asymptotic average length,

. K is the so-called Brody growth rate coefficient (units are yr^{-1}), and

. t_0 is a modeling artifact that is said to represent the time or age when the average length was zero.

production model estimate of MSY was 4,146 metric tons. He concluded that if the goal is to maintain the stock at or above B_{MSY}, then setting a Total Allowable Catch (TAC) of between 3,000 and 4,000 metric tons based on the frequentist model, and at 5,000 metric tons based on the Bayesian model would be satisfactory. In a subsequent analysis Stobberup and Erzini (2006) address the cavala preta stock alone, and based on a biomass dynamic model fit using Bayesian methods, they then suggest that it would be relatively safe to increase catches up to 4,000 metric tons for that species alone. The authors note that because the marginal posterior for the intrinsic growth rate of the stock, *r,* is almost identical to the prior in this Bayesian analysis, the CPUE data has low information content. They conclude that their analysis is based on a typical "one-way trip" in population abundance with a lack of contrast in the data, and unfortunately, this results in considerable doubt as to the value of their conclusions.

Chicharro

The life history characteristics of big eye scad have been described by Martins et al. (2007); and based on the results of length frequency analysis, this small pelagic fish is estimated to grow rapidly (annualized K=1.20) to a maximum length of 25 cm, and has an estimated longevity of 3-4 years (annualized M=1.28). The fish matures during its first year at a length of 18-19 cm. Based on the results of a yield per recruit (YPR) model completed for this species, F0.1 and Fmax were estimated to be 0.91 and 0.94 respectively, and F40% was estimated at 0.68 (Tariche and Martins 2011). The fishing mortality rate on the species was reported to be 0.56 in 2007 based on a Virtual Population Analysis (Tariche and Martins 2011), therefore it was concluded that stock was moderately exploited and that there could be a 20% expansion of landings.

Dobrada

Dobrada is another small pelagic fish species harvested in Cape Verdean waters. According to FishBase.org it has a maximum length of 30 cm, but grows relatively slowly (K=0.2). FishBase.org estimated the annualized natural mortality coefficient (M) for this species at 0.5 according to the Pauly method., However, FishBase.org reports that Dobrada has a life span of 12 years, which appears contradictory to the reported value of M, and more consistent with the slower reported growth. In Cape Verdean waters, Valadares-Costa (2007) estimated the length of 50% maturity for females is 15.5 cm for males and 16.5 cm for females.

Summary

The three species of small pelagic fish analyzed in this investigation have very different life history strategies. Cavala is a moderately long lived species (M=0.4-0.6), and grows at a moderate rate (K=0.3-0.5) to a relatively large length, if not harvested first (L_{inf} =34-38 cm). Chicharro is a relatively short lived species (M=1.3), and grows at much faster rate (K=1.2) to smaller maximum length (L_{inf}=25 cm). Dobrada is the fish species for which there is the least information, but it is believed to be relatively long lived (M=0.3-0.5), and grows slowly (K=0.2) to a moderate maximum length (L_{inf}=30 cm). These differences in life history characteristics may require different management strategies, despite the fact that cavala and chicharro are taken in the same fishery with the same gears. Fortunately, dobrada is taken in separate fishery and may be managed as a separate management unit.

With the exception of the recent work by Stobberup and his colleagues on cavala preta, most the stock assessment analyses conducted thus far on the small pelagic resources of Cape Verde have required specific knowledge of, or made assumptions regarding the growth of the species, that is length at age (Booth,2006; Hilborn and Walters, 1992), as input to the length-frequency analyses. To date there is no length at age data available for cavala or chicharro, and all the analyses are based on length frequency analyses. The problem with this method is that the estimation of life history characteristics is limited by the length-frequencies observed in the catch data. For example, the L_{inf} estimated for cavala in the Almada (1997) analysis was 30.1 cm, but in FishBase.org database, there is a picture of a cavala specimen landed in Praia, Santiago, CV in 2002 and reported to FishBase with a fork length of 38.3 cm and a weight of 900 g. This specimen is 30% larger than L_{inf} predicted by the length-frequency analysis. Only equilibrium and non-equilibrium surplus production models can be used to completely assess both fishery resource stock status and intensity of fishing relative to management reference points without either age-specific data or assumptions about the growth of a particular species. Lacking the ability to directly estimate the absolute stock abundance and fishing intensity, relative indices of stock abundance based LPUE or CPUE, and measures of fishing effort can also be used to assess the current status of a fishery stock and the intensity of fishing relative to past levels of relative stock abundance and intensity of fishing. Yield per recruit (YPR) and spawning stock biomass per recruit (SSBPR) analysis can be used to assess alternative management strategies for the harvest of particular species, based on assumed life history characteristics of a species, the age or length of entry into the fishery, and specified levels of fishing mortality. The output for these analyses can also be used to evaluate the potential for growth or recruitment overfishing of a resource at specific levels of fishing intensity.

METHODS FOR THE ASSESSMENT OF STOCK STATUS AND INTENSITY OF EXPLOITATION

Index assessments

Index models are simple and require minimal data, but also provide minimal understanding of fish stock structure and dynamics, and little ability to forecast future trends in catch or abundance. Despite their apparent simplicity, index models are subject to uncertainty due to errors in landings or fishery effort data, and changes in survey data collection protocol.

Catch per unit effort (CPUE) or landings per unit effort (LPUE) are generally considered to be proxy for the abundance of a species. As long as the unit of effort is properly specified and the efficiency of that unit of effort remains constant over the times series of data, then CPUE is considered to be a reliable estimator of the abundance of a stock. Catch includes landings and discards, and in the Cape Verdean small pelagic fisheries, discards of small, undersize pelagics is assumed to be negligible. Therefore, as noted previously, CPUE is considered to be the same as LPUE. A relative index of abundance can be used as a reference point for management purposes, commonly set as the lowest level of relative stock abundance or some level greater than that, from which the stock has demonstrated recovery. Of course, for a fish stock that has experienced a steady decline in the relative index of abundance, this reference point cannot be determined because recovery from the current level of stock abundance has not been demonstrated.

There are two sources of effort data available for the small pelagic fisheries: artisanal and industrial, and they can be combined for some of the analyses into a standardized unit of total effort (Hilborn and Walters, 1992). To do this, the individual CPUEs for each year were calculated, then they were plotted and a regression performed with a zero intercept to determine the constant of proportionality between the two indices. This constant is essentially factor comparing the efficiency of one unit of effort by one fishery to a unit of effort by the other fishery. A ratio of the two mean CPUE for the artisanal and industrial fisheries was also calculated as a check. The industrial unit of effort was then adjusted based on the constant of proportionality, and the total standardized effort in each year was estimated by adding the artisanal and the industrial effort adjusted by the constant of proportionality. This was repeated for each individual species. While the total standardized effort is needed for the models, is it not intuitive, nor is it useful for management purposes unless it is separated into its two components, accounting for the differences in efficiency.

Fishing intensity or mortality is linked to fishing effort by a constant of proportionality termed the catchability coefficient. Based on the assumption of catchability remaining constant over the time series, fishing effort can be used as a proxy for fishing mortality. Again, for fisheries where the resource has experienced cycles in relative abundance and where there have been cycles in fishing effort, the reference point for maximum fishing effort can be the level of effort associated with the lowest point on the relative index of abundance.

Analysis of the mode of the length-frequency distribution of the landings

As noted in a previous section of this report, length-frequency data from fisheries landings or from fishery independent surveys can be used to investigate the growth, natural mortality, and fishing intensity with various assumptions (Rosenberg and Beddington, 1988). However, at the most fundamental level, comparison of annual length-frequency distribution from the catch can be used to describe the size distribution of the fish landed, and most importantly to identify trends in the mode or mean of the fish landed over time. A reduction in the mean size of the fish landed, or mode of the length-frequency distribution of the fish landed in a developing fishery is perhaps one of the most obvious effects of fishing. A dramatic and continuing reduction in size of the fish landed is an indication of high exploitation (fishing mortality) and possibly overfishing (Beverton and Holt, 1957). In this study the modes of the length-frequency distributions were evaluated as a function of time to investigate possible indications of overfishing.

Yield per recruit and spawning stock biomass per recruit models

A discrete time model (DeAlteris and Riedel, 1996) was developed to investigate the effect of minimum landing size regulations on the yield and potential spawning stock per recruit from a single cohort. The time step is set at 0.01 years, over the range of 0 to 20 years, so as to be able to evaluate knife edge selection at specific fish lengths in whole centimeter units.

The length of the fish (L) at age (t) is calculated using a simplified ($t_0 = 0$) von Bertalanffy growth equation:

$$L_t = L_\infty\left(1 - e^{(-Kt)}\right)$$

where L_∞ is the maximum length, and
K is the instantaneous growth rate.

The weight of the fish (W) at age t is determined using a length-weight relationship:

$$W_t = a\left(L_t\right)^b$$

where a is the L-W conversion factor, and
b is the L-W growth factor

The percent maturity (P_t) of individuals in the cohort at age is expressed using a LCDF:

$$P_t = \left(1 + e^{(-\alpha 1 * (t - \beta 1))}\right)^{-1}$$

where $\alpha 1$ is the steepness of the curve, and

$\beta 1$ is the length at 50% maturity.

Based on specification on knife edge selection as a function of fish length, the probability (PL_t) of individual fish of length (L_L) recruiting to the fishery was specified as either 0 or 1:

$$PL_L = 0 \; for L_L < L_{\min} \; and = 1 \; for L_L > L_{\min}$$

where L_{min} is the minimum fish size allowed to be landed.

Applying length-specific susceptibility to fishing (PL_L) at a specified level of fishing mortality (F) and including natural mortality (M), the number of individuals remaining in the fished cohort (NF_t) at each time step (t) was calculated as:

$$NF_t = NF_{(t-1)} e^{\left\{-[((PL_L)(F))+M]*t*0.01\right\}}$$

Thus, the yield of the fished cohort (Y_t) from each time-step is:

$$Y_t = \left[{(PL_L * F)} \big/ {(PL_L * F + M)} \right] * \left(NF_{(t-1)} - NF_{(t)} \right) * \left(W_{(t)} \right)$$

and the spawning stock biomass of the fished cohort (SSB_t) at each time step is simply:

$$SSB_t = (NF_t) * (W_t) * (P_t)$$

Given these equations and specific values of L_∞, K, a, b, $\alpha 1$, $\beta 1$, and M, and with the specification of fishing conditions (F, L_{min}), the total yield and spawning stock biomass of the fished cohort are determined. By evaluating a wide range of L_{min} and F values, the resulting matrix of data, expressed as the yield per recruit (*YPR*) and % virgin spawning stock biomass per recruit (*%VSSPR*) for various values of L_{min} and F. In this investigation the following data were used for cavala (L_∞= 34.0 cm, K=0.40, a=0.01, b=3.17, $\alpha 1$=1.0 $\beta 1$=21.5, and M=0.45) and chicharro (L_∞= 25.0 cm, K=1.20 a=0.01, b=3.10, $\alpha 1$=0.85 $\beta 1$=18.0, and M=1.28). As insufficient life history is available for dobrada, YPR and SSBPR analyses were not conducted for this species.

Equilibrium and non-equilibrium surplus production models

Surplus production models utilize data on catch (yield), stock abundance, and fishing effort or mortality to determine the maximum sustainable yield at particular levels of stock abundance and fishing effort or mortality. The models are conceptually simple, may be based on assumed equilibrium or non-equilibrium conditions for the stock. The models provide both target and threshold/limit reference points, overfishing reference points and inputs to bio-economic models.

The Schaefer equilibrium surplus production model is represented by a quadratic, parabolic function, where yield or catch is related to the effort required to produce that yield. The surplus production model is derived from the density dependent population growth model by replacing population number (*N*) with biomass (*B*):

$$dB/dt = (\alpha - \beta B)B - FB\ ,$$

where *α* is the difference in the initial birth and death rates

β is the difference in the density dependent birth and death rates

F is fishing mortality

At equilibrium $dB/dt = 0$, and substituting fishing effort (*f*) for *F* assuming catchability is constant (based on *F* = *fq*) results in the generalized Schaefer Model (1954):

$$Y = (a - bf)f = af - bf^2\ ,$$

where *a* is the ratio of *α/β*

b is inverse of β or *1/β*

This model has the parabolic or dome shaped form that relates yield (*Y*) to fishing effort (*f*). The level of effort required to achieve Maximum Sustainable Yield (*MSY*) is determined by taking the derivative of the function and setting it equal to zero, and solving for *f*.

$$f_{MSY} = a/2b$$

MSY is then determined by substituting f_{MSY} back into the original equation:

$$Y_{MSY} = 2a^2b/4b^2 - a^2b/4b^2 = a^2b/4b^2 = a^2/4b$$

Note that the *MSY* occurs at the point of maximum growth (one-half carrying capacity).

The parameters *a* and *b* of the Schaefer model are initially estimated by linearizing the function:

$$Y/f = a - bf\ ,$$

and using linear regression on CPUE $\left(Y/f\right)$ versus effort (*f*). Non-linear, best-fit estimation of the parameters is accomplished using Solver in *Microsoft Excel*, with parameter starting values from the linearized estimation.

An alternative model for fitting the relationship between catch and effort was introduced by Fox in 1970 which assumes that a stock would respond to intense fishing by maximizing productivity thus the yield would never reach zero. This model also assumes that CPUE would decline as effort increases and provides an estimate of the *MSY* usually close to the Schaefer model. The Fox model has the form:

$$Y = fe^{(c-df)}.$$

This model is linearized to:

$$\ln\left(Y/f\right) = c - df\ .$$

MSY for the Fox model is estimated by again taking the derivative of the function, setting it equal to zero to solve for *f* at *MSY*, and finally, substituting that back into the original equation:

$$f_{MSY} = 1/d$$

$$Y_{MSY} = \left(1/d\right)e^{(c-1)}.$$

These models were fit to the annual catch and standardized total effort data using non-linear least squares regression. These models have a parabolic or dome shaped form that relates yield (*Y*) to fishing effort (*f*), and MSY was estimated at the point of zero slope in the function. The limitation of the equilibrium model is that it overestimates *MSY* and f_{MSY} for several reasons (Hilborn and Walters, 1992). Because there are two sources of effort data for the small pelagic fisheries (artisanal and industrial), the equilibrium model was fit using the standardized total effort index.

The Graham-Schaefer model in the form of a differential equation also can be used to describe the dynamic behavior of stock biomass in non-equilibrium:

$$dB/dt = rB\left(1 - B/K\right) - C$$

where *B* is stock biomass,

C is catch,

r is the intrinsic rate of stock growth, and

K is the unfished stock size at carrying capacity.

The catch (*C*) is assumed to be proportional to stock size:

$$C = FB = qfB$$

where *C* is catch,

F is fishing mortality,

B is biomass,

q is catchability coefficient, and

f is fishing effort.

Rearranging this equation:

$$CPUE = C/f = qB\,.$$

The catch per unit effort (*C/f* or CPUE) is directly proportional to stock abundance, through *q*, the catchability coefficient. This equation describes an "observation model" that may result from a fishery or survey CPUE, and it assumes that CPUE declines linearly with increasing effort.

In the discrete-time form the previous differential equation describing the stock biomass time series can be rewritten (Walters and Hilborn 1976):

$$B_{t+1} = B_t + rB_t\left(1 - B_t/K\right) - C_t$$

where B_{t+1} is the stock biomass in year *t*+1,

B_t is the stock biomass in year *t*,

C_t is the catch in year t,

K is the unfished stock biomass at carrying capacity, and

r is the intrinsic rate of stock growth.

The Graham-Schaefer model is symmetrical, and therefore surplus production is maximized at ½ *K*. The term $\left(1 - B_t/K\right)$ provides density dependent feedback into the model, and thus modulates stock growth at high stock biomass. As B_t approaches *K* (high biomass), the term approaches 0, and stock growth is zero. As B_t approaches 0 (low biomass), the term approaches 1, and the rate of stock growth is maximized at the intrinsic growth rate, r. At any biomass less than K, the stock is growing. A catch that matches the potential stock growth or the surplus production will leave the stock at the same biomass level in year t+1 as it was in year t. Catch rates in excess of stock biomass surplus production result in stock decline. Conversely, catch rates less than stock biomass surplus production result in stock expansion.

An alternative surplus production model is the Fox formulation, which again relates catch to effort or CPUE to effort in the equilibrium form, or uses catch and an index of abundance (CPUE) in the discrete time form to generate a trajectory of stock biomass. The Fox model in the discrete time form is:

$$B_{t+1} = B_t + rB_t \ln\left(K / B_t\right) - C_t$$

The Fox model is dome shaped, but maximizes surplus production at less than ½ of K, carrying capacity, whereas the Schaefer model is symmetric and maximizes surplus production at exactly ½ of K.

These models were fit to the landings or catch data and the observed CPUE index, where the sum of the squared differences between the observed and predicted CPUE indices was minimized using a least squares method, while adjusting values of *r, K* and *Bo* using Excel's SOLVER function*.* There are alternative methods for fitting the model that allow for the incorporation of uncertainty into the estimated parameters that include maximum likelihood and Bayesian methods. The reference points *MSY,* B_{MSY} and F_{MSY} were all derived from the final estimates of *r* and *K*, and because of the different forms of the Schaefer and Fox models, the estimation of these reference point required different equations:

Reference Point	Schaefer Model	Fox Model
B_{MSY}	$=K/2$	$=0.368*K$
MSY	$=(r*K)/4$	$=r*B_{MSY}*ln(K/B_{MSY})$
F_{MSY}	$=r/2$	$=MSY/B_{MSY}$

<u>Reference points, control rules and management advice</u>

Some of the reference points that result for surplus production models include:

- MSY is the maximum sustainable yield from the stock under the average productivity conditions during the time period covered by the data,
- f_{MSY} or F_{MSY} is the fishing effort or level of exploitation required to produce MSY, f_{MSY} or F_{MSY} is considered a limit or threshold reference point, and fishing at levels greater than f_{MSY} or F_{MSY} result in generalized overfishing that is likely to reduce the stock size. The target level of fishing mortality is usually 80-90% of $F_{MSY.}$
- B_{MSY} is the biomass level that allows for the production of *MSY.* B_{MSY} is considered a limit reference point, and biomass levels less than B_{MSY} refer to depressed stocks that have lower surplus production than stocks at B_{MSY}. Because stock biomass is expected to fluctuate naturally, fishery management plans generally set a threshold or limit biomass level below which a stock is considered overfished, often ½ $B_{MSY.}$ Higher thresholds are more precautionary and are likely to require less corrective action if they are exceeded.

Harvest control rules are pre-agreed upon protocols that control fishing mortality with respect to stock status and the limit/threshold reference points. They also allow for the illustration of the trajectory or the past, present or future status of the resource and the intensity of fishing relative to pre-established reference points. The control rules may incorporate minimum biomass and maximum fishing mortality thresholds, as well as targets for these parameters, and rebuilding horizons for overfished stocks that include biomass and fishing mortality schedules. Control rules may also specify harvest strategies to achieve maximum sustainable yield (MSY) from the stock under prevailing ecological and environmental conditions. Optimum yield (OY) incorporates economic and social considerations as well as stock dynamics. Optimum yield from a fishery stock will be sustainably achieved when existing biomass exceeds B_{MSY} ($B/B_{MSY} \geq 1$) and when fishing mortality is less than F_{MSY} ($F/F_{MSY} \leq 1$). Maximum economic yield (MEY) is the catch that maximizes the difference between the revenue from the catch and the cost of making the catch. In artisanal fisheries where costs other than labor are minimal and there are few alternative employment opportunities, maximum economic yield is approximately equal to maximum sustainable yield.

RESULTS

The results of the analyses include a description of the trends in CPUE, the results of the length frequency analysis, and the results of the YPR and SSBPR analyses, if there was life history data for the species available. Next, the results of the equilibrium surplus production model are presented, if it was successfully fit to the data, and finally the results of a biomass dynamic model is presented, if it was successfully fit to the data available. An Appendix to this report includes the EXCEL spreadsheets for all data and calculations, is available and has been provided to INDP.

Cavala preta

The catch and effort data used in the analyses for this species are from the circle net fisheries conducted by artisanal and industrial fleets (Table 2). This data represents the majority of the landings of this species, and is the most complete set of effort data available. The trend in CPUE in the artisanal fishery for this species has remained at approximately the same level since the late 1980s at approximately 0.2 mt/day of fishing, with two peaks in CPUE occurring in mid-1990s and 2005. In contrast, effort and landings have slowly declined since 1989 (Figure 8). This suggests that artisanal fishermen are simply leaving this fishery, perhaps to focus on other fisheries. In contrast, the trend in CPUE in the industrial fishery increased sharply from 2001 to 2006, then decreased just as quickly through 2009 (Figure 9). This increase in CPUE in the period 2005-2006, corresponds with an equally dramatic decrease in effort by the industrial vessels. The CPUE of the industrial vessels in recent time is approximately 1.25 mt/day, as compared to the CPUE of the artisanal boats at approximately 0.25 mt/day. Catches of the industrial fleet have increased substantially since the introduction of the 11 m semi-industrial vessels in the early 1990s. The increase in effort in the industrial sector combined with greater overall efficiency of the industrial vessels has resulted in a six fold increase in the landings of this species since the late 1980s. This suggests that the industrial fishery is able to travel further to find the available fish, has larger fishing nets, and is able to deliver more fish to the dock, whereas smaller artisanal boats are simply not able to access the fish, use large scale gear, or carry a large catch. Total catch of cavala preta from 2005 to 2009 averaged about 2000 metric tons, but more importantly there are significant cycles in the landings and the CPUE index that probably correspond to strong year classes moving through the stock over the two decade trajectory of data (Figure 10). Qualitatively, it appears that 2000 mt may be the sustainable catch of this species at the current biomass levels and in the area that has been fished over the last two decades. Note that when annual catch substantially exceed 2000 mt in 2005, the stock biomass as reflected by the standardized CPUE index declined markedly in the following four years.

The results of the modal analysis of the landing data indicated a significant positive trend in the mode of the length-frequency distribution of landings over the period from 1989 to 2009 (Figure 11). There has been an approximate 3 cm increase in the dominant modal length of the fish in the catch over the last two decades, suggesting the level of fishing intensity is decreasing over the period as fish are able to grow larger by living longer before being harvested.

The results of the YPR and SSBPR analysis are summarized in terms of the potential yield that can be taken from a cohort of fish and the % of virgin spawning stock remaining as a function of a minimum landing size. These values of YPR and %VSSBPR were evaluated at two levels of fishing intensity, a low level corresponding to a target growth overfishing reference point ($F_{0.1}$), and a high level corresponding to a recruitment overfishing situation (F=1.0) (Figure 12). The results of the YPR analysis indicate that yield is maximized at both low and high levels of fishing mortality if the minimum length of the fish landed is increased to 22 cm. Interestingly, this length is slightly larger than the estimated length at 50% maturity for this species. The increase in the yield between a minimum length of entry into the fishery from 8 to 18 cm is approximately 20%. Entry into the fishery at too small a size is essentially growth overfishing, in that greater catch weight would be achieved by increasing the length at which fish become susceptible to capture. With regard to the %VSSBPR remaining at low levels of fishing mortality (corresponding to an $F_{0.1}$ reference point level), the effect of the length of entry into the fishery is minimal. In contrast, at high levels of fishing mortality, the impact of the allowing small fish to be landed is considerable, creating a recruitment overfishing situation. For cavala at high levels of fishing mortality, if the minimum length of the landed fish is 8 cm, then the %VSSBPR remaining is 4, if the minimum length is 18 cm, then the %VSSBPR is 12, and finally if the minimum length is 22 cm, then the %VSSBPR is 24. There is a three-fold increase in the %SSBB remaining by ensuring that the current minimum length regulation is observed, and a six fold increase in %VSSBPR can be achieved if the minimum landing length were increased to 22 cm.

The results of the Schaefer equilibrium surplus production model using the linearized form of CPUE versus effort indicates a significant decline in CPUE as a function of increasing effort (Figure 13), and that is a requirement for a surplus production model. The results of the non-linear analysis of catch versus effort for the Schaefer equilibrium surplus production model suggest that MSY for cavala preta is about 2700 mt and that can be achieved at about 10,000 days of standardized effort (Figure 14). The results of the non-linear analysis of catch versus effort for the Fox equilibrium surplus production model suggest that MSY for cavala preta is about 2300 mt and that can be achieved at about 9,350 days of standardized effort (Figure 15).

The results of the Schaefer and Fox non-equilibrium, surplus production or biomass dynamic models using individual artisanal and industrial fishery CPUE indices indicate that *MSY* is approximately 2700 metric tons. The results of the Fox model fit with the individual indices is shown in Figure 16, and the trajectory of harvest control rule suggests that in 1989 the stock was both depressed and overfished (B/B_{MSY} <0.5) , and that overfishing (F/F_{MSY} >1) was occurring, and that in 2009 the stock the stock and the fishery was in similar condition, although the intensity of fishing had reduced, and the stock had a slightly greater biomass (Figure 17). It should be pointed out that the least squares minimization of the objective function was robust, as the ending parameter estimates were very different than the starting values, and convergence to the final parameter estimates were independent of starting values.

<u>Chicharro</u>

The catch and effort data used in the analyses for this species are from the circle net fisheries conducted by artisanal and industrial fleets (Table 3). This data only represents a portion of the landings of this species, but is the most complete set of effort data available. The trend in CPUE in the artisanal fishery for this species has remained at approximately the same level since the late 1980s at approximately 0.06 mt/day of fishing, with one peak in CPUE occurring in 2005. Catch of chicharro in the artisanal circle net fishery has averaged about 130 mt annually, with peaks in 1989 and 2005, and lows in the mid-1990s and late 2000s. Effort has slowly declined since 1989 (Figure 18). As with the cavala fishery this may suggest that artisanal fishermen are simply leaving this fishery, perhaps to focus on other fisheries. In contrast, the trend in CPUE in the industrial circle net fishery increased sharply from 2001 to 2005, then decreased just as quickly through 2009 (Figure 19). This increase in CPUE in the period 2005-2006, corresponds with an equally dramatic decrease in effort by the industrial vessels. The CPUE of the industrial vessels in recent time is approximately 0.3mt/day, as compared to the CPUE of the artisanal boats at approximately 0.03 mt/day. Total catch of chicharro from 2000 to 2009 averaged about 1000 metric tons (Figure 20). Qualitatively, it appears that 1000 mt may be the sustainable catch of this species at the current biomass levels and in the area that has been fished over the last two decades.

The results of the modal analysis of the landing data indicate a positive, and almost significant ($p=0.058$), trend in mode of the length-frequency distribution of landings over the period from 1989 to 2009 (Figure 21). There has been an approximate 1 cm increase in the dominant modal length of the fish in the catch over the last two decades, suggesting the level of fishing intensity is decreasing slightly over the period and fish are able to grow larger by living longer before being harvested.

The results of the YPR and SSBPR analysis are summarized in terms of the potential yield that can be taken from a cohort of fish and the % of virgin spawning stock remaining as a function of a minimum landing size. These values of YPR and %VSSBPR were evaluated at two levels of fishing intensity, a low level corresponding to a target growth overfishing reference point ($F_{0.1}$), and a high level corresponding to a recruitment overfishing situation ($F=1.0$) (Figure 22). The results of the YPR analysis indicate that yield is minimally affected at both low and high levels of fishing mortality by the minimum length that fish are allowed to be landed. This is essentially due to the rapid growth and short life span of this species. With regard to the %VSSBPR, while there is an increase in the %VSSBPR remaining after fishing as a function of the minimum length that fish are allowed to be landed for both low and high levels of fishing mortality, the SSBPR remaining at the smallest of fish lengths landed and at a high level fishing is 20%, and the %VSSBPR only increases from there as the minimum fish length increases or the fishing mortality is decreased. Therefore, in contrast to cavala, there appears to be no strong justification to either enforce the minimum length for landing chicharro, or to increase this length.

The results of the Schaefer equilibrium surplus production model using the linearized form of CPUE versus effort indicates a significant decline in CPUE as a function of increasing effort (Figure 23), and that is a requirement for a surplus production model. The results of the non-linear analysis of catch versus effort suggest that MSY for chicharro is about 980 mt and that can be achieved at about 2800 days of standardized effort (Figure 24).

Unfortunately neither the Schaefer nor Fox non-equilibrium surplus production or biomass dynamic models could be fit using the total catch time series and either the individual artisanal and industrial fishery CPUE indices or a standardized CPUE index. There are several possible reasons for this, first is the landings chicharro by the circle net fisheries for which there is effort data available, only represent a portion of the total landings of chicharro. Additionally, chicharro are for the most part, captured incidentally the cavala fishery, so the circle net effort is not directed to chicharro, and therefore the CPUE indices may not be representative of the chicharro stock abundance. Finally, the CPUE indices are relatively short, and do not provide sufficient contrast for the computer search routine (SOLVER) to be able to converge on a solution.

Dobrada

The catch and effort data used in the analyses for this species is from the artisanal gillnet fisheries conducted by artisanal fleet (Table 4). This data represents the majority of the landings of this species, and is the most complete set of effort data available. The trend in CPUE in the artisanal fishery for this species increased from 1995 to 1998, then has decreased from that year until 2009. The average CPUE for dobrada in the last few years has been 0.1 mt/day. Catch of dobrada in the gill net fishery averaged 200 mt annually from 1985 to 1995, peaked in 2000 and 2003 corresponding to increases in effort, and has decreased to an average of 300 mt in the last few years. Effort has slowly declined since 1989 (Figure 25). Qualitatively, it appears that 200-300 mt may be the sustainable catch of this species at the current biomass levels and in the area that has been fished over the last two decades.

The results of the modal analysis of the landing data indicate a positive, but not significant, trend in mode of the length-frequency distribution of landings over the period from 1989 to 2009 (Figure 26). Therefore there has been neither an increase nor a decrease in the dominant modal length of the fish in the catch over the last two decades, suggesting the level of fishing intensity has remained steady.

YPR and SSBPR analyses could not reliably be conducted for this species due to a lack of information on the life history characteristics of the species.

The results of the Schaefer equilibrium surplus production model using the linearized form of CPUE versus effort indicates a small positive, but not significant, trend in CPUE as a function of increasing effort (Figure 27), thus is was impossible to fit a equilibrium surplus production model. And unfortunately neither the Schaefer nor Fox non-equilibrium surplus production or biomass dynamic models could be fit using the total catch time series and either the individual artisanal and industrial fishery CPUE indices or a standardized CPUE index.

Given the limited amount of quantitative analysis that could be conducted on the dobrada fishery dependent data, it is prudent to investigate the existing data further. As noted earlier in the description of the CPUE index, the trend is negative, that is CPUE appears to be declining, and it is a significant negative trend, with CPUE decreasing to about one half of the 1998 level by 2009 (Figure 28).

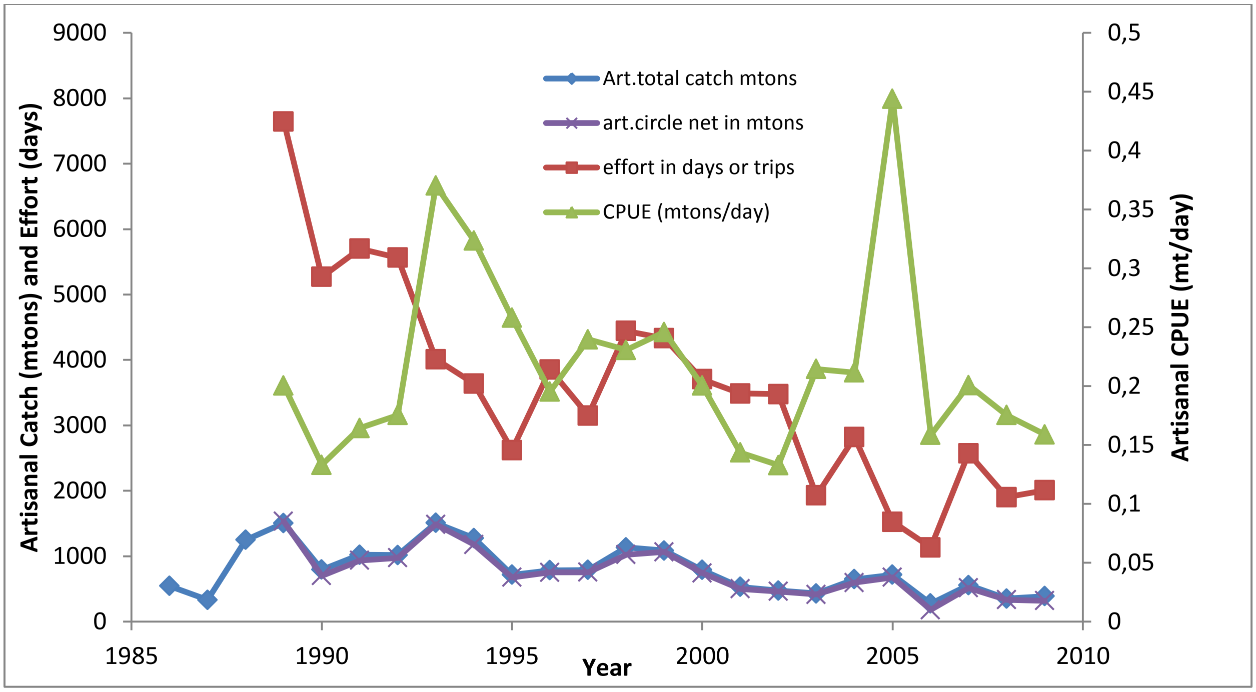

Figure 8. Artisanal catch (mt), artisanal circle net catch (mt), effort (days), and CPUE (mt/day) for cavala preta.

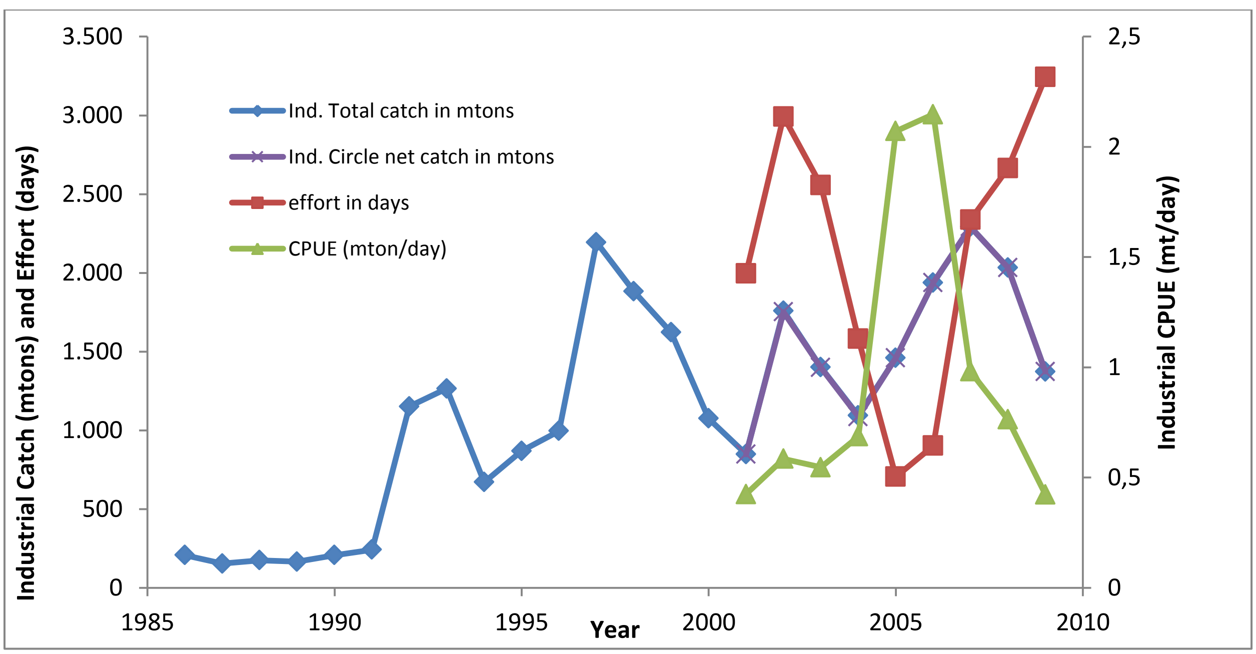

Figure 9. Industrial catch (mt), industrial circle net catch (mt), effort (days), and CPUE (mt/day) for cavala preta.

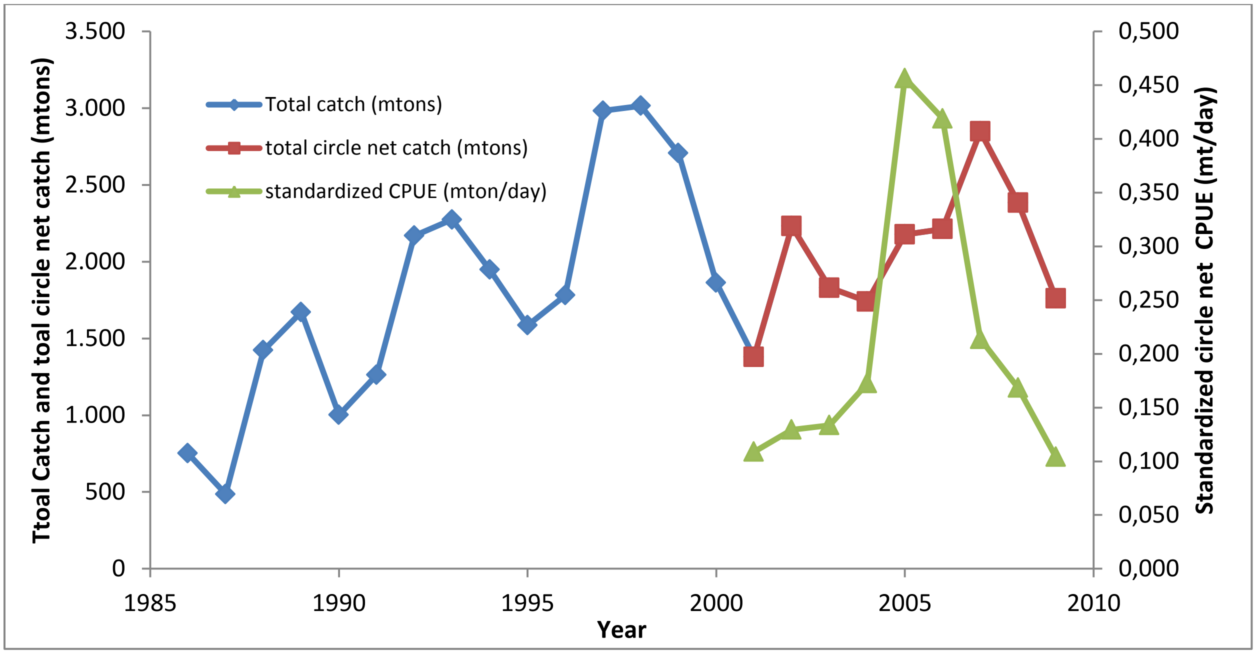

Figure 10. Total catch (mt), total circle net catch (mt) standardized effort (days), and standardized CPUE (mt/day) for cavala preta. Note that the circle net catch accounts for the total catch from 2001-2009.

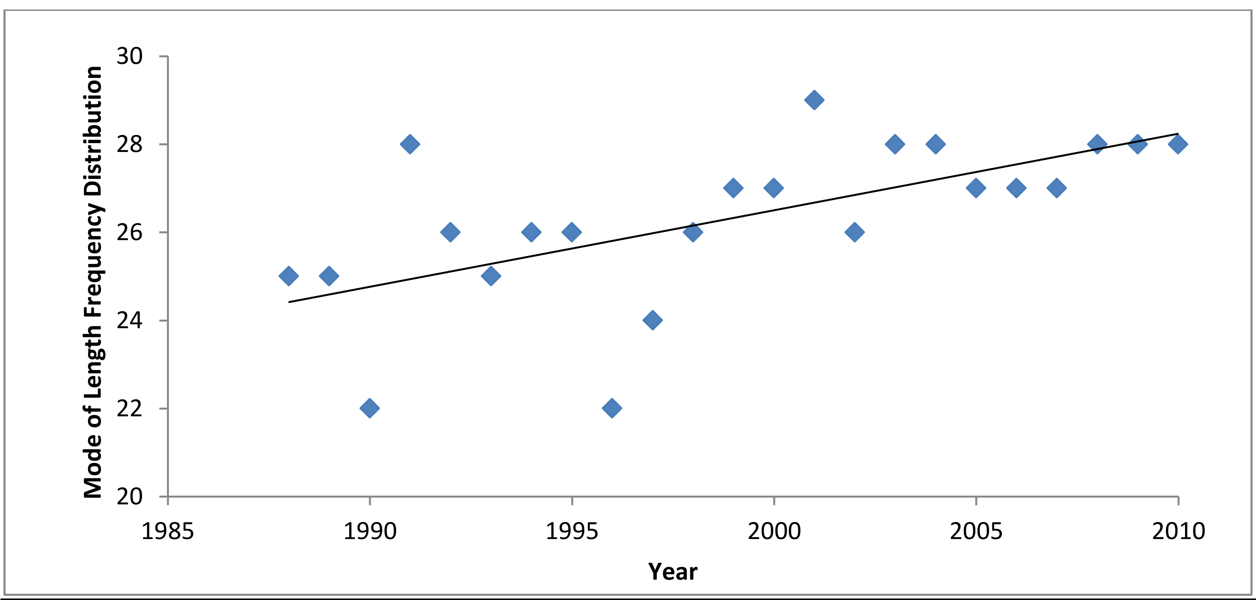

Figure 11. Mode of the length-frequency distribution for the landings of cavala preta during the period 1988 to 2010. This is a significant positive increase in length over the period.

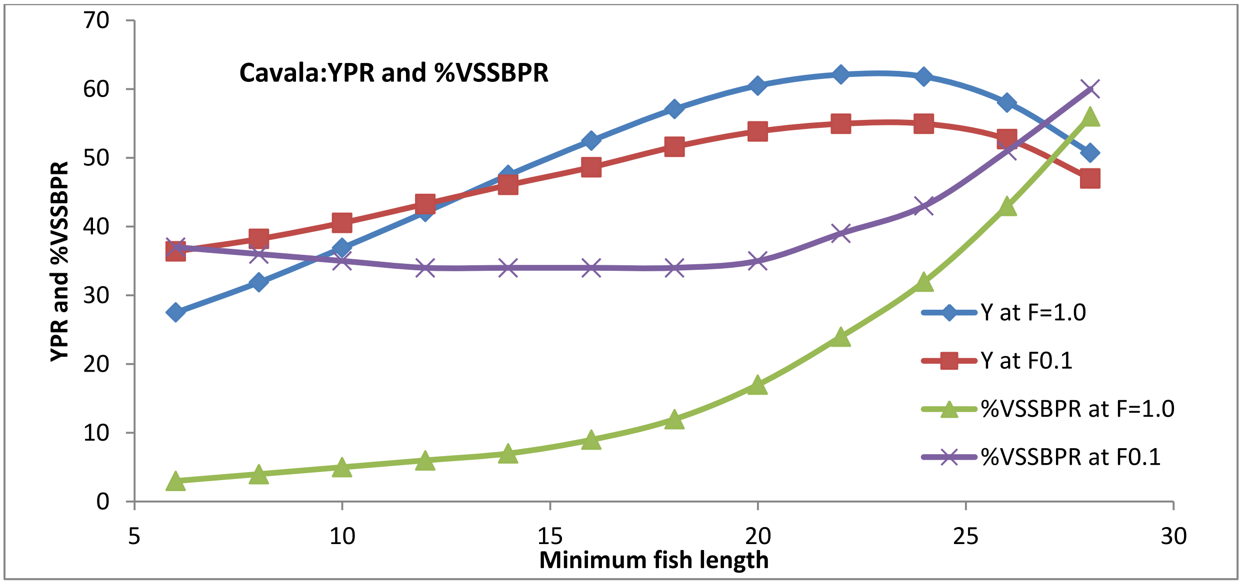

Figure 12. Results of the YPR and SSBPR analysis for cavala preta.

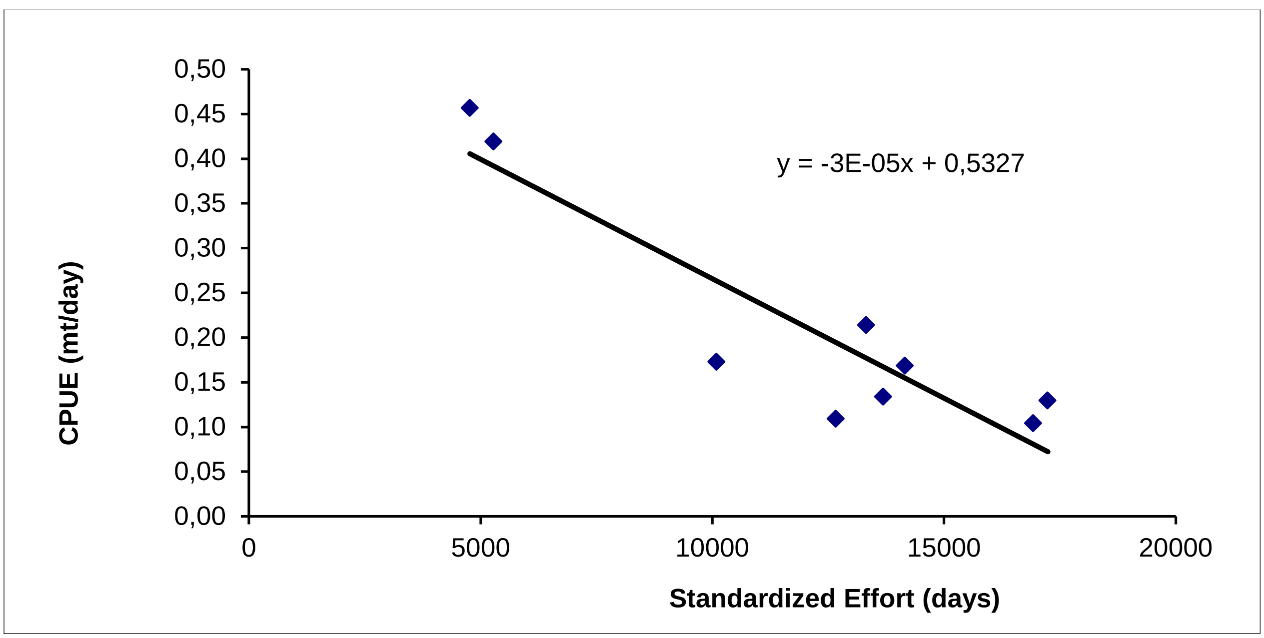

Figure 13. Results of Schaefer Equilibrium Surplus Production Model for cavala in the linearized form, CPUE versus Effort, based on standardized effort data for the period 2001-2009. Note that there is a significant decrease in CPUE (mt/day) as a function of standardized effort (days)

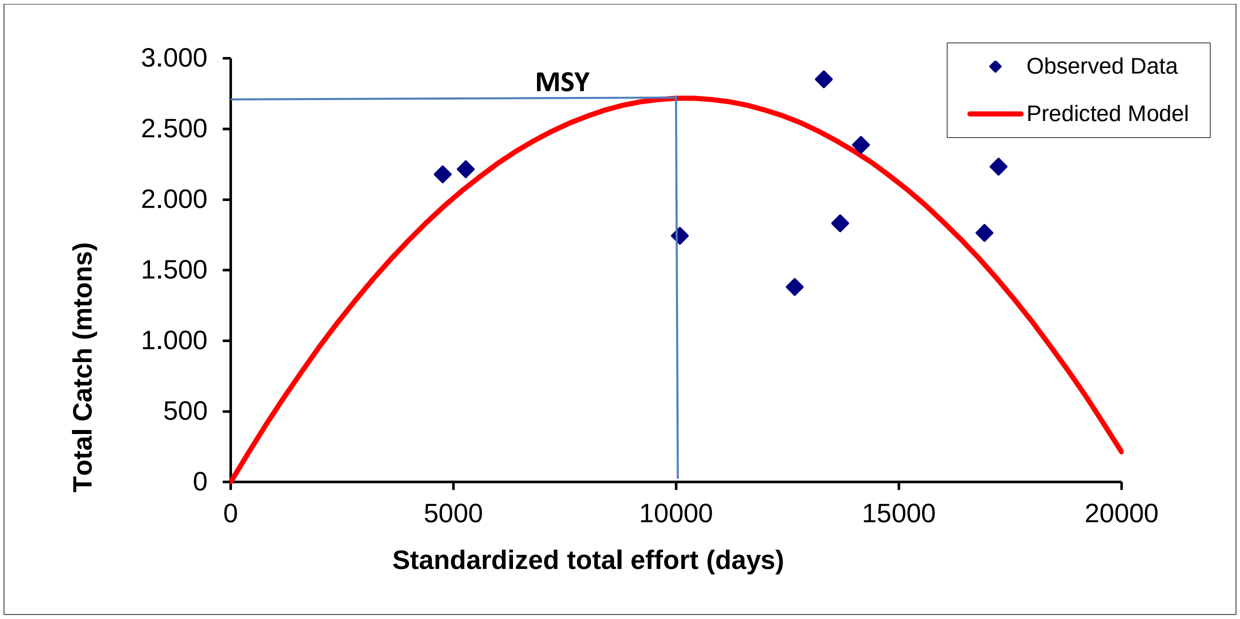

Figure 14. Results of Schaefer Equilibrium Surplus Production Model for cavala in the non-linear form of Catch versus Effort, based on standardized effort data for the period 2001-2009. Note the value of MSY at 2717 mt, and that many of the observed years are in excess of the f_{MSY} of the 10000 standardized days.

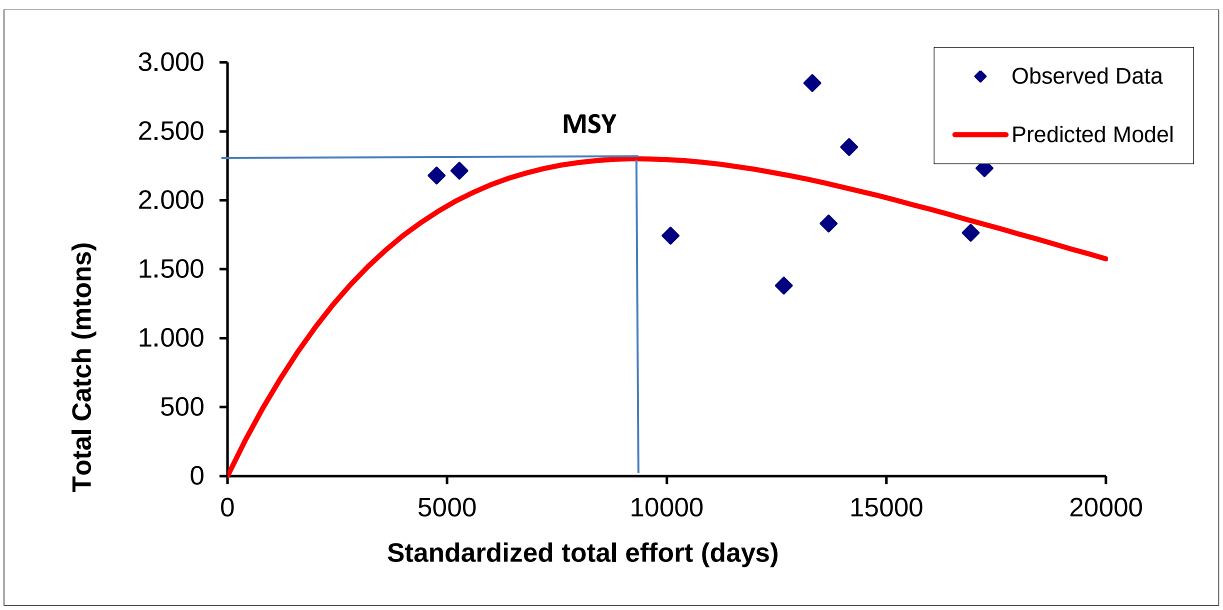

Figure 15. Results of Fox Equilibrium Surplus Production Model for cavala in the non-linear form of Catch versus Effort, based on standardized effort data for the period 2001-2009. Note the value of MSY at 2300 mt, and that many of the observed years are in excess of the f_{MSY} of the 9350 standardized days.

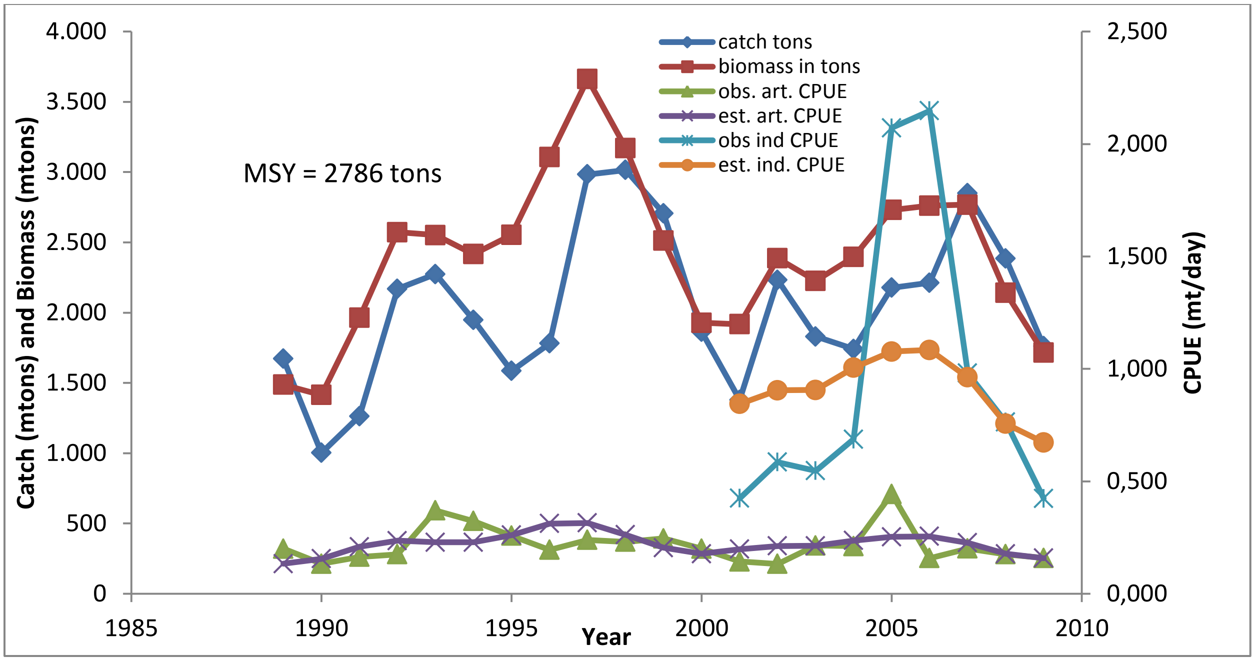

Figure 16. Results of Fox surplus production or biomass dynamic model for cavala preta based artisanal and industrial CPUE indices.

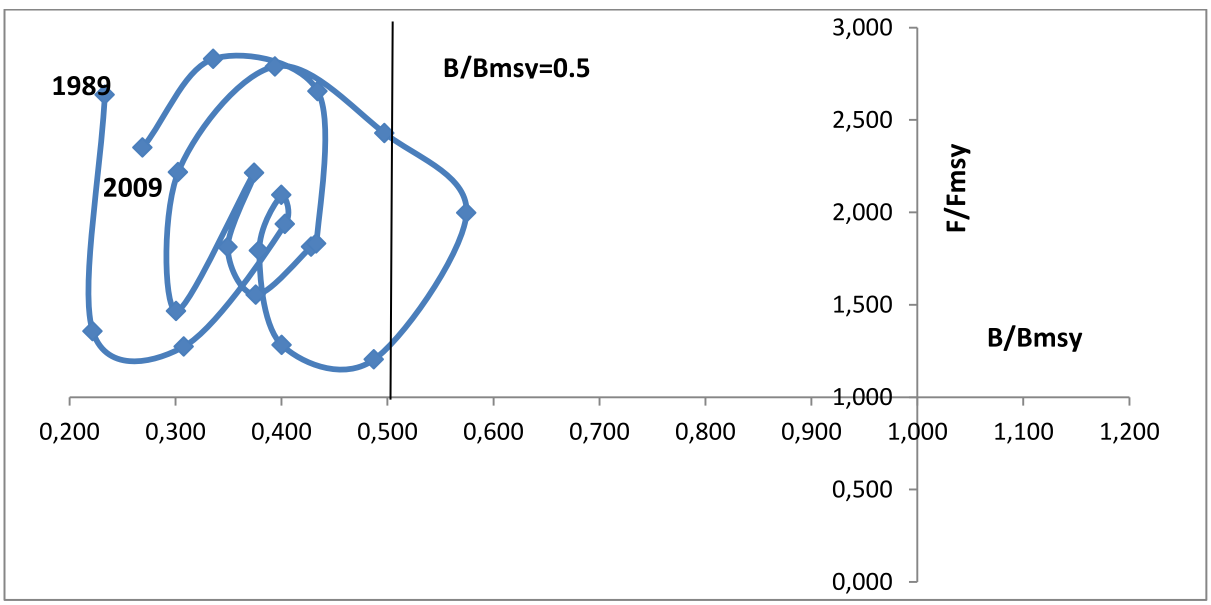

Figure 17. Harvest control rule based on the results of the Fox biomass dynamic model for cavala preta based artisanal and industrial CPUE indices. Note that the stock has been overfished for most of the period, and overfishing has occurred during the entire period.

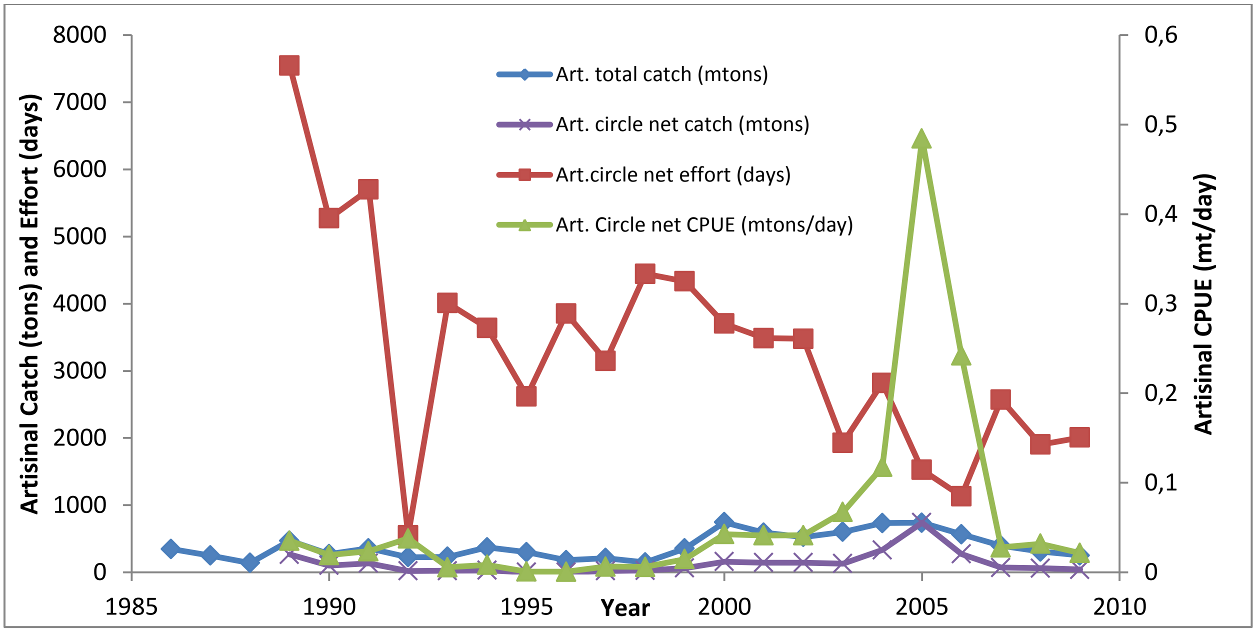

Figure 18. Artisanal catch (mt), artisanal circle net catch (mt), effort (days), and CPUE (mt/day) for chicharro. Note that artisanal circle net landings are only a portion of the total artisanal landings of chicharro.

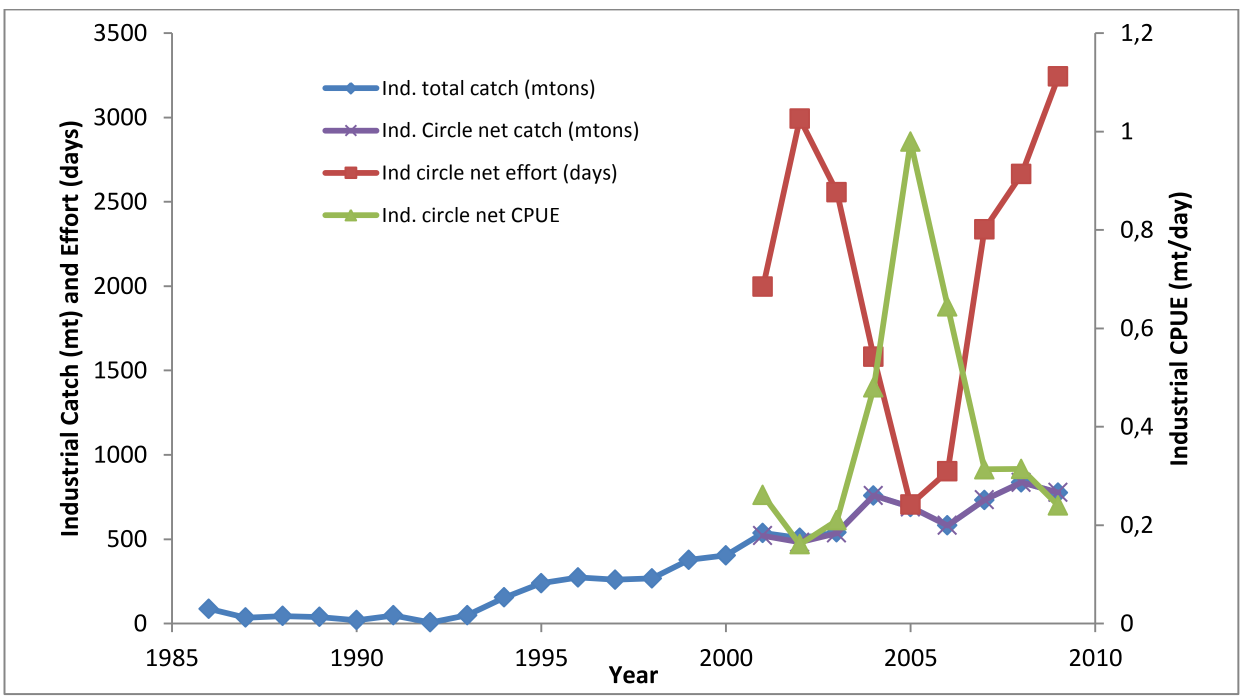

Figure 19. Industrial catch (mt), industrial circle net catch (mt), effort (days), and CPUE (mt/day) for chicharro. Note that circle net landings account for all the landings of chicharro in the industrial fleet.

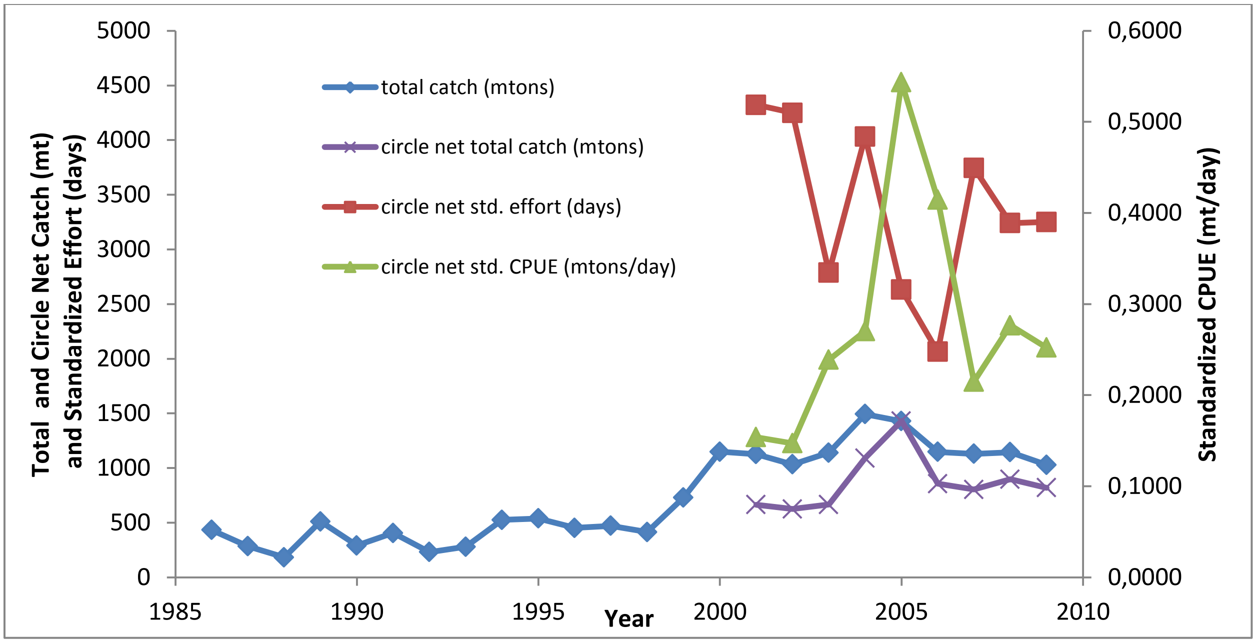

Figure 20. Total catch (mt), total circle net catch (mt), standardized effort (days), and standardized CPUE (mt/day) for chicharro. Note that the circle net catch only accounts for a portion of the total landings of chicharro.

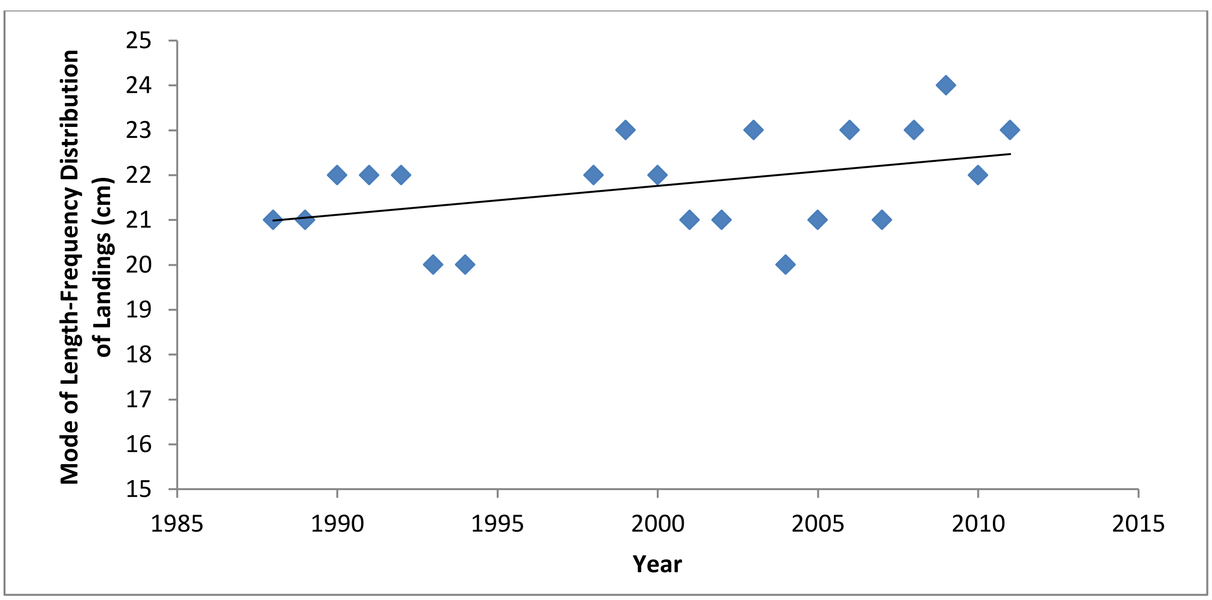

Figure 21. Mode of the length-frequency distribution for the landings of chicharro during the period 1988 to 2010. Note that the slope of the trend line is almost significantly different form 0 (p=0.058).

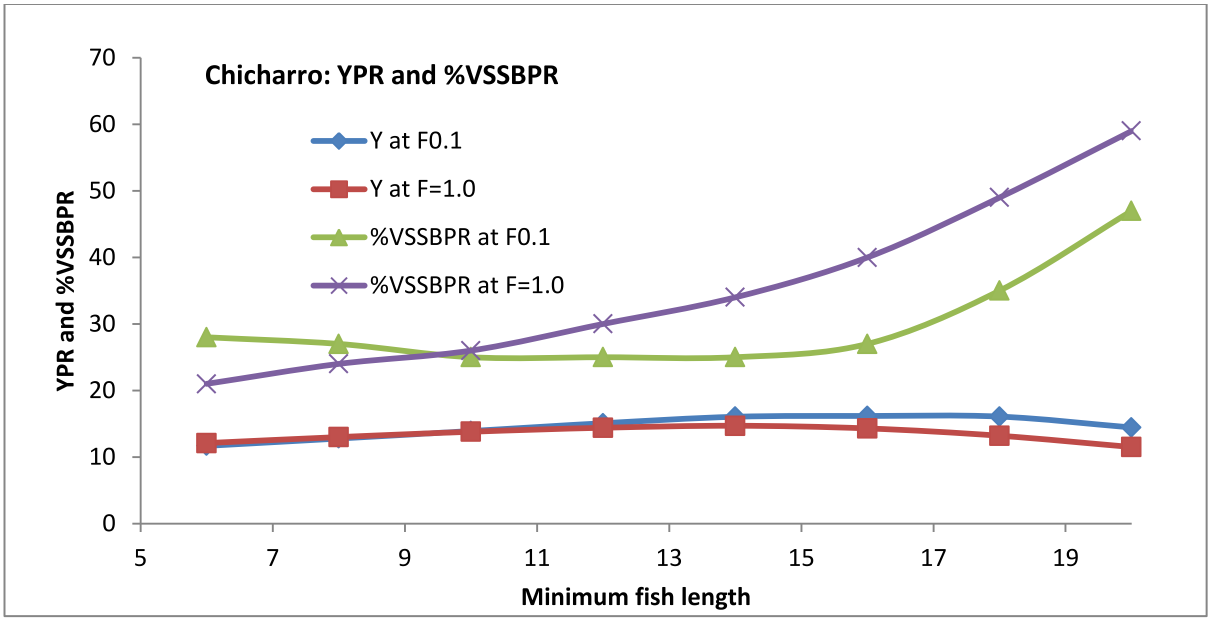

Figure 22. Results of the YPR and SSBPR analysis for chicharro.

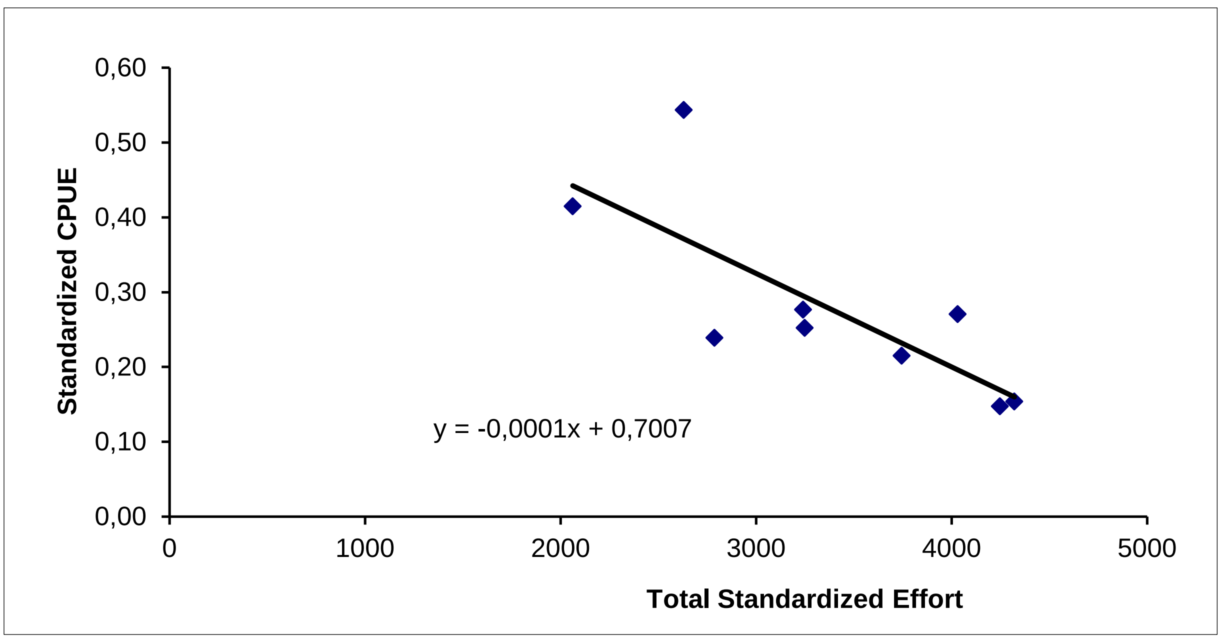

Figure 23. Results of Schaefer Equilibrium Surplus Production Model for chicharro in the linearized form, CPUE versus Effort, based on standardized effort data for the period 2001-2009. Note that there is a significant decrease in CPUE (mt/day) as a function of standardized effort (days).

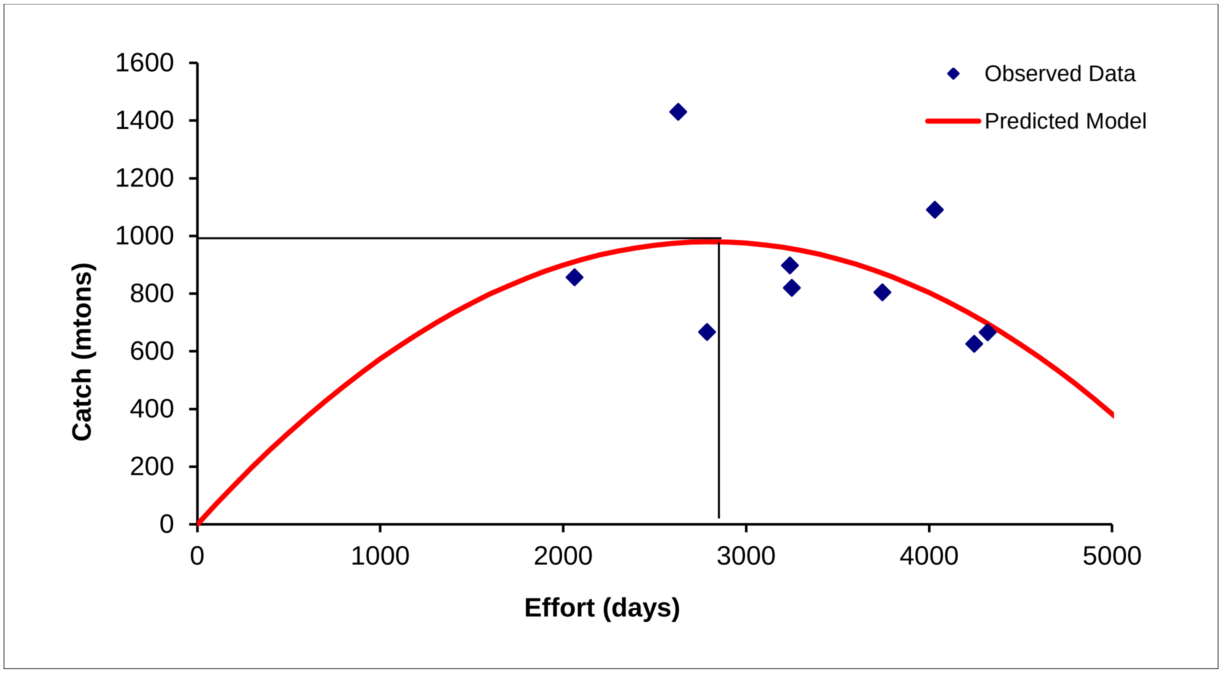

Figure 24. Results of Schaefer Equilibrium Surplus Production Model for chicharro in the non-linear form of Catch versus Effort, based on standardized effort data for the period 2001-2009. Note the value of MSY at 980 mt for the circle net fishery alone.

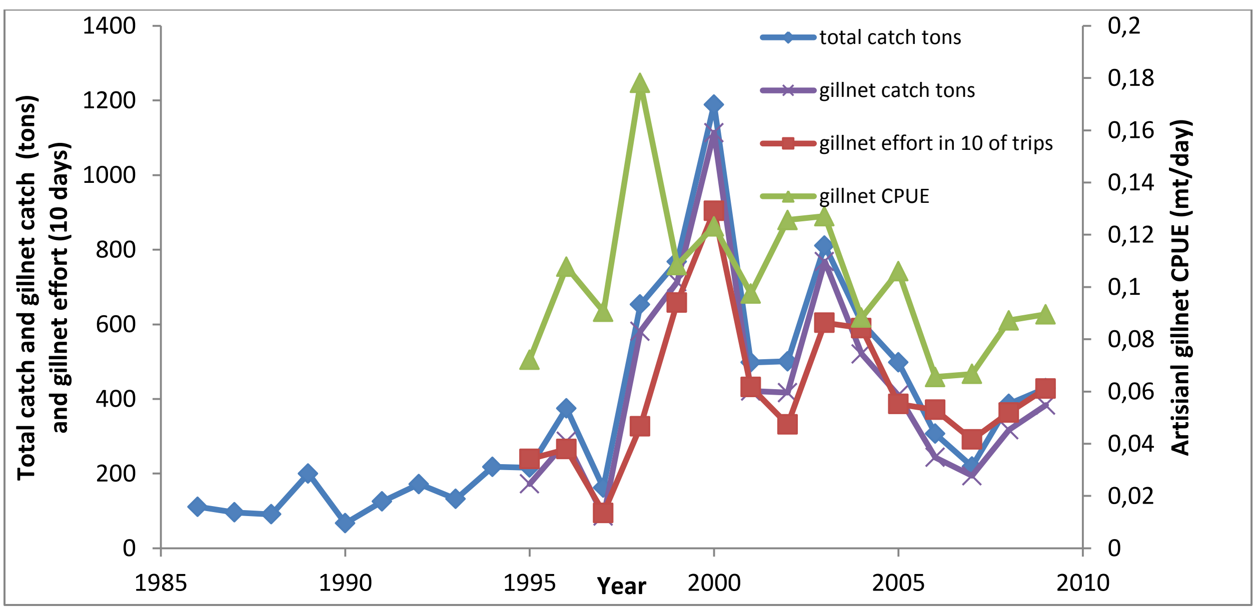

Figure 25. Artisanal catch (mt), artisanal gill net catch (mt), effort (days), and CPUE (mt/day) for dobrado. Note that artisanal gillnet net landings account for nearly all of the total artisanal landings of dobrado.

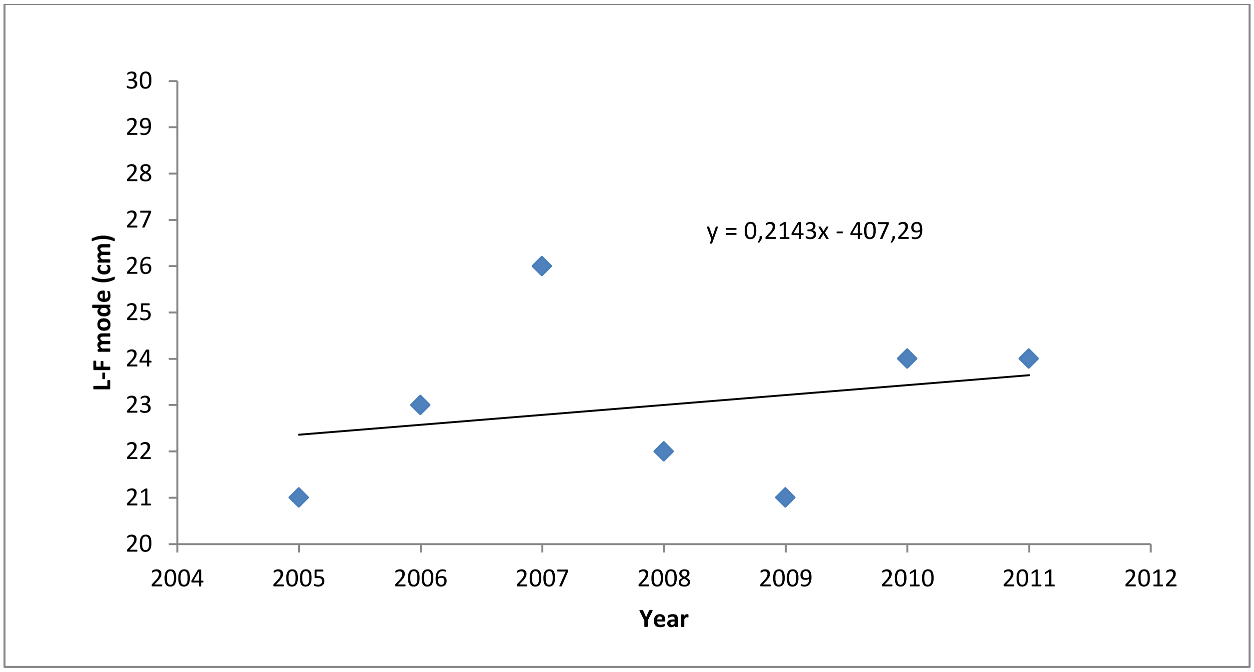

Figure 26. Mode of the length-frequency distribution for the landings of dobrada during the period 1988 to 2010. Note that this is a <u>not</u> a significant increase in length over the period.

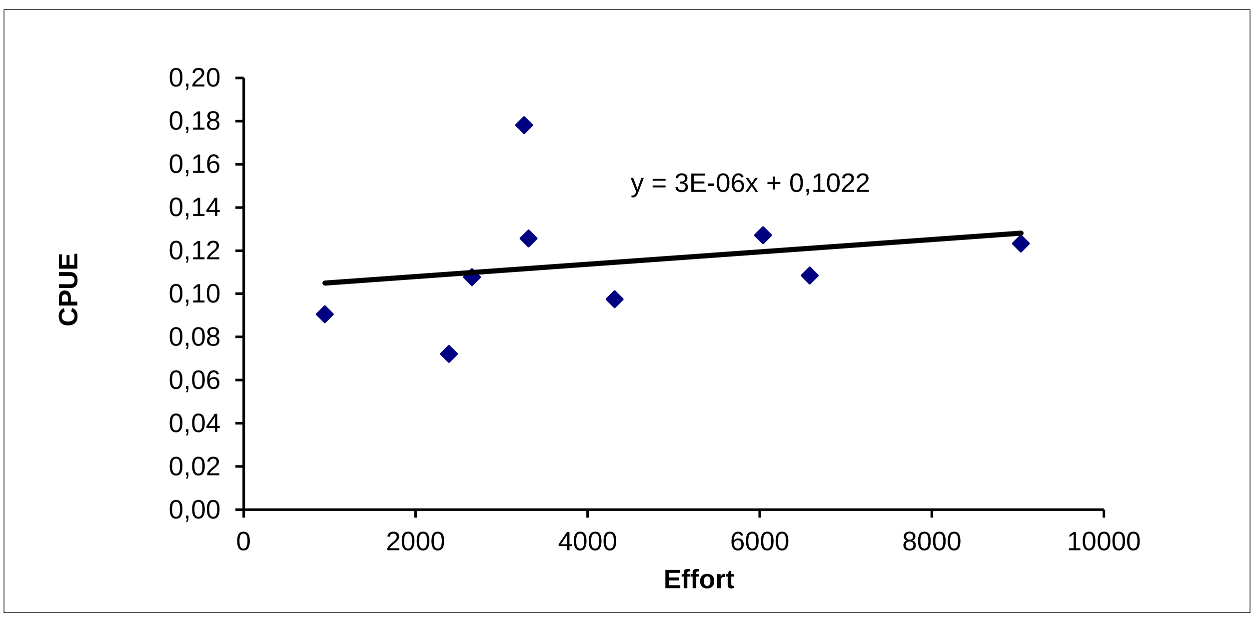

Figure 27. Results of Schaefer Equilibrium Surplus Production Model for dobrado in the linearized form, CPUE versus Effort, based on standardized effort data for the period 2001-2009. Note that there is <u>not</u> a significant decrease in CPUE (mt/day) as a function of standardized effort (days), therefore an equilibrium surplus production model cannot be used.

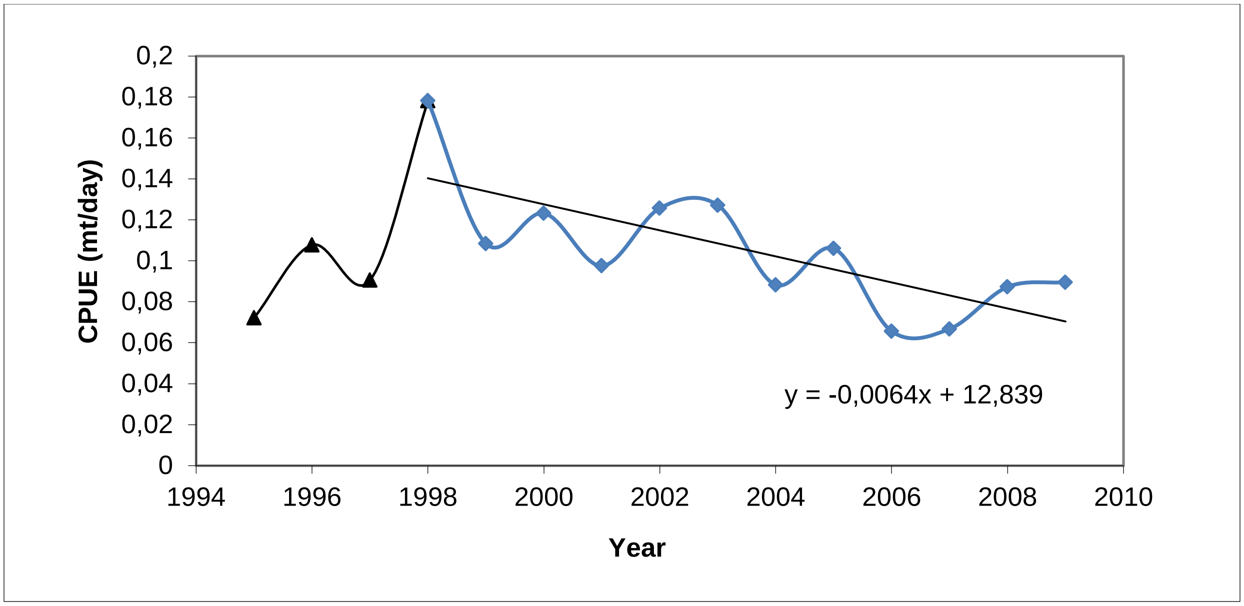

Figure 28. Results of a trend analysis for the CPUE (mt/day) of the artisanal gillnet fishery for dobrada for the period 1998 to 2009. Note that there is a significant decrease in the CPUE over this period.

Table 2. Catch (mt) and effort (days) data for cavala preta in the artisanal and industrial circle net fisheries.

Year	Artisanal Circle net			Industrial Circle net		
	catch (mt)	effort (days)	CPUE (mt/day)	Catch (mt)	effort (days)	CPUE (mt/day)
1986						
1987						
1988						
1989	1533	7644	0.201			
1990	702	5271	0.133			
1991	937	5701	0.164			
1992	976	5563	0.175			
1993	1485	4010	0.370			
1994	1178	3639	0.324			
1995	676	2621	0.258			
1996	753	3854	0.195			
1997	755	3149	0.240			
1998	1025	4444	0.231			
1999	1065	4332	0.246			
2000	743	3705	0.201			
2001	501	3488	0.144	848	1996	0.425
2002	462	3478	0.133	1751	2992	0.585
2003	414	1930	0.215	1398	2557	0.547
2004	596	2819	0.212	1086	1581	0.687
2005	677	1526	0.444	1461	705	2.072
2006	180	1133	0.159	1937	902	2.148
2007	516	2573	0.201	2293	2337	0.981
2008	334	1903	0.175	2034	2664	0.763
2009	319	2008	0.159	1373	3243	0.423
Averages	754	3561	0.218	1576	2109	0.959

Table 3. Catch (mt) and effort (days) data for chicharro in the artisanal and industrial circle net fisheries.

Year	Artisanal Circle net			Industrial Circle net		
	catch (mt)	effort (days)	CPUE (mt/day)	Catch (mt)	effort (days)	CPUE (mt/day)
1986						
1987						
1988						
1989	267	7544	0.035			
1990	101	5271	0.019			
1991	135	5701	0.024			
1992	21	553	0.038			
1993	22	4010	0.006			
1994	30	3639	0.008			
1995	2	2621	0.001			
1996	3	3854	0.001			
1997	20	3149	0.006			
1998	27	4444	0.006			
1999	64	4332	0.015			
2000	158	3705	0.043			
2001	144	3488	0.041	521	1996	0.261
2002	144	3478	0.041	482	2992	0.161
2003	130	1930	0.067	536	2557	0.210
2004	332	2819	0.118	758	1581	0.480
2005	739	1526	0.485	691	705	0.980
2006	274	1133	0.242	581	902	0.644
2007	72	2573	0.028	733	2337	0.314
2008	61	1903	0.032	836	2664	0.314
2009	43	2008	0.022	777	3243	0.239
Averages	133	3318	0.061	657	2109	0.400

Table 4. Catch (mt) and effort (days) data for dobrada in the artisanal gillnet net fishery.

Year	Artisanal gill net					
	catch (mt)	effort (days)	CPUE (mt/day)	Catch (mt)	effort (days)	CPUE (mt/day)
1986						
1987						
1988						
1989						
1990						
1991						
1992						
1993						
1994						
1995	172	2390	0.072			
1996	286	2657	0.108			
1997	86	946	0.091			
1998	581	3264	0.178			
1999	714	6585	0.108			
2000	1114	9038	0.123			
2001	421	4317	0.098			
2002	417	3316	0.126			
2003	768	6042	0.127			
2004	521	5900	0.088			
2005	410	3866	0.106			
2006	243	3712	0.066			
2007	194	2912	0.067			
2008	317	3639	0.087			
2009	383	4281	0.090			
Averages	442	4191	0.102			

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DISCUSSION AND MANAGEMENT ADVICE

Cavala preta

Landings of cavala preta in the last two decades have ranged from less than 500 mt to almost 3000 mt. Previous assessments of stock status of cavala preta in Cape Verdean waters have stated that this species was moderately exploited, and that there was potential for additional yield. Almada's (1997) assessment indicated a potential *MSY* of 5500 mt; and Jardim's (1997) analyses indicated *MSY* estimates of 1548 to 5358 mt depending on the method used. Stobberup and Erzani (2006) suggest that it would be safe to increase landings up to 4000 mt, but in an earlier analysis indicated that *MSY* for the entire small pelagic fish complex was only between 3000 and 4000 mt.

The results of the qualitative analysis of the CPUE data suggest that at the average biomass level in the last two decades, an average harvest of 2000 mt could be sustainable. The results of the trend analysis for the mode of the length frequency distribution indicate a positive trend in the size of the fish landed, suggest that the intensity of fishing has reduced during the observation period, as fish are growing larger due to being in the stock a longer time before being harvested, unless the fishery has expanded into areas where the stock has been less heavily exploited. The results of the YPR and SSBPR analyses indicated the cavala preta is very susceptible to recruitment overfishing when the minimum size landed is less that 18 cm, the current minimum size for landings, and fishing mortality is high. The results of the Schaefer and Fox equilibrium surplus production models estimate MSYs of 2700 and 2300 mt, respectively, but these methods are believed to produce optimistic results. The results of the non-equilibrium surplus production or biomass dynamic model analysis conducted for this project over a 21 year period from 1988 to 2009 indicate that *MSY* for cavala preta is about 2700 mt. The results of all the analyses described in this report have the benefit of being conducted over a longer time series than previous analyses, and this results in more statistical power in the analyses as compared to previous analyses.

Thus according to this analysis, overfishing has occurred, and as a result the resource has been depressed and overfished. Recall that overfishing is defined to be when F/F_{MSY} is >1.0, and when B/B_{MSY} is <1.0, the stock is considered depressed, and when B/B_{MSY} is <0.5 the stock is considered overfished. In 2009 the stock is overfished as B_{2009} is estimated to be well below B_{MSY} and overfishing is occurring as F_{2009} is estimated to well above F_{MSY}. This analysis and the management advice resulting from it assume that the fishery has covered the same area over the history of the data series, and that the catch and effort data from the artisanal and industrial circle net fisheries, and the resulting Catch per Unit Effort (CPUE) is representative of the relative abundance of the stock.

To assess the effectiveness on a stock rebuilding plan, the Fox biomass dynamic model was projected into the future from 2009, using an adjusted catch scenario. While there are many alternative management scenarios that can be evaluated ranging from taking no action, to closing the fishery, the plan evaluated in this study, reduced catch to 1000 mt for a period of 3 years (2010-2012), then slowing increased catch as the stock rebuilds to 1500 mt for 2 years (2013-2014), and finally set the catch just below *MSY* at 2700 mt, as the stock should be rebuilt and at B_{MSY} in 2015 (Figure 26).

The management advice resulting from this study for cavala preta is as follows:

- The analyses of this stock and fishery indicate that the current minimum fish length should be observed and enforced if necessary, to allow for as many fish as possible to mature and contribute to spawning stock biomass and stock rebuilding.
- The stock is over-exploited, that is overfished and overfishing is occurring. As a result, it is recommended the for the next 5 years landings be limited, initially to 1000 mt, then as the stock rebuilds catch is increased to 1500 mt, and in 5 years the catch can be set at the estimated *MSY* or 2700 mt annually, as the stock will be rebuilt to B_{MSY}.
- It also should be noted that without a restriction on landings, the stock is in jeopardy. Not taking additional management action beyond the current minimum landing size of 18 cm and a 2 month closed season, is not consistent with a precautionary approach.
- There is a need for better data on the fishery landings and effort from all sectors that harvest cavala. If length at age data were available for this species, alternative analyses methods could be employed, so it is recommended that effort be made to begin to conduct length at age analyses of this species due to its importance to Cape Verde.

Chicharro

Landings of chicharro in the last two decades have ranged from less than 500 mt in the 1980s and 1990s, to almost 1200 mt in the 2000s. Previous assessments of stock status of chicharro in Cape Verdean waters have stated that this species was moderately exploited, and that there was potential for additional yield. Tariche and Martins (2011) concluded that there could be a 20% expansion of landings.

The results of the qualitative analysis of the CPUE data suggest a sustainable catch at the current biomass level of about 1000 mt. The results of the trend analysis for the mode of the length frequency distribution indicate a almost significant positive trend in the size of the fish landed, suggesting that the intensity of fishing has reduced slightly during the observation period, as fish are growing larger due to being in the stock a longer time before being harvested, unless the fishery has expanded into areas where the stock has been less heavily exploited. The results of the YRP and SSBPR analyses suggest that there is minimal benefit to enforcement of the minimum landed length regulations, and that this is due to the very different life history characteristics of the species, as compared to cavala The results of the equilibrium surplus production model estimate MSY at 1000 mt, but this method is believed to produce generally optimistic results. Unfortunately, a biomass dynamic model could not be fit to the existing data. So, in contrast to previous assessments, the results of this work suggest that chicharro is fully exploited, and that landings should restricted to about 1000 mt, so as to maintain the stock at productive levels.

The management advice resulting from this study for chicharro is as follows:

- The stock is fully exploited at the current level of landings. The fishery should not be expanded, and landings and effort should be closely monitored so as to ensure that the fishery does not expand.
- There is a need for better data on the fishery landings and effort from all sectors that harvest chicharro. If length at age data were available for this species, alternative analyses methods could be employed, so it is recommended that effort be made to begin to conduct length at age analyses of this species due to its importance to Cape Verde.

Dobrada

Landings of dobrada in the last two decades have ranged from less than 200-400 mt in the 1980s and until 1998, to almost 1200 mt in the 2000, and more recently averaged 300 mt. There have been no previous assessments of dobrada, and there is limited life history information available for this species.

The results of the qualitative analysis of the CPUE data suggest a sustainable catch at the current biomass level of 300 mt. The results of the trend analysis for the mode of the length frequency distribution indicate a trend in the size of the fish landed that was not significantly different from 0. The YPR and SSBPR analyses could not be conducted due to a lack of life history information, and a surplus production model could not be fit, as the CPUE index does not decline with increasing effort. The most convincing analysis is the decrease in gillnet fishery CPUE by one half in the last decade, and this suggests that the stock is in decline.

The management advice resulting from this study for dobrado is as follows:

- Given the lack of information on this resource, and the decrease in the fishery dependent CPUE, it is suggested that the management of this resource proceed with caution, and that no further expansion of the fishery be considered, until more data is available on the life history characteristics of the resource, and there are clearer trends in the CPUE index as a function of effort and time.

RECOMMENDATIONS FOR FUTURE WORK

The analyses reported on herein have been severely limited by the availability adequate data for landing and effort that cover all sectors of the fishery, and by the fact that the most recent data available for the fishery in 2012 is only 2009. While INDP is to be commended for summarizing the available landings and effort information annually in the annual Statistical Bulletins, there is no real database available to access the data in any form other than that provided in the annual Statistical Bulletins. More comprehensive data on landings and effort by species and fishery sector, that does not rely on the scaling up of limited observations, input into a database so it can be accessed without being aggregated would be ideal.

The analysis reported on herein have also been limited to global models vice age or length structured models due to the lack of information on the length at age of the three species investigated. Analysis of biological samples in particular aging of fish, so as to be able to do age or length structured models is very important for future stock assessments of the small pelagic species.

There is also a need for fishery independent sampling or surveys of the fishery resources. For the small pelagics resources this could be acoustic sampling, but it must be done on a more frequent basis than is currently done by the Norwegian research vessel.

Finally, there should be minimum mesh size regulations for the various nets used in the small pelagic fisheries that correspond to the minimum legal fish length that can be landed. A mesh size selectivity study that determines the minimum mesh appropriate to the minimum legal landed fish length, would reduce the mortality of juvenile fish.

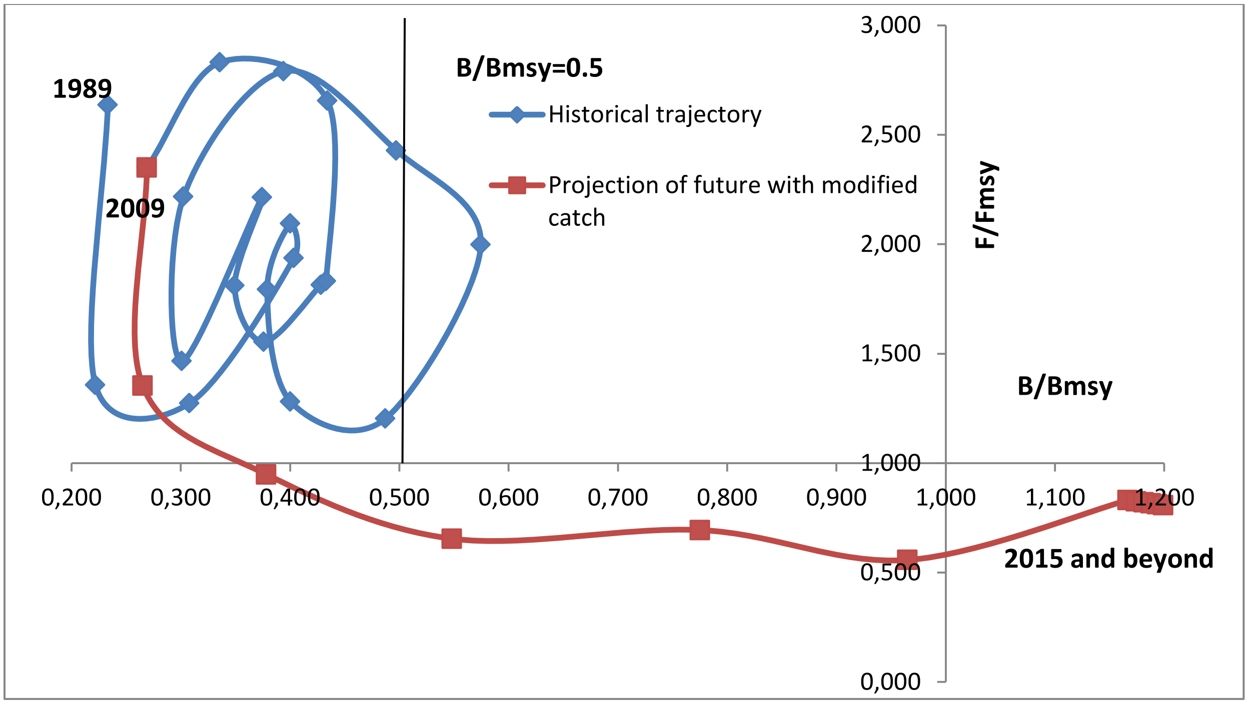

Figure 29. Harvest control rule including projection based on the results of the Fox biomass dynamic model for cavala preta based artisanal and industrial CPUE indices. Note that the projection is based on catches of 1000 mt for 2010 to 2012, 1500 mt for 2013 to 2014, and 2700 mt for 2015 and beyond.

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