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Background Paper: SFA 02

Results of the Catch Assessment Survey (CAS) 2012 and Research Activities for Artisanal Fisheries

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1. Artisanal fisheries statistics 2012

1.1 Catch and effort

1.1.1 Catches

Based upon output from the CAS which has been implemented since 1985 this section of the report reviews the performance of the major artisanal fisheries for 2012 and summarizes major trends.

The total artisanal catch for 2012 was estimated at 2502.1 Mt This represent a decrease of 13% over 2875.0 MT landed in 2011 (Figure 1). Compared to 2011 landings on Mahe decreased by 520MT (20%) whereas landings on Praslin increased by 147 MT (59%).The decline in catch during the past four years was partly due to decline in fishing effort (Figure 3). From 2008 to 2012 in term of fishing effort harpoon handline and trap fishery recorded a decrease of 71% 49% and 5% respectively.

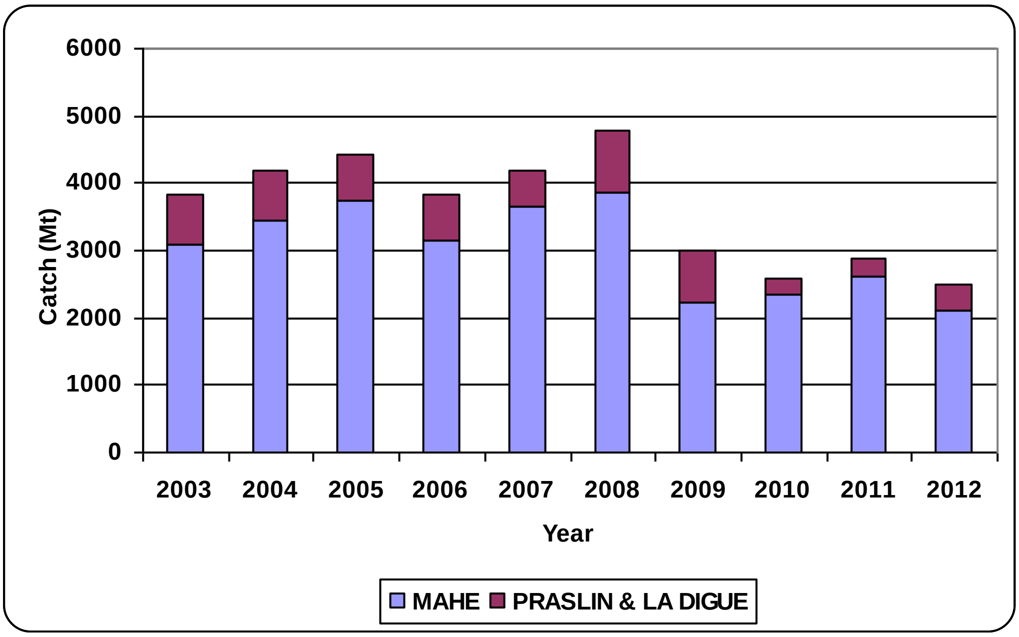


Figure 1. *Artisanal catch (t) for Mahé and Praslin/La Digue: 2003 to 2012*

In terms of catch by gear categories handline fishery handline & trap fishery and the trap fishery decrease by 35% 29% and 12% respectively whilst nets fishery dropline and harpoon fishery recorded an increase of 157% 21% and 3% respectively (Figure 2).

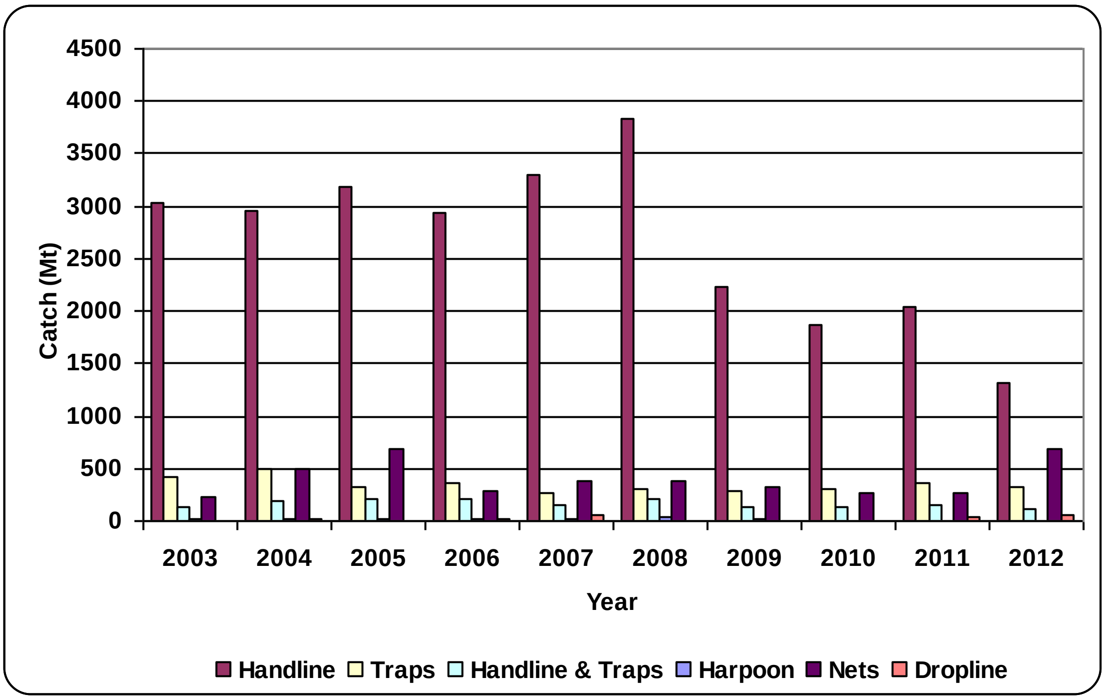


Figure 2. *Catch (MT) by gear category for 2003 to 2012*

The composition of the total artisanal catch by vessel category was dominated by outboard (50.7%) followed by whalers (30.8%).(Table 1)

Table 1. *Percentage (%) of annual catch landed by major vessel types including foot fishermen: 2003– 2012.*

Boat Type	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Pirogue	1.1	1.3	1.6	2.1	0.6	0.6	0.8	0.6	0.4	1.0
Outboard	27.4	34.3	36.2	28.3	25	25.4	37.6	33.9	33	50.7
Whalers	64.1	54.2	50.4	56.9	63.3	64.2	47.6	47.8	51.7	30.8
Schooners	6.8	9	11.1	11.5	9.3	8.9	13.3	17.1	12.9	15.0
Foot Fishers	0.6	0.9	0.7	0.6	0.4	0.8	0.5	0.6	0.4	0.5
Dropline vessels	0	0.3	0	0.6	1.4	0.1	0.2	0	1.5	2.1

1.1.2 Effort

As determined from monthly mean estimates of the number of vessels in operation whereby the maximum value is used as an indicator of fleet activity for the year the fishing activities of outboard vessels increased in 2012 compared to 2011 whilst those of pirogue and whaler have remained the same. The logbook returns from the sport fishery continued to be poor precluding estimation of the number of vessels engaged in that fishery (Table 2).

In term of fishing effort trap handline and harpoon fishery recorded a decrease of 20%14% and 2% respectively whilst nets fishery recorded an increase of 34% in 2012 compared to 2011.(Figure 3)

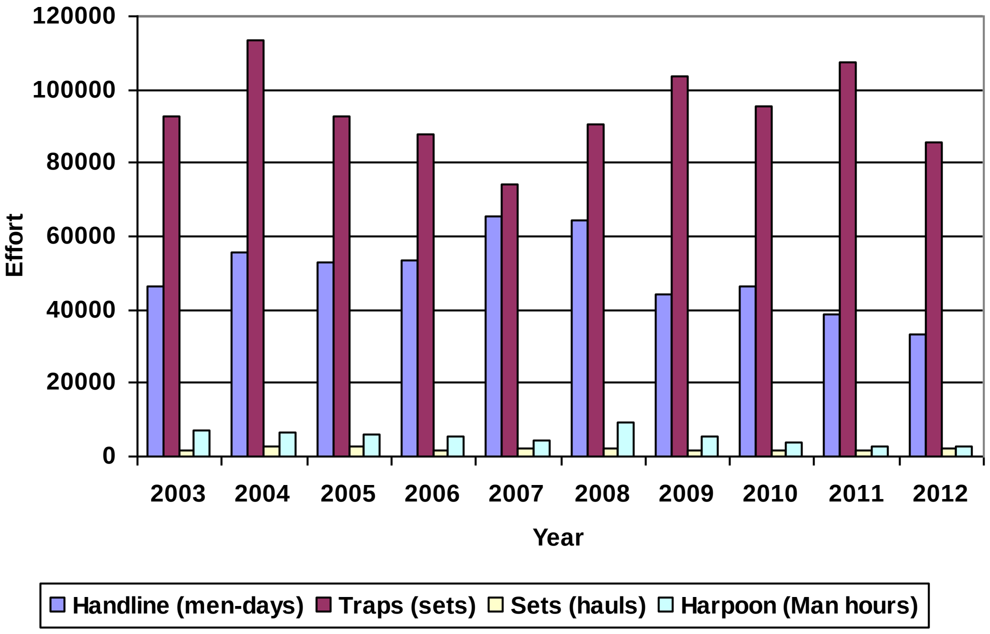


Figure 3. *Fishing effort for the major gear types for 2003-2012*

Table 2. *Maximum monthly fishing vessels in operation: 2008 to 2012.*

Vessel Type	2008	2009	2010	2011	2012
Pirogue*	19	19	16	15	15
Outboard*	293	324	316	294	296
Whaler	107	113	105	106	106
Schooner	22	27	27	32	28
Sport	**	**	**	**	**
Dropline	3	2	1	5	2

***Includes part time fishing vessels. ** Data not available due to poor logbook returns**

1.2 Catch Rates

Catch rates (CPUE) for the handline fisheries decreased from 59 kg/man day in 2011 to 43.3 kg/man day in 2012 (Figure 4a). The whaler handline fishery recorded the highest CPUE compared to the other vessel types. An increase was observed in trap fishery from 4.0 kg/trap in 2011 to 4.2 kg/trap in 2012 (figure 4b).Net and harpoon fishery also recorded an increase in the catch rate from 148.6 kg/set and 10.8 kg/man hour in 2011 to 297.6kg/set and 10.9 kg/man hour in 2012(figure 4c& 4d).

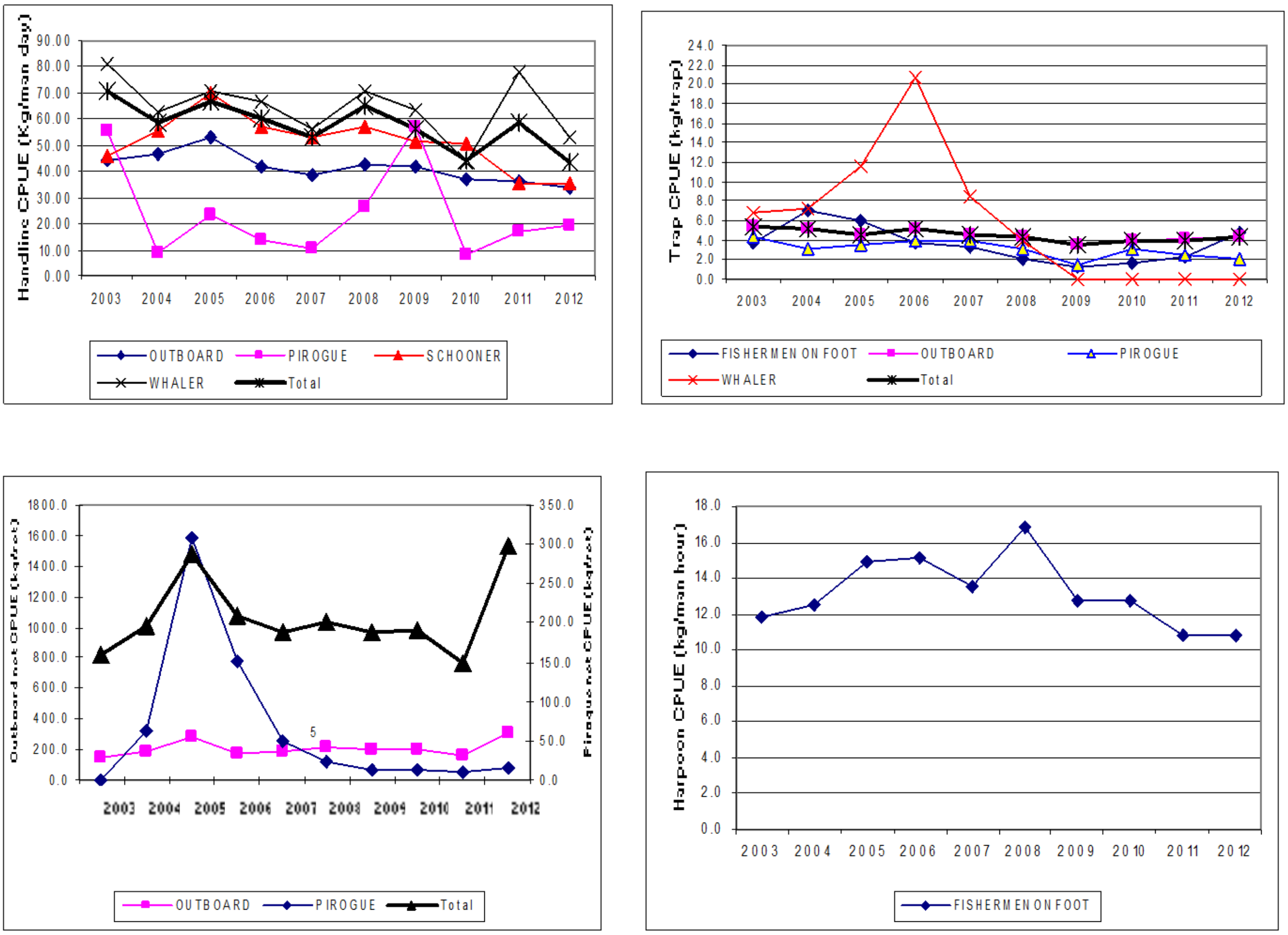


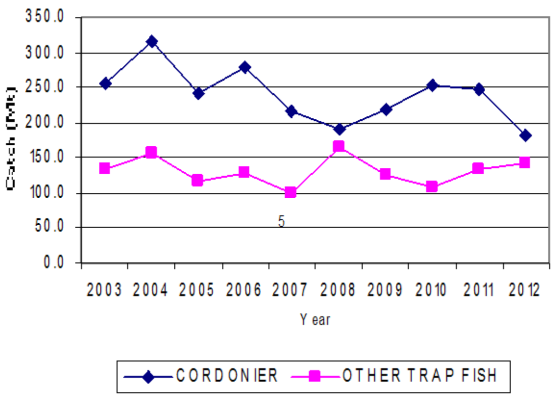
***Figure 4**. Trends in catch rates (CPUE) for the major vessel and gear combinations in the (a) handline fisheries (b) trap fisheries (c) gill net fishery and (d) the harpoon (octopus) fishery for the period 2003-2012.*

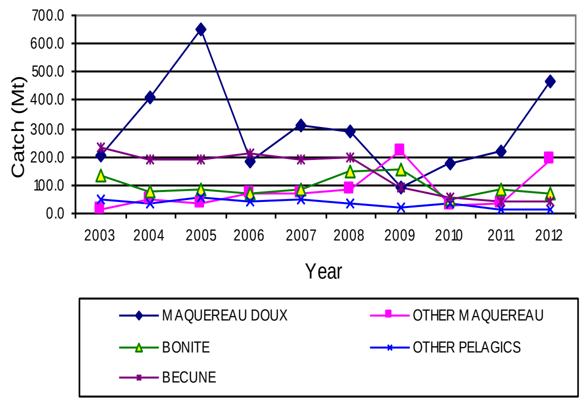
1.3 Species composition

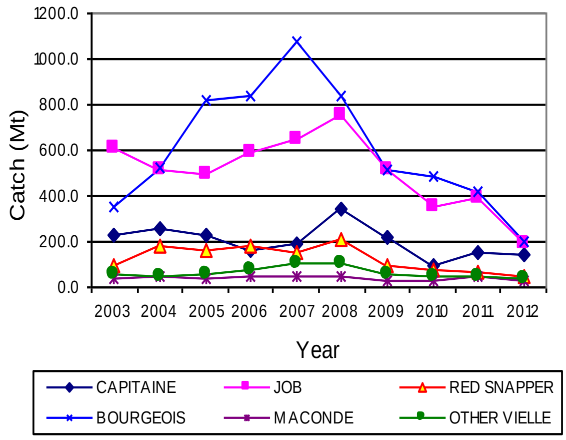
In term of species composition trevally (*Carangoides* and *Caranx spp*.) and mackerel (*Rastrelliger sp.*) were the two species dominating the catch for 2012. Catches of mackerel increased from 219 MT in 2011 to 469 MT in 2012 whereas catches for trevally decreased from 833 MT to 552 MT.Catches of jobfish red snapper rabbitfish and groupers all recorded a decrease of 51% 47% 27% and 21% respectively compared to the previous year (Table 3).

***Table 3**. Percentage (%) species/species-group composition of artisanal catch for the period 2008-2012*

Species Group		**Percentage (%) of total annual catch**				
English/Scientific	**Kreol**	**2008**	**2009**	**2010**	**2011**	**2012**
Trevally (*Carangoides* spp.)	Karang	25.8	17.9	26.2	28.9	22.1
Red snapper (*Lutjanus* spp.)	Bourzwa Bordomar	22	20.4	21.6	17.6	10.6
Jobfish (*Aprion virescens*)	Zob gri	15.8	16.9	13.6	14.0	7.9
Emperors (*Lethrinus* spp.)	Kaptenn	7.2	7.2	3.7	5.3	5.7
Bonito (*Euthynnus affinis*)	Bonit	3.1	5	1.8	3.0	2.8
Groupers (*Epinephelus* spp.)	Vyey	3.2	2.7	3	3.5	3.2
Rabbitfish (*Siganus* spp.)	Kordonnyen	4	7.3	9.8	8.6	7.3
Mackerel (*Rastrelliger* sp.)	Makro dou	6.1	2.9	6.7	7.6	18.7
Others		12.8	19.7	13.6	11.5	21.7
Total annual catch (MT)		**4777.1**	**3019.1**	**2595.4**	**2870.1**	**2502.1**







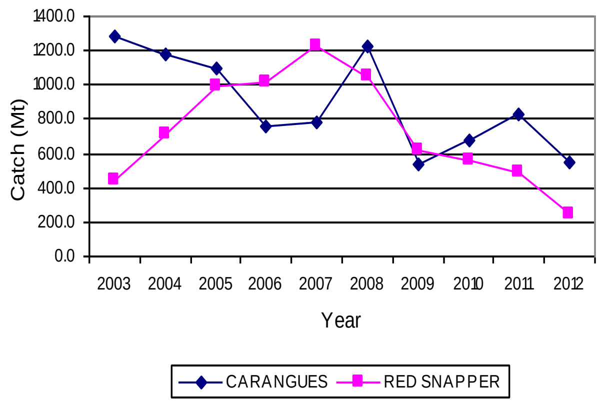


Figure 5*. Trends in catches (Mt) for the major species and species groups for the periods 2003-2012 in terms of (a) comparison of the dominant species/groups in the artisanal catch (b) semi-pelagic fisheries (c) demersal and (d) trap fisheries.*

1.4. Update on sea cucumber fishery

In 2012, the total catch of sea cucumber was 620,100 pieces, representing a slight decrease of 3% from the 642,404 pieces recorded in 2011 (Table 4.). Decreases were observed across all species groups except for Pentard where an increase of 17% was observed.

Table 4. *Reported number of sea cucumbers caught between January to December 2007 to 2012.*

Year	Black teat	Sandfish	White teat	Prickly red	Pentard	Others	Total
2007	7883	433	57837	19693	181670	63499	331015
2008	5687	1842	57084	21272	155674	24650	266209
2009	6230	303	134978	44885	290285	13950	490631
2010	31434	1639	125472	35480	306725	30452	531202
2011	10764	2018	117791	82710	348431	80690	642404
2012	6854	1806	83517	69366	409326	49231	620100

1.5. Update on lobster fishery

The 2012/2013 lobster season was opened for a period of three months from 1st December 2012 to 28th February 2013. The species targeted were Pronghorn spiny lobster (*Panulirus penicillatus*) Long-legged spiny lobster (*P. longipes*) Painted spiny lobster (*P. versicolor*) and Ornate spiny lobster (*P. ornatus*). The total catch recorded for the 2012/2013 season was 2.11 t compared to 3.30 t recorded for the 2011/2012 season (Figure 6). The most common techniques used to catch lobsters were snorkelling and skin diving. A total of 208 trips were undertaken during the 2012/2013 season which gave a CPUE of 10.14 kg per trip. The effort remained stable compared to the 2011/2012 season where 206 trips were undertaken. The most abundant species caught for this season was *P. penicillatus* with 1370 kg recorded followed by *P. longipeds* with 710kg. An assessment of stock indicators over the last 3 fishing seasons has lead to the conclusion that overfishing may have occurred. Significant declines in the total catch CPUE for the snorkelling gear and CPUE by fishing location were observed over the last 2 fishing seasons. From these observations it was recommended that the lobster fishery remain closed for a period of one to two years to allow the stock time to recover and for fisheries independent surveys to be carried out to monitor changes in the state of the stock.

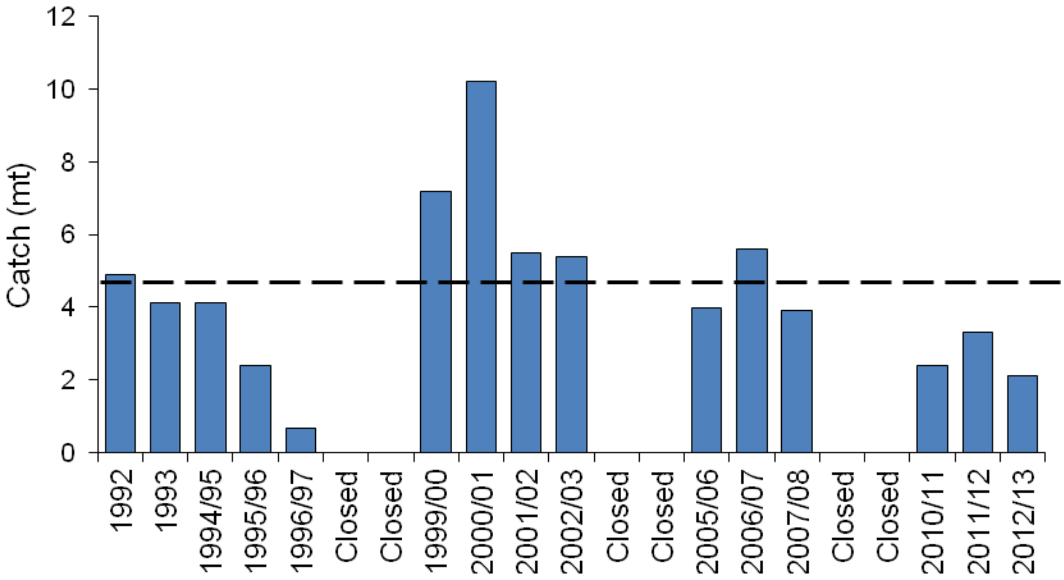


Figure 6. *Historical seasonal catch (metric tonnes, t) of spiny lobsters. Dashed line indicates mean seasonal catch since monitoring began in 1992.*

2. Research Activities

2.1. Stock assessments

Assessments were undertaken for three key indicator species of the demersal handline fishery. The number of size samples collected in 2012 for *Aprion virescens* was higher compared to 2010. In contrast, size samples of *Epinephelus chlorostigma* and *Lutjanus sebae* were lower compared to 2010.

Review of data collection procedures of size-frequency

Recently, the Seychelles Fishing Authority has begun a review of the procedures utilized to obtain size-frequency information for these species, as the validity of many of the conclusions will be constrained by the extent that the size-frequency information obtained constitutes a representative sample of the size-frequency distribution of the population (required in many of the equilibrium estimates of total mortality or, at least, a representative sample of the size-frequency distribution of the catch.

The sampling for size frequency is conducted separately from the routine monitoring of the catch, and it is done at the two processing plants for the fish. There is no strict protocol, in terms of target sample sizes or as to how to select the samples at the sampling site. In 2012, as the proportion of smaller fish in the catch of some of the species was deemed to be under-represented in the catches being sampled at the processing sites, a supplemental sampling was conducted in two landing sites.

The sampling for the smaller fish was conducted opportunistically, which complicates estimation of the size of this component in the total catch. In practice, the sizes of the smaller fish were added to the samples obtained at the landing sites. This *ad hoc* procedure does not provide sufficient guarantees that the size-frequencies obtained are representative of the population or the catch size-frequency distribution and, therefore, a review of the sampling procedures is currently underway.

Such a review, still under consideration, might include embedding the size-frequency sampling into the protocol of the Catch Assessment Survey, which involves weighting individual fish or ‘packets’ of fish in some cases. Since the field personnel already handle the fish when it weighs it, it is a simple procedure to proceed to measure the fish at the same time. Of course, the recommendation is to continue, in addition to this new measuring at the landing sites, with the usual procedure of collecting size-frequency data at the processing for a period of two years, in order to assess any possible differences in the two procedures.

2.1.1. *Aprion virescens*

In 2012, 1309 samples were taken for this species. The same growth parameters were used as previous years: age-based growth parameters derived in FMSP Project R6465 were used in FiSAT II (K=0.1, L_{∞}=89.9, t0=-2.3) to provide estimates of mortality (Z, F, M) and length at first capture (L_{c50}). Two estimates of natural mortality (M) were used, the first (M1) from Pauly (1980) with a temperature of 22°C. Since this method tends to overestimate M for slow growing species, we also used the derivation from Jenson (1996; reviewed in Hoggarth et al., 2006), where M = 1.5K to estimate this parameter (M2).

Table 5. *Aprion virescens*: Estimates of fishing mortality, and related parameters, for two different estimates of natural mortality (M1 and M2), and corresponding estimates of length at first capture (L_{c50}). Length at first maturity (L_{m50}) estimates and sample sizes (n) also provided.

Parameter	2006	2007	2008	2009	2010	2012
Z	0.28	0.32	0.33	0.34	0.43	0.35
CI of Z	*-0.30*-0.86	0.28-0.35	*-0.28*-0.93	*-0.30*-0.98	*-0.72*-1.57	*-0.03*-0.73
r^2	0.97	0.99	0.98	0.98	0.96	0.99
M1	0.26	0.26	0.26	0.26	0.26	0.26
F	0.02	0.06	0.07	0.08	0.17	0.09
E	0.07	0.18	0.21	0.23	0.39	0.26
L_{c50} (cm) – Logistic	70.30	70.70	69.70	72.08	75.45	75.37

L_{c50} (cm) – Running av.	67.67	68.48	68.54	68.51	69.09	68.23
F/M	0.077	0.23	0.27	0.30	0.65	0.35
M2	0.15	0.15	0.15	0.15	0.15	0.15
F	0.13	0.17	0.18	0.19	0.28	0.20
E	0.46	0.53	0.55	0.56	0.65	0.57
L_{c50} (cm) – Logistic	70.38	70.73	69.71	72.20	75.71	76.02
L_{c50} (cm) – Running av.	67.62	68.45	68.52	68.48	69.07	68.19
F/M	0.87	1.13	1.2	1.27	1.87	1.33
L_{m50} (Mees 1992; MRAG 1999)	62-64; 65 cm					
n	169	88	410	530	579	1309

In 2012, L_{c50} was greater than L_{m50} for both estimate of M, as was the case in previous years. We looked at the ratio F/M as a possible indicator of over-exploitation, considering that F=M has been suggested as a proxy for F(MSY). The conclusions are different depending on the value of M that is assumed. The F/M ratio has been consistently above one in the calculations done over the past few years with M2=0.15, while for M1=0.26, the ratio has been consistently below one.

However, similar to previous years, total mortality (Z) estimates were subject to considerable uncertainty, and for several yeasr the lower bound of the C.I. for Z are unrealistically negative values (Table 5). This could be the result of the level of aggregation in the size classes done, prior to the LFDA analysis.

YPR analyses were not conducted for this species.

2.1.2. *Epinephelus chlorostigma*

The sample size for *E. chlorostigma* was lower compared to previous years. The same growth parameters were used as in previous years, based on average of three estimates from Grandcourt (2002), Mees (1992) and Sanders et al. (1988), where K=0.21 and L_∞=57.19. L_{c50} was assessed against a published maturity estimate for females (Moussac, 1996), rather than for males, since this species is suspected of protogynous hermaphroditism. Maturity was also calculated from $0.5L_\infty$. As was the case with *Aprion virescens,* two estimates of M were applied in the assessment, the first (M1) the standard Pauly (1980) method with a water temperature of 22°C, and the second (M2) calculated using M=1.5K, with K=0.21.

Table 6. *Epinephelus chlorostigma*: Estimates of fishing mortality, and related parameters, for two different estimates of natural mortality (M1 and M2), and corresponding estimates of length at first capture (L_{c50}). Length at first maturity (L_{m50}) estimates, based on $0.5L_{\infty}$ and Moussac (1986), and sample sizes (n) also provided.

Parameter	2006	2007	2008	2009	2010	2012
Z	0.85	0.78	0.47	1.82	0.68	0.72
CI of Z	*-5.69*-7.39	*-5.04*-6.6	0.17-0.77	*-3.44*-7.07	0.02-1.35	*-1.85*-3.29
r^2	0.73	0.75	0.99	0.95	0.84	0.93
M1	0.48	0.48	0.48	0.48	0.48	0.48
F	0.37	0.30	-0.01	1.34	0.20	0.24
E	0.43	0.38	-0.02	0.74	0.29	0.33
L_{c50} (cm) – Logistic	31.14	31.26	34.70		36.22	35.03
L_{c50} (cm) – Running av.	31.91	31.48	34.73	34.81	33.65	33.60
F/M	0.77	0.63	-0.02	2.80	0.42	0.50
M2	0.315	0.315	0.315	0.315	0.315	0.315
F	0.54	0.47	0.16	1.51	0.28	0.41
E	0.63	0.60	0.33	0.83	0.47	0.56
L_{c50} (cm) – Logistic	31.07	31.20	34.46		36.28	35.01
L_{c50} (cm) – Running av.	31.73	31.29	34.56	34.81	33.61	33.56
F/M	1.71	1.49	0.50	4.80	0.89	1.30
L_{m50} ($0.5L_{\infty}$; Moussac , 1986)	28.95 cm TL; 31 cm TL for females					
n	348	78	178	250	437	143

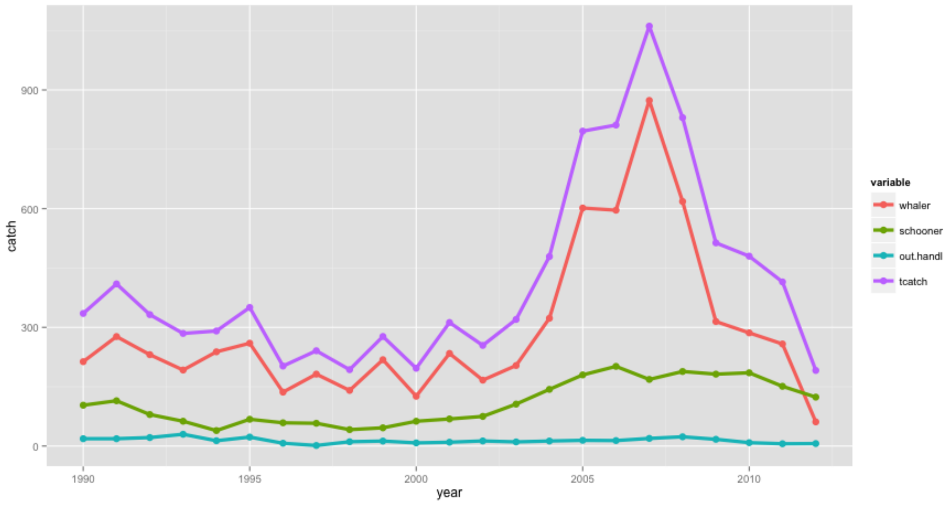
The total mortality (Z) was higher (0.72) compared to the one estimate in 2010. Based on the lower estimate of M (M2), the L_{c50} was greater than the L_{m50}. The estimates of Z (and therefore of F/M) are subject to considerable variability, often giving unrealistic negative values in the lower bound of the confidence interval. (Table 6). As in the case of *A.virescens*, this could be the result of small samples sizes for classes above L_{c50} and the aggregation of the size classes. If that proved to be the case, and given that the methods used are based on an assumption of equilibrium, future analysis might combined samples coming from more than one year.

2.1.3. *Lutjanus sebae*

The fishery

Catches of *L. sebae* have shown a large increase in the mid-2000's, followed by a considerable decrease following 2007 (Figure 7). This pattern has been mostly driven by the catches of the whaler fleet. If the data available is accurate, catches of *L. sebae* more than triple during 2002-2007, to fall to a historical low in 2012. As it will be discussed later, this raises some concerns about assuming equilibrium conditions, an assumption required by the methods used in the assessment.

Figure 7. Catch in mt of *L. sebae* by fleet

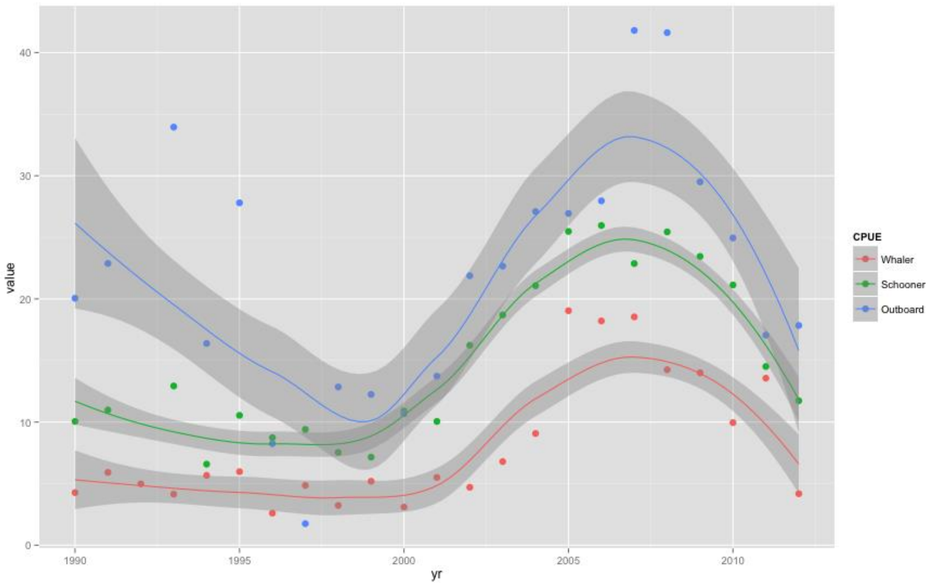


Catch-per-unit-effort

Primarily for illustrative purposes, CPUE were calculated for the three main fisheries. The results are shown in Figure 8, where the points indicate the individual values calculated, and the lines are drawn according to a loess smoother ran on the data by fleet to help in assessing the overall trend.

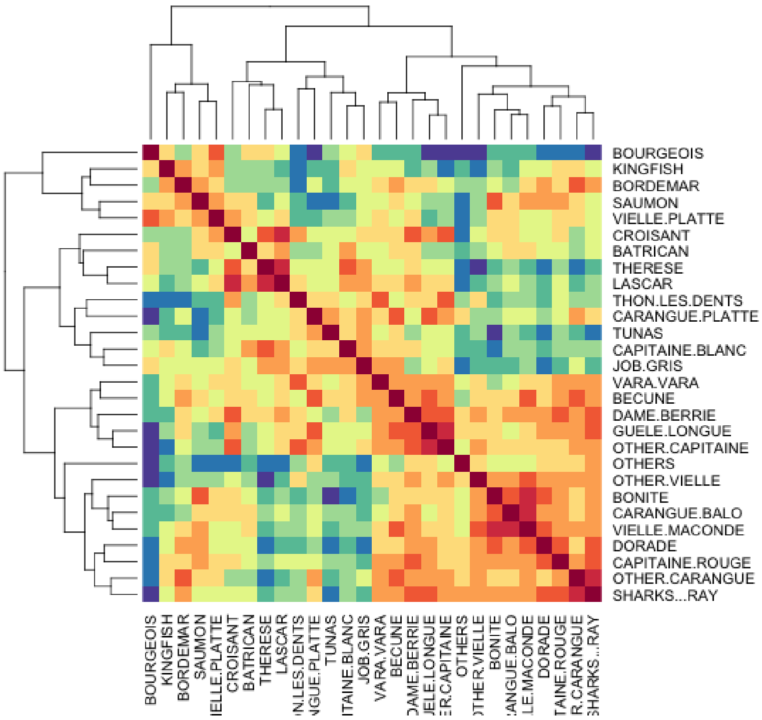
These nominal CPUEs follow, in general, the same pattern of the catches, suggesting an apparent increase in relative abundance in the second half of the 2000's. However, this is not the only hypothesis that explains the pattern. Concentrating our attention on the catch of the whaler fishery, that dominates the catch and shows the strongest pattern, we ran a cluster analysis comparing the species on the basis of the catches by year (see Figure 9). Although the analysis is based of a linear correlation matrix that might not be the best measure of association, still *L. sebae* is the first species to be separated from other species according to their presence in the catch. This is consistent with the hypothesis that fishing practices and gear configuration can be adjusted to target *L.sebae*, over other, more pelagic, species such as carangids, provided that the expected catch rate would be above a certain threshold. In other words, it is conceivable that there whalers simply switched to targeting more L. sebae in response to a higher level of relative abundance, going back to targeting a more mixed aggregation of species as the relative abundance decline.

Figure 8. Nominal Catch-per-unit-effort for the different fisheries. Whaler: catch in kg/line/day; Schooner: catch in kg/man/day; Outboard handline: catch in kg/man/100h



Such a switching behavior would have amplified differences in the CPUE between the high-abundance years and the rest of the years, leading us to overestimate the amplitude of the population fluctuations. Future analyses, based on looking at individual vessels data, might shed some light on this issue.

Figure 9. Heatmap based on a correlation matrix of the catches for the period 1990-2012, warmer colours indicate higher correlation. The marginal dendrograms are derived from a hierarchical cluster based on the correlation matrix.



Another plausible explanation is that the increase in catch rates is due to an increase in catchability, rather than abundance, a possibility that will be further explored in the future.

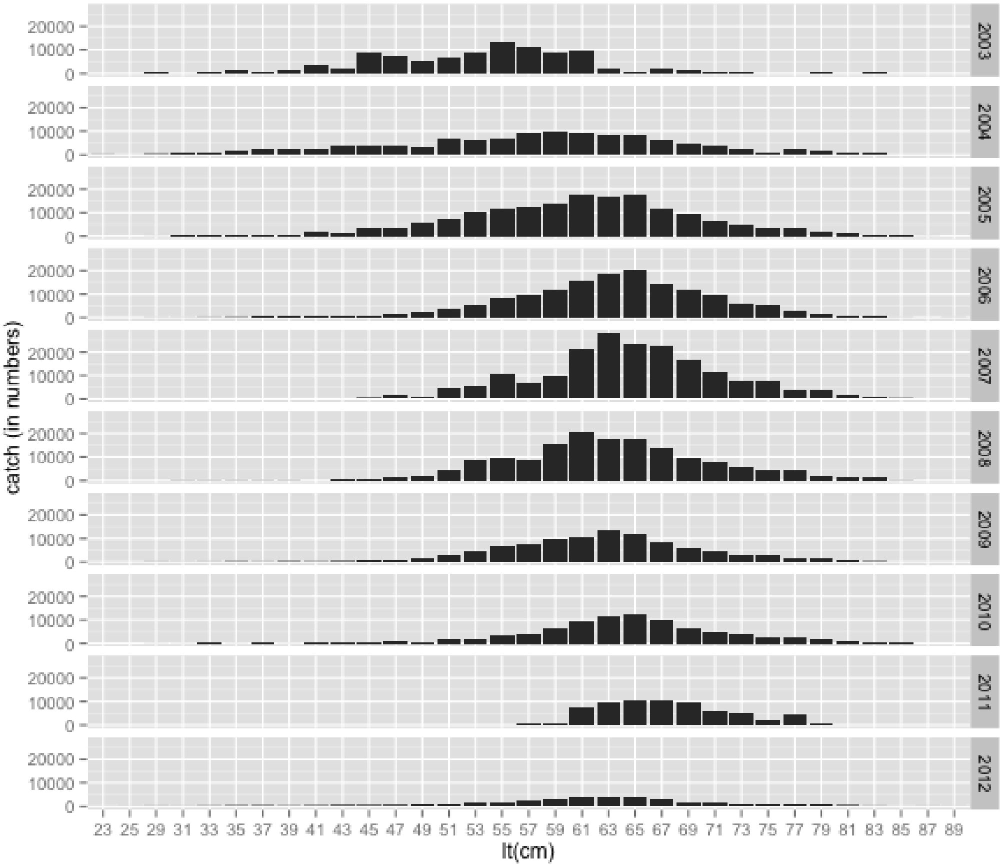
Evidence in support of an increase could also come from the distribution of size and ages in the catch. Given that the exploitable biomass for *L. sebae* is composed of more than 20 age classes (Grandcourt et al., 2008), such a clear signal in the catch, and the CPUE, would be explained by very large recruitments coming over a concentrated period, in order to have a clear influence in the overall biomass. Therefore, an analysis of the size-frequency distribution in the coming section will explore that possibility.

Size-frequency data

An estimate of the catch-at-size was obtained by raising the combined size-frequency distribution for a particular year to the total catch of the year. Note that this is based on the rather strong assumption that the samples measured at the processing plants are an accurate reflection of the distribution of sizes in the catch, something that cannot be verified yet.

The catch-at-size by year shows that the catch was dominated by size classes between 65-70 cm at the time of the largest historical catches (Figure 10). This could suggest the transit of one or more strong year classes through the exploitable biomass, but it could be explained by a different selectivity by the whaler fishery caused by different areas or fishing practices.

Figure 10. Catch-at-size for the combined fisheries, raised to the total catch.



Age- frequency data

Constructing a mapping from length to age: age-length keys

Given that there are direct age readings of otoliths available from past year (from the work of Grandcourt et al, 2008), there is an opportunity to convert size-frequency distributions to age-frequency distributions and take advantage of an age-structured analysis. Several approaches were explored to develop a mapping of sizes to ages.

The first approach is to construct an age-length key from the observed distribution of ages. While this is straightforward, it also has the disadvantage of being constrained to the coverage of ages and sizes in the sample that was subject to the direct ageing.

An alternative is to utilize the observed data to construct a model-based mapping by proposing a formulation for the conditional distribution of ages, given a particular size. In other words, the basic idea is that the conditional distribution function can be summarised in a parametric form by assuming that the distribution of ages by length can be reasonably well approximated by a distribution indexed by a mean and a variance function (which could be length dependent)[2]. This is similar to how a parametric bootstrap is constructed

For example, if $P(a\,|\,l) \sim N(\mu, \sigma^2)$ we could use plugin estimates:

$$\hat{\mu} = t_0 - \frac{1}{k}\left(\log\left(\frac{l}{L_\infty} - 1\right)\right) \qquad (1)$$

$$\hat{\sigma}^2 = g(l) \qquad (2)$$

In other words, the mean age-at-length is assumed to follow an inverse von Bertalanffy curve, while the variance of age-at-length has been assumed to follow some function of length.

The final step is to integrate the conditional distribution of ages over a particular length interval, centered around the target age, so that the probability that a fish of length l_a is of age $a_k \in [a_a, a_b]$, is

$$P(a_k \in [a_a, a_b] \,|\, l = l_a) = \Phi_{l_a}(a_b) - \Phi_{l_a}(a_a)$$

Where Φ_{l_a} is the appropriate cumulative distribution function that corresponds to the length l_a.

Note that this is different from fitting the growth curve in the usual way (i.e. taking age as an independent variable) and then using the parameters thus obtained in an inverse von Bertalanffy (IVB) model. The problem is that through that estimation procedure we get an unbiased estimate of the conditional distribution of sizes given a particular age. That is, we get *E(lt|a)*, rather than *E(a|lt)*, the conditional distribution of ages given a particular size, which is our objective.

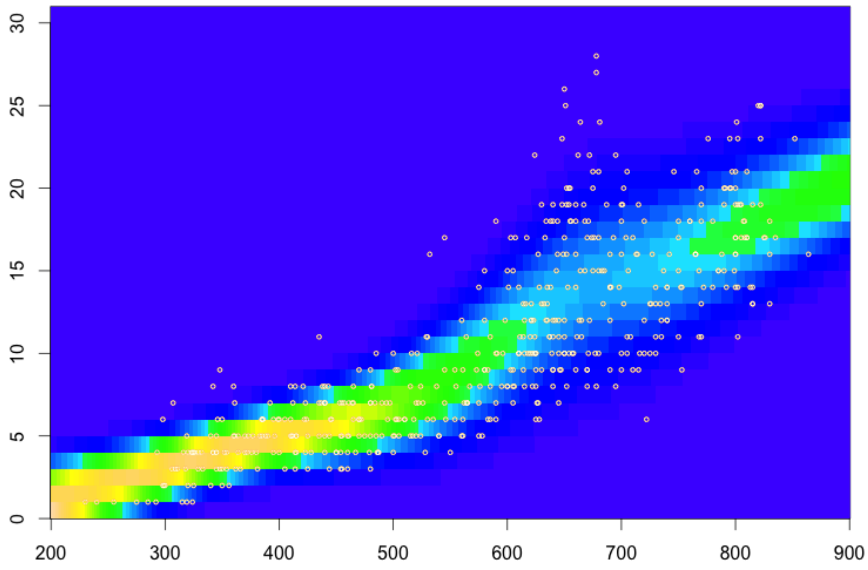
A trial of the IVB model was discarded, as the fit was influenced by the large number of observations centered at about 65 cm, which meant that the fitted model was not appropriate to predict the distribution of ages for larger size classes.

Therefore, a generalised additive model (GAM) was fitted to the same data, using a spline smoother with 5 d.f. to obtain the mean age at size. The variances are modeled as described in equation as a function of length, also utilizing a GAM on the distribution of the squared residuals. The two models were used to estimate the means and the variance of the conditional distribution of ages. The resulting distribution is

[2] The motivation here is similar to that behind the parametric bootstrap when, in a regression context, for example, the residuals are used to compute the parameters of a distribution to re-sample from, rather than re-sample from the residuals directly.

shown in Figure 11, where the distribution of the observed ages and lengths from the original dataset from Grandcourt et al. (2008) is shown.

Figure 11. Parametric age-length key resulting from modeling mean and variance of ages-at-length by GAM.

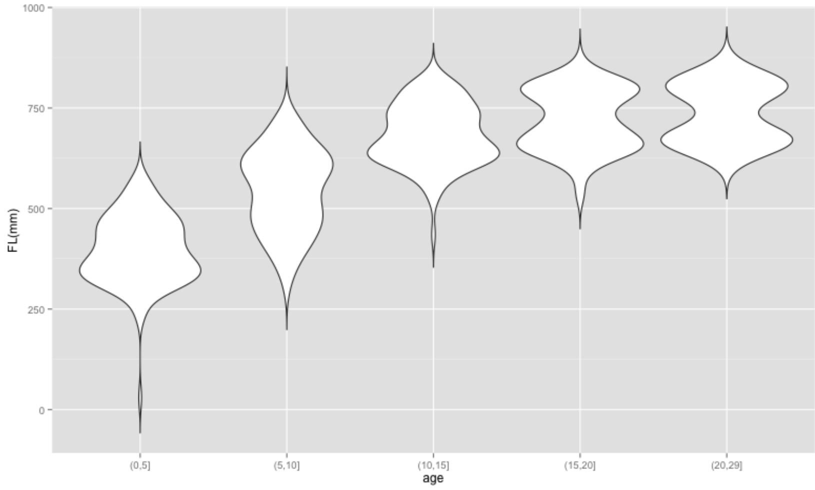


A clear feature of this age-length key is the flatness of the conditional distribution of ages at sizes around 65-70 cm, which had also affected the fit of an IVB model. In fact, the patterns in the distribution of these data lead us to consider the possibility of differences in growth by sex.

Apparent sexual dimorphism in growth.

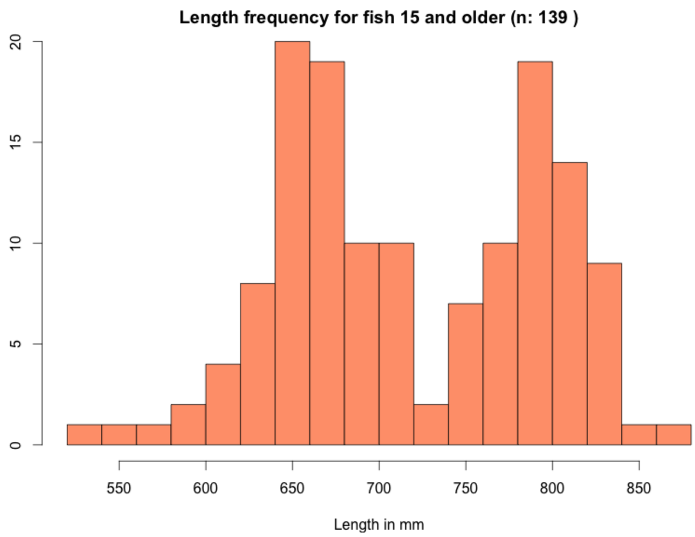
Already in the original data as published in Grandcourt et al (2008) there are hints of two modes in the distribution of sizes of older fish, which is more evident when we look at the distribution of ages by length in Figure 11. This pattern becomes more apparent when we group the fish in 5-cm categories and look at the distribution of sizes per group (Figure 12). As the growth rate begins to decrease for older ages, two modes become quite evident.

Figure 12. Violin-plot showing smoothed distribution of sizes per 5-cm categories.



In Figure 13, we can see that the distribution of all fish aged 15 and older show two distinct modes, separated approximately by 15cm.

Figure 13. Size-frequency distribution for fish older than 15 years old in the dataset from Grandcourt et al. 2008



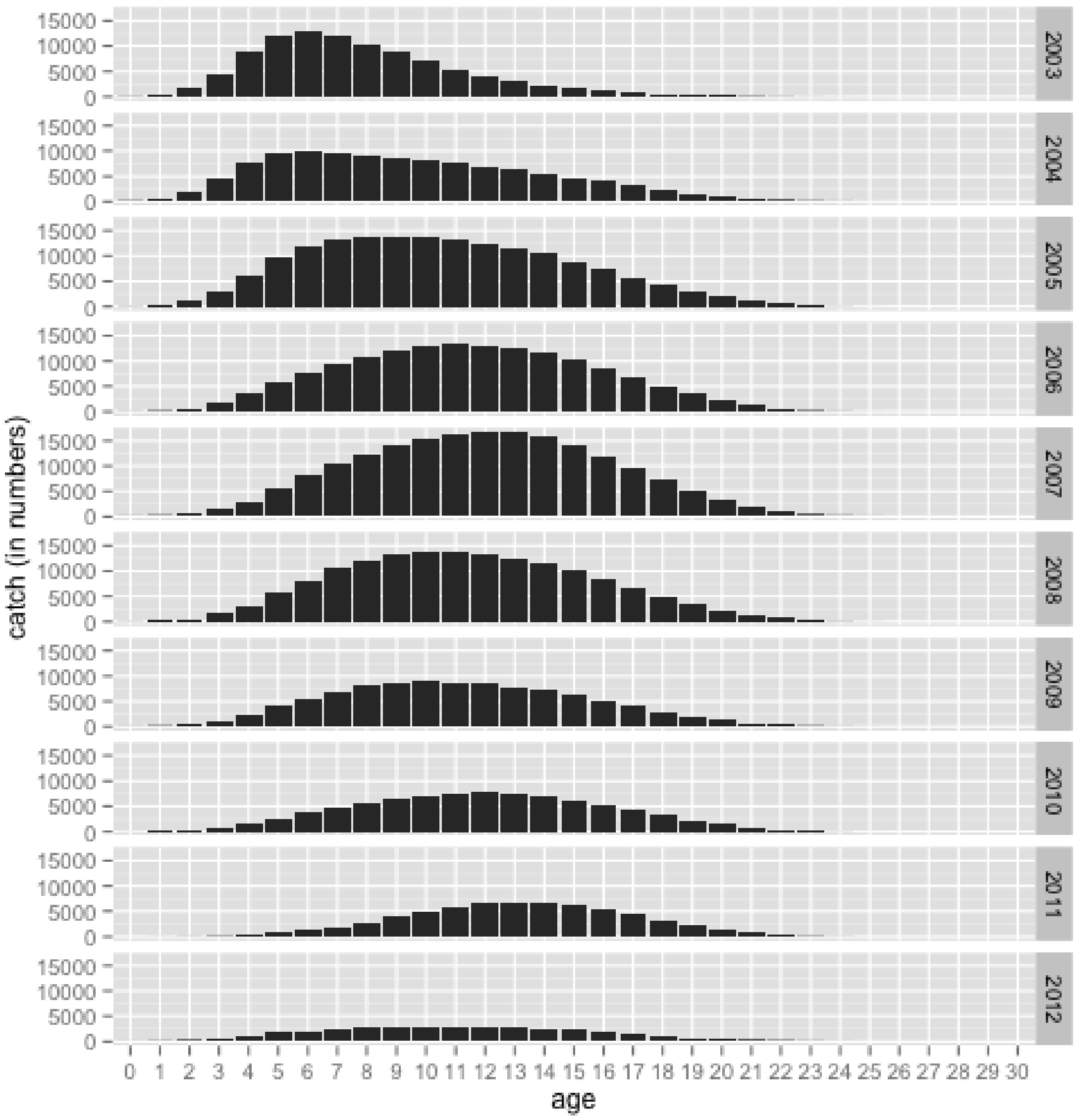
There are reports of sexual dimorphism in growth for similar species in the literature. Newman and Dunk (2002) reports for *L. sebae* in north-western Australia asymptotic lengths for males and females that are separated by approximately 14.5 cm (62.8 cm for males and 48.3 cm for females), which is consistent with the difference between the modes shown in Figure 13, although the same species seems to reach larger sizes in Seychelles.

This presumed dimorphism would have to be confirmed through future sampling, as fish will have to be sexed at the time of otolith extraction and, when possible, information about sex composition in the catch will also have to be collected.

Age distribution in the catch

The age distribution of the catch, obtained by applying the age-length key as described above, is shown in Figure 14. The figure seems to support the hypothesis of one or more strong cohorts coming through the fishery.

Figure 14. Catch-at-age distribution for the period 2003-2012



Mortality and capture estimates

In addition to analyses at the Plateau level, sample data were sufficient to perform analyses of the NW (sectors 9 and 10) area only.

Application of YIELD software

Due to problems in obtaining reliable performance of the YPR models in the Yield software using point estimates of growth parameters, we use an average of 2 age-based estimates (Grandcourt et al. 2008 and Newman 2000) and 2 length-based estimates (Mees 1996), where K = 0.163; L_∞ = 88.6; t0 = -0.95. We used an estimate of natural mortality based on an average derived from two methods; M = 1.5K and an age-based estimate derived by Grandcourt et al. (2008) using the Hoenig (1983) empirical equation.

The higher estimate of length at first capture (63.86 cm) was higher than the length at first maturity (62 cm) for all sectors combined in 2012 (Table 7). Similarly, in the NW area (sectors 9 and 10), the higher estimate of L_{c50} was higher than the L_{m50}, whist the F/M ratio was 1.87 (Table 8).

Table 7. *Lutjanus sebae*: Estimates of mortality and corresponding estimates of length at first capture (L_{c50}) from 2004 to 2012. Length at first maturity (L_{m50}) estimates, based on Mees (1992), and sample sizes (n) also provided.

Parameter	2005	2006	2007	2008	2009	2010	2012
Z	0.52	0.58	0.55	0.50	0.56	0.56	0.52
CI of Z	0.10-0.95	0.35-0.82	0.39-0.71	0.24-0.76	0.44-0.68	0.41-0.63	0.36-0.68
r^2	0.99	0.99	0.99	0.99	0.99	0.98	0.97
M	0.182	0.182	0.182	0.182	0.182	0.182	0.182
F	0.34	0.40	0.37	0.32	0.38	0.38	0.34
E	0.65	0.69	0.67	0.64	0.68	0.68	0.65
L_{c50} (cm) – Logistic	59.13	64.32	62.29	61.70	60.50	62.23	63.86
L_{c50} (cm) – Running av.	60.07	64.08	62.56	60.59	57.55	58.67	57.86
F/M	1.87	2.19	2.03	1.76	2.09	2.09	1.87
Maturity	62 cm FL						
n	4797	4109	807	1430	2975	2243	2040

Table 8. *Lutjanus sebae*: Estimates of mortality and corresponding estimates of length at first capture (L_{c50}) for 2010 and 2012. Length at first maturity (L_{m50}) estimates, based on Mees (1992), and sample sizes (n) also provided.

Parameter	All sectors (2010)	SE (Sectors 5&6) (2010)	All sectors (2012)	NW (Sectors 9&10) (2012)
Z	0.56	0.57	0.52	0.52
CI of Z	0.41-0.63	0.36-0.77	0.36-0.68	0.37-0.68
r^2	0.98	0.96	0.97	0.98
M	0.182	0.182	0.182	0.182
F	0.38	0.39	0.34	0.34
E	0.68	0.68	0.65	0.65
L_{c50} (cm) – Logistic	62.23	61.92	63.86	65.90
L_{c50} (cm) – Running av.	58.67	59.03	57.86	58.64
F/M	2.09	2.14	1.87	1.87
Maturity	62 cm FL			
N	2243	539	2040	391

Yield per recruit

<u>All sectors</u>

In the absence of spawner recruit consideration, the yield-per-recruit analysis indicated that MSY would occur when F is around 0.9. However, the SSB would be reduced to less than 20% (a usual limit reference point) when F = 0.40 (Figure 15). From the histograms, maximum yield-per-recruit is achieved when F is around 0.65-1.35 (median= 0.92, CI=0.80-1.04) (Figure 16), but at the expense of reducing the spawning stock biomass to unacceptable levels. To prevent SSB per recruit to reach the limit level of 20% of unexploited biomass, F should be below 0.22-0.50 (median= 0.42, CI= 0.38-0.46) (Figure 17). The estimate of current F (0.34; range = 0.18-0.50) is very close to the value that would push the spawning stock biomass below the critical values.

Figure 15. Yield per recruit and Spawning Stock Biomass per recruit against levels of fishing mortality for all sectors combined

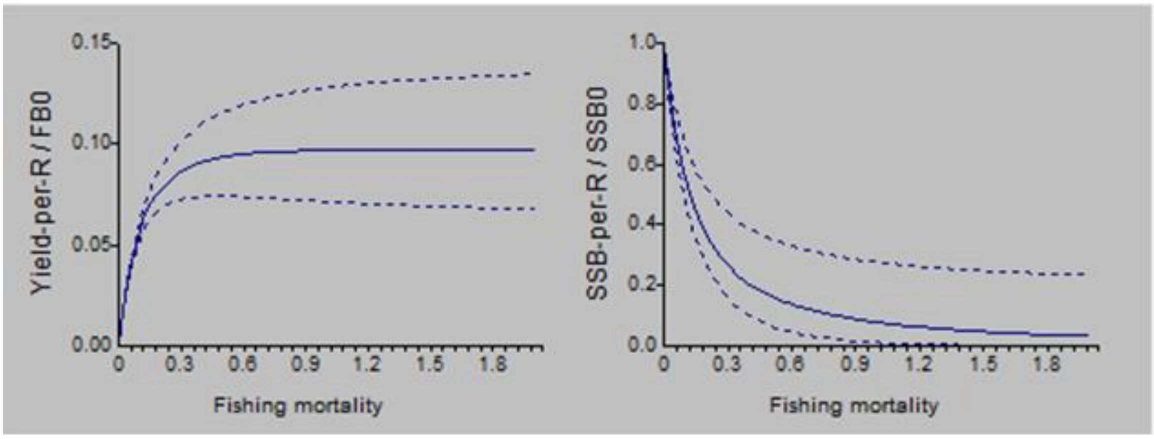


Figure 16. Frequency distribution of fishing mortality that produces maximum yield-per-recruit for all sectors combined

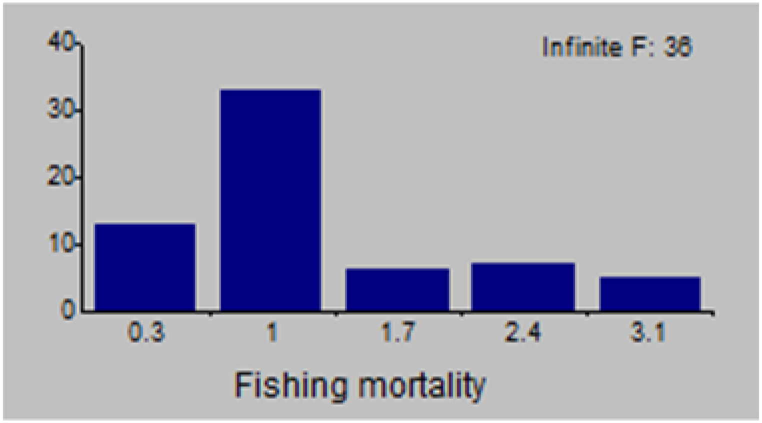
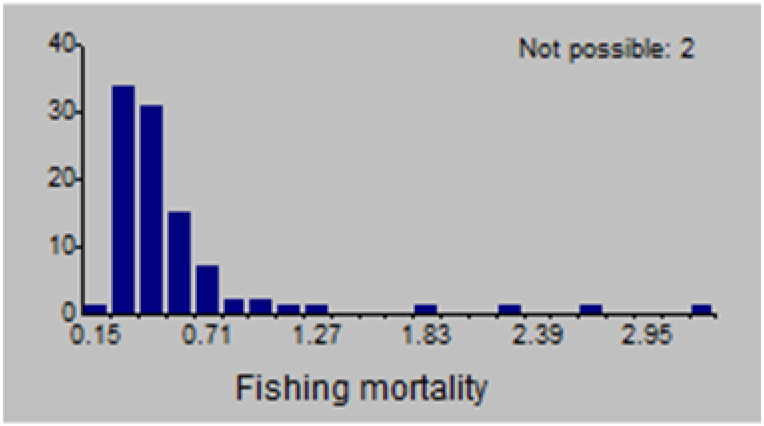


Figure 17. Frequency distribution of fishing mortality that maintains Spawning Stock Biomass at 20% of its unexploited value for all sectors combined



<u>Sectors 9 and 10 (NW area)</u>

YPR indicated that MSY per recruit occurs when F is around 1.50. SSB is reduced to less than 20% when F = 0.42 (CI=0.26->2) (Figure 18). From the histograms, MSY per recruit is achieved when F is around 0.7-1.3 (median=0.96, CI=0.75-1.17), however there was a high number of infinite F (Figure 19). To maintain SSB above the 20% level, F should be in the range of 0.23-0.49 (median=0.39, CI=0.34-0.45) (Figure 20). The estimate of current F (0.34; range = 0.19-0.50) is within the range of CI for $F_{SSB20\ per\ recruit}$. However, the upper range of current F exceeds the upper limit of $F_{SSB20\ per\ recruit}$.

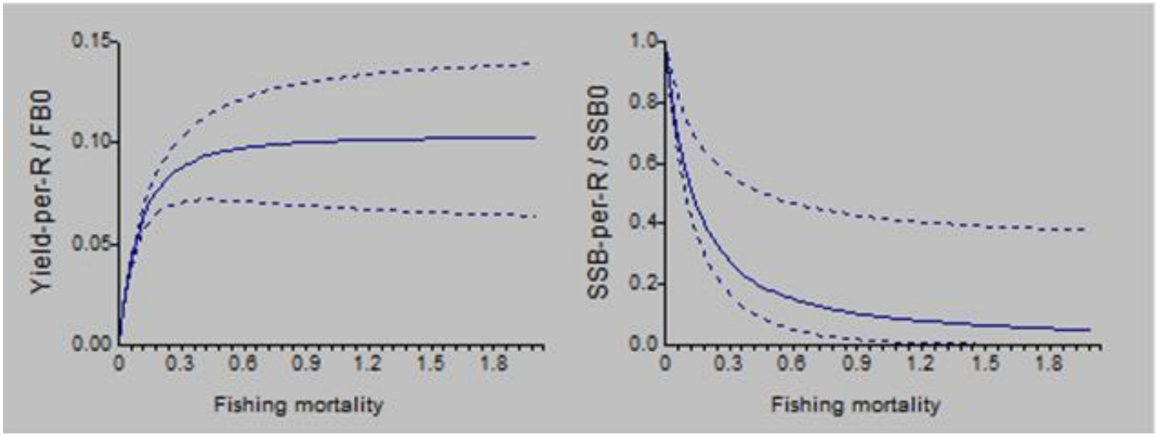


Figure 18. Yield per recruit and Spawning Stock Biomass per recruit against levels of fishing mortality for sectors 9 and 10

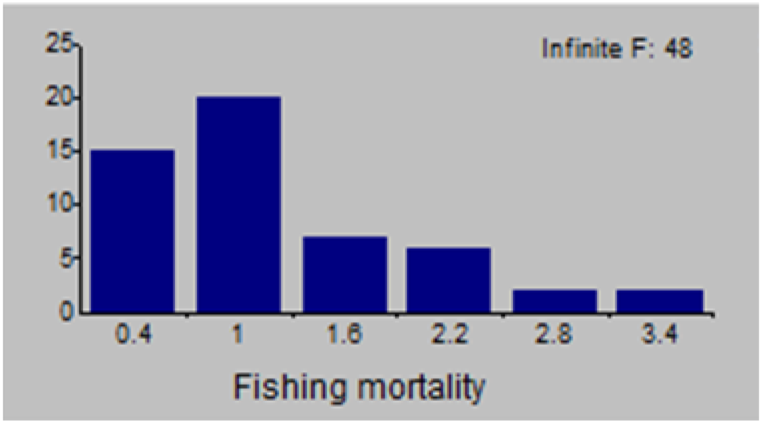


Figure 19. Frequency distribution of fishing mortality that produces maximum yield-per-recruit for sectors 9 and 10

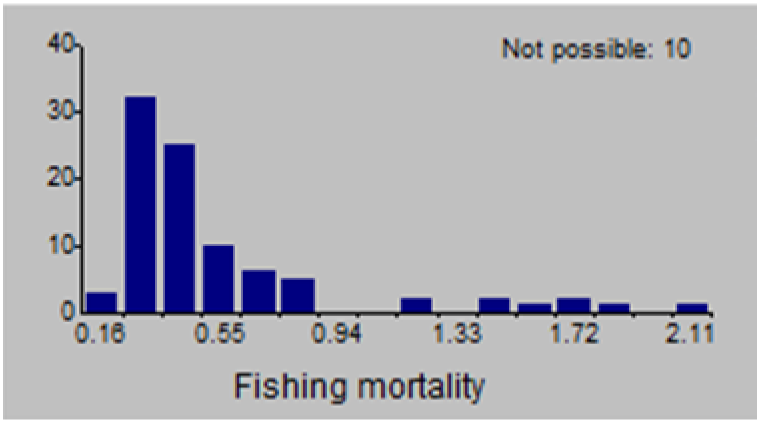


Figure 20. Frequency distribution of fishing mortality that maintains Spawning Stock Biomass at 20% of its unexploited value for sectors 9 and 10

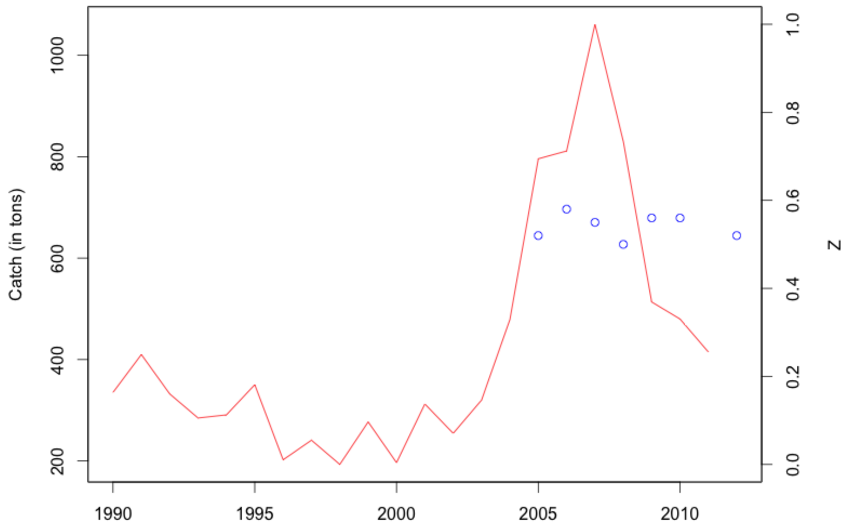
At both the Mahe plateau and the NW area level, $F_{current}$ is within the range of estimates of the limit reference point F_{SSB20}, suggesting that action will have to be considered to prevent future recruitments to be seriously affected (Table 9). Although the F/M ratio has decreased compared to previous years, it is still consistently close to twice the reference value, suggesting that fishing pressure has been too high. Moreover, there was an increase in the L_{c50}. Possible shifts in fishing pressure from the N-NW area of the Mahe plateau to other areas due to piracy activity from 2009 to 2011 might have alleviated pressure on the stock in that area.

Caution should be taken in interpreting the stock status considering that samples were only collected during the first quarter of the year. Finally, there are also concerns about the representativeness of the size-frequency data, and even the catch data.

Nevertheless, when considered in combination with the consistent declines in CPUE for all three fisheries, and the declines in the catches of past years, there are reasons for concern about the status of *L. sebae.*

One feature that raises concern about the quality of the size data available is the relatively stable distribution of the both the sizes and, therefore, ages in the catch, in spite of large fluctuations in the total catch. As we can see in Figure 21, the catch has increased during the late 2000's by a factor of 3, and then declined almost to the previous levels and, yet, there is virtually no change in the estimates of total mortality.

Figure 20. Catch of *L. sebae* in tons (red line) and estimates of total mortality (blue dots) from this study.



This stability in the total mortality (and ultimately in the fishing mortality, as natural mortality is assume constant) would indicate that the increase in the catch in the mid 2000's came from one or more very strong year classes. The patterns in catch-at-age are not inconsistent with this explanation. However, the uncertainty in the mapping from size to age means that high abundance in a size class will be perceived as coming from several year classes, even if it is originated in only one or two strong cohorts. This uncertainty is a string argument for conducting regular age readings as part of the monitoring.

But even if we assume that some increased recruitment took place in the late 1990's or early 2000's, it seems unlikely that this would explain the observed increases in the CPUE, especially for the whaler fishery. The possibility cannot be ruled out that fishermen, aware of the increased relative abundance, switched targeting during this period, followed by a period in which they returned to their normal practices. This rapid switching would result in drastic changes in catchability and, possibly, changes in selectivity.

In any case, the information that is available could be used, in principle, in a statistical catch-at-age analysis that would not require the assumption of equilibrium. This, together with a better estimation of size and age compositions in the catch, should improve future assessments.

Table 9. Summary results of the YPR for *Lutjanus sebae*. Estimates of F required to achieve maximum yield per recruit (F_{MSYPR}) and F to maintain spawning stock biomass at 20% of unexploited biomass (F_{SSB20}).

	All sectors	**SE (Sectors 5 and 6)**
F_{MSYPR}	0.9	1.5
F_{SSB20}	0.38-0.46	0.34-0.45
$F_{current}$ (CI)	0.34 (0.18-0.50)	0.34 (0.19-0.50)

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