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BY-CATCH AND DISCARDS OF THE EUROPEAN PURSE SEINE TUNA FISHERY IN THE INDIAN OCEAN. ESTIMATION AND CHARACTERISTICS FOR THE 2003-2007 PERIOD

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Abstract

By-catch and tuna discards estimation and characteristics for the various species groups are presented for the European purse seine tuna fishery (France and Spain) for the period 2003-2007. Data were collected through French and Spanish observer programs representing a total of 1,958 observed fishing sets. Total by-catch and tuna discards estimation were derived from a stratification based on fishing mode, seasons (quarters) and spatial area. The estimation relied on raising factors based on major commercial tuna catch expressed in tons per 1000 t of tuna landed. Total tuna discards and by-catch was estimated to be about 9,585 t corresponding to 35.5 t per 1000 t of tuna landed. Tuna discards represents 54 % (19.2 t/1000 t) of the total amount, followed by fishes (33.7 %, 12.0 t/1000 t), sharks (10.1, 3.6 t/1000 t), billfishes (1.5 %, 0.5 t/1000 t), and rays (0.7 %, 0.2 t/1000 t). By-catch species composition, main species length and sex structure, and percentage of utilization are also presented. Total by-catch estimates and ratios are compared with those previously published in the literature. The issue raised by the choice of a consistent extrapolation method is finally discussed.

Keywords : Tuna fishery, purse seine, by-catch, discards, Indian Ocean

1 INTRODUCTION

Incidental by-catch and associated discarding are difficult to estimate on the basis of log-book information because they are poorly reported by fishing masters and their importance varies according to several interrelated factors (Rochet and Trenkel 2005). The issues raised by by-catch and discarding are, however, of increasing concern because such practices are responsible for economic loss, juvenile mortality, ecological effects on key species which are relevant to the overall ecosystem structure and functioning, and added threat to endangered or high ethical value species (for example: Alverson et al. 1994, Pascoe 1997, Garcia et al. 2003, Kelleher 2004). In addition, catches of juvenile tunas that are discarded or sold on local fish markets are generally absent of official statistics whereas they should be included in the available statistics and in the catch-at-size database used as inputs of stock assessment models.

On the basis of data collected through observer programs of France and Spain, the objective of this paper is to present a preliminary estimate of total tuna discards and associated by-catch for the European tuna purse seine fishery including here only France and Spain. It also intends to give a full description of species composition, length and sex structure.

2 DATA AND METHODS

The following terminology is used in the paper: "tuna discards" are the major tunas species and small tunas that are discarded for commercial reasons. "By-catch" are the other associated species caught incidentally that may be discarded totally.

2.1 Data collection

Since 2001, the EU in support to its Common Fishery Policy established a mandatory sampling programme for the collection of data in the fisheries sector (PNDB) under the EU Data Collection Regulations (EC) No 1543/2000, 1639/2001 and 1581/2004. One of the objectives of the sampling programs set up in this framework is to estimate the discards of by catch species in EU fisheries. In particular, observer programs are promoted to estimate fisheries by-catch and discards. France and Spain, the major European acting countries in the tropical tuna purse seine fishery in the Atlantic and Indian Oceans, coordinate their scientific and technical effort in that purpose. IEO and AZTI for Spain and IRD for France developed a common framework for collecting, monitoring, analysing tuna fishery by-catch and discards, with an objective of 10% effort coverage in each ocean as recommended by ICCAT and IOTC[1]. The methodology used by the 3 research institutes relies on 5 data collection modules each one supported by specific forms:

- **Route and environment**. This form summarizes permanently during the all trip the fishing boat activity. It aims at collecting information on date, hour, wind and temperature conditions, location, observed systems and instruments used.
- **Fishing operation**. This form is filled up for each set (positive or null). It gathers information on the set characteristics (date, hour, location, time duration …) and the resulting catch (tuna species composition, estimated weight, weight categories and well number; associated species composition, estimated weight, mean length or weight, utilization …).
- **Tuna size distribution.** This form aims at recording tuna length with priority on discarded specimens.
- **Associated species biological and length characteristics**. This form aims at recording length and sex data on associated species.
- **Floating device**. This form aims at recording information on the type of device encountered, the operations conducted and the satellite transmitting buoys characteristics. Some observations about species potentially entangled in the fishing device can also be recorded through this form.

IEO, AZTI, and IRD use the same software to record observer data and a common database (Obstuna) is being currently developed to include historical observer program data on tropical purse seine fishery that have been conducted in the past. This approach allows developing both common procedures for data validation and common analyses such as the present one.

[1] According to an analysis carried out within the framework of the Inter-American Tropical Tuna Commission on a quasi exhaustive sampling during four years of the purse seine by-catches on floating objects of five groups of species (sharks, marlins, rays, dolphin fishes and other large fish), such a 10% sampling allows a precision going from 10 to 40% according to the group of species concerned (Lennert-Cody, 2001). Even if this estimate may be ocean-specific a 10% target value appears as a reasonable objective, at least in the lack of additional studies by species/groups.

The Spanish observer program started in 2003 and the French one in 2005 and preliminary results were presented at IOTC (Delgado et al., 2005; Pianet, 2006; Sarralde et al., 2006; Gonzalez et al., 2007). The data used here cover the whole period since the beginning of programs in 2003 until 2007 and reach a total of 1,958 observed sets (1,162 free school sets, 762 log-school sets, and 34 sets made on seamounts). Sets are categorized between log-school sets (FAD), free school sets (FSC) and seamounts sets (MsM) according to direct information given by observers. For seamounts sets an automatic allocation was also performed based on a 5 miles radius circle around known seamounts.

2.2 Analysis and extrapolation

There are many factors influencing discards and by-catch variability: oceans, ports, vessel carrying capacity, areas, seasons, fishing modes (for a general review of the variability of discards, see Rochet and Trenkel, 2005). However, in the case of the tuna purse seine fishery it has been shown that the major source of variability for by-catch is due to the fishing modes (Delgado de Molina et al, 2000; Romanov, 2002).

In this preliminary approach and in order to take into account the great variability of observations, a stratification of the data was used to estimate total tuna discards and by-catch for large species groups: sharks, rays, billfishes, and other finfishes. Strata were defined as a combination of a fishing mode (FSC, FAD or MsM), a quarter and an ET area (ET is related to the EC research program "Echantillonnage thonier"; Pallares and Hallier, 1997; Pianet et al., 2000). Note that ET areas are the units considered for the multispecies sampling scheme used for the correction of the species composition of the catches reported in logbooks by the purse seine fisheries in the Atlantic and in the Indian oceans and may not be suitable for this type of analysis.

In such a stratified design, a ratio estimator (i.e. raising factor) can be used to estimate total by-catch/discards independently in each stratum, then total by-catch/discards can be estimated by summing across strata. In this paper, discards and by-catch estimations are based mainly on raising factors calculated on tuna fishery production as a main attempt. In this method, we calculated for each stratum the mean ratio by dividing the total by-catch or discards by the total corresponding tuna landings for each species group. To account for uncertainty around the mean ratio, the within-stratum variance was estimated through a bootstrap method. The variance was calculated using the following resampling procedure:

1. 1,000 samples of size equal to the sample size, i.e. the number of fishing sets observed in the stratum through the observer program, were created;
2. for each sample, the total tuna landings, i.e. sum of tuna catches in the observer data and the total by-catch for each species group or tuna discard were estimated;
3. the ratio and the within strata variance were estimated based on the 1,000 bootstraped samples.

Finally, the total by-catch for each species group was calculated by multiplying the calculated ratio by the annual (estimated as an average over the 5 years period) total tuna landings of the European purse seine fishery (France and Spain).

At last, this stratified estimation based on production was compared with 3 others evaluations, respectively:

- a stratified estimation based on effort by sets: in that case, we calculated for each stratum the sum of observed by-catch or tuna discards divided by the number of observed sets (i.e. the mean discards and by-catch by set). Then, in each stratum the total by-catch for each species group was calculated by multiplying the estimated ratio by the annual (estimated as an average over the 5 years period) number of sets of the European purse seine fishery (France and Spain).
- a simple unstratified estimation based on total ratio of effort by sets.
- a simple unstratified estimation based on total ratio of production.

To study species composition of the by-catch, the total observed sets were used. The length and sex frequencies by species were estimated by summing up length measurements in each sample weighted by the number of individuals in each set.

3 RESULTS

3.1 Data coverage

The total sampling coverage has been significantly improved since the beginning of the observer programs, reaching at the end of 2007 an 8% coverage of all fishing sets, progressing to our 10% objective (Figure 1 and Table I). The coverage has also been improved relatively to the fishing mode. Log school sets were over-represented at the beginning of the programs and this may be related to the very low representation of the first year quarter in the sampling (Fig. 2), this period being a period when free school sets are predominating. This low sampling coverage in the first year quarter and hence of free school sets has been partly corrected but a level of under-sampling currently remains. The un-balanced character in sampling coverage illustrates the necessity to use a prudent stratification for total by-catch estimation.

The aggregation of data collected through Spanish and French observer programs greatly contributes to a good spatial coverage of the whole fishing area (Figures 3-4). This grouping relies on the assumption that the by-catch quantities and composition are not related to the purse seiners nationality and size (Spanish ones being larger than French ones). If this hypothesis, which has been checked with regards to the tunas (sizes and species composition, Pallares and Hallier, 1997) is assumed to be reliable for by-catches, it may probably be different with tuna discards rates for which French and Spanish skippers have different behaviour, with assumed larger rates for the former than for the later.

3.2 Total European by-catch and tuna discards, and by-catch estimation by large groups of species

According to the method based on tuna production, i.e. estimating the ratio between observed by-catch and observed tuna production, and using a mean annual production of 270,235 t for the 2003-2007 period, the European tuna purse seine fishery (France and Spain) annual by-catch and discards is estimated to be 9,585 tons corresponding to 35.5 t/1000 t of landed tunas (i.e. 3.4 % of the total catch = tuna production + tuna discards + by-catch) (Table II). Tuna discards represent the main part, i.e. 19.2 t/1000 t corresponding to 54% of the total (Figure 5); the other species representing 46% (16.3 t/1000 t) with fishes reaching 34% (12.0 t/1000 t) and sharks reaching 10.1% and a level of 3.6 t/1000 t.

Tuna discards and by-catch are higher on FAD sets than on free school sets, particularly for finfish (Figure 6). It is worth noting that estimation of tuna discards and finfish's by-catch is associated with large confidence intervals.

Tuna discards and by-catch were slightly lower during the first two quarters of the year - the second quarter being the lowest one - and grow sharply during the second semester mainly due to tuna discards (Figure 7). This pattern may be explained by the fact that, during the first part of the year, the fishery is mainly targeting free schools while FAD sets are predominating in the second part of the year (Table I).

The spatial distribution of tuna discards and by-catch by species group (Figure 8) indicates by order of importance the East Somalia, the NW Seychelles, the North Somalia and the SE Seychelles areas.

3.3 Tuna discards

According to the total estimation presented above, tuna discards reached a mean annual of 5,177 tons representing 54 % of the total by-catch and tuna discarded with a mean ratio of 19.2 t/1000 t of unloaded tuna (Table II).

Table III and Figure 9 show tuna discard species composition by fishing mode for the whole period considered, skipjack (*Katsuwonus pelamis*) and frigate or bullet tuna (*Auxis thazard, Auxis rochei*) being the predominant species whatever the fishing mode considered.

Figures 10, 11 and 12 present discards length distribution for both log and free schools sets for the major tuna species. Major tuna species like bigeye (*Thunnus obesus*), yellowfin (*Thunnus. albacares*) and skipjack (*Katsuwonus. pelamis*) are generally discarded when length is less than 40-45 cm fork length (FL) - corresponding to a 1.5 kg individual weight - while minor tuna species like *Auxis sp.* and *Euthynnnus* sp. are discarded at all lengths.

3.4 Billfishes

A total of 406 billfishes (41 t) were caught over the whole period covered by the French and Spanish observer programs. According to the above estimate, the mean annual billfish's by-catch amounted a total of 148 t, which is 1.5 % of the total by-catch and tuna discards with a mean ratio of 0.5 t/1000 t of unloaded tuna (Table II).

Six main species are encountered: *Makaira indica*, the black marlin, *Tetrapturus audax*, the stripped marlin, *Makaira nigricans*[2], the blue marlin, *Istiophorus platypterus*, the indo pacific sailfish, *Xiphias gladius,* the swordfish and *Tetrapturus angustirostris*, the shortbill spearfish. Species composition in number and in weight is indicated in Table IV and Figure 13. Species composition is dominated by the black marlin, as the main species followed by the stripped marlin. Except for the indo pacific sailfish, which is more frequently associated with free schools, all the other billfish species are more frequent on FAD-associated sets.

As indicated from the samples (all fishes were measured), length structure of billfishes in tuna purse seine by-catch varies from 64 to 420 cm (in fork length, all species included) with a major mode between 210 and 225 cm (Figure 14). Billfish length structure seemed to strongly differ between log and free school sets but statistical tests were not performed in the present analysis.

Billfish catches are in 85% of cases either valorised (20%) or discarded dead (65 %). Exceptionally, in 7% of the cases, they are discarded alive (Figure 15).

3.5 Sharks and Rays

3.5.1 Sharks (excepting whale sharks)

A total of 6,704 sharks (169 t) were caught over the whole period. According to the above estimates, the mean annual sharks (excepting whale sharks) by-catch reached a total of 964 t which is 10.1% of the total by-catch and tuna discards with a mean ratio of 3.6 t/1000 t of unloaded tuna (Table II).

The main family encountered was Carcharinids which represented 97% of identified sharks in numbers and 93% in weight, with two species (*Carcharhinus falciformis*, the silky shark and *Carcharhinus longimanus*, the oceanic whitetip shark) largely dominating this group, representing 94% of the individuals caught and 90% of total weight. Some other species are also encountered but very occasionally like: *Carcharhinus obscurus*, *Galeocerdo cuvieri*, *Isurus oxyrinchus*, *Megachasma pelagios*, *Prionace glauca* and *Sphyrna lewini.*

Considering the 2 main species, the length frequencies indicates that the majority of silky sharks with more than 5,000 individuals measured and sexed were caught at a length between 60 and 160 cm total length with a mode around 100 cm and some infrequent large specimens around 200 and 250 cm (Figures 16-17). Sex ratio was balanced. For oceanic whitetip shark with more than 600 individuals measured and sexed, length distribution was similar with a main range from 65 to 165 cm and a mode around 100 cm. Some large specimens reaching 300 cm were also encountered. Sex ratio was balanced.

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[2] Considered here as a synonym of *Makaira mazara*

3.5.2 Rays

A total of 173 rays (15 t) were caught over the whole period. According to the above estimate, rays are the last component of species group with a mean annual by-catch reaching a 65 t which is 0.7 % of the total by-catch and tuna discards and corresponds to a mean ratio of 0.2 t/1000 t of unloaded tuna (Table II).

The main species encountered and identified at the level of species are: *Dasyatis violacea*, the pelagic stingray, *Manta birostris*, the giant manta, *Mobula coilloti*, the Chilean devil ray, *Mobula mobular*, the devil fish, and *Mobula rancurelli*, the spine tail mobula.

Due to large variation in size and weight between species, specific composition differs greatly between estimates in number and weight (Figure 18). *Dasyatidae* being the species group the most frequent in number (53 individuals). Rays are caught on log and free school sets, with no clear dominance of any fishing mode.

Rays are seldom valorised: globally most individuals observed were discarded and 33 % were discarded alive (Figure 19).

3.6 Finfishes

A total of 569,550 fishes (731 t) were caught over the whole period. According to the above estimates, fishes are the second component of species group in by-catch after tuna discards reaching a total of 3,231 t which is 33.7 % of the total by-catch and tuna discards with a mean ratio of 12.0 t/1000 t of unloaded tuna (Table II).

The species list as reported by observers identified 55 species categories (Appendix 1). In fact, very few species or higher taxonomic groups dominate the by-catch in terms of numbers as well as weight (Figure 20). In both cases, the 7 following categories represent around 99 % of the total finfish by-catch:

- Triggerfish (*Canthidermis maculatus*, *Aluterus monoceros*, *Abalistes stellatus*, Balistidae)
- Rainbow runner (*Elagatis bipinnulata*)
- Dolphinfishes (*Coryphaena hippurus*, *C. equiselis*, Coryphaenidae)
- Mackerel scad (*Decapterus macarellus*)
- Carangids (*Carangoides orthogrammus*, *Caranx sexfasciatus*, *Caranx crysos*, *Uraspis helvola*, *Uraspis uraspis*, *Uraspis secunda*, *Uraspis sp.*, *Naucrates ductor*, *Decapterus sp.*, *Seriola rivoliana*, Carangidae)
- Wahoo (*Acanthocybium solandri*)
- Barracuda (*Sphyraena barracuda*, *Sphyraenidae*)

Fishes are mainly caught during Fad-associated sets: 93 % in terms of individuals and of weight. Fishes are in general discarded dead for more than 90% of the numbers and 80% of weight. Wahoo, common dolphinfishes, baraccudas and carangids were the most valorised categories generally for cooking onboard (Figure 21).

3.7 Turtles

Observations of turtles were occasional and almost exclusively made on log school sets (95%). Over the whole period of observations a total of 74 individuals were caught for an estimated weight of 1.8 t. These observations were mainly reported during the second part of the year when the fishery is actively fishing on FADs.

Turtles species composition was dominated by 3 species: *Lepidochelis olivacea,* the olive ridley turtle; *Chelonia mydas,* the green turtle and *Eretmochelys imbricata*, the hawksbill turtle (Figure 22). According to the observations, *L. olivacea* seems the most impacted by the fishery and most of the by-catches occurred in the north of the west Indian Ocean (up to the equator). *C. mydas* and *E. imbricata* that showed the lower by-catch rates were predominant in the north of Mozambic Channel (Figure 23). Near 90 % of the turtles caught were discarded alive (Figure 24).

As indicated in Figure 25 almost all the individuals caught are juveniles (size at maturity, Sm: *L. olivacea,* probably between 50 and 70 cm Curved Carapace Length; *C. mydas,*> 70 cm CCL; *E. imbricata*, > 60 cm CCL). *C. mydas* and *E. imbricata* are coastal species. However, juveniles of these two species are frequently encountered in the pelagic habitat in their early years of life before reaching coastal habitat at an average size of 30–50 cm CCL. No capture of adults was recorded for these two species and this is not surprising as adults in open sea phase are in nesting or post nesting migrations and do not use to stop and rest on natural or artificial drifting devices (J. Bourjea com. pers.).

Due to the low level of observation, no formal attempt was made to extrapolate by-catch for this species group at the fishery level but, as an order of magnitude, it can be roughly estimated that over the sampling period (2003-2007) less than 300 sea turtles were killed while operating purse seine, which is less than 60 individuals per year. However, it should be underlined that this raw assessment does not take into account the hidden and non estimated mortality due to entangling of turtles while resting on FADs.

4 DISCUSSION

This study based on about 2,000 observed fishing sets gives a good picture of the current (2003-2007) profile of tuna discards and associated species by-catch in the European purse seine fishery. Moreover, the description and specific composition of this fishery by-catch and discards can be described extensively based on those observations. It shows and confirms the well known fact that fishing on FADs is the main source of by-catch (Fonteneau et al. 2000) which is dominated by fishes and sharks. Romanov (2002) studied the by-catch composition and quantities from some 500 fishing sets collected by scientific observers aboard Soviet purse seiners in the western Indian Ocean (WIO) during 1986-1992. This author's description of by-catch in terms of species composition in the different taxonomic groups and their relative catch rates among fishing modes is quite similar with our results.

Based on 180 fishing sets observed during 2005-2007, Chassot et al (2008) have recently shown that tuna discards of the French purse seine fishery of the Atlantic Ocean were higher than in the present analysis, with a general discard to landing ratio of 41.3 t/1000 t compared to 19.2 t/1000 t in the Indian Ocean. In the Atlantic Ocean, tuna discards were almost exclusively observed on FAD-associated schools and dominated by skipjack and frigate tunas while the other associated species represented a minor part of discards. Such differences might be due to factors such as the only inclusion of French purse seiners and lower sample size in the discard analysis for the Atlantic Ocean but could also be explained by differences in the underlying ecosystems and the importance of local West African markets such as Abidjan, where associated species can be sold for local consumption instead of being discarded at sea (Romagny et al., 2000). Regarding the similarity between the purse seine fishing fleets, further analysis comparing tuna discards and by-catch between the 2 oceans would provide useful insights to better understand the factors involved in such practices and eventually assess the ecosystem effects of purse seine fishing.

Romanov (2002) also attempted to estimate the total tuna purse seine fishery by-catch in the Indian Ocean using ratios on tuna production and fishing effort. His estimations reached a level of 27.17 t/1000 t of by-catch without considering tuna discards. Our corresponding estimate (16.3 t/1000 t, excluding tuna discards) is largely lower, from almost a half. Such differences could stem from the methods used to assess levels of by-catch, differences between the Soviet and European tuna purse seine tuna fisheries or changes in associated fauna abundance and composition through time (more than ten years between the two studies).

Relatively to methodology, the results of different alternate methods to extrapolate tuna discards and by-catch are presented on Figure 26. Estimations are fairly similar, the lowest one being the stratified estimation based on sets which results are detailed in Table V. The two estimates based on raw raising factors, either on tuna production or on total sets without considering any stratification, give similar results, higher when not stratified. This may be explained by the fact that the observed number of sets being important we have a good and linear relationship between the tuna landings and the number of sets (Figure 27). An estimate based on tuna production ratios is then similar than an estimate based on a by set ratio. However these direct extrapolations do not take into account the well known differences between fishing modes for example. Stratification is supposed to improve the estimate and also unable us to calculate confidence intervals. However stratification should respect a number of criteria of homogeneity within strata and criteria of heterogeneity between strata which condition the liability of estimates. Most of the extrapolations are driven by few observations because for most of the species groups the probability of presence in the catch is low. In other words, the uncommon presence of the by-catch in the observations made difficult to get an accurate figure of total by-catch per species group. Nevertheless, a minimum number of observations by stratum should be defined that insure an independence of raising factors with the number of observations for being able to use it for extrapolation to total catch (Sánchez et al., 2007).

Because information available to raise the by-catch/discards estimates to the fleet level is commonly the yearly landings, many studies estimate "discard rates" (i.e., the ratios of discards to landings or to total catch). This ratio may however be unrelated to the amount caught. Rochet and Trenkel (2005), focusing on discard studies in demersal fisheries, recognized the interest of using total production or total effort as dimension to extrapolate by-catch and discards. Nevertheless, they stated that there are many examples where the underlying assumption of proportionality is not fulfilled. This seems to be the case for the purse seine tuna fishery as can be seen on Figure 28 which indicates the relative weakness of the relationship between tuna discards or by-catch with tuna landings or number of sets at the stratum level.

Future analyses should account for more detailed fishing modes. For instance, it was evidenced that large pelagic species can be concentrated on seamounts (e.g., hammerhead sharks; Klimley et al., 1988). This aspect led Gaertner et al. (2002) to distinguish between sets made on seamounts from the usual tuna fishing modes (i.e. free school sets and FAD sets) in their assessment of incidental catches of billfishes by the EC purse seine fishery in the Atlantic Ocean. Similarly, Stretta et al (1998) and Romanov (2002) in his analysis of by-catches on the Soviet purse seiners operating in the western Indian Ocean showed differences in species composition and in the amount of by-catch between whale-associated schools and free-swimming schools. Lastly, it appears also that some by-catch (mainly billfishes and sharks) can occasionally be realised on negative sets and then not be taken into account using production based discard ratio; the magnitude of this catch should also be investigated in future work.

5 CONCLUSION

Observer programs conducted by Spain and France within the European Data Collection regulation provided reliable information on by-catch and discards. Coordination between programs, as is currently occurring between French and Spanish scientific teams, allows gathering data and achieving good levels of observations. However, when quantitative estimates have to be performed on these relatively low levels of by-catch and discards, methods to be used should be carefully examined and compared.

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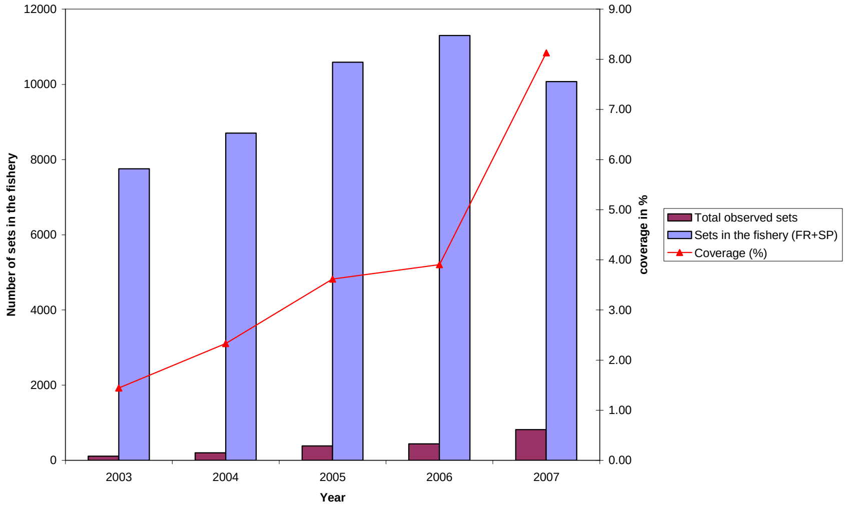


Figure 1: Number of observed sets in the Spanish and French observer program by year and percent coverage of the total fishing effort

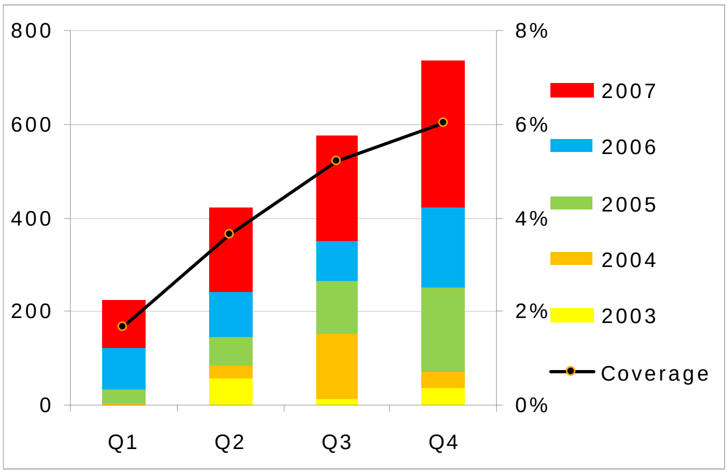


Figure 2: Number of observed sets by quarters and associated percent coverage

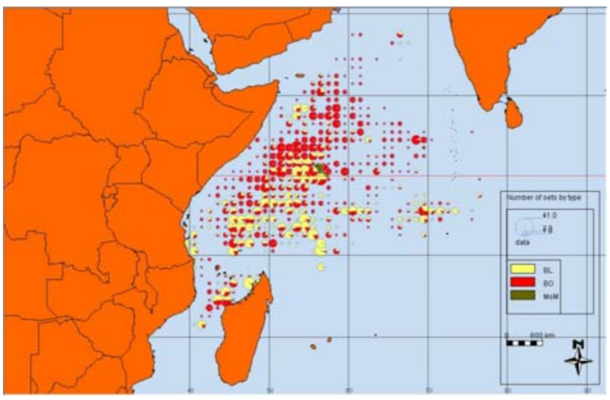


Figure 3: Number of observed sets by fishing mode .BL = free school; BO = FAD-associated school; MsM = Seamount.

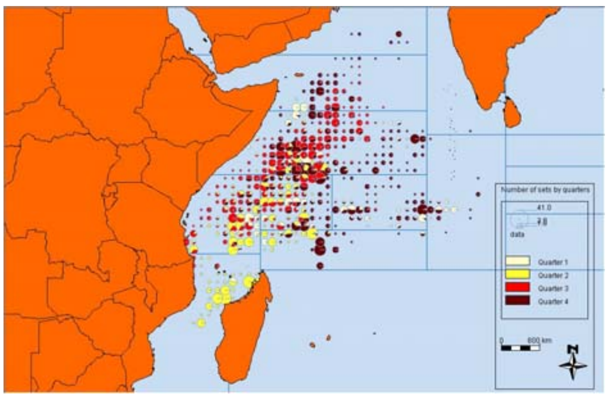


Figure 4: Number of observed sets by quarter and by ET area

Table I: Number of observed sets in the Spanish and French observer program by year and associated percent coverage of the total number of sets by fishing mode. BM = free school; BO = FAD-associated school; MsM = Seamount-associated school

Year	Fishing mode	Observed sets/quarter 1	2	3	4	Total observed sets	Sets in the fishery (FR+SP)	Coverage (%)
	BL		37	1	5	43	4116	1.04
2003	BO		15	14	34	63	3550	1.77
	MsM		6			6	89	6.74
	Tot		**58**	**15**	**39**	**112**	**7755**	**1.44**
	BL	4		28		32	5156	0.62
2004	BO	1	28	101	31	161	3463	4.65
	MsM			9	1	10	86	11.63
	tot	**5**	**28**	**138**	**32**	**203**	**8705**	**2.33**
	BL		13	65	65	143	6005	2.38
2005	BO	29	49	44	114	236	4498	5.25
	MsM			2	2	4	85	4.71
	Tot	**29**	**62**	**111**	**181**	**383**	**10588**	**3.62**
	BL	79	42	9	12	142	5825	2.44
2006	BO	10	53	79	151	293	5326	5.50
	MsM				6	6	146	4.11
	Tot	**89**	**95**	**88**	**169**	**441**	**11297**	**3.90**
	BL	59	126	86	131	402	4856	8.28
2007	BO	42	52	130	185	409	5136	7.96
	MsM		1	7		8	84	9.52
	Tot	**101**	**179**	**223**	**316**	**819**	**10076**	**8.13**
	BL	142	218	189	213	762	25958	2.94
2003-2007	BO	82	197	368	515	1162	21973	5.29
	MsM	0	7	18	9	34	490	6.94
	Tot	**224**	**422**	**575**	**737**	**1958**	**48421**	**4.04**
Sets in the fishery (FR+SP)	BL	9119	7631	3718	5490	25958		
	BO	4233	3870	7255	6615	21973		
	MsM	133	110	92	155	490		
	Tot	**13485**	**11611**	**11065**	**12260**	**48421**		
Coverage %		**1.66**	**3.63**	**5.20**	**6.01**	**4.04**		
%BO		**31.39**	**33.33**	**65.57**	**53.96**	**45.38**		

Table II: Tuna discards and by-catch estimations (raising factor based on tuna production) by species group in terms of tons, percentage and tuna production ratios

	FAD			FSC			MsM			Total		
Species group	**tons**	**%**	**t/1000 t**	**tons**	**%**	**t/1000 t**	**tons**	**%**	**t/1000 t**	**tons**	**%**	**t/1000 t**
Tuna discards	4114	49.8	26.5	1026	79.7	9.3	37	83.6	7.4	5177	54.0	19.2
Fishes	3063	37.1	19.7	167	13.0	1.5	1	2.4	0.2	3231	33.7	12.0
Sharks	932	11.3	6.0	32	2.5	0.3	1	1.2	0.1	964	10.1	3.6
Billfishes	106	1.3	0.7	40	3.1	0.4	2	4.1	0.4	148	1.5	0.5
Rays	39	0.5	0.2	22	1.7	0.2	4	8.8	0.8	65	0.7	0.2
Total (t)	**8253**	**100.0**	**53.1**	**1288**	**100.0**	**11.7**	**44**	**100.0**	**8.9**	**9585**	**100.0**	**35.5**
Total fishery (t)	**155494**			**109781**			**4960**			**270235**		

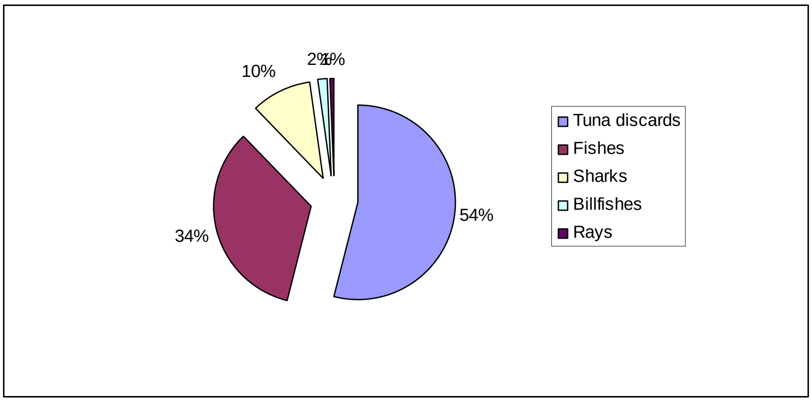


Figure 5: Percentage of tuna discards and other by-catch species groups in the total estimate (raising factor based on tuna production) for European tuna purse seine fishery (France and Spain)

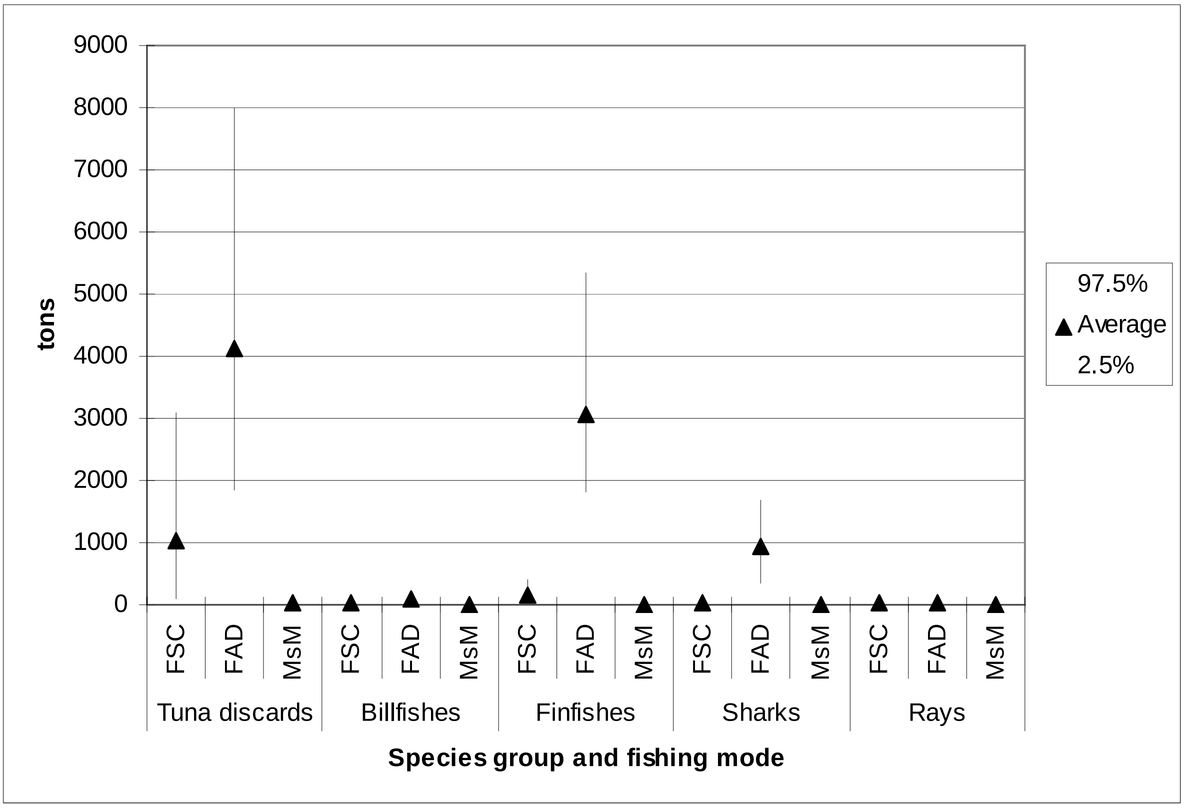


Figure 6: Estimations of tuna discards and by-catch (raising factor based on tuna production) with indication of 95 % confidence intervals by species group and fishing mode

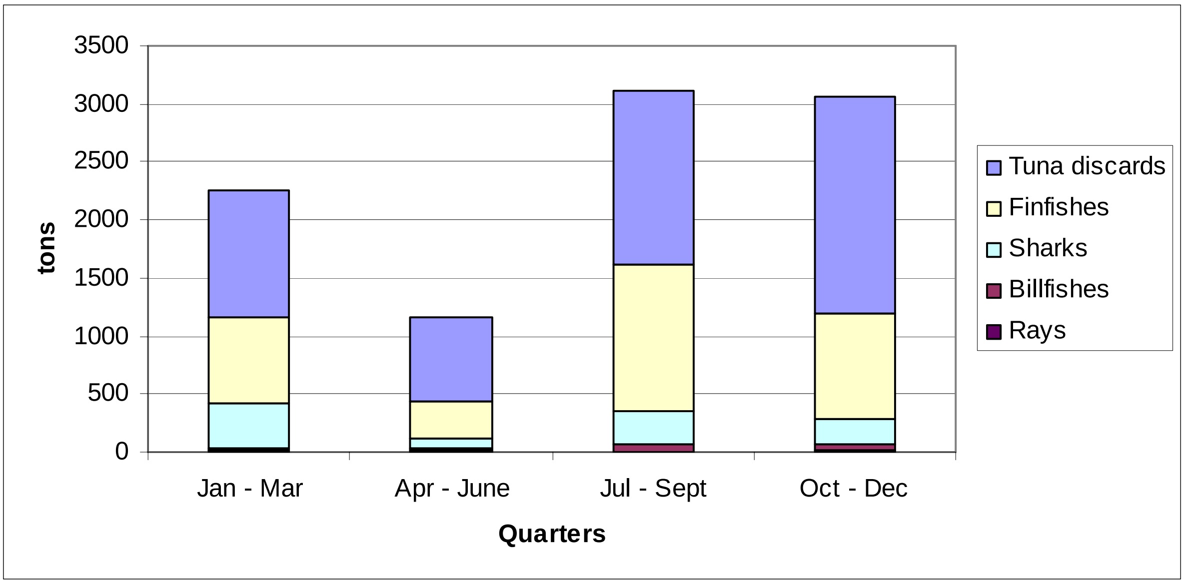


Figure 7: Tuna discards and by-catch estimations (raising factor based on tuna production) by quarters for the European purse seine fishery (France and Spain)

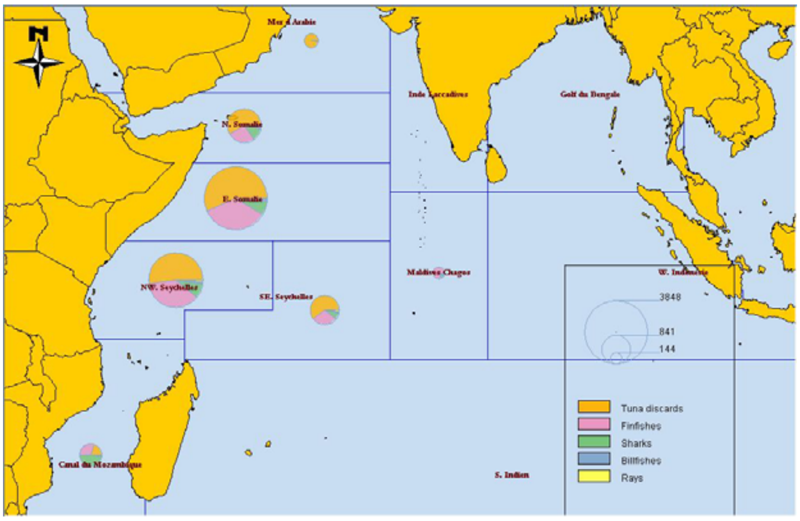


Figure 8: Tuna discards and by-catch estimation (raising factor based on tuna production) for the European purse seine fishery by ET area (see text).

Table III: Tuna discards composition (in %) by fishing mode for the all periods considered. FAD = FAD-associated school; FSC = free school; MsM = Seamount-associated school; Unk = Unknown.

2003 – 2007			
	FAD	FSC	MsM
ALB	0.00	0.09	0.09
BET	1.73	3.95	2.59
BLT	8.19	36.60	11.55
FRI	18.91	16.80	42.47
FRZ	5.24	0.55	0.91
KAW	1.02	8.89	0.88
SKJ	52.94	25.75	36.98
YFT	10.82	7.38	4.45
Unk.	1.15	0.00	0.06

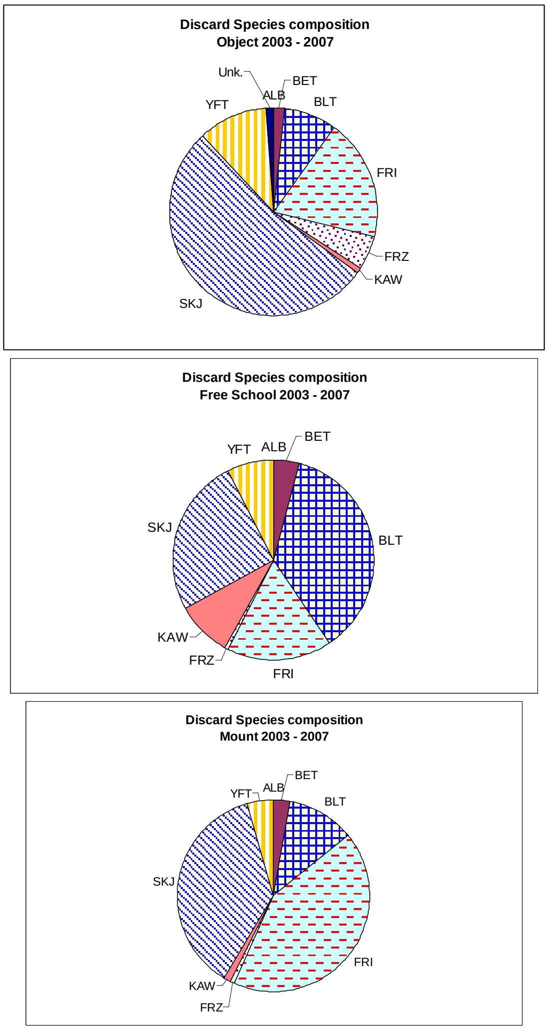
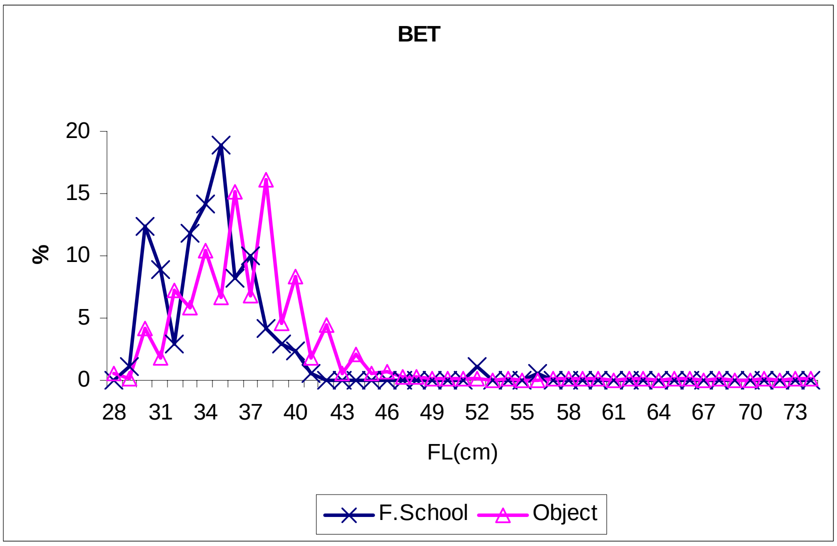
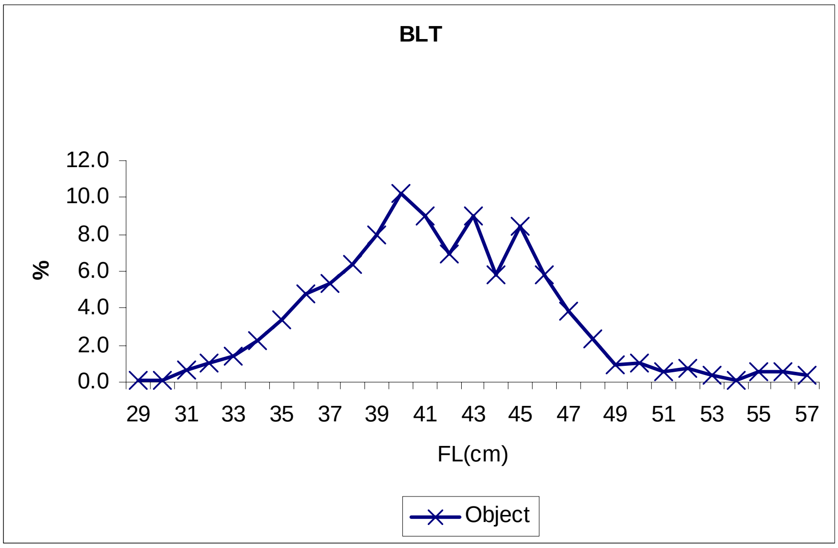


Figure 9: Species composition of tuna discard for 3 fishing modes (FAD-associated, free school and seamount)





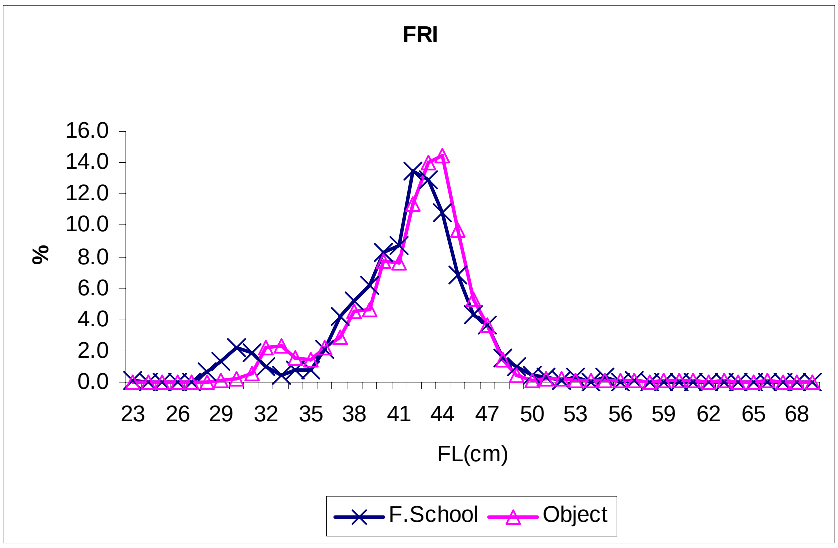


Figure 10: Bigeye (*Thunnus obesus; BET*), bullet tuna (*Auxis rochei; BLT*) and frigate tuna (*Auxis thazard; FRI*) discard length distribution on log and free school sets.

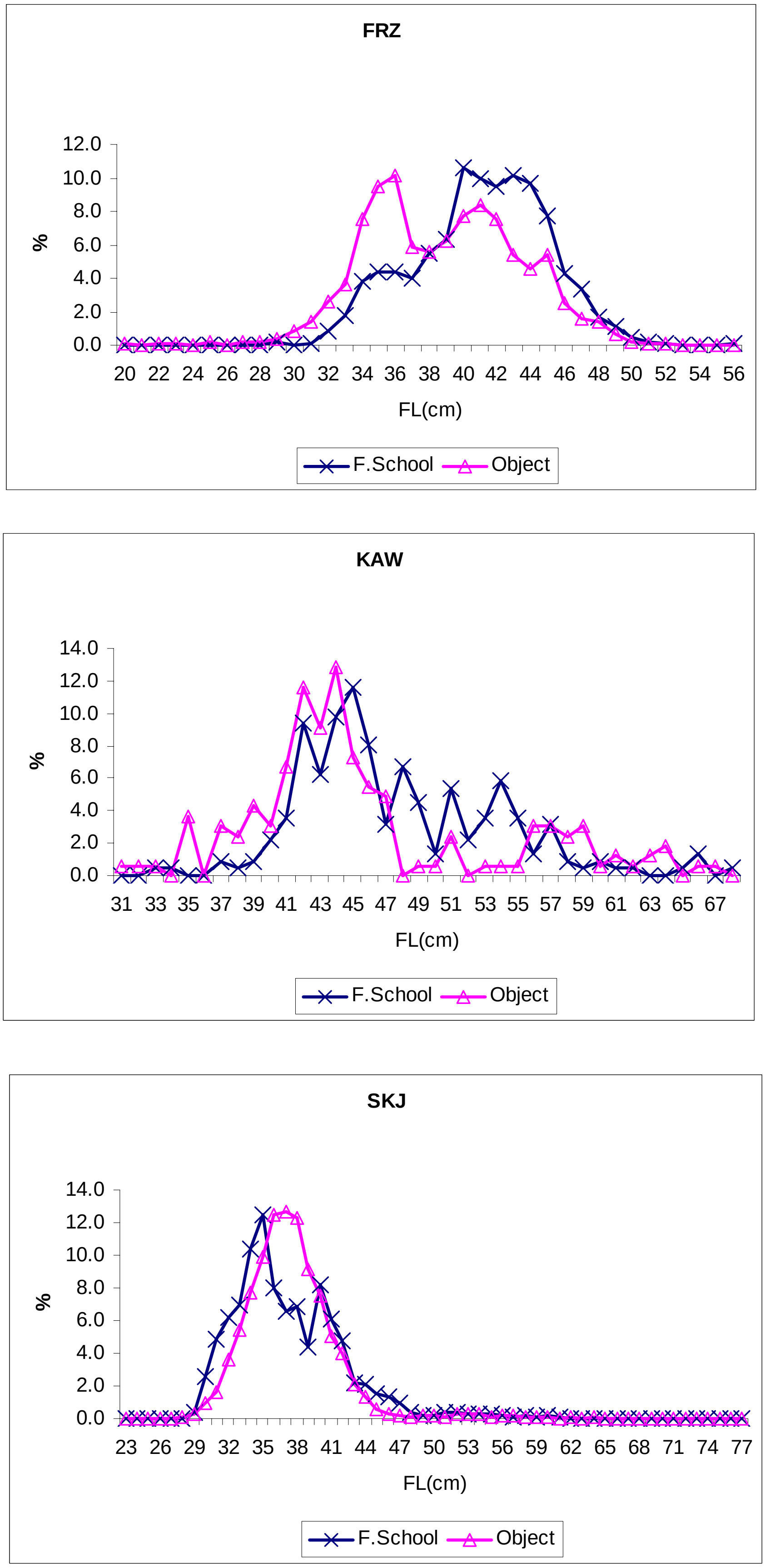


Figure 11: Auxis (*Auxis sp.; FRZ*), kawakawa (*Euthynnus affinis; KAW*) and skipjack (*Katsuwonus pelamis; SKJ*) discard length distribution on log and free school sets.

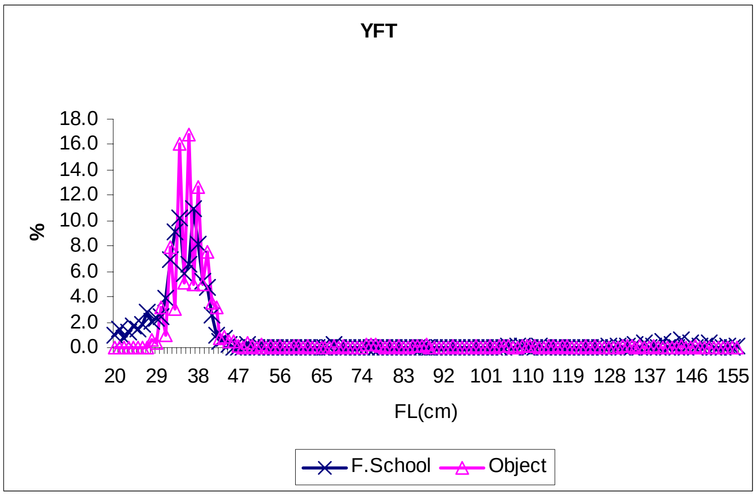


Figure 12: Yellowfin (*Thunnus albacares)* discard length distribution on logs and free school sets

Table IV: Frequency of occurrence of billfish by-catch by fishing mode. BL = free school; BO = FAD-associated school; MsM = Seamount

Type of sets	BL		BO		Msm		Total	
Name	Nb	% BL	Nb	% BO	Nb	% Msm	Nb	% Total
Makaira indica	23	3.0	59	5.1		0.0	82	4.2
Famille des Istiophoridés	8	1.0	55	4.7		0.0	63	3.2
Tetrapturus audax	13	1.7	39	3.4		0.0	52	2.7
Istiophorus platypterus	17	2.2	18	1.5	1	2.9	36	1.8
Makaira nigricans	7	0.9	29	2.5		0.0	36	1.8
Xiphias gladius	1	0.1	5	0.4	1	2.9	7	0.4
Tetrapturus angustirostris	2	0.3	3	0.3		0.0	5	0.3
Total	71	9.3	208	17.9	2	5.9	281	14.4
Number of sets	762		1162		34		1958	

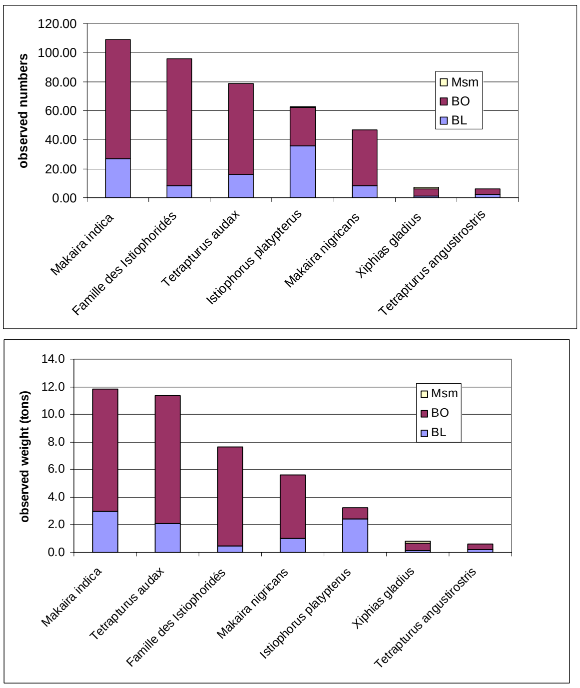


Figure 13: Billfishes species composition by type of sets in number and in weight, respectively

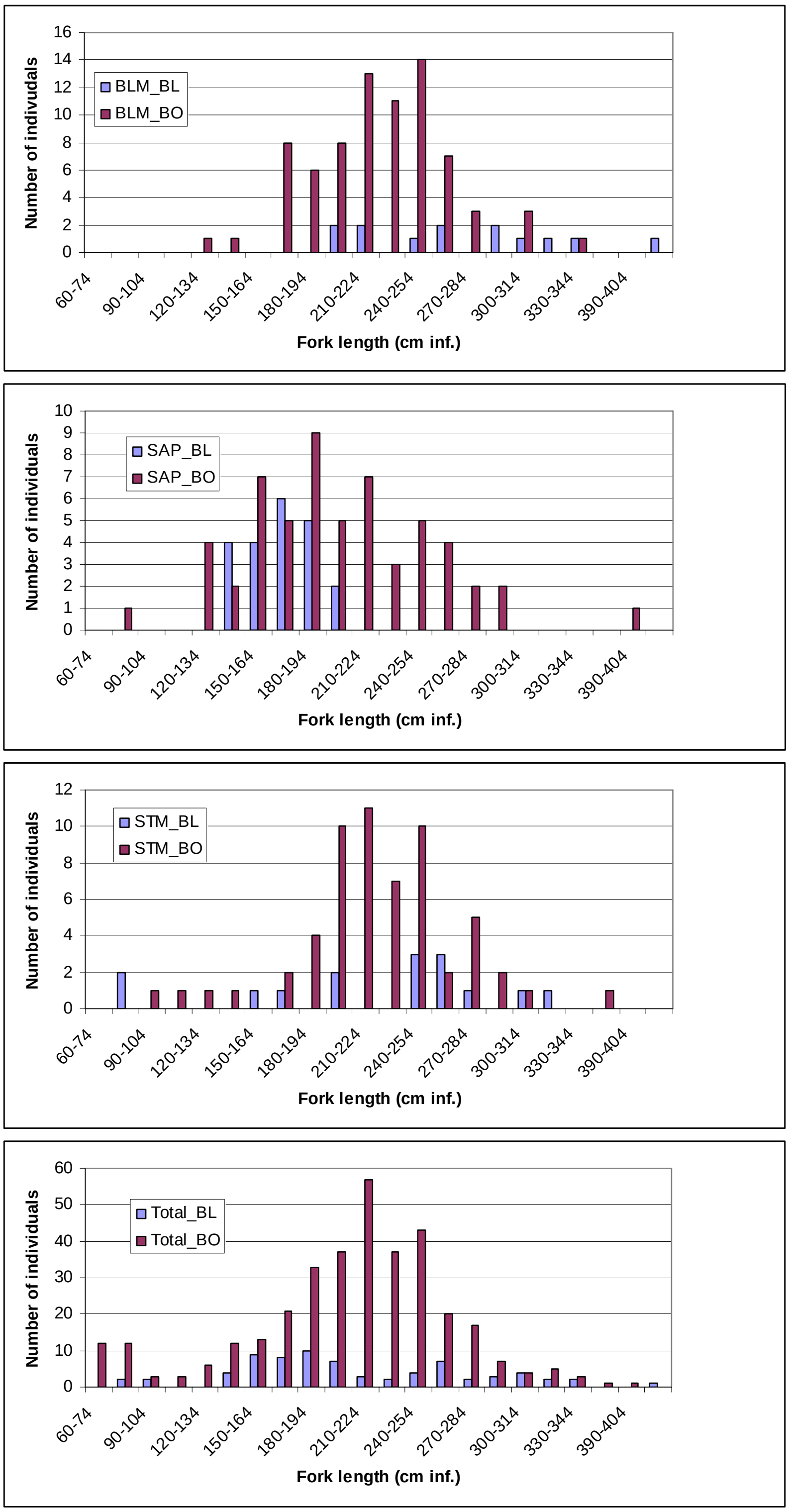


Figure 14: Length frequency of billfishes according to fishing mode for *Makaira indica* (BLM), *Istiophorus platypterus* (SAP), *Tetrapturus audax* (STM) and for all species of billfish

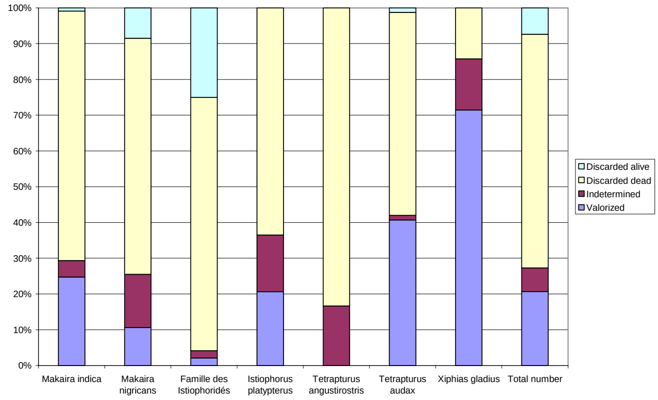


Figure 15: Frequency of utilization of billfishes by-catch (numbers)

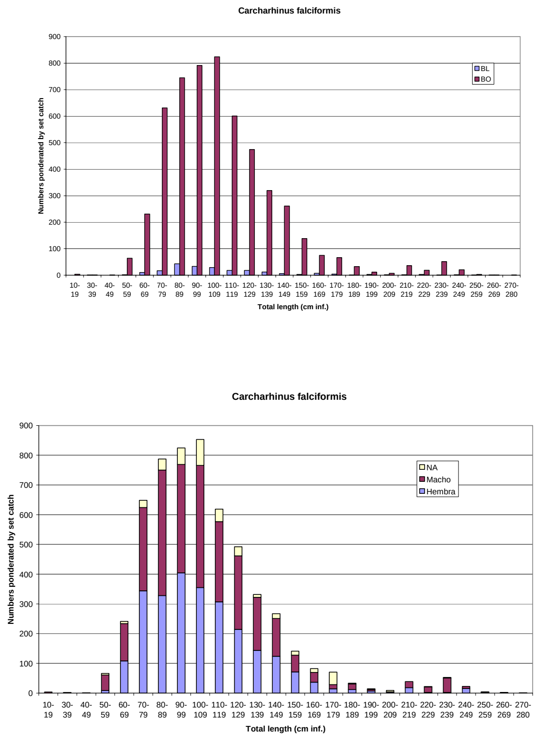


Figure 16: Length frequency and sex of *Carcharhinus falciformis* (numbers are weighted by set catch)

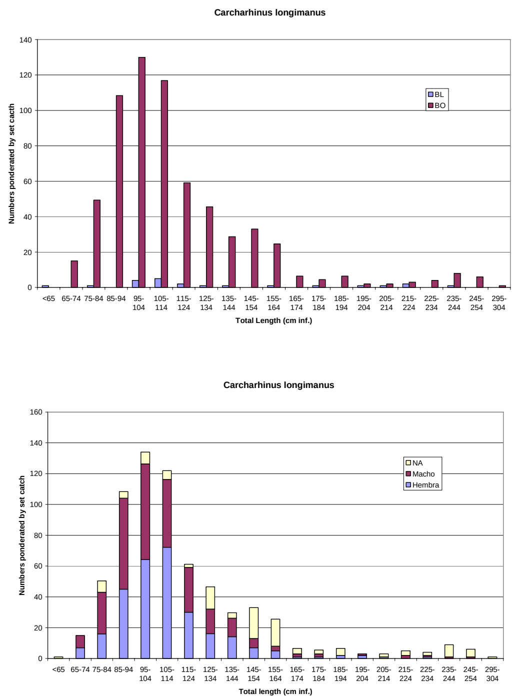


Figure 17: Length frequency and sex of *Carcharhinus longimanus* (numbers are weighted by set catch)

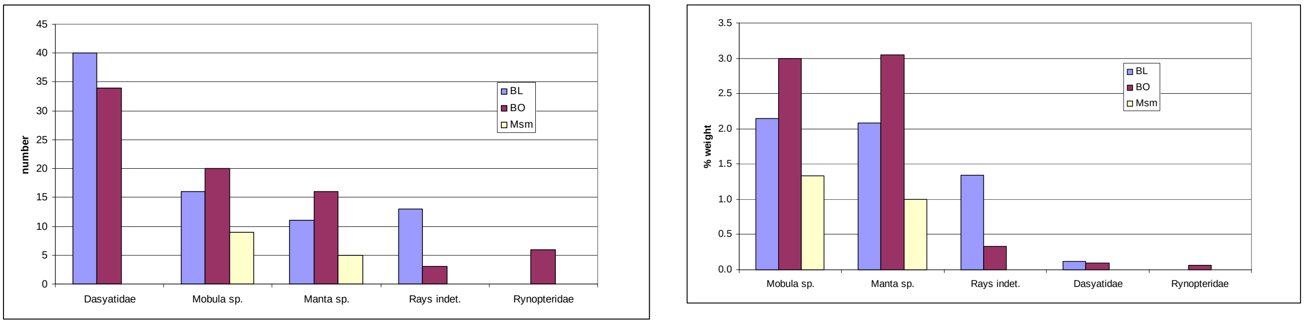


Figure 18: Species composition of rays by fishing mode for number and weight, respectively

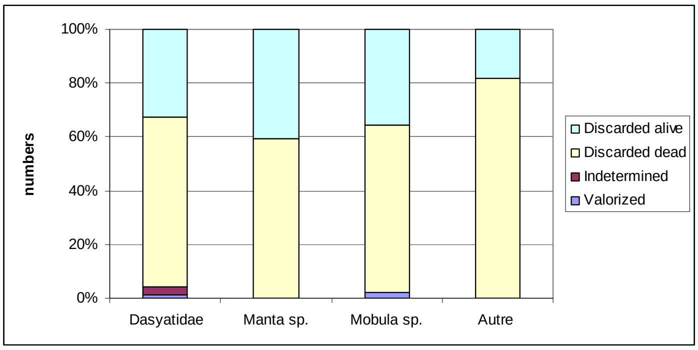


Figure 19: Utilization of rays

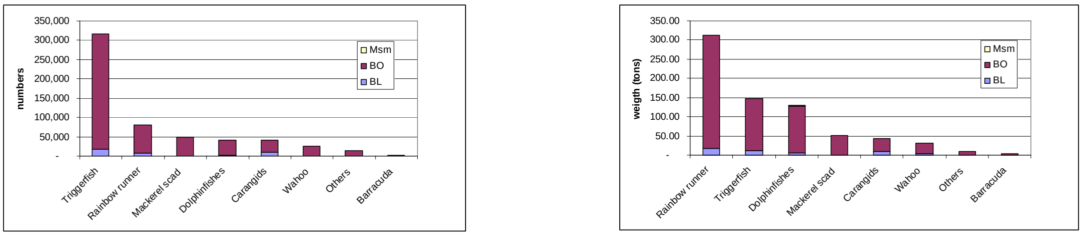


Figure 20: Species composition of fishes by fishing mode in number and weight, respectively

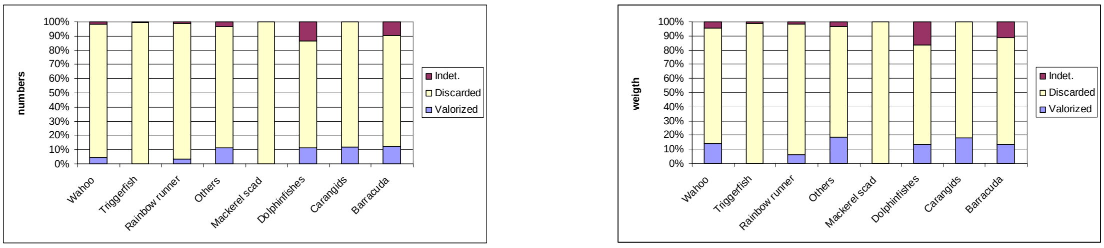


Figure 21: Percentage of utilization of fishes expressed in number and weight

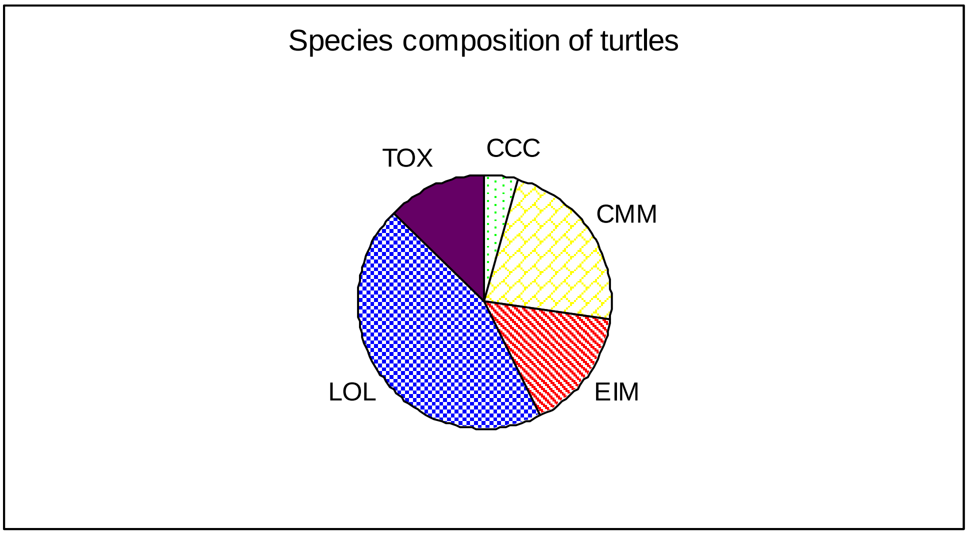


Figure 22: Species composition of the turtles in the sets observed (CMM = *Chelonia mydas*; CCC = *Caretta caretta*; EIM = *Eretmochelys imbricata*; LOL = *Lepidochelis olivacea;* TOX = not identified

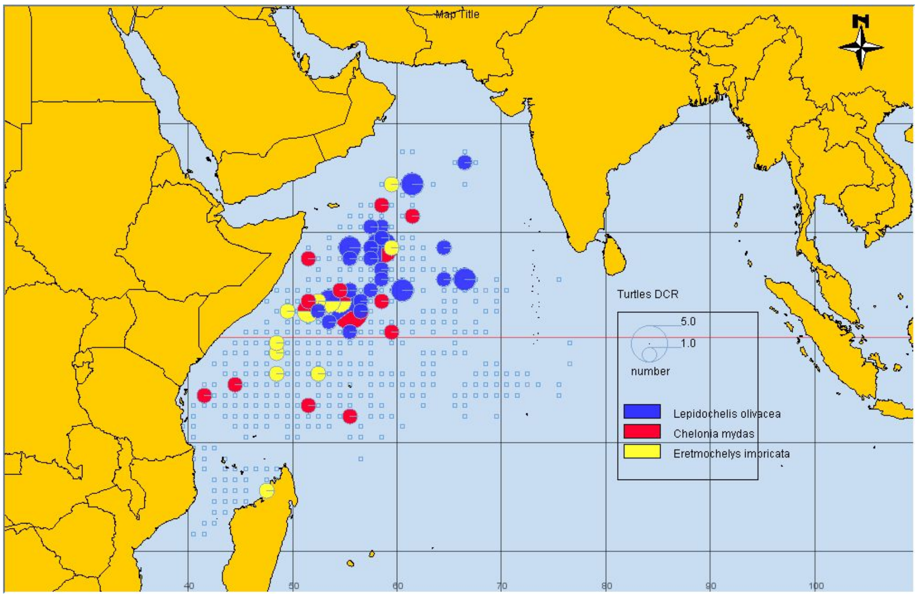


Figure 23: Distribution and species of turtles caught during the whole sampling 2005-2007

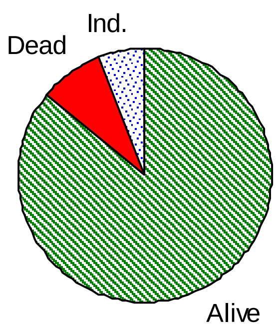


Figure 24: Turtles after capture (Ind : not known)

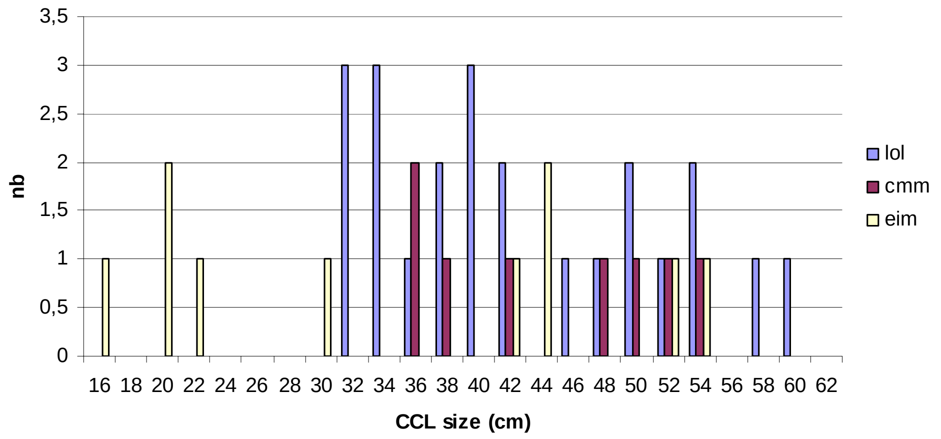


Figure 25 : Size distribution of the different species of turtles caught during the whole sampling period 2005-2007(CMM = *Chelonia mydas*; EIM = *Eretmochelys imbricata*; LOL = *Lepidochelis olivacea)*

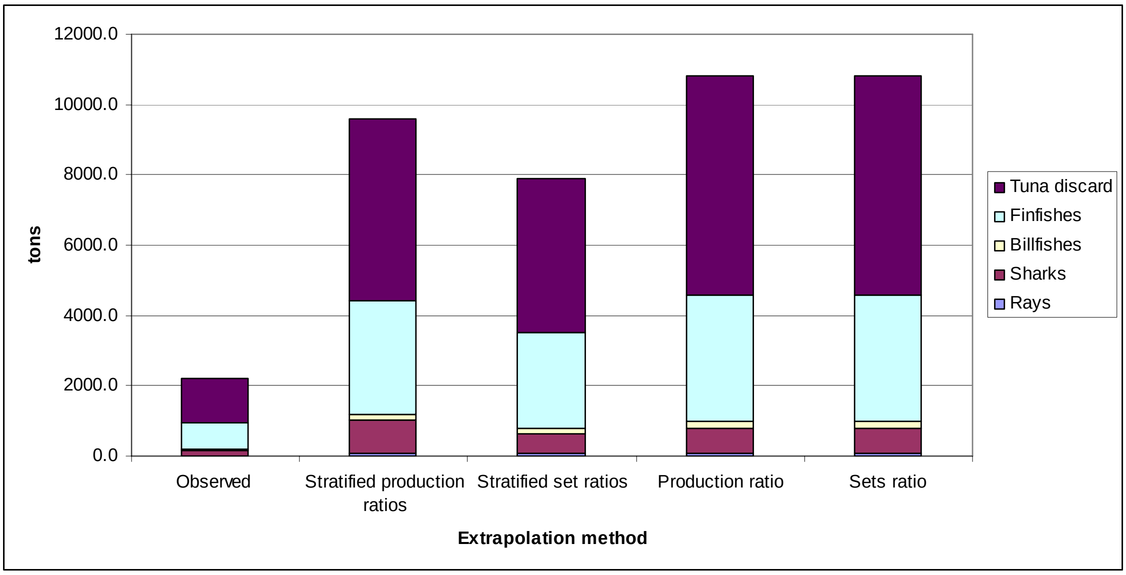


Figure 26 : Tuna discards and by-catch estimations according to alternate extrapolation methods

Table V: Tuna discards and by-catch estimations (raising factor based on stratified effort by sets) by species group in terms of tons, percentage and tons by set

	FAD			FSC			MsM			Total		
Species group	**tons**	**%**	**t/set**	**tons**	**%**	**t/set**	**tons**	**%**	**t/set**	**tons**	**%**	**t/set**
Tuna discards	3336	51.1	0.8	972	74.4	0.2	70	89.9	0.7	4378	55.4	0.5
Fishes	2531	38.8	0.6	211	16.1	0.0	1	1.3	0.0	2743	34.7	0.3
Sharks	534	8.2	0.1	34	2.6	0.0	0	0.4	0.0	568	7.2	0.1
Billfishes	100	1.5	0.0	57	4.4	0.0	0	0.6	0.0	157	2.0	0.0
Rays	22	0.3	0.0	33	2.6	0.0	6	7.8	0.1	62	0.8	0.0
Total (t)	**6523**	**100**	**1.5**	**1307**	**100**	**0.3**	**78**	**100**	**0.8**	**7908**	**100**	**0.8**
Total fishery (sets)	**4395**			**5192**			**98**			**9684**		

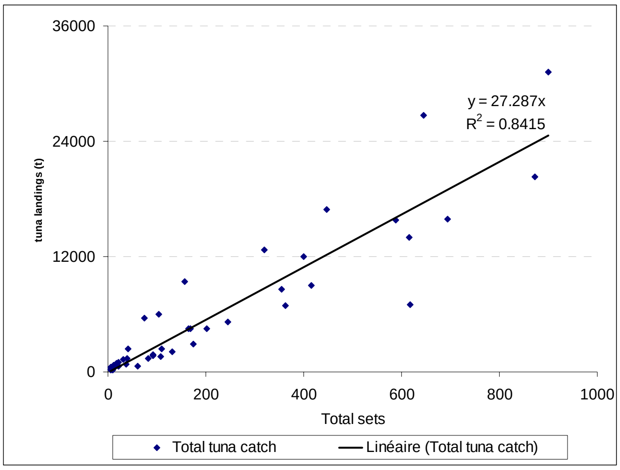


Figure 27 : Relationship between tuna landings and number of sets in the different strata

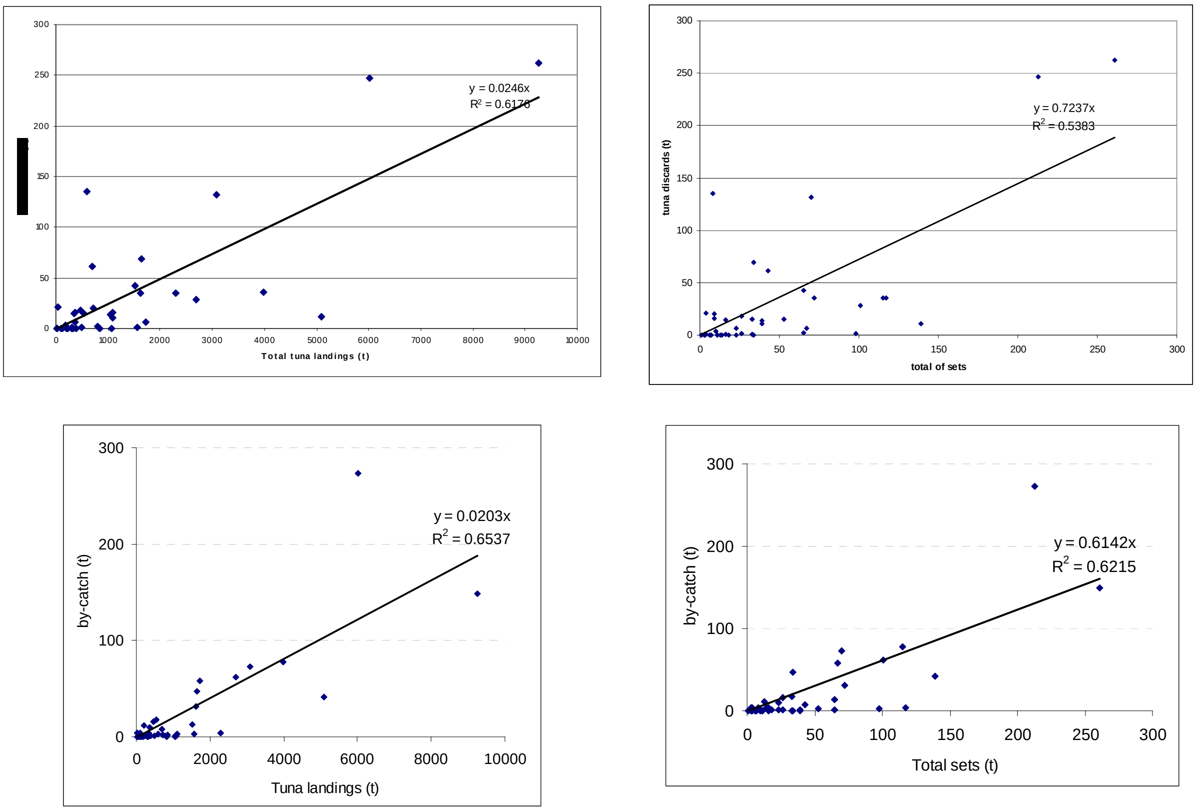


Figure 28 : Relationships between tuna discards and by-catch relatively to total tuna landings and total numbers of sets in the 45 strata (combination of quarters, fishing mode and ET areas)

Appendix 1: List of species or species group reported by observers during the Spanish and French observer program on tropical purse seine fishery (2003-2007)

N°	**Species group**	**Family**	**Species name**	**Free school sets**	**Log school sets**	**Seamounts sets**
1	Billfishes	*Istiophoridae*	*Makaira indica*	+	+	-
2	Billfishes	*Istiophoridae*	*Makaira nigricans (=mazara)*	+	+	-
3	Billfishes	*Istiophoridae*	*Family Istiophoridae*	+	+	-
4	Billfishes	*Istiophoridae*	*Istiophorus platypterus*	+	+	+
5	Billfishes	*Istiophoridae*	*Tetrapturus angustirostris*	+	+	-
6	Billfishes	*Istiophoridae*	*Tetrapturus audax*	+	+	-
7	Billfishes	*Xiphiidae*	*Xiphias gladius*	+	+	+
8	Fishes	*Pomacentridae*	*Abudefduf vaigiensis*	+	+	-
9	Fishes	*Balistidae*	*Abalistes stellatus*	+	+	-
10	Fishes	*Monacanthidae*	*Aluterus monoceros*	+	+	-
11	Fishes	*Balistidae*	*Canthidermis maculatus*	+	+	-
12	Fishes	*Belonidae*	*Ablennes hians*	-	+	-
13	Fishes	*Bramidae*	*Family Bramidae*	+	+	-
14	Fishes	*Carangidae*	*Decapterus macarellus*	+	+	-
15	Fishes	*Coryphaenidae*	*Coryphaena equiselis*	-	+	-
16	Fishes	*Coryphaenidae*	*Coryphaena hippurus*	+	+	+
17	Fishes	*Carangidae*	*Carangoides orthogrammus*	-	+	-
18	Fishes	*Carangidae*	*Caranx sexfasciatus*	+	+	-
19	Fishes	*Carangidae*	*Uraspis helvola*	-	+	-
20	Fishes	*Carangidae*	*Uraspis secunda*	+	+	+
21	Fishes	*Carangidae*	*Uraspis sp.*	-	+	-
22	Fishes	*Diodontidae*	*Diodon hystrix*	+	+	+
23	Fishes	*Diodontidae*	*Diodon sp.*	+	+	+
24	Fishes	*Carangidae*	*Elagatis bipinnulata*	+	+	+
25	Fishes	*Balistidae*	*Family Balistidae*	+	+	-
26	Fishes	*Belonidae*	*Family Belonidae*	+	+	-
27	Fishes	*Coryphaenidae*	*Family Coryphaenidae*	+	+	+
28	Fishes	*Carangidae*	*Family Carangidae*	+	+	-
29	Fishes	*Echeneidae*	*Family Echeneidae*	+	+	-
30	Fishes	*Ephippidae*	*Family Ephippidae*	-	+	-
31	Fishes	*Exocoetidae*	*Family Exocoetidae*	+	+	-
32	Fishes	*Fistularidae*	*Family Fistularidae*	+	-	-
33	Fishes	*Kyphosidae*	*Kyphosus sp.*	+	+	-
34	Fishes	*Molidae*	*Family Molidae*	+	-	-
35	Fishes	*Pomacentridae*	*Family Pomacentridae*	-	+	-
36	Fishes	*Scombridae*	*Family Scombridae*	-	+	-
37	Fishes	*Tertaodontidae*	*Family Tetraodontidae*	-	+	-
38	Fishes	*Kyphosidae*	*Kyphosus cinerascens*	+	+	+
39	Fishes	*Kyphosidae*	*Kyphosus vaigiensis*	+	+	-
40	Fishes	*Lampridae*	*Lampris guttatus*	-	+	-
41	Fishes	*Tertaodontidae*	*Lagocephalus lagocephalus*	+	+	-
42	Fishes	*Lobotidae*	*Lobotes surinamensis*	+	+	+
43	Fishes	*Molidae*	*Masturus lanceolatus*	+	+	-
44	Fishes	*Scombridae*	*Scomberomorus tritor*	-	+	-
45	Fishes	*Molidae*	*Mola mola*	+	-	-

Appendix 1: (continued)

N°	Species group	Family	Species name	Free school sets	Log school sets	Seamounts sets
46	Fishes	*Carangidae*	*Naucrates ductor*	+	+	-
47	Fishes	*Ephippidae*	*Platax sp.*	-	+	-
48	Fishes	*Ephippidae*	*Platax teira*	+	+	-
49	Fishes	*Echeneidae*	*Remora australis*	-	+	-
50	Fishes	*Echeneidae*	*Remorina albescens*	-	+	+
51	Fishes	*Echeneidae*	*Remora remora*	+	+	-
52	Fishes	*Gempylidae*	*Ruvettus pretiosus*	-	+	-
53	Fishes	*Carangidae*	*Decapterus sp.*	-	+	-
54	Fishes	*Carangidae*	*Seriola rivoliana*	+	+	+
55	Fishes	*Scombridae*	*Scomber japonicus*	-	+	-
56	Fishes	*Sphyraenidae*	*Sphyraena barracuda*	+	+	-
57	Fishes	*Sphyraenidae*	*Family Sphyraenidae*	-	+	-
58	Fishes	*Belonidae*	*Tylosurus crocodilus*	-	+	-
59	Fishes	*Nomeidae*	*Cubiceps capensis*	+	-	-
60	Fishes	*Carangidae*	*Uraspis uraspis*	+	+	-
61	Fishes	*Scombridae*	*Acanthocybium solandri*	+	+	+
62	Fishes	*Zanclidae*	*Zanclus cornutus*	+	-	-
63	Sharks	*Carcharhinidae*	*Carcharhinus falciformis*	+	+	+
64	Sharks	*Carcharhinidae*	*Carcharhinus longimanus*	+	+	-
65	Sharks	*Carcharhinidae*	*Carcharhinus obscurus*	-	+	-
66	Sharks	*Carcharhinidae*	*Galeocerdo cuvieri*	+	-	-
67	Sharks	*Carcharhinidae*	*Prionace glauca*	+	-	-
68	Sharks	*Carcharhinidae*	*Family Carcharhinidae*	+	+	-
69	Sharks	*Sphyrnidae*	*Sphyrna lewini*	+	+	-
70	Sharks	*Sphyrnidae*	*Family Sphyrnidae*	-	+	-
71	Sharks	*Lamnidae*	*Isurus oxyrinchus*	-	+	+
72	Sharks	*Megachasmidae*	*Megachasma pelagios*	+	-	-
73	Sharks	*Rhincodontidae*	*Rhincodon typus*	+	+	-
74	Rays	*Dasyatidae*	*Dasyatis violacea*	+	+	-
75	Rays	*Dasyatidae*	*Family Dasyatidae*	+	+	-
76	Rays	*Myliobatidae*	*Aetobatus narinari*	+	-	
77	Rays	*Myliobatidae*	*Manta birostris*	+	+	+
78	Rays	*Myliobatidae*	*Manta sp.*	+	-	-
79	Rays	*Myliobatidae*	*Mobula tarapacana (=coilloti)*	+	+	+
80	Rays	*Myliobatidae*	*Mobula mobular*	+	+	-
81	Rays	*Myliobatidae*	*Mobula japanica (=rancurelli)*	+	+	+
82	Rays	*Myliobatidae*	*Mobula sp.*	+	-	+
83	Rays	*Rhinopteridae*	*Family Rhinopteridae*	-	+	-
84	Turtles	*Cheloniidae*	*Caretta caretta*	-	+	-
85	Turtles	*Cheloniidae*	*Chelonia mydas*	-	+	-
86	Turtles	*Cheloniidae*	*Eretmochelys imbricata*	+	+	-
87	Turtles	*Cheloniidae*	*Lepidochelis olivacea*	+	+	-
88	Cetaceans	*Balaenopteridae*	*Balaenoptera physalus*	+	+	-
89	Cetaceans	*Globicephalidae*	*Pseudorca crassidens*	-	+	-