INTER-AMERICAN TROPICAL TUNA COMMISSION
SCIENTIFIC ADVISORY COMMITTEE
SEVENTH MEETING
La Jolla, California (USA)
09-13 May 2016

DOCUMENT SAC-07-03e

THE FISHERY ON FISH-AGGREGATING DEVICES (FADS) IN THE EASTERN PACIFIC OCEAN – UPDATE

Martín Hall and Marlon H. Román

CONTENTS

This document is an update and extension of Document SAC-05-04a, presented at the 5th meeting of the Scientific Advisory Committe in May 2014.

As part of their data collection duties, observers aboard purse-seine vessels record the characteristics and use of fish-aggregating devices (FADs), both those fabricated and deployed for the sole purpose of attracting fish and those that are improvised at sea from flotsam to which the fishers attach a variety of materials that will make them more attractive to the fish. The information presented in this document is based on observer records; as such, it is predominantly from Class-6[1] purse-seine vessels, but also includes data from a small number of Class-5 vessels that have carried observers.

Until the 1990s, the majority of purse-seine catches in the eastern Pacific Ocean (EPO) consisted of yellowfin tuna caught in association with dolphins; the rest were caught in sets on unassociated tunas or sets associated with drifting floating objects, mostly tree trunks or branches. Fishers would add radio beacons to floating objects they encountered to enable them to be found again. Eventually, the concept of fish-aggregating devices (FADs) began to emerge as an alternative strategy, but the numbers and proportion of sets of this type were not significant. However, in the 1990s the fishery on FADs expanded rapidly (Figure 1), due in part to the closure of the US market to tuna caught in association with dolphins, which motivated fishers to explore alternative ways of catching tunas.

During the early years of the FAD fishery, fishers experimented with FAD construction, where and when

---

[1] Carrying capacity greater than 363 tons; Class-5 vessels are of carrying capacities between 273 and 363 tons.

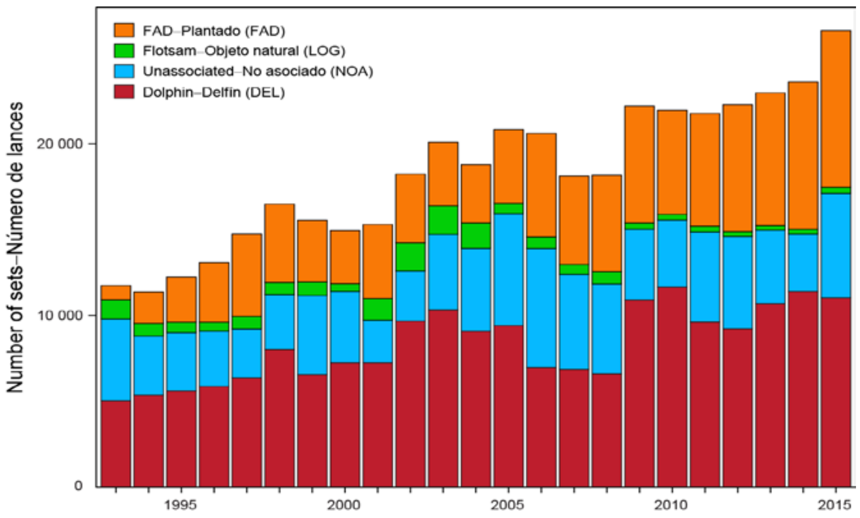


FIGURE 1. Number of sets, by type, 1993-2015**.**

to deploy FADs, how frequently to revisit them, technologies for monitoring and tracking FADs, *etc*. The development of spatial-temporal strategies, taking into account oceanographic factors, management restrictions, access to fishing areas, and other factors, was a key component. In parallel to these developments, the industries producing tracking and acoustic technologies developed products for this new market, and the changes have been fast and very significant.

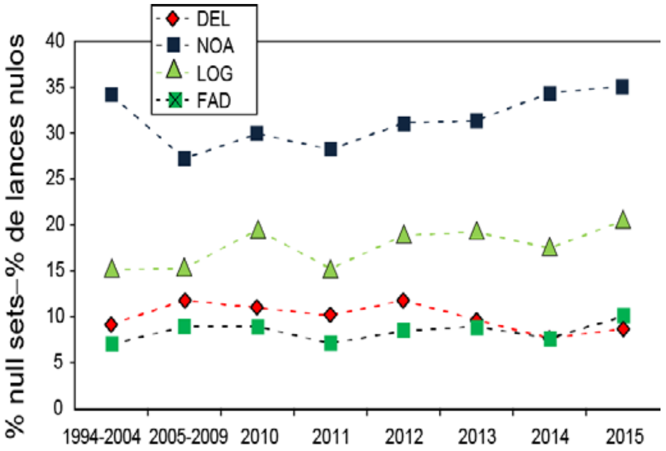


FIGURE 2. Percent of null sets by set type, 1994-2015

The total number of sets has continued increasing, and 2015 is the highest record observed. There is a large increase in school sets in 2015. FAD sets remained at the high level they had reached in 2014. Log sets are a small proportion of the total, but are slightly higher in 2015. We need to consider that the El Nino phenomenon that is affecting the area may affect the number and spatial distribution of the effort.

1. FADs: CHARACTERISTICS AND DYNAMICS

In the early days of the FAD fishery, fishers relied on visual cues, such as flags, to locate FADs, but soon these gave way to sophisticated electronic methods. Currently, essentially all FADs are equipped with satellite tracking devices, and about a third are also outfitted with sonar buoys, which can be monitored via satellite from the vessel. These buoys, which are used by fishers to determine remotely the biomass associated with a FAD, could potentially improve the efficiency of fishing operations by (a) reducing the proportion of null sets (sets with no capture) and (b) increasing catches from FAD sets, by allowing fishers to set on those FADs with the greatest potential catches. However, in general, the increased use of sonar buoys does not seem to have reduced the proportion of null sets of any type (Figure 2). This is still the case by 2015. School sets are showing a trend upwards in the proportion of skunk sets that may be caused by changes in the fishing area visited (see maps below on FAD deployment distribution. The average capture per positive set (CPS>0) did not show differences before 2010, but since then the average captures in sets on FADs with sonar buoys have been considerably higher than in sets without such buoys (Figure 3), possibly due to improvements in the

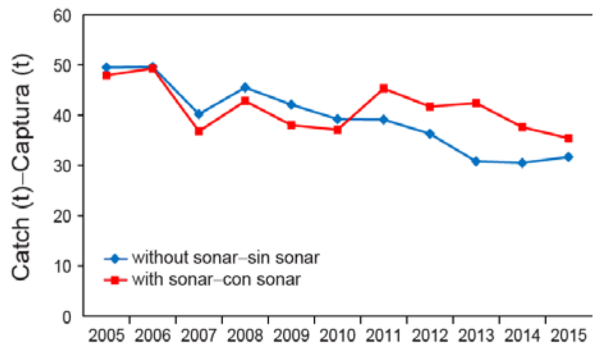


FIGURE 3. Total capture per set on FADs with and without sonar, 2004-2015.

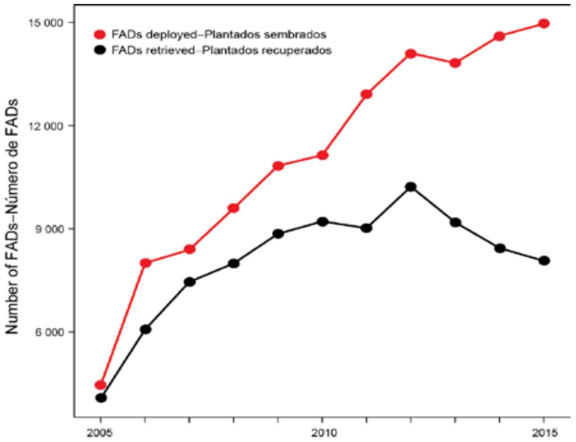


FIGURE 4. Number of FADs observed deployed and retrieved in the EPO by year, 2005-2015.

technology and/or the skill of the fishers in interpreting the data transmitted by the buoys. The average catches per set in positive sets (Table 3) have decreased steadily for log and FAD sets, perhaps reflecting the increase in the density of objects, changes in abundance of the tuna species involved or both. The decrease is close to one third of the original tonnage per set. School sets don't have a clear trend in cps. Dolphin sets have remained stable after a 25% drop by 2005-2009. These analyses are preliminary, and do not take into account potential differences in the spatial and temporal distributions of effort, of FADs with and without sonic buoys, differences in FAD construction, or differences in the characteristics of the purse-seine nets used.

FAD deployments: Figure 4 shows the deployments and retrievals of FADs recorded by observers during 2005-2013. The total number of FADs deployed per year has increased steadily, from about 4,000 in 2005 to almost 15,000 in 2015, the highest number on record, although there seems to be a reduction in the annual rates of increase (*e.g.* the curve is reaching an asymptote). But the number of FADs recovered has declined significantly, and the difference planted minus recovered has experienced a large increase. This may mean: a) more FADs are being lost, or b) more FADs are left for more time in the water to resume fishing on them, or c) both. It is important to determine the reason for this change.

Most FADs are retrieved, although the percentage retrieved from the EPO was less in 2014 and 2015 than in previous years; those that are not either continue to be monitored and used for fishing (some, perhaps outside the EPO) or are lost. It should be noted that the recording process is interrupted when an observer leaves a vessel at the end of a trip, thus this data and the conclusions that might be drawn from them are limited because there is no continuity in the counting of FADs. With the aim of eventually overcoming the limitations of these data and pursuant to the

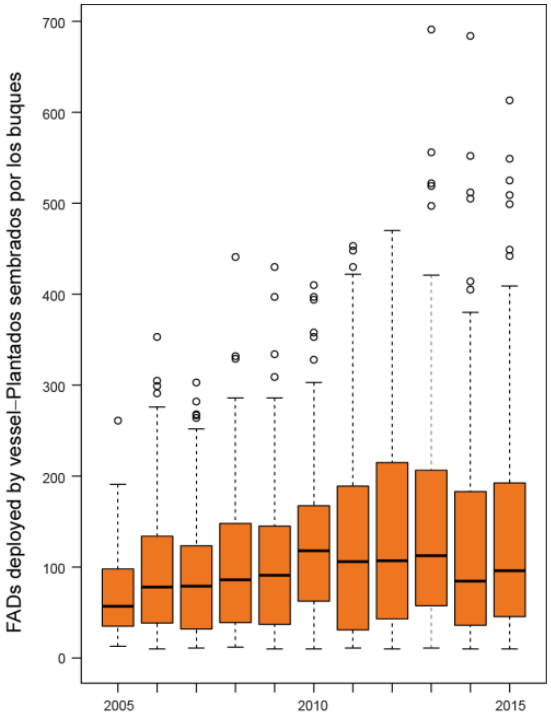


FIGURE 5. FAD deployments by vessels, 2005-2015. Excludes vessels deploying less than 10 FADs in a year.

direction provided by CPCs, the IATTC staff has been evaluating options for enhanced monitoring and data collection regarding use of FADs (see Document SAC-05-05).

The number of FADs deployed per vessel has increased as well. Figure 5 shows the number of FADs deployed per vessels annually. In 2005, the average number of FADs deployed per vessel was 71; and the highest number of FADs deployed during a single trip was about 250. By 2012 the average number of FADs deployed per observed trip had increased to 131, with some vessels deploying nearly 500. Fleets with several vessels often share FADs, so a vessel may have many more FADs available than it deploys.

1.1. Patterns of FAD distribution in the EPO

The patterns of FAD deployments by month, based on observer data for the periods 2010-2012 and 2013-2015, are illustrated in a comparative way in Figure 6, that presents the changes occurring month by month when comparing similar periods of time in earlier years and at the present. The lines are not tracks of deployed FADs, but rather the sequential FAD deployments that occur as a vessel follows a given course. The effects of the current strong El Nino may be reflected in the 2015 changes in deployment patterns observed, but the maps were prepared for multiyear periods to retain the comparability.

In summary, FAD deployments in the more recent period show an extension of the fishing season off Peru beginning much earlier than before, in October, shifting to the area around the Galapagos during the second quarter, and then to the offshore equatorial region west of the Galapagos for the rest of the year.

Humboldt Current system: The deployments in this region (roughly between 5°S and 25°S within 600 miles of the coast) are quite seasonal, coinciding with the presence of a “tongue” of warm water that spreads south from the equatorial region to northern Chile. Most of the deployments occur from October to March, moving north in April as the warm water recedes. Surface current speeds in this system are slow, and FADs do not move long distances. The proportion of FADs planted in the Humboldt Current system area has increased considerably in recent years. The fishing season now goes from October to March.

Galapagos system: This system occupies the area west of 85°W and east of 100°W between 3°N and 5°S. FAD deployment occurs here year-round, peaking from May to October. The current patterns around Galapagos are complex; during the second quarter there are flows even in an easterly direction, which are quite rare in the region.

Offshore Equatorial area: Deployments in this area, between about 100°W to the western boundary of the IATTC Convention Area at 150°W, occur along the Equator. The westward-flowing currents north and south of the Equator are the fastest in the Pacific Ocean, especially during the second quarter of the year, and the longitudinal movements of FADs are significantly greater than in other periods. Deployment rates in this system are lowest in November-December, because of the movement of vessels to the Humboldt region, then typically increase from January to a peak in June and July. Their distribution in this area in October is influenced by the closure of the area between 96º and 110ºW from 4°N to 3°S (“*corralito*”). The reduction in deployments at the end of the year is even more marked in recent years.

Figure 7 shows the number of FADs deployed per month by region. The largest numbers of FADs are deployed around Galapagos in June-July and September-October. The numbers decline further to the west.

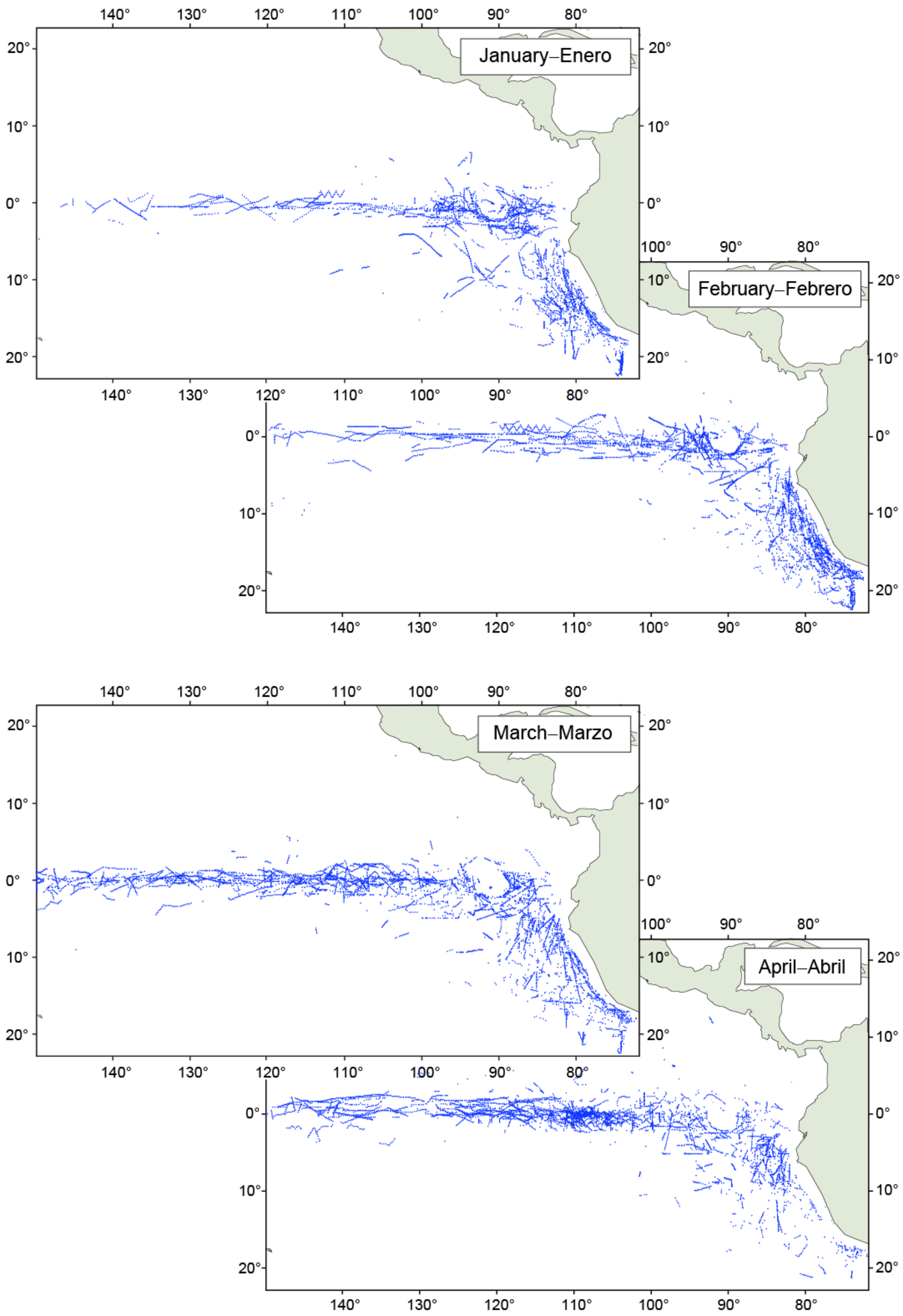


FIGURE 6. Distribution of FAD deployments, by month, 2011-2015

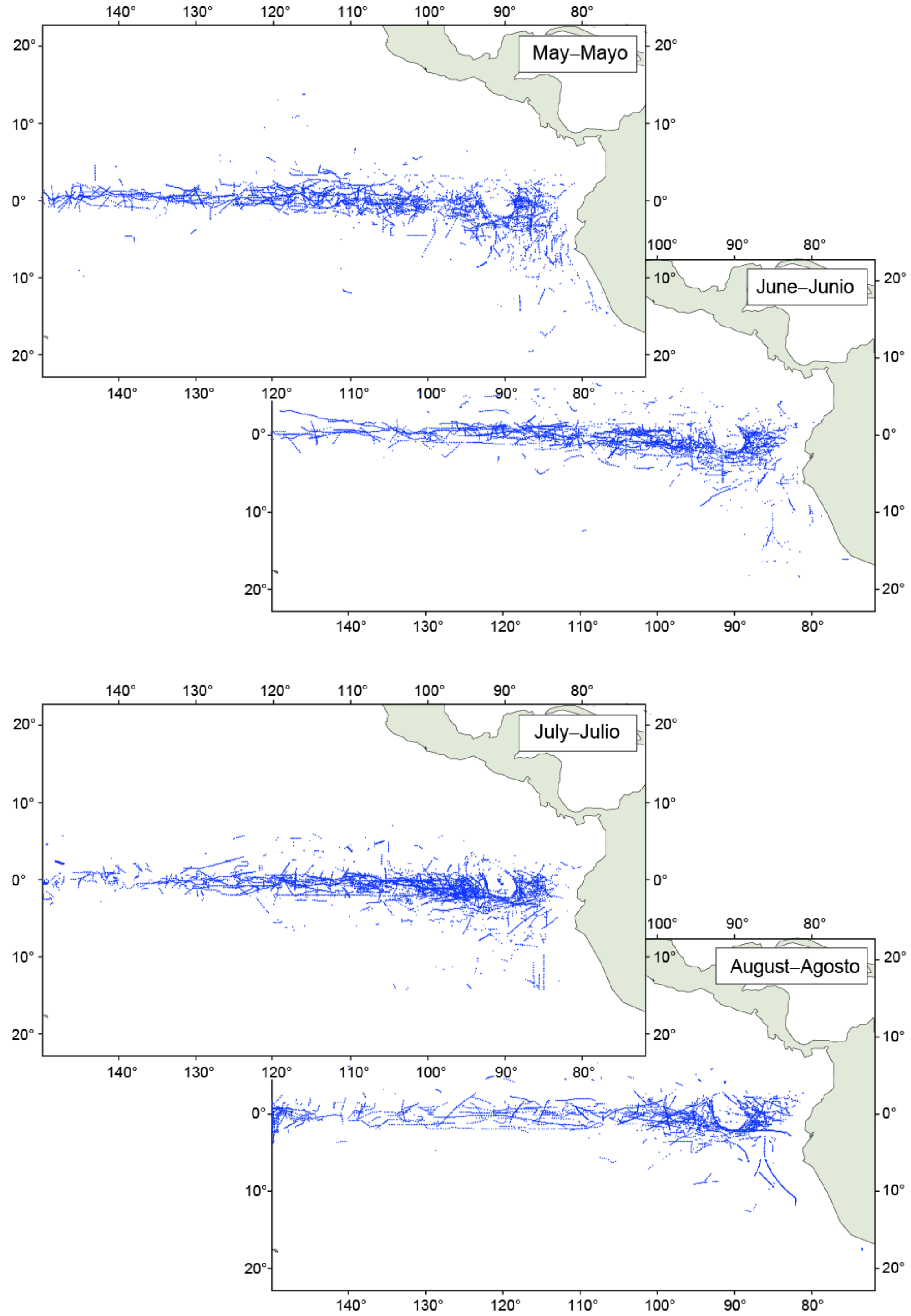


FIGURE 6 (cont.) Distribution of FAD deployments, by month, 2011-2015

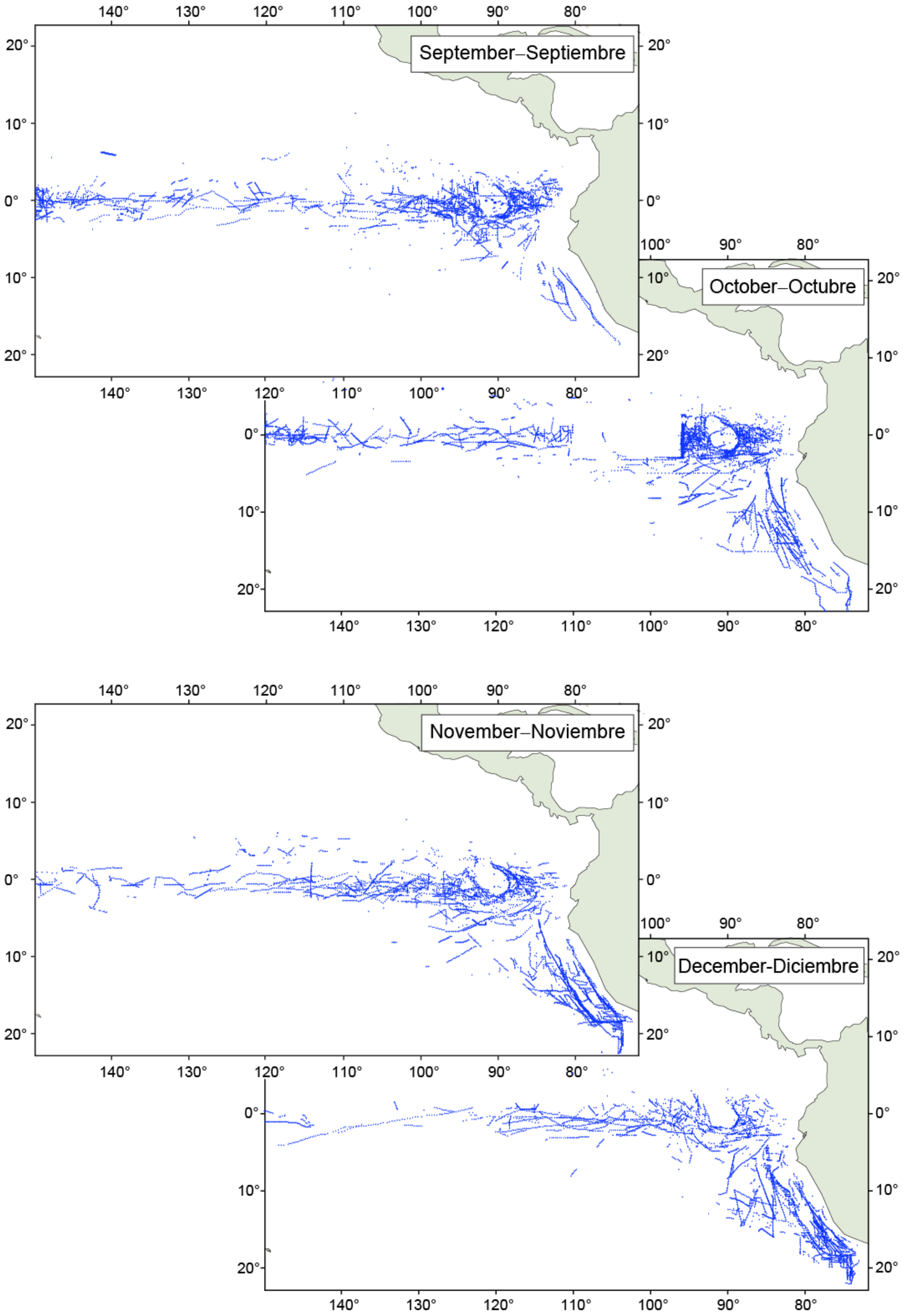


FIGURE 6 (cont.) Distribution of FAD deployments, by month, 2011-2015

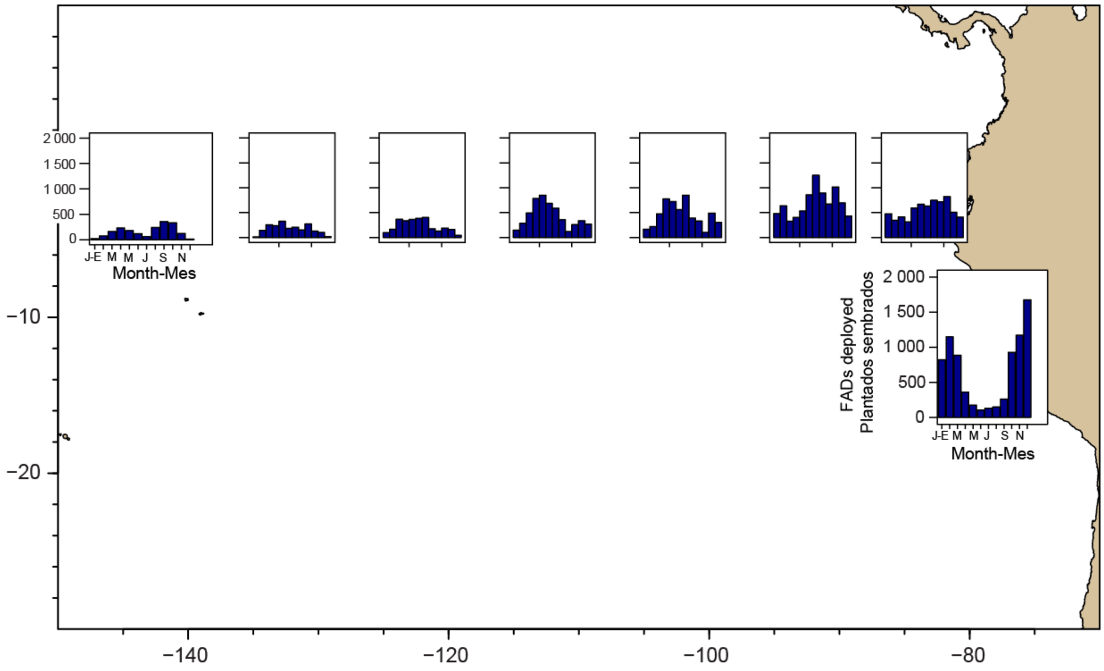


FIGURE 7. Number of FADs deployed by month and by area. Period 2010 – 2015

1.2. FAD depth

From the beginning of the FAD fishery, pieces of webbing, usually old netting materials, have been added under the FADs to increase their attractiveness to the fish. Figure 8 illustrates the changes in FAD construction over the years: a rapid increase in the depth of the materials hung from the FAD in the

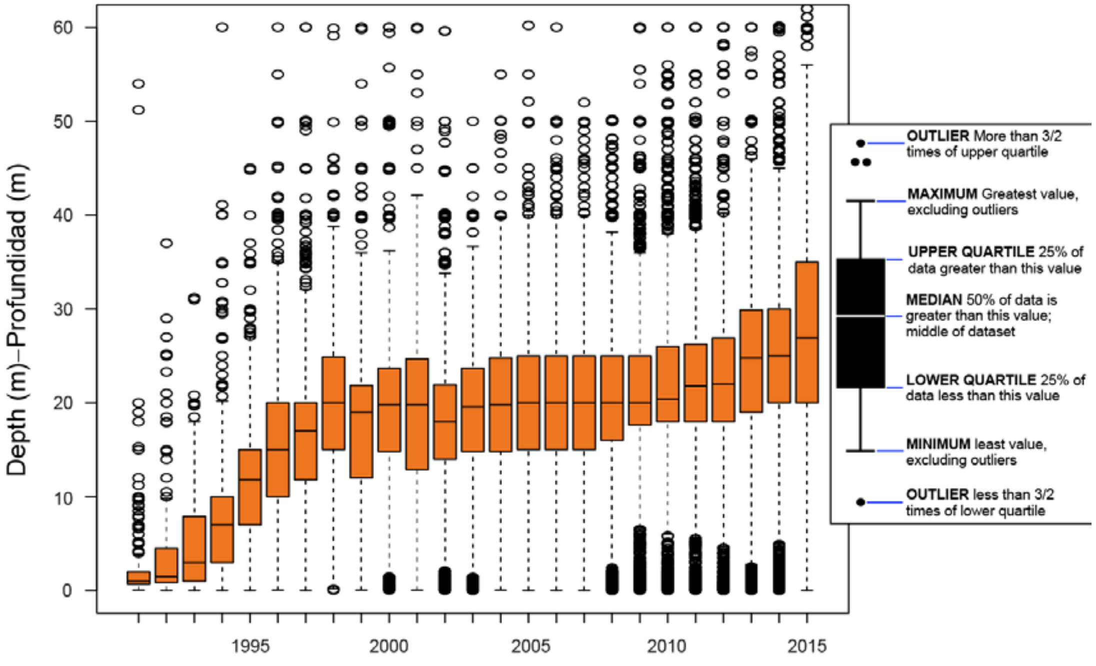


FIGURE 8. Box plots showing average depth of FAD net webbing, by year. Period 1991-2015

early years, followed by a stable period from the late 1990s, with a median depth around 25-30 m. More recently, the median depth appears to be increasing again, apparently following the practice in other oceans, with depths of 40 m becoming more common, and with some approaching 80 m. This trend, towards deeper FADs is accentuated in the most recent years.

2. DEFINITIONS USED IN THE BYCATCH SECTION

TOTAL CAPTURE, or CAPTURE for short, is the product of the physical action of encircling in the net (for a purse seine), and the the action itself. It can be intentional or incidental (e.g. a whale may swim into the seine). The total number of individuals or biomass encircled of any species (target or not) is the CAPTURE. [Spanish: CAPTURA TOTAL]

CATCH or RETAINED CATCH is the portion of the CAPTURE that is retained for utilization by the crew (e.g. for food or bait) or sale. The CATCH can be legal or illegal, depending on the permits the vessel has. The bycatch section definitions of CATCH does not imply any recognition by IATTC of the legality of the operation; it is simply a statement of fact identifying the fate of a portion of the CAPTURE. [Spanish: CAPTURA RETENIDA]

BYCATCH is the portion of the biomass or the numbers of individuals encircled in the net that is not retained, and is discarded dead, either from the net or from the deck. The BYCATCH of the major tuna species object of the fishery is synonymous of DISCARDS, and it has been used that way in IATTC tables.

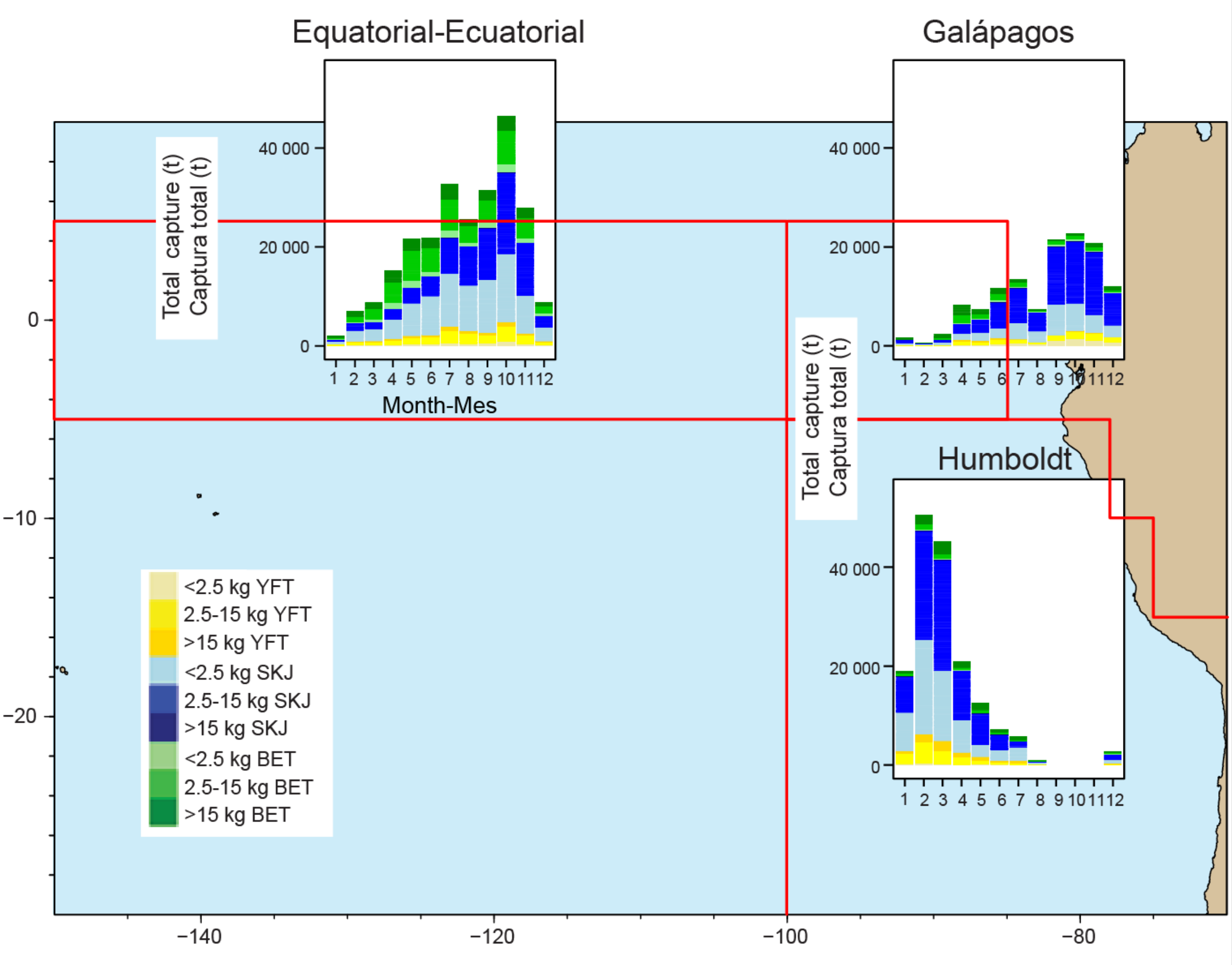


FIGURE 9. Total captures of tunas, by species and size, in sets on FADs, by month and area, 2010-2015

It is presumed to be dead, even if it is returned to the sea, so it is considered among the impacts of the fishery. [Spanish: CAPTURA DESCARTADA o DESCARTE]

Individuals that are captured in the net intentionally or incidentally can be released alive. This fraction is called the RELEASE (e.g. almost all dolphins in dolphin sets) and they are not included in the BYCATCH because they are expected to survive their release. [CAPTURA LIBERADA]

3. SPECIES COMPOSITIONS OF CAPTURES IN FAD SETS

Total tuna captures (Figure 9): shows aggregate FAD set catches in the three regions partitioned by size and species. For example, the region off Peru shows a predominance of larger sizes of yellowfin and skipjack in proportion to the other sizes, when compared with the other locations, and the captures of small skipjack constitute the bulk of the Equatorial offshore captures for most of the year. The increases in deployments off Peru, later in the year, does not result in catches in that period; the catches peak early in the year. Around Galapagos, the bulk of the catches are taken close to the end of the year.

Diel patterns: In the EPO, the vast majority of FAD sets are made within an hour of sunrise. Researchers in other regions have suggested that some fleets were increasing the number of sets on FADs later in the day. However no such increase is evident as of yet in the EPO (Figure 10). This conclusion remains valid.

4. BYCATCHES

Tuna bycatches (Discards): Over the past two decades, the proportions of captured tunas subsequently discarded have declined in all set types. Typical reasons for discards of tuna include: the vessel is full; sizes of the tunas are too small to be marketable; the tunas are in bad condition and not fit for consumption (usually after a very long set), *etc*. Figure 11 show the average percentage of tuna capture discarded as bycatch, by year, for floating-object sets (inclusive of FAD sets), unassociated sets and dolphin sets, respectively. Historically, sets on dolphins have produced the lowest level of tuna bycatch, and sets on floating objects the highest. However, all tuna discard rates have declined: since the mid-

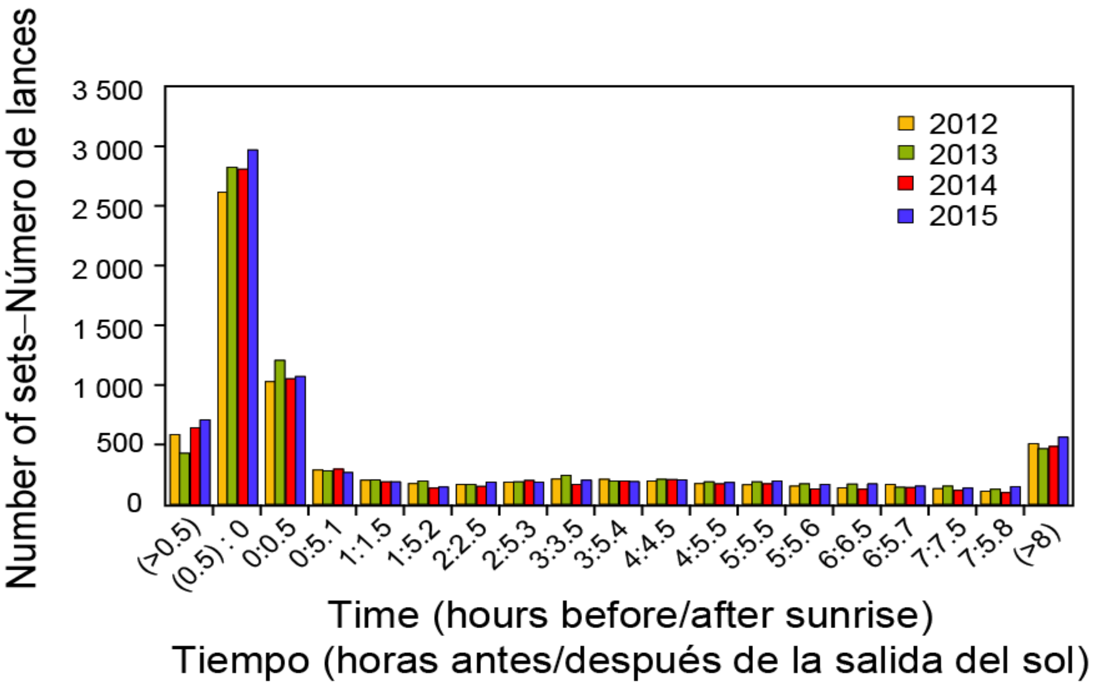


FIGURE 10. Timing of FAD sets relative to sunrise, 2012-2015

1990s they have fallen from around 16% to about 1% in floating-object sets, from 2% to close to 0.8% in unassociated sets, and from about 0.6% to essentially zero in dolphin sets. The main reasons for this are probably the increased marketability of small tunas, and the full retention requirements established by the IATTC (see Resolutions C-00-08, C-13-01).

Utilization of non-tuna species: Even though some non-target species have always been retained, the rates of retention of some species have increased considerably. The distinction between target and non-target species may change with economic or management actions. Billfishes, mahi-mahi, wahoo, and other large pelagic species are utilized in a variety of forms as small parallel industries to process them have developed. In order to improve retention of some of these species, several changes in the fishing operations have occurred: for example, divers harpoon individual specimens for high-quality markets, and some vessels dedicate wells to species other than tuna, where they are stored using methods other than the brine solution used to store tuna, while others store some species, such as mahi-mahi, in tuna wells, but later on wash away the salt and restore the appearance of the fish. Figure 12 shows the increasing utilization of species such as mahi-mahi and wahoo captured in FAD sets. However, not all species have found markets: rainbow runners and yellowtail captured in FAD sets are still typically discarded (Figure 13). Nonetheless, the overall retention of non-tuna species has increased from 30% in 1993 to 75% in 2012 (Figure 14).

Recent developments and current levels of bycatch: Table 1a. reflects observer data on total captures and bycatches for the year 2013. Table 1b. shows captures and bycatches but expressed per 1000 MT of tuna capture Tables 2a and 2b add the new figures for 2015 to facilitate the comparison. Errors may be introduced by misidentifications, unobserved mortalities, etc., but it is believed that most of the mortality is accurate and accounted for; estimation of the tonnage should add uncertainty in the weight figures. Dolphins are excluded from these tables. Practically all species show lower bycatch rates in recent years than in the earlier years of the fishery. Where reduced rates are observed, the possible sources of the reductions should be considered carefully. Such reductions may reflect changes in abundance, changes in fishing areas or methods, higher utilization rates, or some combination of factors. For example, based on what is known about the status of oceanic whitetip sharks, the increasing rarity of this species in EPO purse-seine sets likely tracks closely with their relative abundance.

On the other hand, the reduced bycatch rates of some large pelagic species (billfishes, mahi-mahi, wahoo, *etc*.) is likely due, at least in part, to higher utilization rates due to expanded markets for these fish, as can be seen when looking at the differences between captures and bycatches..

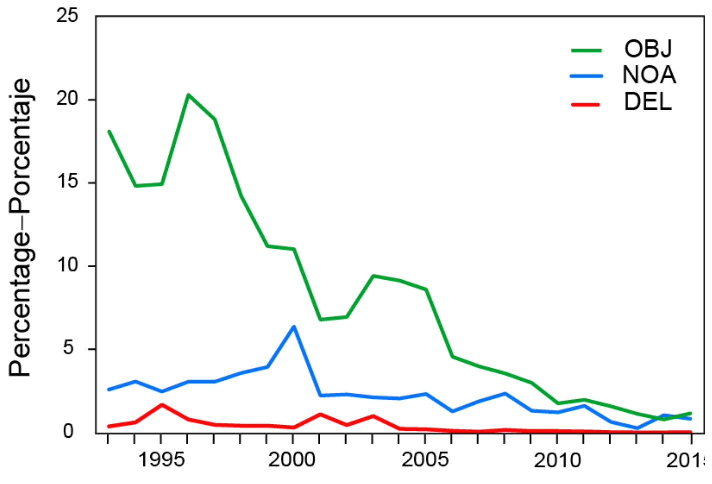


FIGURE 11. Percentage of tuna discards, by set type, 1993-2015

The increasing utilization of individuals that would have been discarded dead otherwise, does not add to the fishing mortality resulting from the harvest. To the extent that non-tuna species increasingly occupy well space on PS vessels, this may be a positive step in the sense that it may result in a reduction in capacity for tuna species by taking up well space, and distributing the impact of the fishery among more components of the ecosystem, and thus more in line with an ecosystem-based approach to harvesting the oceans. Greater retention of non-tuna species also produces economic benefits from what was wasted before and may provide socio-economic benefits to coastal communities, without increasing the impacts on the ecosystem. Marlins, wahoo and mahi-mahi continue their high and increasing level of utilization. The changes observed in the most recent period are a) an increase in the utilization of yellowtail, and b) general reductions in the bycatches of this species and of rainbow runners, perhaps a consequence of changes in fishing areas. The later is the species that is slower in developing a market, but it is also increasing its utilization.

In dolphin sets, the 2015 incidental captures are very low as usual. Only Other/unidentified sharks, silky sharks and spinetail manta ray are over 20 MT for the year. The reversal in prevalence between giant manta and spinetail manta ray may be due to area changes, or identification issues. The total annual bycatch in dolphin sets was of 53.23 MT.

In school sets, the total capture was 293 MT, with 138 MT been discarded dead, or presumed to die as a consequence of the fishing operation. The only species with bycatches over 20 MT was the silky shark (captures higher than in 2013), followed by other/unidentified sharks, giant manta and Other large fish with slightly over 10 MT.

Sets on floating objects show the higher captures and bycatches. Captures of mahi-mahi are still the highest, but they have decreased compared to 2013. The same is observed for wahoos. There is also an increase in the captures and bycatches of silky sharks. Blue marlin captures have also increased, but their level of utilization is very high.

None of the sea turtle species of conservation concerns appeared in the capture or bycatch databases for all types of sets in 2015.

The total bycatch of species other than tunas in 2015 was close to 900 MT, out of the 3,154 MT captured

Table 1b shows the rates in MT per 1000 MT of tuna captures. The main observation on these tables for 2013 and 2015 are:

The highest rate is for mahi-mahi and it has declined by close to 1/3. The next highest rate is now the silky shark which has more than doubled the 2013 rate. The wahoo was the second highest in 2013.

The values of these rates are all so low, that the differences may be the result of the weight estimation process, observer errors, etc.

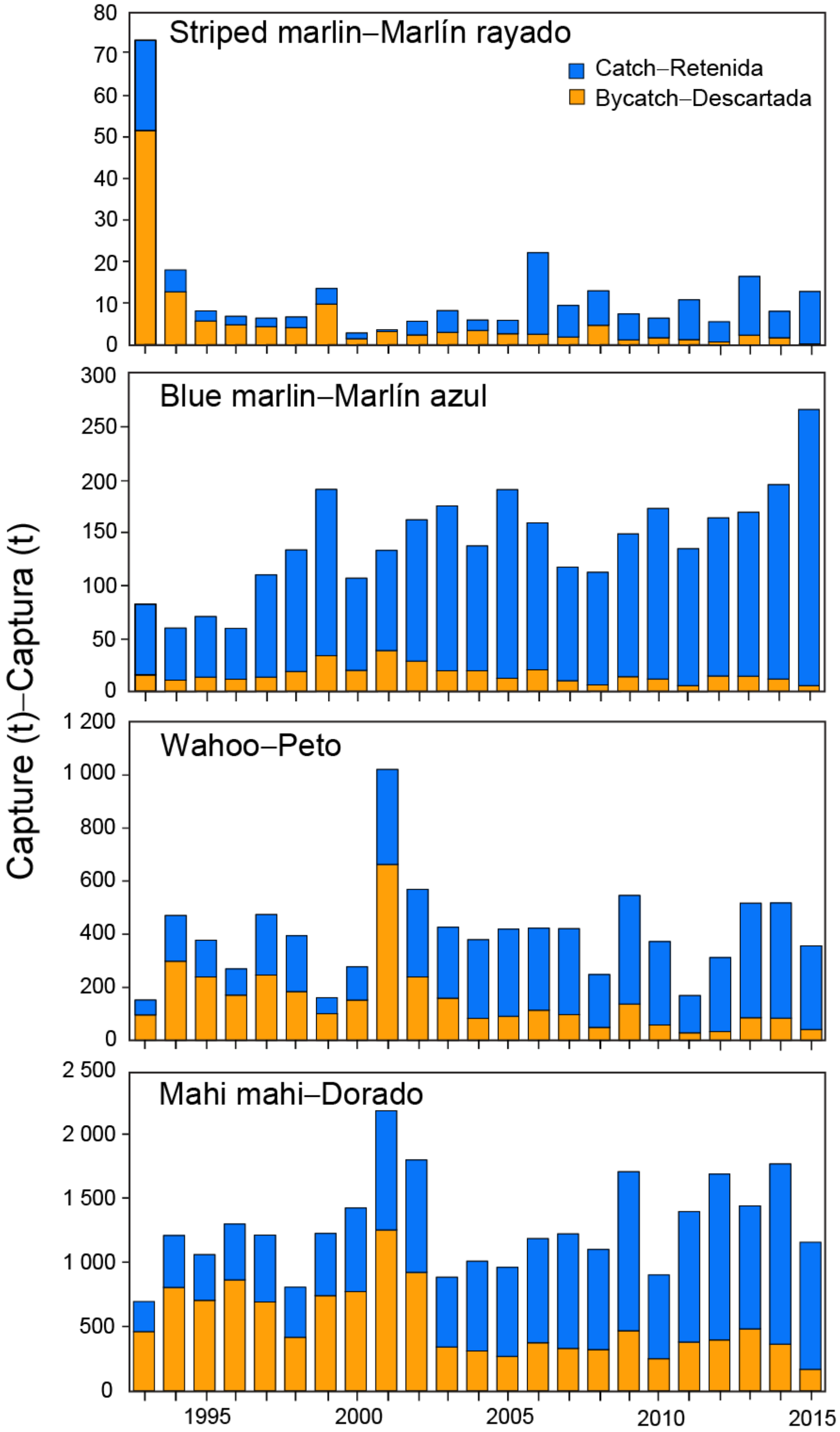


FIGURE 12. Utilization of striped marlin, blue marlin, wahoo, and mahi mahi captured in FAD sets, 1993-2015

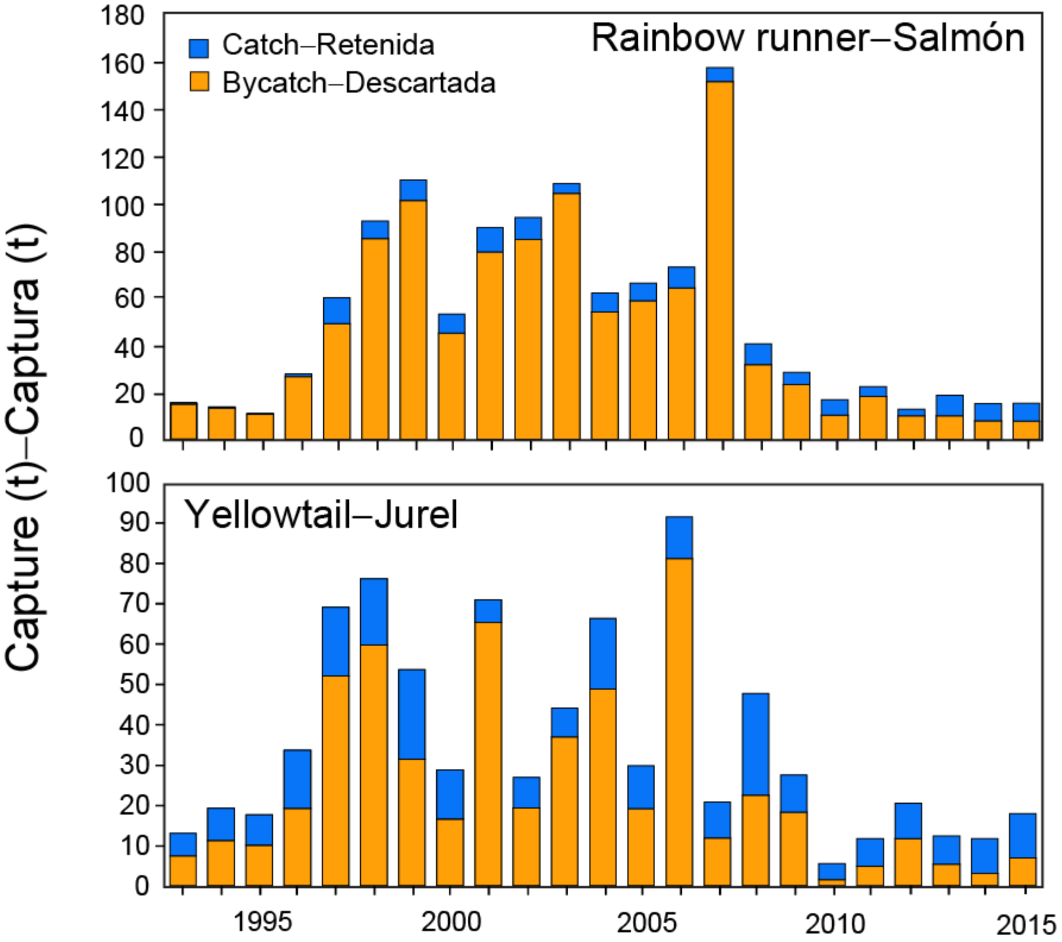


FIGURE 13. Discards of rainbow runner and yellowtail in FAD sets, 1993-2015.

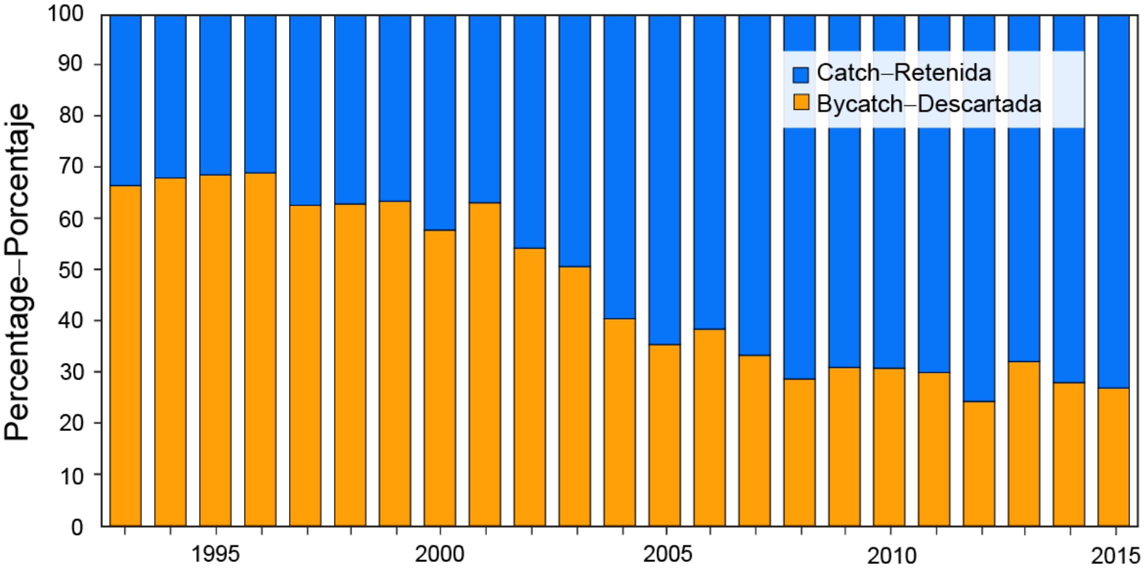


FIGURE 14. Utilization of non-tuna species captured in FAD sets, 1993-2015.

TABLE 1a. Estimated total bycatch (excluding marine mammals and sea turtles) and bycatch per 1000 t of tunas (yellowfin, skipjack, and bigeye) captured by Class-6 purse-seine vessels in the EPO, in metric tons (t), by set type and all sets combined, 2014

Species	Total bycatch (t)				Bycatch/1,000 t tuna capture			
	Dolphin	School	FAD/Log	All Sets	Dolphin	School	FAD/Log	All Sets
Sailfish	0.42	0.12	0.28	0.83	0.00	0.00	0.00	0.01
Blue marlin	0.00	0.26	11.58	11.84	0.00	0.00	0.04	0.05
Black marlin	0.00	0.26	4.19	4.45	0.00	0.00	0.02	0.02
Striped marlin	0.00	0.00	0.61	0.61	0.00	0.00	0.00	0.00
Other/Unid billfish	0.02	0.12	1.70	1.84	0.00	0.00	0.01	0.01
Silky shark	1.58	27.09	280.09	308.76	0.01	0.46	1.10	1.56
Oceanic whitetip shark	0.00	0.00	2.48	2.48	0.00	0.00	0.01	0.01
Scalloped hammerhead	0.14	0.66	20.41	21.21	0.00	0.01	0.08	0.09
Smooth hammerhead	0.11	0.14	34.59	34.83	0.00	0.00	0.14	0.14
Other/Unid HH shark	0.36	0.43	20.43	21.22	0.00	0.01	0.08	0.09
Other/Unid shark	4.29	3.93	32.93	41.15	0.02	0.07	0.13	0.22
Giant manta	0.00	4.50	0.75	5.25	0.00	0.07	0.00	0.08
Spinetail manta ray	4.43	6.31	15.88	26.62	0.02	0.11	0.06	0.19
Chilean devil ray	0.54	0.81	0.53	1.89	0.00	0.01	0.00	0.02
Smoothtail manta	2.62	0.75	0.60	3.98	0.01	0.01	0.00	0.03
Munk's devil ray	0.43	0.12	0.12	0.66	0.00	0.00	0.00	0.00
Unid Manta/devil rays	2.08	2.89	1.35	6.31	0.01	0.05	0.01	0.07
Pelagic stingray	0.29	0.12	0.46	0.86	0.00	0.00	0.00	0.01
Other/Unid rays	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mahi mahi	0.00	3.60	366.09	369.69	0.00	0.06	1.44	1.50
Wahoo	0.00	0.75	83.84	84.60	0.00	0.01	0.33	0.34
Rainbow runner	0.00	0.04	7.88	7.92	0.00	0.00	0.03	0.03
Yellowtail	0.00	0.03	2.98	3.01	0.00	0.00	0.01	0.01
Other large fish	0.77	8.52	2.98	12.27	0.00	0.14	0.01	0.16

TABLE 1b. Estimated total bycatch (excluding marine mammals and sea turtles) and bycatch per 1000 t of tunas (yellowfin, skipjack, and bigeye) captured by Class-6 purse-seine vessels in the EPO, in metric tons (t), by set type and all sets combined, 2015

Species	Total bycatch (t)				Bycatch (t)/1,000 t tuna capture (3 spp.)			
	Dolphin	School	Log	All Sets	Dolphin	School	Log	All Sets
Sailfish	3.43	3.76	0.37	7.57	0.02	0.03	0.00	0.05
Blue marlin	0.03	5.27	5.55	10.85	0.00	0.02	0.02	0.04
Black marlin	0.28	4.65	8.59	13.52	0.00	0.02	0.03	0.05
Striped marlin	0.09	0.00	0.00	0.09	0.00	0.00	0.00	0.00
Other/Unid billfish	0.35	1.19	0.25	1.79	0.00	0.01	0.00	0.01
Silky shark	2.85	77.78	362.92	443.54	0.02	0.62	1.29	1.93
Oceanic whitetip shark	0.03	0.38	3.21	3.62	0.00	0.00	0.01	0.01
Scalloped hammerhead	0.18	0.64	8.85	9.67	0.00	0.01	0.03	0.04
Smooth hammerhead	0.15	2.36	32.92	35.44	0.00	0.02	0.12	0.14
Other/Unid HH shark	0.64	0.56	10.98	12.18	0.00	0.00	0.04	0.05
Other/Unid shark	2.81	10.78	35.15	48.75	0.02	0.09	0.13	0.23
Giant manta	0.58	10.50	0.63	11.71	0.00	0.08	0.00	0.08
Spinetail manta ray	20.95	1.36	2.64	24.94	0.13	0.01	0.01	0.15
Chilean devil ray	6.21	2.30	1.23	9.74	0.04	0.01	0.00	0.05
Smoothtail manta	3.15	1.53	0.50	5.18	0.02	0.01	0.00	0.03
Munk's devil ray	1.36	0.30	0.17	1.83	0.01	0.00	0.00	0.01
Unid Manta/devil rays	8.91	3.51	0.95	13.37	0.05	0.02	0.00	0.08
Pelagic stingray	0.42	0.18	0.22	0.82	0.00	0.00	0.00	0.00
Other/Unid rays	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mahi mahi	0.00	0.22	168.96	169.18	0.00	0.00	0.61	0.61
Wahoo	0.00	0.02	41.30	41.33	0.00	0.00	0.15	0.15
Rainbow runner	0.00	0.00	7.73	7.74	0.00	0.00	0.03	0.03
Yellowtail	0.00	0.00	6.83	6.83	0.00	0.00	0.02	0.02
Other large fish	0.77	10.91	6.54	18.22	0.00	0.07	0.02	0.10

A. **ADDENDUM**

As the fishery on FADs has developed in three distinct regions, a more detailed look at some of the parameters in each of them will be useful to interpret changes in catch rates, species composition, etc. The regions are: a) the Galapagos area, from 5° N to 5° S, and 85° W to 100° W; b) the Equatorial front area (called Equatorial for short), from the western border of the Galapagos area to 150° W, and c) the Humboldt system area, off Peru to 100° W. The map (Figure 9) shows the boundaries of these areas (in red).

As the FAD fishery has expanded, the number of FADs deployed has grown (see Figures 4 and 5). It is interesting to explore the question of whether these increases in FAD numbers change the effectiveness and the productivity of the vessels. Two factors can be influenced by the number of FADs available for a skipper: a) more FADs may mean that it is less likely to hit skunk sets, because there is a previous verification of the existence of fish under a FAD, and the closeness of the association because of the information from the acoustic equipment; or b) the average catch per set, of the positive sets (captures ≥ 0.5 MT), increases when more options are available to the skipper.

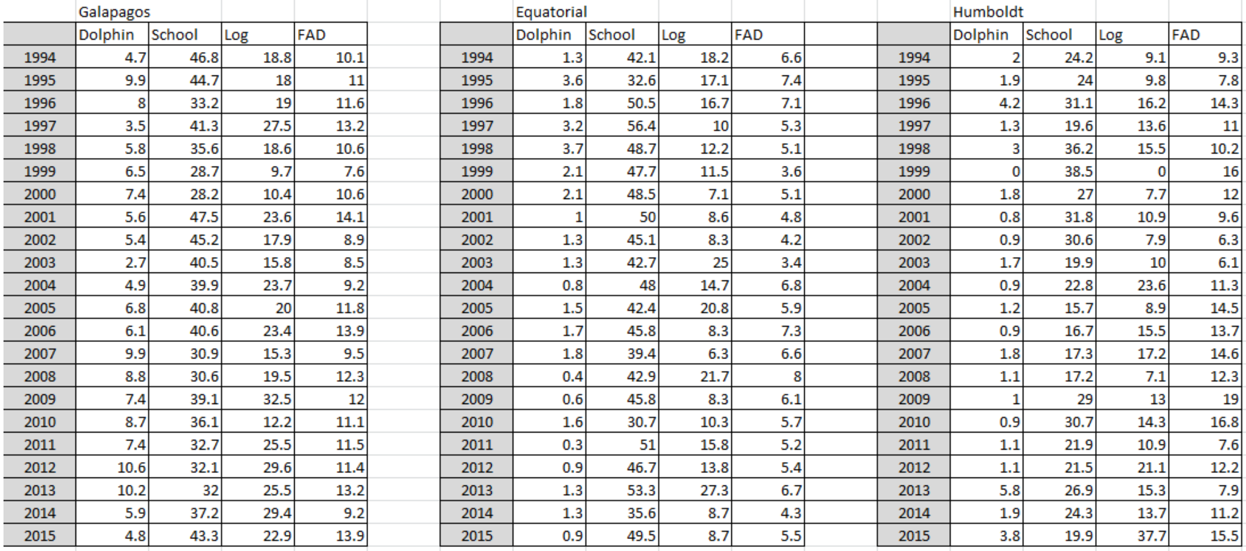
The impacts of the current El Nino event may affect all these variables (e.g. changes in thermocline depth may increase the proportion of skunk sets), but the precise information needed to quantify them and to separate these impacts is not available.

5. **% SKUNK SETS:**

These sets, defined as those that produce less than 0.5 MT, may happen in any fishing operation, but they are by far more common in school sets. The lack of association of the school results in less predictable behavior, and perhaps an earlier escape response.

Table 2 shows the proportion of skunk sets for the three areas, and for four types of sets (dolphin, school, logs, and FADs). For the corresponding figures (15a to 15c) the series for log sets in the Equatorial area was eliminated because of limited sample sizes.

TABLE 2. Percentage of skunk sets by set type and by region.



	Galapagos			
	Dolphin	School	Log	FAD
1994	4.7	46.8	18.8	10.1
1995	9.9	44.7	18	11
1996	8	33.2	19	11.6
1997	3.5	41.3	27.5	13.2
1998	5.8	35.6	18.6	10.6
1999	6.5	28.7	9.7	7.6
2000	7.4	28.2	10.4	10.6
2001	5.6	47.5	23.6	14.1
2002	5.4	45.2	17.9	8.9
2003	2.7	40.5	15.8	8.5
2004	4.9	39.9	23.7	9.2
2005	6.8	40.8	20	11.8
2006	6.1	40.6	23.4	13.9
2007	9.9	30.9	15.3	9.5
2008	8.8	30.6	19.5	12.3
2009	7.4	39.1	32.5	12
2010	8.7	36.1	12.2	11.1
2011	7.4	32.7	25.5	11.5
2012	10.6	32.1	29.6	11.4
2013	10.2	32	25.5	13.2
2014	5.9	37.2	29.4	9.2
2015	4.8	43.3	22.9	13.9

	Equatorial			
	Dolphin	School	Log	FAD
1994	1.3	42.1	18.2	6.6
1995	3.6	32.6	17.1	7.4
1996	1.8	50.5	16.7	7.1
1997	3.2	56.4	10	5.3
1998	3.7	48.7	12.2	5.1
1999	2.1	47.7	11.5	3.6
2000	2.1	48.5	7.1	5.1
2001	1	50	8.6	4.8
2002	1.3	45.1	8.3	4.2
2003	1.3	42.7	25	3.4
2004	0.8	48	14.7	6.8
2005	1.5	42.4	20.8	5.9
2006	1.7	45.8	8.3	7.3
2007	1.8	39.4	6.3	6.6
2008	0.4	42.9	21.7	8
2009	0.6	45.8	8.3	6.1
2010	1.6	30.7	10.3	5.7
2011	0.3	51	15.8	5.2
2012	0.9	46.7	13.8	5.4
2013	1.3	53.3	27.3	6.7
2014	1.3	35.6	8.7	4.3
2015	0.9	49.5	8.7	5.5

	Humboldt			
	Dolphin	School	Log	FAD
1994	2	24.2	9.1	9.3
1995	1.9	24	9.8	7.8
1996	4.2	31.1	16.2	14.3
1997	1.3	19.6	13.6	11
1998	3	36.2	15.5	10.2
1999	0	38.5	0	16
2000	1.8	27	7.7	12
2001	0.8	31.8	10.9	9.6
2002	0.9	30.6	7.9	6.3
2003	1.7	19.9	10	6.1
2004	0.9	22.8	23.6	11.3
2005	1.2	15.7	8.9	14.5
2006	0.9	16.7	15.5	13.7
2007	1.8	17.3	17.2	14.6
2008	1.1	17.2	7.1	12.3
2009	1	29	13	19
2010	0.9	30.7	14.3	16.8
2011	1.1	21.9	10.9	7.6
2012	1.1	21.5	21.1	12.2
2013	5.8	26.9	15.3	7.9
2014	1.9	24.3	13.7	11.2
2015	3.8	19.9	37.7	15.5

School sets: They always have the highest failure rate. The highest values are found in the Equatorial area, ranging more commonly from 40% to 50% of this type of set attempted. In the Galapagos region, it is 30% to 45%, and in the Humboldt region it is lower, usually in the range 20% to 35%. The deeper thermocline and the fastest currents in the Equatorial area may explain this. Current speeds are usually lower in the Humboldt area. Also the species and size composition of the schools may play a role, with bigeye tuna been much less abundant in the Humboldt area (Figure 9).

Dolphin sets: These are quite reliable. In the Equatorial and Humboldt areas the rate of skunk sets in usually below 2% of sets attempted, while in the Galapagos area raises to 5% to 10% (Table 2). The dolphin species involved, and the crew's experience in this type of sets may cause this difference.

FAD sets: The Equatorial region has the lowest values of % skunk sets (3.4% - 8.0%), consistently lower than the other regions. In the Galapagos area, the range is 7.6% - 14.1%, and in the Humboldt region it is 6.1% - 19.0% (Table 2). None of these show clear trends, suggesting that environmental factors (e.g. currents speeds, thermocline depth) and school behavior, rather than crew's skill determine the outcome. Sets on natural floating objects (Log sets) have higher failure rates than sets on FADs, but the sample sizes are smaller and do not facilitate the comparisons. For instance, the high value in 2015 in the Humboldt region comes from a relatively small sample size.

As a preliminary conclusion, it doesn't appear that the number of FADs deployed affects the success rate of the setting operations that are highly variable and show no obvious trends. The figures indicate the p-value for the significance of the slopes in a linear regression as a basic measure of the trend. (Figures 15a to 15c).

6. CATCH PER POSITIVE SET:

This is not a measure of catch per unit effort, but rather informs on the school sizes and the numbers of schools of the same or different species that are encountered feeding or associated with FADs or dolphins. The sum of the catches of all three major tropical tuna species (yellowfin, skipjack, and bigeye) was utilized to compute the catch per positive sets (CPPS) in each region of interest. In general, FAD and log sets produce larger CPPS than school sets, and all these are higher than dolphin sets (Table 3; Figures 16a to 16c). Combining this fact with the lower proportion of skunk sets shows that FAD fishing is the most productive way of fishing in terms of total tonnage produced per set attempted.

Captures in school sets show very little change, and the trends are not significant at the 0.05 level. (Figures 16a to 16c). Captures in dolphin sets also show a relative stability, and no significant slopes. Captures in log sets in Galapagos have a significant decline, but the sample sizes are relatively low. The variability of CPPS in FAD sets is very high; after a peak in 1999-2000 in all regions, the values show some declines in recent years.

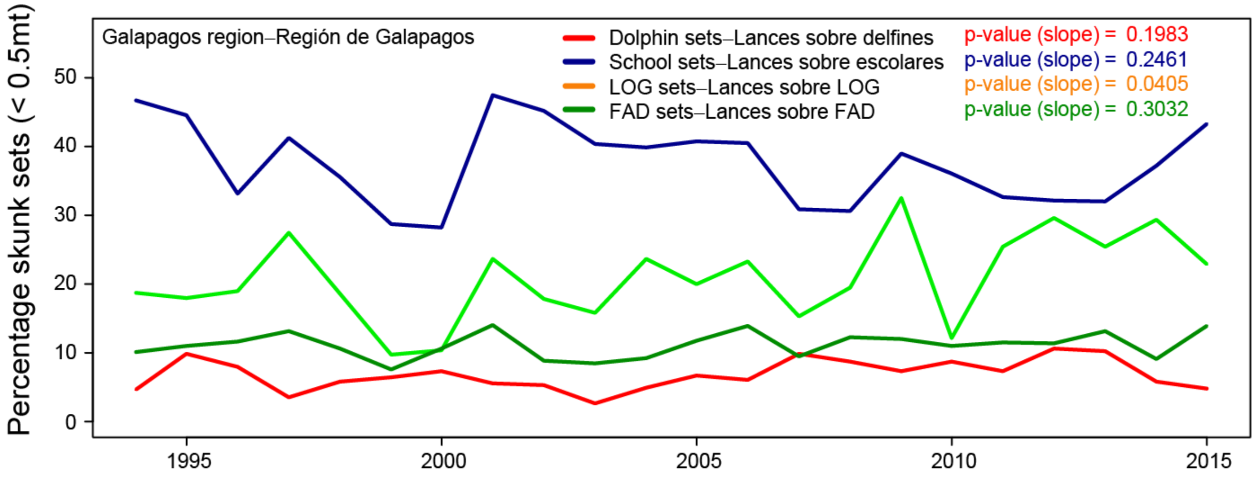


FIGURE 15a. Percentage of skunk sets by set type in the Galapagos region.

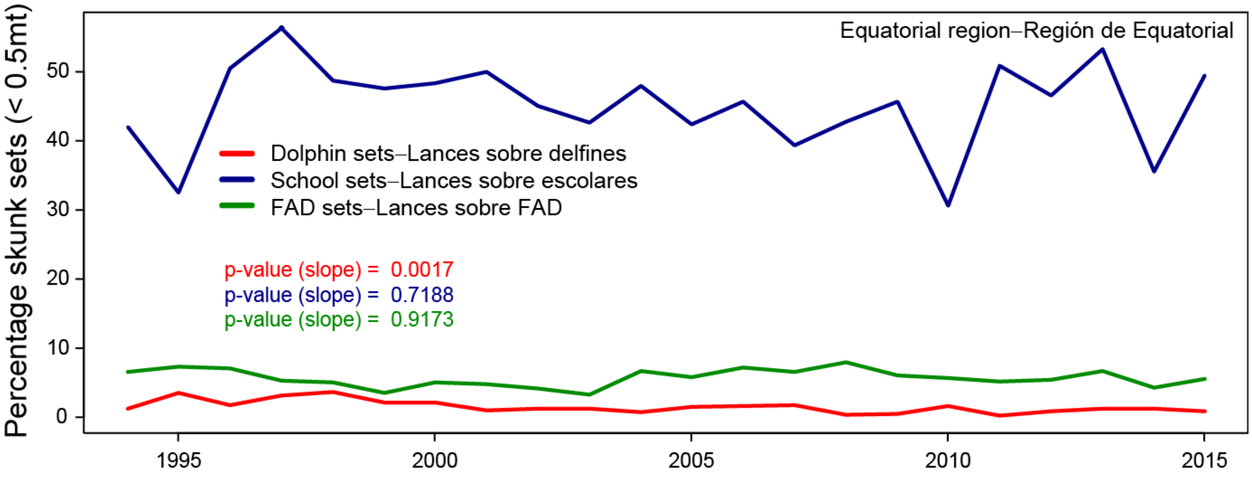


FIGURE 15b. Percentage of skunk sets by set type in the Equatorial region.

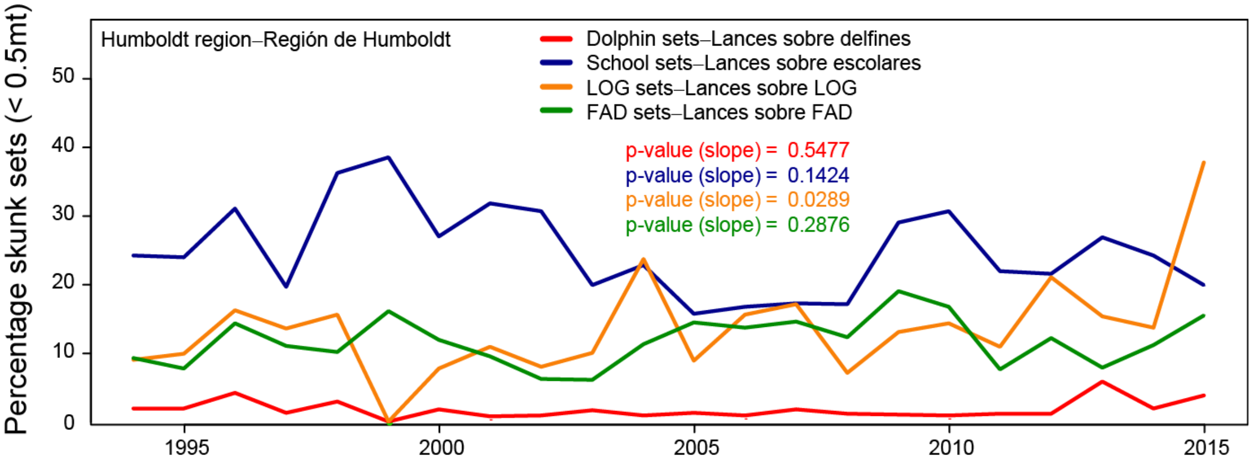


FIGURE 15c. Percentage of skunk sets by set type in the Humboldt region.

7. NUMBER OF FADs DEPLOYED BY REGION VERSUS CAPTURE PER POSITIVE SET (CPPS):

As the numbers of FADs deployed increased with time, it appeared interesting to explore the changes in CPPS with higher densities of FADs. Ideally, this type of study should be done with local densities of FADs and not aggregated over large regions, but with the current data available, it would require either running drift models for the objects deployed, or receiving from the companies the drifts of the FADs from satellite data.

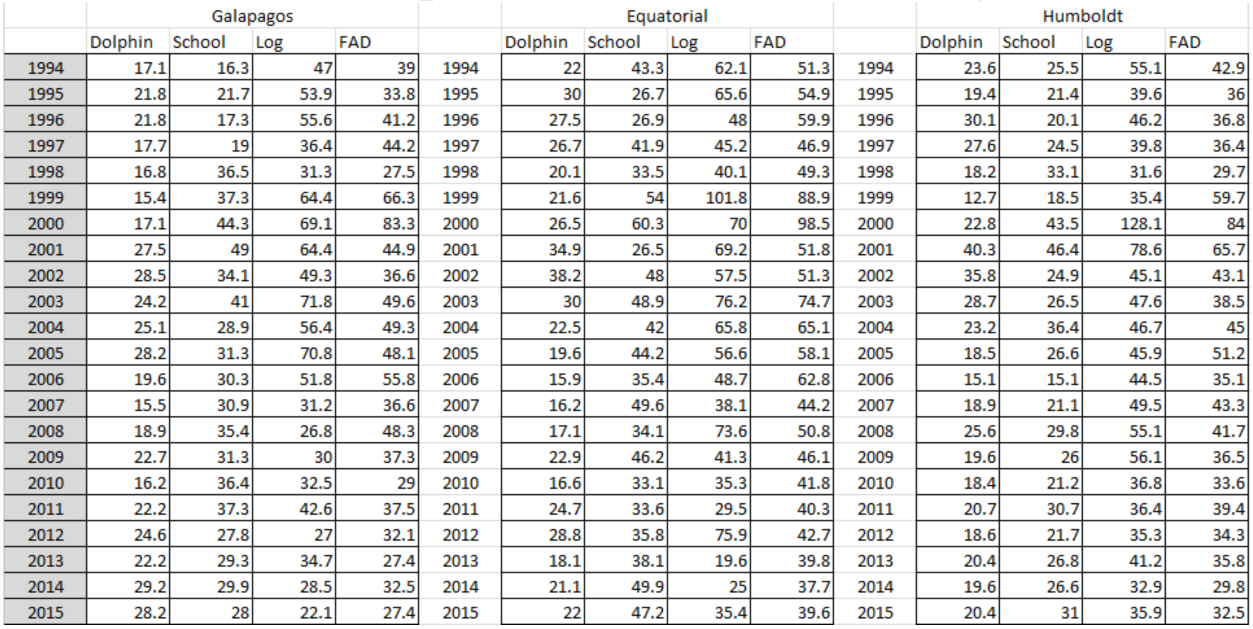
With more FADs in the water, there are several possible alternatives for their impacts on the fishery:

a. Skippers have more options, so they can pick FADs with more fish (then CPPS should increase), and avoid FADs with small schools or schools that are not closely associated with the FAD, based on acoustic data (then skunk sets should decrease).

b. With FADs “competing” with each other for the tuna schools, CPPS should go down. When there are few FADs in an area, they may attract several schools of tuna, and end up with higher CPPS values. With many FADs, many will end up with only one school or none. This issue can be further explored by looking at the length frequency data from individual sets, since the variability should be reduced when only one school becomes the prevalent case.

c. As the increase in number of FADs has been going on for a decade or more, the increased productivity of the fishery may be reflected on the biomasses of the species captured. Declines of abundance of tuna species may in turn be reflected in a) declines in the number of schools, or b) declines in average school size, or c) both. The first alternative could have been explored by looking at the changes over time of the proportion of FADs without any tuna aggregated or to some encounter rate measure, not available in this dataset. The second alternative may affect the CPPS value.

TABLE 3. Table 3_Capture per positive set by set type and by region.



	Galapagos					Equatorial					Humboldt			
	Dolphin	School	Log	FAD		Dolphin	School	Log	FAD		Dolphin	School	Log	FAD
1994	17.1	16.3	47	39	1994	22	43.3	62.1	51.3	1994	23.6	25.5	55.1	42.9
1995	21.8	21.7	53.9	33.8	1995	30	26.7	65.6	54.9	1995	19.4	21.4	39.6	36
1996	21.8	17.3	55.6	41.2	1996	27.5	26.9	48	59.9	1996	30.1	20.1	46.2	36.8
1997	17.7	19	36.4	44.2	1997	26.7	41.9	45.2	46.9	1997	27.6	24.5	39.8	36.4
1998	16.8	36.5	31.3	27.5	1998	20.1	33.5	40.1	49.3	1998	18.2	33.1	31.6	29.7
1999	15.4	37.3	64.4	66.3	1999	21.6	54	101.8	88.9	1999	12.7	18.5	35.4	59.7
2000	17.1	44.3	69.1	83.3	2000	26.5	60.3	70	98.5	2000	22.8	43.5	128.1	84
2001	27.5	49	64.4	44.9	2001	34.9	26.5	69.2	51.8	2001	40.3	46.4	78.6	65.7
2002	28.5	34.1	49.3	36.6	2002	38.2	48	57.5	51.3	2002	35.8	24.9	45.1	43.1
2003	24.2	41	71.8	49.6	2003	30	48.9	76.2	74.7	2003	28.7	26.5	47.6	38.5
2004	25.1	28.9	56.4	49.3	2004	22.5	42	65.8	65.1	2004	23.2	36.4	46.7	45
2005	28.2	31.3	70.8	48.1	2005	19.6	44.2	56.6	58.1	2005	18.5	26.6	45.9	51.2
2006	19.6	30.3	51.8	55.8	2006	15.9	35.4	48.7	62.8	2006	15.1	15.1	44.5	35.1
2007	15.5	30.9	31.2	36.6	2007	16.2	49.6	38.1	44.2	2007	18.9	21.1	49.5	43.3
2008	18.9	35.4	26.8	48.3	2008	17.1	34.1	73.6	50.8	2008	25.6	29.8	55.1	41.7
2009	22.7	31.3	30	37.3	2009	22.9	46.2	41.3	46.1	2009	19.6	26	56.1	36.5
2010	16.2	36.4	32.5	29	2010	16.6	33.1	35.3	41.8	2010	18.4	21.2	36.8	33.6
2011	22.2	37.3	42.6	37.5	2011	24.7	33.6	29.5	40.3	2011	20.7	30.7	36.4	39.4
2012	24.6	27.8	27	32.1	2012	28.8	35.8	75.9	42.7	2012	18.6	21.7	35.3	34.3
2013	22.2	29.3	34.7	27.4	2013	18.1	38.1	19.6	39.8	2013	20.4	26.8	41.2	35.8
2014	29.2	29.9	28.5	32.5	2014	21.1	49.9	25	37.7	2014	19.6	26.6	32.9	29.8
2015	28.2	28	22.1	27.4	2015	22	47.2	35.4	39.6	2015	20.4	31	35.9	32.5

As a preliminary look, we have computed the average CPPS in FAD sets by year for the three regions we have utilized in these analyses (Figure 17). We have used calendar year data, which could be close enough in some of the regions, but, for instance, it would fail to reflect deployments in November and December that affect catches in the first months of the year. This issue should be more important for the Humboldt reason because the seasonality of the fishery includes parts of two years.

For the three regions, CPPS showed significant declining trends when plotted against the number of FADs deployed (Figure 17). As this number has increased with time, the variable is confounded with a possible temporal change in the abundance of tuna stocks or with some environmental factor with a persistent increase over this period. However, the conclusion that deploying more FADs may result in lower CPPS may be useful for management, and deserves an in-depth look.

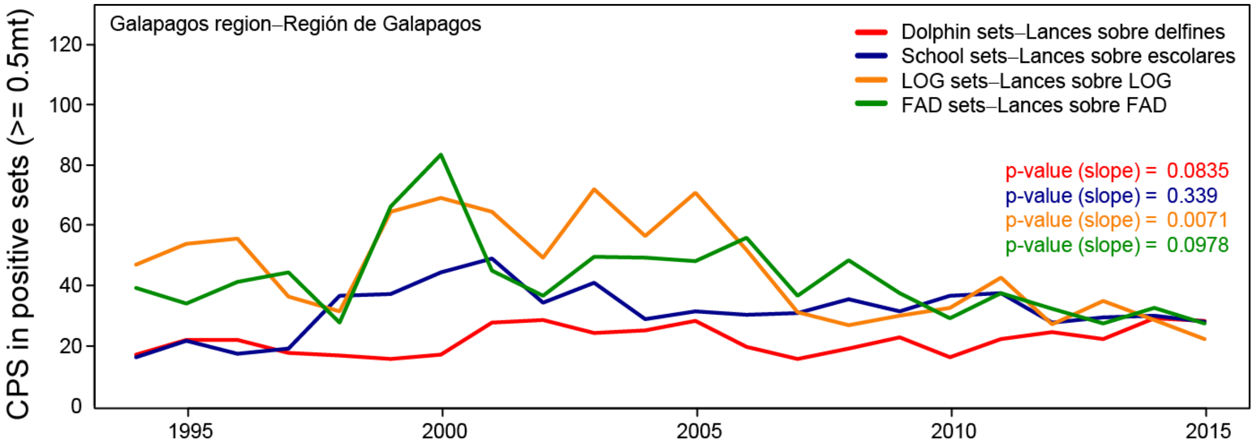


FIGURE 16a. Tuna capture per positive sets by set type in the Galapagos region.

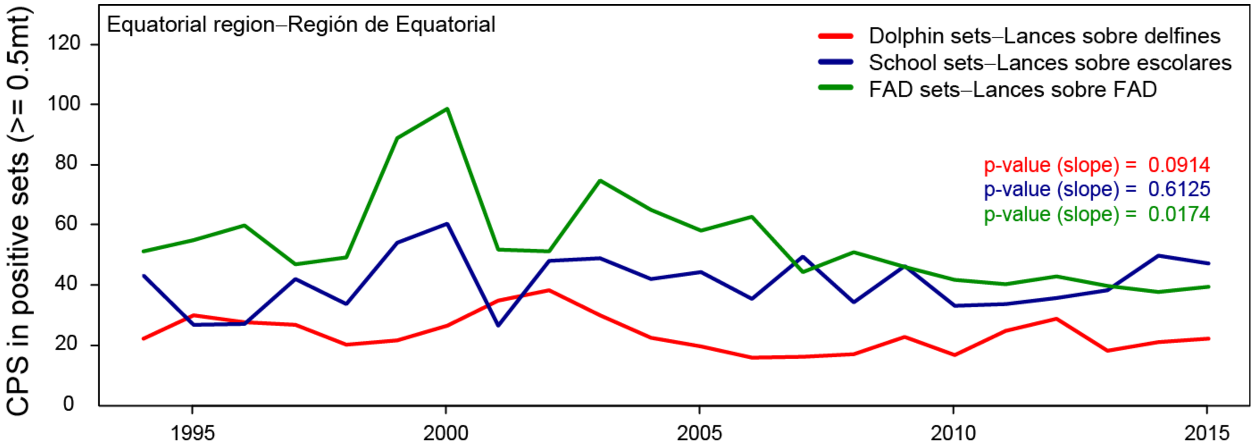


FIGURE 16b. Tuna capture per positive sets by set type in the Equatorial region.

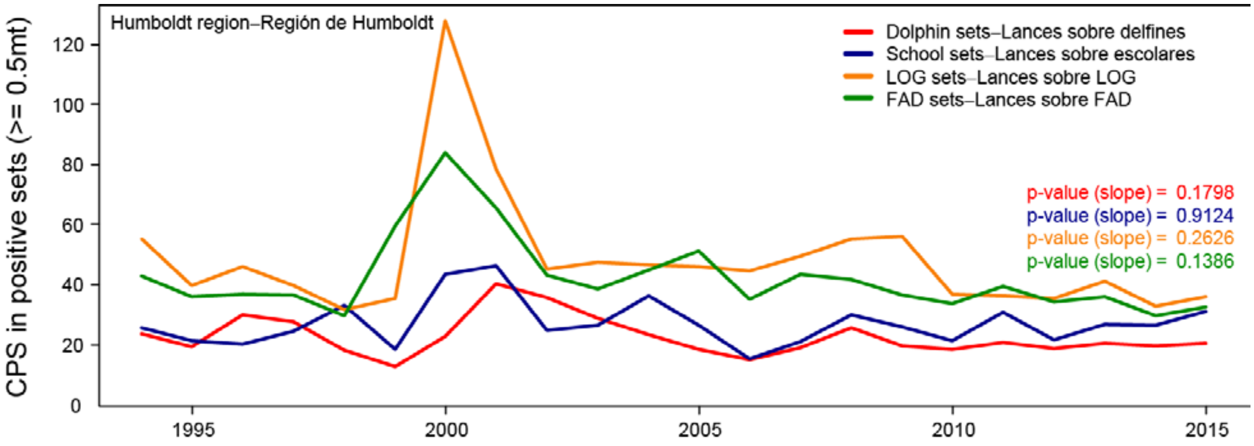


FIGURE 16c. Tuna capture per positive sets by set type in the Humboldt region.

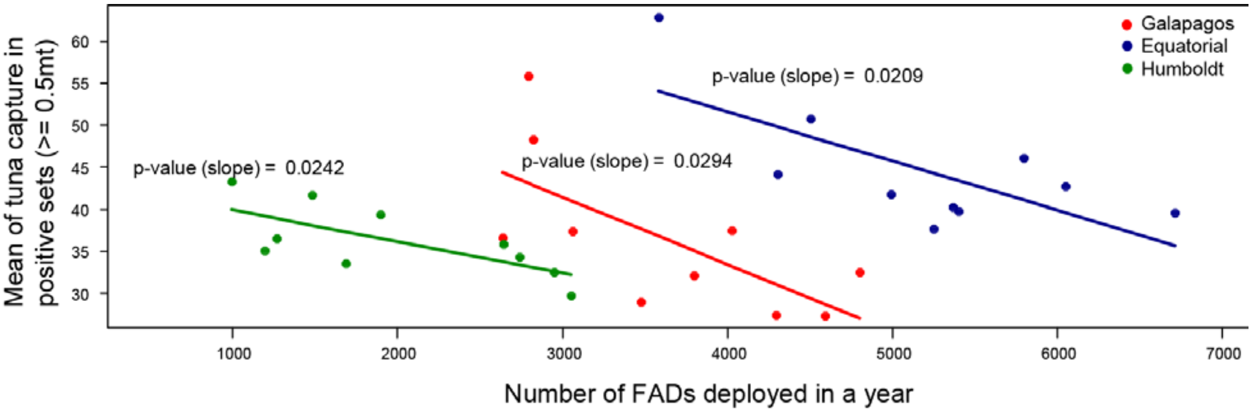


FIGURE 17. Average of the capture per positive sets of yellowfin, skipjack and bigeye tuna in FAD sets by year and by region.