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Circle hook effectiveness for catch of target species and incidental catch of sea turtles on a Taiwanese longline fishing vessel in the tropical Atlantic Ocean[1]

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Abstract

Considering the negative impacts of longline fishing on sea turtle populations worldwide, fishing trials were conducted to identify methods to reduce the incidental capture and mortality of sea turtles in commercial longline fishing gear. Specifically, research tested the effectiveness of relatively large circle hooks (18/0 circle hooks with a 10° offset) with whole finfish bait as compared to traditionally-used Japanese tuna hooks (4.2 sun). All experiments were conducted on board a single Taiwanese longline fishing vessel operating in the tropical Atlantic Ocean. The experiment was conducted from September 2012 to May 2013 between 2° S and 12° S and 17° W and 26° W. Traditional tuna and circle hooks were sequentially alternated throughout the experimental portion of the set with a 1:1 ratio. Bait types used were milkfish (*Chanos chanos*), mackerel (Family Scombridae), and sardines (Family Clupeidae), which were comparable in size (182-220g). Fisheries observers monitored 200 sets that included comparisons of 407,677 hooks. Overall, 36 turtles were hooked and an additional 19 were entangled in the mainline, branch line or buoy line. Species' totals included 47 leatherback (*Dermochelys coriacea)*, 7 olive ridley (*Lepidochelys olivacea*) and one loggerhead (*Caretta caretta*) turtle. Randomization tests were used to test for significant differences in target bigeye tuna (*Thunnus obesus*) catch, sea turtles and other commonly caught species. There were no significant differences for sea turtle catch rates by hook type (p=1.000), but there was a significantly higher catch rate of bigeye tuna (p=0.0002), yellowfin tuna (p= 0.0045), swordfish (*Xiphias gladius*, p=0.0001), and blue sharks (*Prionace glauca*, p= 0.0209) on circle hooks as compared to traditional tuna hooks. Significantly higher catch rates were observed for albacore tuna (p=0.0010) and spearfish (*Tetrapturus pfluegeri*)

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(p=0.0097) caught on tuna hooks as compared to circle hooks. In conclusion, use of circle hooks was found to increase the catch rate of a number of targeted fish species. However, there was no reduction (or increase) in sea turtle catch rates. Fishermen perceived the increase in catch rates on circle hooks due to higher retention perhaps due to the greater (10°) offset as compared to no offset in the traditional tuna hook.

Keywords: leatherback turtle, loggerhead turtle, bycatch, longline

1. Introduction

Sea turtle bycatch occurs in a broad array of fisheries, including trawl gear, gillnets and longline fisheries (FAO 2009). Numerous studies have shown relatively high rates of sea turtle captures in longline gear in all major ocean basins (Wallace et al. 2013, Wallace et al. 2010). These interactions have been documented in the Atlantic Ocean (Barceló et al. 2013, Sales et al. 2010, Watson et al. 2005, Witzell 1999), Pacific Ocean (Donoso and Dutton 2010, Lewison et al. 2004, Swimmer et al. 2010a, Swimmer et al. 2010b), and in the Mediterranean Sea (Camiñas et al. 2006, Piovano et al. 2009). In the Atlantic Ocean, the estimated sea turtle bycatch rates were highest at 2.4 per thousand hooks for leatherback (*Dermochelys coriacea)* and 14 per thousand hooks for loggerhead turtles (*Caretta caretta*) according to summarized sea turtle bycatch data between 1980 and 2008 (Lewison et al. 2004). For conservation purposes, both leatherback and loggerhead sea turtles, as well as all sea turtle species, are listed as endangered and are protected under Taiwanese and United States laws.

Considering the negative impacts of incidental catch by longline fisheries on sea turtle populations, there has been extensive research aimed to identify means to both maintain target species capture rates while simultaneously reducing sea turtle bycatch in longline fishing gear. A number of experiments have shown that use of relatively large circle hooks in combination with finfish bait can significantly reduce the frequency of sea turtle hooking as compared to J-hooks or tuna hooks with squid bait (Read 2007, Serafy et al. 2012, Watson et al. 2005). Additionally, it is widely assumed that “use of circle hooks is more likely to result in superficial hooking, such as in the jaw or flipper, as compared to more frequent deep ingestions of hooks observed on J-hooks or tuna hooks. Hence, when properly handled, a sea turtle with a superficial hooking is believed to have a higher probability of survival after being released than a deep-hooked animal” (Serafy et al. 2009). Based upon the conservation values attributed to circle hook use, some regional fisheries management organizations largely promote, and in some cases, advocate (e.g., Western and Central Pacific Fisheries Commission Conservation and Management Measure 2008-03) circle hook use in shallow set longline fisheries. However, there is some concern that use of circle hooks may result in reduced capture rates of target species, in particular swordfish (*Xiphias gladius)*, as has been observed in some experimental trials (Read 2007, Serafy et al. 2009).

Despite the extensive research aimed to determine the conservation value of circle hook use in longline fisheries, there has been limited information on circle hook use on large-scale deep water tuna longline fleets on the high seas. The effects of circle hook use on deep-set longline fleets are less clear, largely due to the substantially lower interaction rates of sea turtle hooking on deeper set hooks (Gilman et al. 2006). In a number of fisheries, including in Hawaii, it has been observed that deeper sets have less sea turtle bycatch than shallow sets (see Gilman et al. 2006, US National Marine Fisheries Service 2002), but it remains unclear if these differences are due to hook depth alone or to other aspects of the operation, such as day vs. night-setting (Gilman et al. 2006).

In this study, we seek to better understand the effects of circle hook in a deep-set bigeye tuna (*Thunnus obesus*) fishery. Use of circle hooks may reduce turtle bycatch in deep-set fishing and possibly reduce the severity of injury of hooking for animals that will be released alive. Specifically, this study compared catch rates of bigeye tuna and sea turtles in a deep set longline fishery in the Atlantic Ocean between large circle hooks (18/0 circle hooks [>49mm]) and a traditional Japanese style tuna hook (4.2 sun) on a Taiwanese fishing vessel operating in the tropical Atlantic Ocean.

2. Materials and Methods

2.1 Study region and fishing gear

There are three fleets of Taiwanese longline vessels operating in the Atlantic Ocean. Specifically, fleets that target albacore (*Thunnus alalunga*) in the north and south Atlantic, and a bigeye targeted fishery in the tropical Atlantic. Among the three fleets, the bigeye fleet in the tropical areas has the highest rate of sea turtle captures as compared to the albacore fleets (Huang 2012).

This study was conducted on a Taiwanese commercial longline fishing vessel of 51.65 m and a GRT of 496 tons. The vessel operated in the tropics between 2° and 12° S and between 17.0° and 26.0° W during September 2012 to May 2013 (Figure 1).

The fishing gear consisted of a standard multi-stranded monofilament mainline of 4 mm diameter, with 16-17 branch lines between floats. Each branch line was ~53 m in length and the length of the floatline was 45 m.

On each set, approximately 3500 hooks were deployed, of which the initial ~2040 hooks were observed in the experiment. Lines were deployed at approximately 0400~0600 and were soaked 5-7 hours prior to initiating retrieval. Gear haul back started at approximately 1200-1400 hours and lasted for 15-17 hours.

2.2 Sampling design and Data Collection

A power analysis was used to calculate the minimum number of sets (and hooks) in order to detect a difference in bigeye capture rates between hook type with alpha=0.10 and beta= 0.2 or power=80% assuming two-sided hypothesis on two proportions (null being no difference in the two catch rates versus alternative being difference). We determined that a sample size of 200 sets was sufficient for our experimental goals. Experimental and control hooks were sequentially alternated along the length of the experimental portion of the line in a 1:1 ratio.

A size 18/0 stainless steel and Korean-made circle hook with 10° offset (<49mm max dimension) was used as the experimental hook and a Japanese tuna hook (4.2 sun) was used as the control (Figure 2). Both hooks had rings. In consideration for the observer's time and workload, the experimental portion of the gear consisted of approximately the first 2,040 hooks, 1,020 of each type, which were arranged in an alternating fashion along the mainline (e.g., control hook, experimental hook, control hook, etc.). The gear was deployed with 16-17 branch lines evenly spaced between floats. Branch lines were marked at the snaps to assist with identifying the hook type on the other end.

Three species of whole finfish were used for bait throughout the experiment. The bait types were milkfish (*Chanos chanos*), mackerel (Family Scombridae) and sardine (Family Clupeidae), which were comparable in size (182-220g). The weight of milkfish and mackerel were ~ 180-220 g and the average weight of sardine was 200 g. Baiting techniques remained consistent throughout the experiment and are described as single-threaded (Figure 3).

For each set, the fisheries observer recorded the start times and locations (latitude and longitude) of initial set and retrieval, number of hooks deployed, sea water temperature (SST), bait types, catch and bycatch information. Whenever possible, catch composition information included the number of individuals (including bycatch) by species retained, discarded, and live-released by hook type and hook position between floats. Additionally, weights of retained catch (kg) and evidence of depredation by sharks, cetaceans, and unknown animals was also recorded. Additional data collected on incidentally caught sea turtles included bait type, condition when landed and released (dead/alive), catch (hooked or entangled), and if hooked, the hooking location (e.g., flippers, mouth, beak), turtle size (e.g., carapace curve length [CCL]), and, if possible, sex. Whenever possible, turtles were landed on board and hooks were removed by the observer using NOAA-approved methods (Epperly 2004). Due to the large size of leatherback turtles, however, some of them were immediately released by cutting off the line without bringing the turtle on board, and as such, it was often not possible to determine if turtles had also been hooked in addition to their entanglement. Some leatherbacks were landed on board using a fabricated harness prior to release to sea.

2.3 Data Analysis

Descriptive statistics were used to estimate the nominal catch rate. Due to the non-normal distribution of sea turtle bycatch, a randomization test (Manly 2007) was used to assess catch differences between hook types as described in a review on experimental design and statistical methods for longline fisheries. The null hypothesis was that there would be no difference in catch between paired hook types. The test statistic (S) was the mean difference in catch between paired control circle hooks and circle hooks by set. Data were randomized, re-sampled 10,000 times, and scored for whether or not the re-sampled S value was equal to or greater than the observed S value (R Development Core Team 2008, version 2.7.2 for Linux). Randomization tests provide a measure of the strength of evidence against a null hypothesis.

3. Results

3.1 Fisheries operation

A total of 200 sets were conducted with a mean number of hooks per set= 2,672 (± 457). In each set, around 2,040 hooks were observed, with a total of 407,677 hooks observed. Locations of fishing effort are illustrated in Figure 1. The sea surface temperature ranged between 25°C and 29°C.

3.2 Sea turtle incidental catch and the effect of hook type on turtles

In total, 55 turtles were captured, including 18 caught on circle hooks, 18 on traditional Japanese tuna 4.2 sun hooks, and 19 entangled either in the mainline (n=12), branch line (n=2) or buoy line (n=5). The bycatch distribution by species is illustrated in Figure 1. Leatherback turtles represented the highest proportion of turtle catch by species (85.5%, n=47), followed by olive ridley (12.7%, n=7) and one loggerhead turtle (1.8%). The loggerhead and the majority (57%) of olive ridley turtles (n=4) were caught on Japanese tuna hooks. Leatherback turtle captures were evenly distributed by hook type and entanglement (14 on Japanese tuna hook, 15 on circle hooks and 18 entangled) (Table 1).

Of the 200 sets, 30 sets (15%) caught at least one sea turtle, and no turtles were caught on 170 sets. The highest bycatch occurred when 2 turtles were hooked and 2 turtles were entangled on a single set on November 15, 2012. Overall, multiple captures occurred on 12 sets, representing 6% of total sets. All (100%) hooked turtles were captured on the 4 hooks closest to the floats, and 64% (23 of 36) were captured on the first two hooks closest to the floats.

Regarding the live/dead status, all (n=8) hard-shelled turtles (loggerhead and olive ridley) were dead upon retrieval. The majority (66%) of leatherback turtles were released alive. Of the 16 dead leatherback turtles, 11 (69%) had been entangled in the line (Table 1).

Regarding the anatomical hooking location, the majority of hard-shelled turtles were hooked externally, and this did not differ between hook types. Of the 47 leatherback turtles captured during the experimental trials, 18 (38%) were entangled in the lines, and the majority were externally hooked (Table 2).

Hooked leatherback turtles ranged in size (curved carapace length, CCL) from 92 to 151 cm (average = 118.9 for tuna hooks and 124.0 for circle hooks). Olive ridley turtles ranged in size from 56 cm to 65 cm (average 58.3 for tuna hooks and 62.3 for circle hooks). The loggerhead turtle was 78 cm (Table 3).

Our analysis included hooked leatherback (n=29), olive ridley (n=6) and loggerhead (n=1) turtles. Catch rates of combined sea turtle species (n=36) were similar between hook types ($p = 1.000$) (Table 4). Entangled turtles were omitted from comparative hook analysis.

3.3 Effect of hook type on fish catch composition

In total, there were 38 species caught, of which six were commercial species with greater than 100 individuals caught per species. These included three species of tuna (bigeye, yellowfin, albacore), swordfish, spearfish, and blue shark. Lengths of the major retained species captured were similar between hook types (Table 3).

Catch rates of bigeye tuna (p=0.0002), blue shark (p=0.0209), swordfish (p=0.0001), and yellowfin tuna (p=0.0449) were statistically higher on circle hooks as compared to Japanese tuna hooks (Table 4). Catch rates of albacore tuna (p= 0.0100) and spearfish (p=0.0097) were significantly higher on Japanese tuna hooks compared to circle hooks; Table 4), while catch rates for other recorded species were similar (Table 4).

We observed that survival rates (proportion alive) upon retrieval were slightly higher for bigeye tuna and slightly lower for albacore on circle hooks as compared to tuna hooks, but that survival rates upon retrieval were similar for the other major species recorded (Table 5). For sea turtles, the percentage of turtles alive upon retrieval appears slightly higher for leatherback turtles caught on circle hooks as compared to tuna hooks, but statistical analyses were not conducted.

4. Discussion

Capture rates were higher on circle hooks as compared to Japanese tuna hooks for bigeye tuna, swordfish, and blue sharks, yet there was no difference in the catch rates of sea turtles between hook types. Significantly higher catch rates of albacore and spearfish were observed on Japanese tuna hooks as compared to circle hooks. Additionally, there was no difference in the size distribution of any species between hook types.

Circle hook use has been shown to have inconsistent results with regards to catch composition, likely as a result of the difficulty in isolating explanatory variables. For example, it is abundantly clear that aspects of the gear and fishing operation play large roles in influencing catch composition and abundance, but the relative roles of each remain largely uncertain. Important variables to consider include hook shape, hook size, bait type (e.g., squid vs. fish), presence of ring, degree of hook offset, baiting technique, and fishing location. At present, it is largely believed that factors such as bait type (e.g., fish vs. squid), hook size, hook shape and depth are largely responsible for catch composition (Serafy et al. 2012), yet even in this study the fishermen report their belief that the findings were largely a result of degree of offset. In an investigation on the potential selective advantages of a 10 degree hook offset in Costa Rican longline fishery, Swimmer et al. (2010a) found catch composition, abundance, and anatomical hooking locations to be similar for circle hooks with and without an offset. Differences due to hook type, however, may be more apparent when an offset circle hook is compared to a non-offset tuna hook, as in this study.

The finding of higher capture rates of targeted bigeye tuna on circle hooks compared to tuna hooks is consistent with other results in similar studies in the Atlantic ocean (Domingo et al. 2012, Sales et al. 2010, Watson et al. 2005). Additionally, we observed that circle hooks resulted in higher catch rates of yellowfin tuna and swordfish, both of which are highly valued. Additionally, the higher rates of bigeye tuna retrieved alive on circle hooks also suggest a higher fish quality with increased commercial value. Subsequent to these findings in various studies, many fishers have substituted circle hooks for traditional hooks.

We are uncertain as to the exact role of bait given that three species of fish were used as bait throughout the experiment. However, use of fish as opposed to squid may account for the relatively low catch rates of hooked sea turtles observed in this study given that use of fish bait (vs. squid) has been shown to reduce sea turtle capture rates in other studies (Watson et al. 2005, Yokota et al. 2009). Type of bait is also believed to play a role in capture of sharks. The higher capture rates of blue sharks on circle hooks as compared to tuna hooks in the study is incongruous with the results of Curran and Bigelow (2011) and Yokota et al. (2006) in the Pacific Ocean, yet similar to findings of Watson et al. (2005) and Sales et al. (2010) in the Atlantic Ocean. In the case of sharks, hook type, size, bait and even ocean basin may play a role in capture rates.

This study found higher catch rates of swordfish on circle hooks as compared to tuna hooks, which was somewhat surprising given lower catch rates of swordfish by circle hooks observed in other studies (Domingo et al. 2012, Piovano et al. 2009, Sales et al. 2010, Watson et al. 2005). However, Watson and colleagues (2005) found that use of fish bait (vs. squid) resulted in a significant increase (19% by weight) of swordfish caught on circle hooks vs. J hooks, suggesting that use of fish bait may have accounted for the differences (Serafy J et al. 2012) and that differences in metrics (e.g., # of individuals vs. weight) can also play a role in study results. In this study, there were no differences in the sizes of swordfish caught between hook types.

With regards to the conservation value of circle hooks, their use in this study was not associated with fewer sea turtles captured, unlike observations in some other studies (Piovano et al. 2009, Sales et al. 2010). This study is one of very few, however, whereby the majority of sea turtles captured represent leatherback turtles as opposed to loggerheads, which is the species most often associated with capture in longline fisheries.

The somewhat higher percentage of leatherback turtles captured alive on circle hooks as compared to tuna hooks suggests that circle hook use on a wider scale might reduce the negative impacts of longline fisheries in areas where fisheries and leatherback foraging grounds overlap, such as the tropical Atlantic.

The relatively high capture rate of leatherback turtles as well as their relatively high immediate survival rate may be a direct result of fishing gear depth and the somewhat shallow distribution of leatherback turtles. All (100%) of hooked turtles were caught on the 4 hooks closest to the floats, and the majority of these were caught on the first two, providing further evidence for the shallow distribution and hooking interactions between sea turtles and longline fishing gear (Gilman et al. 2006). We believe the survival rate was higher for leatherbacks as compared to the two species of hard-shelled turtles due to the relatively large size and known strength of leatherback turtles that allow them to swim to surface to breathe.

Overall there were fewer turtles captured in this experiment than what was expected, likely as a result of the deep setting of hooks. Achieving these depths was facilitated by the unusually long length of the branch lines, which may have been beyond the depth range typically occupied by turtles. The nature of entanglement interactions, particularly with leatherback turtles, precluded the ability to determine the depth of the initial entanglement.

According to comments of the captain and crew, the experimental hooks have the problem of not bending. The hardness of the stainless steel hook doesn't allow the crew to re-shape the hook back to its original configuration, thus the crew changes the circle hooks more often than tuna hooks. The replaced hooks cannot be recycled and repaired by regular methods, but the crew thought it an advantage of circle hooks that they better retained caught fish, since they are not easily de-hooked. However, this may also result in increased injuries associated with efforts to de-hook and release incidentally caught fish, thereby possibly reducing chances of it's post-release survival.

As an aside, neither marine mammals nor seabirds were captured during the 200 sets in this study. Seabirds were not expected to be captured due to the latitudes of fishing activity.

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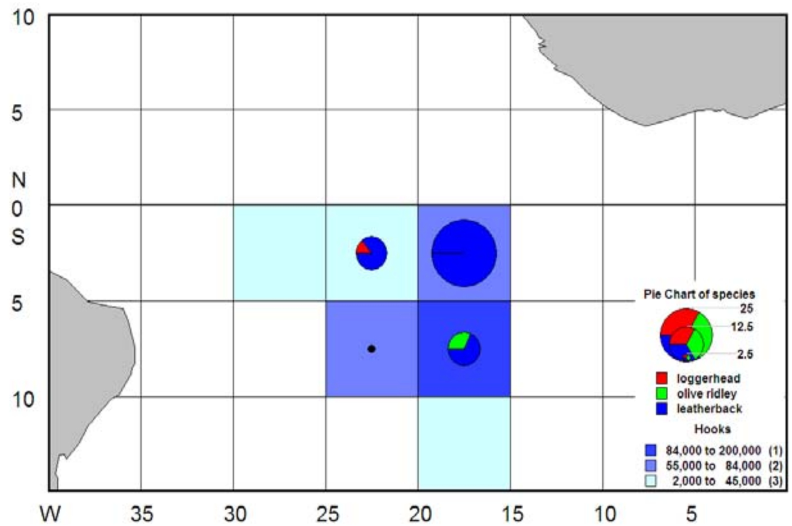

Figure 1. Fishing Positions and bycatch distribution by turtle species

Figure 2. Dimensions of tuna (left) hook and circle hooks (right)


Figure 3. Threading technique

Table 1. Sea turtle catch number by species and number of individuals by hook type

	Loggerhead	Olive ridley	Leatherback	**total**
Tuna hook	**1**	**3**	**14**	**18**
Dead	1	3	4	8
Alive	0	0	10	10
Circle hook	**0**	**3**	**15**	**18**
Dead	0	3	2	5
Alive	0	0	13	13
Entangled	**0**	**1**	**18**	**19**
Dead	0	1	10	11
Alive	0	0	8	8
Total	**1**	**7**	**47**	**55**

Table 2. Sea turtle anatomical hooking locations

Unit: number

	Tuna hook	Circle Hook	Entangled	Total
Not hooked			***19***	***19***
Unknown hooking location	***2***	***1***		***3***
External	***11***	***11***		***22***
front flipper	6	2		8
shoulder	1	1		2
armpit	1			1
rear flipper	1	2		3
beak	1	1		2
neck	1	5		6
Internal	***5***	***6***		***11***
Beak-upper-jaw		2		2
Beak-lower-jaw	4	1		5
mouth-tongue	1			1
roof of mouth		2		2
mouth-jaw joint		1		1
Total	***18***	***18***	***19***	***55***

Table 3. Catch size composition (cm) by species and hook type

	Tuna hooks		Circle hooks	
Species	**Average (±SE)**	**Range(cm)**	**Average (±SE)**	**Range(cm)**
Turtles (CCL)				
Loggerhead	**78.00**	78 ~78		
Olive Ridley	**58.33±3.21**	56 ~62	**62.33±3.06**	59 ~65
Leatherback	**118.92±19.79**	93 ~151	**124.00±15.68**	92 ~147
Tuna				
Albacore	**104.14±4.32**	92 ~126	**103.95±3.88**	96 ~111
Bigeye tuna	**134.45±23.53**	76 ~193	**135.44±23.31**	76 ~192
Yellowfin tuna	**139.74±13.97**	103 ~164	**140.02±13.37**	117 ~170
Billfish				
Swordfish	**163.77±23.72**	113 ~248	**169.93±25.56**	76 ~265
Blue marlin	**200.63±18.22**	157 ~226	**201.42±23.92**	169 ~263
Spearfish	**162.31±10.84**	131 ~206	**162.36±18.32**	130 ~282
Sharks				
Blue shark	**185.34±17.50**	70 ~ 232	**183.90±16.79**	70 ~255
Mako shark	**147.75±48.87**	80 ~185	**174.67±22.24**	151 ~227

Table 4. Catch of species by hook type and statistical comparison based on randomization tests

	Hook type	Total number	Average number Per set	p value
Bigeye tuna	C	1155	5.78	0.0002
	Tuna	945	4.73	
Yellowfin tuna	C	65	0.33	0.0449
	Tuna	41	0.21	
Albacore	C	67	0.34	0.0010
	Tuna	103	0.52	
Swordfish	C	341	1.71	0.0001
	Tuna	220	1.10	
Spearfish	C	115	0.58	0.0097
	Tuna	146	0.73	
Blue shark	C	611	3.06	0.0209
	Tuna	564	2.82	
Sea turtles (combined)	C	18	0.09	1.0000
	Tuna	18	0.09	

Table 5. Percentage of alive and dead by hook type and species

Hook type	**Circle Hook**			**Tuna Hook**		
Species	**Alive**	**Dead**	**Not recorded**	**Alive**	**Dead**	**Not recorded**
bigeye tuna	45.5%	50.6%	3.8%	41.9%	54.7%	3.4%
blue shark	67.8%	31.9%	0.3%	68.6%	31.0%	0.4%
swordfish	15.0%	83.0%	2.1%	15.0%	82.7%	2.3%
spearfish	13.9%	85.2%	0.9%	12.3%	84.2%	3.4%
albacore	31.3%	67.2%	1.5%	22.3%	74.8%	2.9%
yellowfin	29.2%	67.7%	3.1%	26.8%	68.3%	4.9%
Loggerhead	0%	0%	0%	0%	100%	0%
Olive ridley	0%	100%	0%	0%	100%	0%
Leatherback	86.7%	13.3%	0%	71.4%	28.6%	0%