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## Differential loggerhead by-catch and direct mortality due to surface longlines according to boat strata and gear type

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**SUMMARY:** Surface longline gears are used to fish different species, mainly albacore *Thunnus alalunga* (Bonnaterre, 1788), bluefin tuna *Thunnus thynnus* (Linnaeus, 1758), and swordfish *Xiphias gladius* Linnaeus, 1758, and are considered highly dangerous for threatened marine turtles. Loggerheads *Caretta caretta* (Linnaeus, 1758) can be incidentally captured by surface longlines. A number of captured individuals die during the fishing operation, which we consider direct mortality due to fishing. We analysed the relative loggerhead by-catch and direct mortality associated with each type of boat and gear from April to December during the period 1999-2004 in the Spanish surface longline fleet that fishes in the western Mediterranean Sea, an important fishing area for this fleet. We used different indices to compute the catch per unit effort (CPUE) according to the number of hooks and to the number of fishing operations for each type of boat and gear. Both by-catch and direct mortality differed significantly according to the type of boat and gear. With respect to the number of hooks, boats longer than 12 m not using a roller and targeting bluefin tuna captured the highest number of loggerheads, whereas boats longer than 12 m with a roller that targeted swordfish caused the highest direct mortality. With respect to the number of fishing operations, boats longer than 12 m without a roller that targeted albacore captured the highest number of loggerheads; the highest direct mortality was caused by this type of boat and by boats longer than 12 m using a roller and targeting swordfish.

**Keywords:** *Caretta caretta*, drifting longline, fisheries, incidental capture, pre-release mortality, sea turtle.

**RESUMEN:** DIFERENCIAS EN LAS CAPTURAS NO DIRIGIDAS Y MORTALIDAD DIRECTA DE TORTUGA BOBA EN PALANGRE DE SUPERFICIE DE ACUERDO AL ESTRATO DE FLOTA Y TIPO DE APAREJO. – El palangre de superficie es usado para la pesca de diferentes especies, fundamentalmente atún blanco *Thunnus alalunga* (Bonnaterre, 1788), atún rojo *Thunnus thynnus* (Linnaeus, 1758) y pez espada *Xiphias gladius* Linnaeus, 1758, y es considerado altamente peligroso para las tortugas marinas amenazadas. La tortuga boba *Caretta caretta* (Linnaeus, 1758) puede ser capturada incidentalmente por el palangre de superficie y un número considerable de ellas puede morir durante la operación de pesca, y son consideradas como muertas directamente en el palangre. En este trabajo se analizan la capturas incidentales y la mortalidad directa relativa asociada a cada tipo de barco y aparejo de pesca, desde abril a diciembre durante el periodo 1999-2004, en la flota palangrera española en el Mediterráneo occidental, una importante área de pesca para esta flota. Se usaron diferentes índices para calcular las capturas por unidad de esfuerzo (CPUE) de acuerdo al número de anzuelos y al número de operaciones de pesca para cada tipo de barco y aparejo. Tanto las capturas no dirigidas de la tortuga boba como la mortalidad directa presentan diferencias significativas en función del tipo de barco y aparejo. Con respecto al número de anzuelos, los barcos mayores de 12 m de eslora sin rulo y especie objetivo atún rojo presentaron el mayor número de capturas relativas de tortuga boba, mientras que los barcos mayores de 12 m de eslora con rulo y especie objetivo pez espada presentaron los mayores valores de mortalidad directa. En función del número de operaciones de pesca, los barcos mayores de 12 m de eslora sin rulo y especie objetivo atún blanco presentaron el mayor número de capturas relativas de tortuga boba, mientras que los mayores índices de mortalidad directa relativa fueron observados en éstos y en los barcos mayores de 12 m con rulo y especie objetivo pez espada.

**Palabras clave:** captura no dirigida, *Caretta caretta*, mortalidad directa, pesquerías, tortugas marinas, palangre de superficie.

## INTRODUCTION

*Caretta caretta* (Linnaeus, 1758) is included in the red list of threatened species of the IUCN (2001) (<http://www.redlist.org/>), and is considered to be a species of interest in the European Union and Spain (Official Journal of the European Union 1997 - 8.11.97/L305/50-; B.O.E. 1990 -5.4.90/9470/82-). Surface longline is considered one of the most dangerous fishing gears for threatened marine turtles (Lewison *et al.*, 2004), and is the main threat for the marine turtle populations of the western Mediterranean Sea (Aguilar *et al.*, 1992; Camiñas 1997; Camiñas and Valeiras, 2001). Many Mediterranean countries use this surface gear to target different species, mainly albacore *Thunnus alalunga* (Bonnaterre, 1788), bluefin tuna *Thunnus thynnus* (Linnaeus, 1758), and swordfish *Xiphias gladius* Linnaeus, 1758.

Loggerheads can be incidentally captured by surface longlines but information on direct mortality of this or other marine turtles is scarce (Laurent *et al.*, 2001). As a number of loggerheads are caught dead, we consider this number as the direct pre-release mortality, and we will refer to it as direct mortality hereafter. Surface longline fishery is a very important activity for the Spanish fleet in the Mediterranean Sea (Camiñas *et al.*, 1992), which is comprised of different boat strata that target different species by modifying the surface longline (using different lengths, baits, fishing depths, hooks and rollers) according to the season, target species abundance, market conditions and boat length (see Table 1). Since 2003 a new gear type called “american” and also “roller” has been introduced into the fleet, which implies a reduction in the number of hooks and an increase in the main line length and the depth of fishing (Báez *et al.*, 2005). This modified surface longline increases the distance between hooks (21 m in traditional long-line SWB and 90 m in SWBr, abbreviations as in Table 1) and the length of the gear (30-40 nautical miles in traditional long-line and 60-70 nautical miles total length in SWBr),

reducing the average number of hooks to 1000 (versus >2500 mean number of hooks in traditional surface longline), and the time needed to board the gear to 6-7 hours, which entails a 2-3 hour reduction with respect to the traditional longline.

An onboard observer program was implemented by the IEO (Spanish Institute of Oceanography) to obtain direct information from the fisheries regarding target and incidental species. In this paper we analyse the data obtained in the above mentioned program, focusing on the comparison between loggerhead incidental by-catch and direct mortality caused by different types of boats and gears, observed from April to December during the period 1999-2004 in the Spanish surface longline fleet fishing in the western Mediterranean Sea.

## MATERIAL AND METHODS

The Spanish surface longline fleet from Mediterranean ports consists of 105 vessels from 12 to 27 m in length licensed for surface longline fishing around the year, and more than 2000 shorter boats licensed for artisanal gears, including surface longline, fishing mainly in summer (<http://www.mapya.es>). The fishing grounds include a large area of the western Mediterranean between 36° and 44°N and 02°W and 05°E. The strongest fishing effort is carried out around the Balearic Islands and in the Ibiza Channel (Camiñas and de la Serna, 1995; Camiñas and Valeiras, 2001; Valeiras and Camiñas, 2003).

A total of 1546 fishing operations were observed onboard from April to December, during the years 1999 to 2004, which represent 3825292 hooks controlled directly. The number of boats with onboard observers and the total number of fishing boats each year can be seen in Table 2. We took data on effort (number of hooks), environmental data (superficial temperature of the water, distance to the coast, depth and weather conditions), standardised fishing parameters (time and spatial co-ordinates, number of attracting lights, and type and size of the bait),

TABLE 1. – Boat strata used in this paper and their respective abbreviations.

Target species	Boats <12 m in length, without a “roller”	Boats >12 m in length, without a “roller”	Boats >12 m in length, with a “roller”
Albacore	---	ALB	---
Bluefin tuna	---	BFT	BFTr
Swordfish	SWA	SWB	SWBr

TABLE 2. – Number of boats with onboard observers and total number of fishing boats (in parentheses) each year according to boat strata. Abbreviations as in Table 1.

Year	BFT (105)	BFT <sub>r</sub> (<105)	SWA (>2000)	SWB (105)	SWB <sub>r</sub> (<105)	ALB (105)
1999	1	0	3	9	0	2
2000	6	0	3	9	0	1
2001	2	0	1	3	0	0
2002	4	0	0	4	0	0
2003	1 (<105)	1	0	5 (<105)	1	0
2004	1 (<105)	2	2	6 (<105)	2	0

fishing strategies, and fleet dynamics (see Valeiras and Camiñas, 2003). We classified the fleet into six boat strata with some differences in structure and target species (Table 1). Sea turtle by-catch and direct mortality were recorded and classified according to gear type and boat strata.

As the catch per unit effort (CPUE) measure we used the index R (number of incidental catches / number of hooks<sup>-3</sup>), R<sub>dead</sub> (number of direct turtle mortalities / number of hooks<sup>-3</sup>) (Yeung, 1998; Laurent *et al.*, 2001; Valeiras and Camiñas, 2003; Lewison *et al.*, 2004), F rate (number of incidental catches / number of fishing operations), and F<sub>dead</sub> (number of direct mortalities / number of fishing operations). We tested the inter-annual differences in R and F within boat strata and gear, and differences in R, R<sub>dead</sub>, F, and F<sub>dead</sub> among boat strata and gears with data from all years pooled together, using the chi-squared ( $\chi^2$ ) test. Expected values in the  $\chi^2$  tests were calculated according to the number of hooks for R and R<sub>dead</sub>, and to the number of fishing operations for F and F<sub>dead</sub>.

## RESULTS

The number of fishing operations observed for each boat strata, type of gear, and year, and the corresponding values of loggerhead by-catch and direct mortality can be seen in Table 3. Direct mortality is a low frequency phenomenon. We observed 3480 loggerhead incidental catches, 46 of which the turtle was dead, so the proportion of dead turtles was 1.32% of the incidental catches. Inter-annual differences in R and F were significant for every boat strata except BFT<sub>r</sub> (Table 3). These inter-year differences may be explained by variations in sea turtle concentrations in feeding areas according to the variations in environmental factors and migratory patterns. Thus, it is preferable to study all catches pooled together to mitigate the effect of inter-annual concentration differences. In addition, the low number of directly dead turtles prevents analysing R and F within a single year.

We observed direct mortality in all boat strata (Table 4), but the relative direct mortality varied among them. Both the by-catch and the direct mortality differed significantly according to the type of boat and gear but the results differed according to whether they were measured in function of the number of hooks or in function of the number of fishing operations (Table 4). With respect to the number of hooks, boats longer than 12 m without a roller that targeted bluefin tuna captured the highest number of Loggerheads, whereas boats longer than 12 m with a roller that targeted swordfish caused the highest direct mortality. With respect to the number of fish-

TABLE 3. – Number of hooks in thousands (first number) and fishing operations (second number) observed for each boat strata and year. In brackets, the number of by-catch (first number) and dead turtles (second number). The asterisks indicate significant inter-annual differences. Abbreviations as in Table 1.

Year	BFT	BFT <sub>r</sub>	SWA	SWB	SWB <sub>r</sub>	ALB
1999	14/14 (0/0)	0/0	31.46/21 (43/0)	555.06/180 (162/0)	0/0	280.32/63 (293/4)
2000	224.5/148 (391/13)	0/0	24.6/15 (5/0)	727.9/242 (1,068/8)	0/0	18.65/7 (61/1)
2001	54.704/37 (286/0)	0/0	115.7/74 (73/2)	531.894/143 (283/1)	0/0	0/0
2002	61.7/30 (26/0)	0/0	0/0	408.883/115 (74/0)	0/0	0/0
2003	58.22/23 (41/0)	17.168/12 (24/0)	0/0	219.644/87 (246/1)	77.952/56 (14/0)	0/0
2004	11.9/14 (2/0)	33.922/19 (30/1)	53.75/35 (4/0)	52.85/33 (4/0)	123.114/155 (340/15)	0/0
df	5	1	4	5	1	1
R $\chi^2$ -value	138.104	0.157	80.82	236.54	24.39	8.55
P	<0.001*	0.9	<0.001*	<0.001*	<0.001*	<0.001*
F $\chi^2$ -value	444.79	0.75	49.096	846.89	92.62	20.57
P	<0.001*	0.1	<0.001*	<0.001*	<0.001*	<0.001*

TABLE 4. – Total effort, sea turtle mortality, and mortality rates for boat strata during 1999–2004. Abbreviations as in Table 1. R: number of incidental turtle catches / number of hooks (in thousands); F: number of incidental turtle catches / number of fishing operations;  $R_{\text{dead}}$ : number of dead turtles / number of hooks (in thousands);  $F_{\text{dead}}$ : number of dead turtles / number of fishing operations. There are two values in each square of the  $\chi^2$ -value column, the top value is the  $\chi^2$ -value if the distribution of hooks is random, and the bottom value is the  $\chi^2$ -value if the distribution of the fishing operations is random. The numbers with two asterisks indicate the highest values.

	BFT	BFT <sub>r</sub>	SWA	SWB	SWBr	ALB	$\chi^2$ -value	P
Hooks	525.02	51.09	180.51	2496.181	261.165	298.970	---	---
fishing operations	276	31	145	800	211	70	---	---
Sea turtle catch	746	54	125	1837	354	354	325.92	<0.001
Sea turtle dead	13	1	2	10	15	5	426.79	<0.001
							65.805	<0.001
							28.0058	<0.001
% Sea Turtle dead	1.74	1.85	1.6	0.54	4.24	1.41	---	---
R	1.41**	1.057	0.69	0.74	1.36	1.18	---	---
F	2.70	1.74	0.86	2.29	1.68	5.057**	---	---
$R_{\text{dead}}$	0.025	0.019	0.011	0.00401	0.057**	0.017	---	---
$F_{\text{dead}}$	0.047	0.032	0.014	0.016	0.071**	0.071**	---	---

ing operations, boats longer than 12 m without a roller that targeted albacore captured the highest number of loggerheads; the highest direct mortality was caused by this type of boat and by boats longer than 12 m with a roller that targeted swordfish.

## DISCUSSION

There is increasing global interest in the studies of loggerhead incidental catches and mortality associated with different fisheries: driftnet (i.e. Silvani *et al.*, 1999), gillnet (i.e. Julian and Beeson, 1998), trawls (i.e. Robins, 1995; Poiner and Harris, 1996), coastal seiner (i.e. Cheng and Cheng, 1997) and surface longline (i.e. Wetheral, 1977; Witzell, 1999; Chaloupka *et al.*, 2004; Lewison *et al.*, 2004). For example, several studies have focused on fishery-related loggerhead mortality in the Spanish surface drifting longline fisheries (Aguilar *et al.*, 1992; Camiñas and de la Serna, 1995; Camiñas, 1997; Camiñas and Valeiras, 2001); however, these studies did not analyse the differences linked to the type of boat and gear.

According to recent research, the Spanish longline vessels should be classified according to the type of boat and gear (Laurent *et al.*, 2002). Our results imply that it is necessary to study the CPUE of the different boat and gear types. The fishing effort depends not only on the number of hooks but also on other characteristics such as the use of a roller, the economic potential for buying bait and materials, the boat length, and the number of fishermen. Although the CPUE is usually calculated in function of the number of hooks (as an R-index) (Yeng, 1999; Laurent *et al.*, 2002; Lewison *et al.*,

2004), we consider the R rate inadequate for comparing the effort of the different gear types. Table 4 shows that the results of F and  $F_{\text{dead}}$  are more consistent than those of R and  $R_{\text{dead}}$ . Therefore, the F rate seems to be more adequate for relating the incidental catch or direct mortality to the fishing effort.

Lewison *et al.* (2004), estimated the number of incidental loggerhead catches in the Mediterranean surface drifting longline fishery as approximately 60000 to 80000, but they assumed that CPUE (measured as an R-index) was homogeneous, which is not exactly so. Differences in incidental catch rates could be due to differential fishing techniques. For example, SWBr had lower F but higher  $F_{\text{dead}}$  than SWB. The main cause of direct mortality due to longlines is drowning (Work and Balazs, 2002). The “roller” gear has fewer hooks and is less time in the water, and so the number of turtle captures is decreased; however, with the deeper hooks the captured loggerheads cannot come up to the surface to breathe and therefore direct mortality is increased. These results seem to indicate that using a roller may increase Loggerhead direct mortality as it increases the probability of drowning.

Our conclusion is that in order to calculate loggerhead incidental catch or direct mortality due to surface longlines it is necessary to know the CPUE of each boat and gear type. Moreover, it is preferable to estimate the CPUE according to fishing operations. For this reason, the current database in the ICCAT (<http://www.iccat.es/>) should be improved by including data about boat and gear types for it to be useful for estimating the incidental catch or direct mortality in the Mediterranean due to surface longlines.

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