NON-TARGET BY-CATCH IN THE MALTESE BLUEFIN TUNA (*THUNNUS THYNNUS*) LONGLINE FISHERY (CENTRAL MEDITERRANEAN)

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SUMMARY

*The bluefin tuna longline fishery is one of the most important pelagic fisheries in the Mediterranean but recently there has been increasing concern about the catches of non-target species. This study presents an assessment of the non-target by-catch from the Maltese bluefin tuna longline fleet and examines the effect of various environmental and spatio-temporal factors on non-target species catch rates. Field observations were made during 85 fishing days. In terms of number, bluefin tuna comprised a relatively small portion of the total catch while the loggerhead turtle (*Caretta caretta*) was the predominant by-catch species. Catch Per Unit Effort (CPUE) was calculated in terms of weight (kg/1000hooks/hr) and number (no/1000hooks/hr) for all the species caught. Generalized Linear Mixed Models (GLMMs) were applied to examine the effect of environmental and spatio-temporal variables on non-target by-catch CPUE. The model for CPUE (number) was not found to be significant. Date, lunar cycle, species and longitude were found to be significantly correlated with CPUE (weight). The results of this study suggests the need for the continual implementation of mitigation measures to minimise the impacts of fishing activities on threatened non-target species in the Mediterranean.*

RÉSUMÉ

*La pêcherie palangrière de thon rouge est une des pêcheries pélagiques les plus importantes en Méditerranée, mais récemment les captures d'espèces non-ciblées suscitent une inquiétude croissante. Cette étude présente une évaluation des captures accidentelles des espèces non-ciblées réalisées par la flottille palangrière maltaise de thon rouge et examine les effets de plusieurs facteurs environnementaux et spatio-temporels sur les taux de capture des espèces non-ciblées. Des observations sur le terrain ont été effectuées au cours de 85 jours de pêche. En termes de nombre, le thon rouge a représenté une proportion relativement faible de la prise totale, tandis que la tortue caouanne (*Caretta caretta*) a été l'espèce la plus fréquente dans les prises accidentelles. La prise par unité d'effort (CPUE) a été calculée en poids (kg/1000hameçons/hr) et en nombre (no/1000hameçons/hr) pour toutes les espèces capturées. Des modèles Mixtes Linéaires Généralisées (GLMM) ont été appliqués afin d'examiner l'effet des variables environnementales et spatio-temporelles sur les CPUE des captures accidentelles des espèces non-ciblées. Le modèle pour la CPUE (nombre) n'a pas été significatif. La date, le cycle lunaire, les espèces et la longitude ont présenté une corrélation importante avec la CPUE (poids). Les résultats de cette étude suggèrent que l'application continue de mesures d'atténuation est nécessaire pour minimiser les impacts de l'activité de pêche sur les espèces non ciblées ménacées dans la Méditerranée.*

RESUMEN

La pesquería de palangre de atún rojo es una de las pesquerías pelágicas más importantes del Mediterráneo, pero recientemente ha habido cada vez mayor preocupación acerca de las especies no objetivo. Este estudio presenta una evaluación de la captura fortuita no objetivo de

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*la flota de palangre maltesa dirigida al atún rojo y examina el efecto de varios factores medioambientales y espacio-temporales sobre las tasas de captura de las especies no objetivo. Las observaciones de campo se realizaron durante 85 días de pesca. En términos de número, el atún rojo representaba una parte relativamente pequeña de la captura total mientras que la tortuga boba (*Caretta caretta*) era la especie de captura fortuita predominante. La captura por unidad de esfuerzo (CPUE) se calculó en términos de peso (kg/1000 anzuelos/hr) y número (nº/1000 anzuelos/hr) para todas las especies capturadas. Se aplicaron modelos lineales mixtos generalizados (GLMM) para examinar el efecto de las variables medioambientales y espacio-temporales sobre la CPUE de la captura fortuita no objetivo. Se halló que el modelo para la CPUE (número) no era significativo. Se descubrió que la fecha, el ciclo lunar, la especie y la longitud estaban significativamente correlacionados con la CPUE (peso). Los resultados de este estudio sugieren la necesidad de la implementación continua de medidas de mitigación para minimizar los impactos de las actividades pesqueras en las especies no objetivo amenazadas en el Mediterráneo.*

KEYWORDS

Long lining, tuna fisheries, by-catch, CPUE, environmental factors

1. Introduction

In recent years there has been a global expansion of fishing activity without much regard for sustainable management resulting in more than two-thirds of global fisheries being categorized as fully exploited, overexploited or depleted (Botsford *et al*. 1997). Another concern arising from this is by-catch, which refers to non-target organisms that become hooked or entangled in the fishing gear (Soykan *et al*., 2008). Alverson *et al*. (1994) estimated mean global by-catch at between 17.9 - 39.5 million metric tonnes annually, or 31% of total marine fisheries catch at that time. This makes by-catch a major management and conservation issue, especially with the incomplete data associated with fisheries worldwide. Data on by-catch are even more limited as this information cannot rely solely on reported landings but requires on-board observers or the keeping of logbooks, which is expensive (Lewison *et al*, 2004).

Pelagic longlines are one of the main methods of catching fish worldwide, targeting mainly tuna, swordfish and billfish. Erzini *et al*. (1996) investigated species and size selectivity of longlines using different hook sizes and found that all hook sizes caught a wide variety of size classes of non-target species. Apart from poor selectivity and widespread use, pelagic longlines cover large spatial areas since a single longline can be many kilometres in length. Therefore, the incidental mortality of elasmobranches, sea birds and turtles on these longline hooks requires immediate attention (Brothers *et al*. 1999).

The Mediterranean Sea contains important biological diversity, with many species at risk of extinction, but is characterised by high fishing intensity; it is estimated that 2.3 million pelagic longline hooks are set each year, with large pelagic species contributing ca 4% of the reported landings (Ancha, 2008). Here we present a preliminary assessment of non-target by-catch resulting from the Maltese pelagic longline fleet operating in the central Mediterranean. The influence of various environmental and spatio-temporal factors was also examined to determine their effect on catch rates.

2. Methodology

Field observations were made on board six different longline vessels in the period 30 April to 30 June 2008 during 85 fishing days, with a total fishing effort of 109,155 hooks and an average 1, 284 hooks/ day. Fishing activity was concentrated in the Central Mediterranean, between N34’47.167, E012’19.850 and N36’50.200, E015’13.853 **(Figure 1)**.

The target species was bluefin tuna (*Thunnus thynnus*) and depending on the size of the vessel, between 500 and 1800 hooks were set on each line. The most common bait used was mackerel (*Scomber* spp.) and Japanese squid (*Illex coindetti*). For each fishing operation, data on location, number of hooks deployed, and mean soaking time

was recorded together with detailed data on the individuals caught including length (cm) and estimated weight (kg).

The mean soak time was defined as the difference between the mean setting time and mean hauling time. catch per unit effort (CPUE) was expressed in number of individuals caught/1000 hooks/hour (N) and calculated for individual species on each fishing day using the following equation:

$N = ((n/x)*1000)/t$

Were ***n*** = *total number captured*; ***x*** = *total number of hooks deployed* and ***t*** = *average soak time*.

CPUE was also expressed as weight (kg/1000 hooks/hour) (W) and calculated for individual species on each fishing trip using the following equation:

$W = ((w/x)*1000)/t$

Were *w = total weight/kg* of each species captured.

Hence two measures of CPUE were used for the analysis CPUE (wt) and CPUE (no).

Two separate analyses were conducted to investigate factors influencing CPUE (no) and CPUE (wt) respectively. The first included species, wind speed, wind direction, temperature, lunar phase, date, latitude and longitude as independent variables in a Generalized Linear Mixed Model (GLMM), using a Poisson distribution, log link and CPUE (no) as a response variable with observer and vessel.fitted as random effects. The second analysis utilised the same independent variables as the first but included CPUE (wt) as a response variable again with observer and vessel fitted as random effects. Mixed models were used to account for variation associated with individual vessels and observers. All analyses were conducted in GenStat 6th edition (VSNi, 2008). MapInfo Professional, version 8.5 was utilized to plot the location of the vessel on each fishing day.

3. Results

The observers recorded 94 individual bluefin tuna (*Thunnus thynnus*) totalling 9,767.1 kg caught on the tuna longline, during this study. This represented only 11.8% of the total catch in number but 65.7% of the total catch in weight. The remainder of the catch consisted of 13 other marine species, of which three species dominated in terms of number: loggerhead turtle (*Caretta caretta*), broadbill swordfish (*Xiphius gladius*), and violet stingray (*Pteroplatytrygon violacea*) **(Table 1)**. When measured as a percentage of total catch in weight, the majority of the non-target by-catch was comprised of two species: 21.1% broadbill swordfish (*Xiphius gladius),* and 7.3% loggerhead turtle (*Caretta caretta*) **(Table 1)**.

Date, longitude, moon phase and species had a significant effect on CPUE (wt) **(Table 2)**. Date and longitude had a significant positive effect on CPUE (wt), whilst latitude, temperature, wind direction and wind speed had no significant effect. Relative to phase 1 (new moon), the 5th lunar phase (full moon) had the highest positive effect on CPUE (wt) for all non-target by-catch species **(Figure 2)**. Blue shark (*P. glauca*) had the largest estimated positive effect on CPUE (wt) relative to loggerhead turtle (*C. caretta*) i.e. total catch biomass of non-target species was higher when this species was captured. Long-fin tunny (*T. albacore*) had the largest estimated negative effect on CPUE (wt) relative to *C. caretta* i.e. total catch biomass of non-target species was lower if this species was captured. White shark and silver scabbardfish were not included in the model as data on their CPUE (wt) was missing. None of the variables in incuded in the model investigating CPUE (no) had a significant effect.

4. Discussion

When measured as numbers of individuals captured, non-target species far outnumbered the target species (bluefin tuna). Loggerhead turtles (*C. caretta*) were the most abundant non-target by-catch species.

High catch rates of broadbill swordfish were also recorded. In summer this species migrates towards temperate and cold waters from the warmer waters it resides in over autumn and winter (Damalas *et al.* 2005). This

coincides with the migration of bluefin tuna into the Mediterranean Sea. Carey & Robinson (1981) reported that swordfish preferred to stay at a depth of ca 90m during the day and move up to the surface at night, while Holts *et al.* (1994) found that these fish spent about 75% of their time at depths between 10-50m or just below the upper mixed layer, therefore bringing them into contact with the pelagic tuna longlines. This agrees with a study carried out in the Pacific that found swordfish catch to primarily result from by-catch in longline fisheries targeting bigeye (*Thunnus obesus*) and southern bluefin tuna (*Thunnus maccoyii*) (New Zealand Fish. Serv. 2006).

In terms of weight of individuals captured, the target species accounted for the majority of the total catch, compared to the non-target by-catch. Two factors contributed to this: (a) weight of by-catch species was underestimated as not all observers provided weight data on these, and (b) the sheer weight of bluefin tuna compared to any of the other species captured. The average weight of an individual bluefin tuna captured by the vessels under investigation was 105.3kg, compared with an average weight of 13.3kg for loggerhead turtles captured.

The model analysing CPUE (no) was not explained by any of the eight environmental or spatio-temporal factors used. This could be due to the large variation in numbers of small species captured compared to large species.

For the model analysing CPUE (wt), date were found to be having a positive effect with an increasing trend from May through to June. As an explanatory variable this incorporates environmental factors such as temperature, as well as biological factors such as migration of certain species through the central Mediterranean. During the summer months, loggerhead turtles move into shallower waters to breed on beaches in the area i.e. Sicily, Lampedusa, Tunisia, Libya, Cyprus, Greece and Turkey. Baez *et al*. (2006) found the capture of sea turtles and swordfish hard to avoid when targeting bluefin tuna off southern Spain as these species have a similar distribution at this time of year.

The Mediterranean is also an important breeding area for the Broadbill Swordfish which moves into shallower waters in late spring through summer to spawn.

The results suggest that the highest rate of by-catch CPUE (wt) occurs during the full moon period. The behaviour of many animals is known to be attuned to the phases of the moon. Di Natale & Mangeno (1995) reported a significant relationship between phases of the moon and CPUE of swordfish in the Italian driftnet fishery, as well as for the total catch. Two possible reasons suggested were: (a) behaviour is affected by the different ambient light produced at night by the moon, and (b) a change in distribution of prey species. This is consistent with a study carried out by Santos & Garcia (2005), who investigated the effect of moon phase on CPUE of swordfish in the Portuguese fishery. These authors found that the full moon plays an important role in horizontal and vertical movements associated with prey location in swordfish.

Gandini & Frere (2006) found by-catch in the Argentinean longline fishery to be significantly affected by moon phase, with 65% of the seabird by-catch occurring 5 days before and 5 days after the full moon, which concurs with the hypothesis that seabird by-catch is reduced by darkness.

The present study demonstrated a spatial effect in that fishing further north decreased CPUE (wt) of non-target by-catch. Maltese fishers believe that bigger catches are obtained closer to Libya (south of Malta) as this area has not experienced the intense fishing effort found elsewhere in the Sicilian Channel.

An increase in CPUE (wt) was noted towards the east of the study area. Megalofonou *et al.* (2005) also found area to be a significant factor affecting the incidental capture of sharks by the tuna and swordfish longline fisheries in the Mediterranean. Location embraces information on habitat and bathymetry for example, which are important factors associated with the presence or absence of particular species. However, it should be noted that fishing activity tends to be concentrated in certain areas, leading to a masking of the actual situation i.e. fishers do not spread their activity evenly over space and time. This is a continual problem associated with most fisheries studies.

As the wind speed increased CPUE (wt) decreased. When wind speed reached >7 knots, CPUE (wt) decreased significantly. One reason for this could be that very little fishing activity occurred when wind was greater than force 4 or 5, therefore producing a malapportioned effort.

Highest total CPUE (wt) was obtained when wind speed reached 4-5 knots. Maltese fishers felt this was because the bait moved more, therefore giving the impression it was alive and so helping to attract predators.

The main aim of this study was to present a preliminary assessment of non-target by-catch resulting from the Maltese tuna pelagic longline fleet operating in the central Mediterranean. Data on by-catch species in the Mediterranean is seriously lacking. In a review, Cooper *et al.* (2003) reported that quantitative data on seabird by-catch was only available for Spain. The present results indicate that the Maltese pelagic longline fleet is not exempt from the global problem of non-target by-catch, however the threatened (IUCN) loggerhead turtle (*C. caretta*) and the pelagic stingray (*P. violacea*) by-catch are the greatest concern as opposed to seabird by-catch, which resulted to be negligible.

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Table 1. Species captured during the sampling period by Maltese tuna longliners fishing in the central Mediterranean expressed as a % of the total catch recorded in number and as a % of the total catch in weight.

Common name	*Latin name*	*Total catch in no. (%)*	*Total catch in wt. (%)*
Loggerhead turtle	*Caretta caretta*	40.3	7.3
Broadbill swordfish	*Xiphius gladius*	31.0	21.1
Bluefin tuna	*Thunnus thynnus*	11.8	65.7
Violet or pelagic stingray	*Pteroplatytrygon violacea*	9.8	0.7
Dolphin fish	*Coryphaena hippurus*	2.5	1.3
Oilfish	*Ruvettus pretiosus*	1.6	0.1
Longfin tunny	*Thunnus alalonga*	1.0	0.2
Mediterranean spearfish	*Tetrapterus belone*	0.8	0.6
Blue shark	*Prionace glauca*	0.4	0.3
Ocean sunfish	*Mola mola*	0.3	0.5
Devil fish	*Mobula mobular*	0.3	1.0
Porbeagle shark	*Lamna nasus*	0.3	1.2
Silver scabbardfish	*Lepidopus caudatus*	0.1	*
White shark	*Carcharodon carcharias*	0.1	*
Total		**100 (796 individuals)**	**100 (14, 871.5 kg)**

* refers to missing data.

Table 2. Fixed effects included in the GLMM with CPUE (wt) as the response variable, their corresponding degrees of freedom (d.f.), parameter coefficients ± SE ($\beta \pm SE$) and p-values (p), NS= not significant.

Fixed effects	*d.f.*	$\beta \pm SE$	p
Date	1	0.018 ± 0.010	$p < 0.001$
Latitude	1	-0.790 ± 0.250	NS
Longitude	1	0.030 ± 0.320	$p < 0.01$
Moon phase	7	-	$p < 0.001$
1		0.000 ± 0.466	-
2		-0.045 ± 0.466	-
3		-0.487 ± 0.466	-
4		-0.021 ± 0.466	-
5		0.843 ± 0.466	-
6		-0.166 ± 0.466	-
7		-0.796 ± 0.466	-
8		0.080 ± 0.466	-
Species	10	-	$p < 0.001$
M. mola	-	-0.210 ± 0.613	-
C. caretta	-	0.000 ± 0.613	-
C. hippurus	-	-0.999 ± 0.613	-
L. nasus	-	0.687 ± 0.613	-
M. mobular	-	1.289 ± 0.613	-
P. glauca	-	1.007 ± 0.613	-
P. violacea	-	-1.972 ± 0.613	-
R. pretiosus	-	-2.544 ± 0.613	-
T. belone	-	-0.656 ± 0.613	-
T. alalonga	-	-1.439 ± 0.613	-
X. gladius	-	0.087 ± 0.613	-
Temperature	1	-0.007 ± 0.070	NS
Wind direction	1	0.000 ± 0.001	NS
Wind speed	1	-0.060 ± 0.040	NS

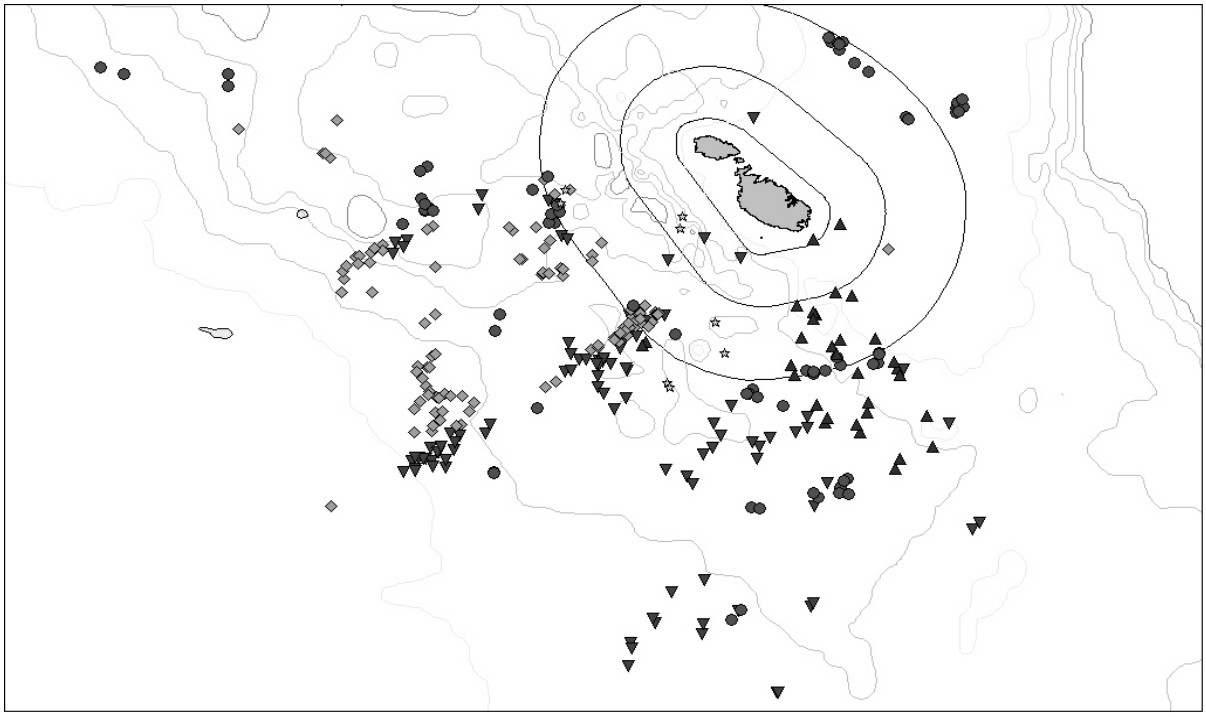


Figure 1. Map showing fishing stations for each vessel during the study period. Each symbol corresponds to a different fishing vessel. The 25 nautical mile isobar (the outermost one) indicates the boundary of the Malta Fisheries Management Zone.

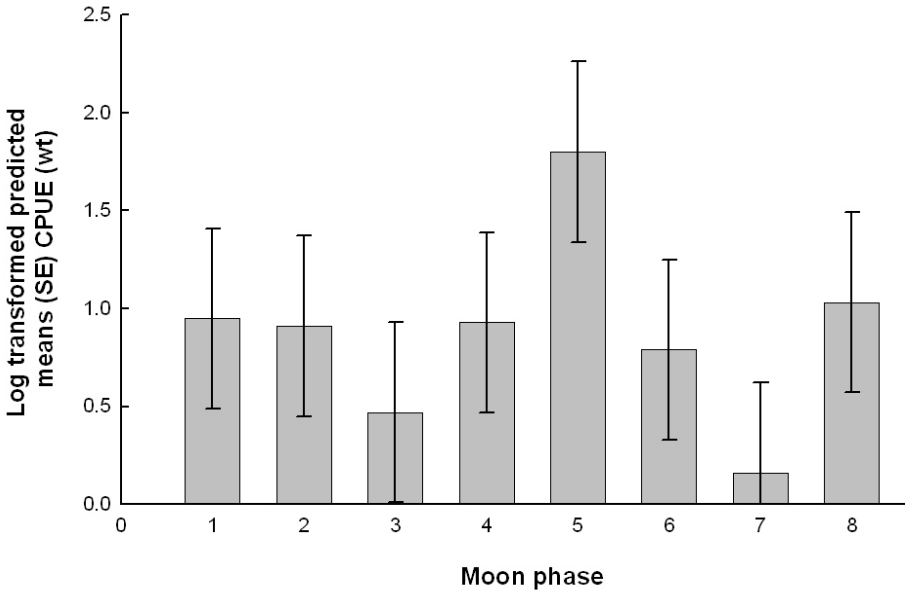


Figure 2. Log transformed predicted means ± SE of CPUE (wt) of non-target by-catch species for individual moon phases.