THE EFFECT OF THE LUNAR PHASE ON THE CATCH PER UNIT EFFORT (CPUE) OF THE TURKISH SWORDFISH LONGLINE FISHERY IN THE EASTERN MEDITERRANEAN SEA

Tevfik CEYHAN[1*], George TSERPES[2], Okan AKYOL[1], and Panagiota PERISTERAKI[2]

[1]*Faculty of Fisheries, Ege University, Bornova, Izmir, Turkey*

[2]*Institute of Marine Biological Resources, Hellenic Centre for Marine Research, Thalassocosmos, Heraklion, Crete, Greece*

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Background. The swordfish, *Xiphias gladius* Linnaeus, 1758, is a pelagic and highly migratory species distributed in the Atlantic, Indian, and Pacific oceans as well as in the Mediterranean Sea. Swordfish fishing has been carried out in the Mediterranean with longlines, gillnets, harpoons, and traps since the Roman times. Although information is available on the influence of the lunar phase on the catch per unit effort (CPUE) for the swordfish longline fishery in the Atlantic and Pacific oceans, the data concerning the Mediterranean is rather limited. The aim of this study was to examine the relation between the lunar phase and the swordfish CPUE, based on data from Turkish longline fisheries, targeting swordfish in the eastern Mediterranean during the 2008–2016 fishing seasons.
Material and methods. We monitored randomly the daily fishing activity of longliners based at the ports of Fethiye and Özdere during 2008–2016. A total of 86 surveying operations were carried out, including 79 in the area between Fethiye and Alanya, the remaining ones were in Özdere in the southern Aegean coasts along the eastern Mediterranean Sea. The effect of the lunar phase on the swordfish catch rates, expressed in terms of kg · 1000 hooks^{-1}, was examined by means of the Generalized Additive Modelling (GAMs) techniques.
Results. The observed CPUE rates ranged from 0 to 700 kg · 1000 hooks^{-1}. The mean swordfish CPUEs in the dark and light periods of the lunar cycle were equal to 178.10 ± 19.01 and 175.27 ± 19.56 kg · 1000 hooks^{-1}, respectively. Although no significant differences among phases of the Moon were found ($P > 0.05$), CPUEs differed significantly between years ($P < 0.05$).
Conclusion. It seems that the mechanism linking swordfish CPUE variations with the lunar cycle involves several factors, making difficult the identification of direct relations. Further studies are needed to better clarify the impact of the lunar phase on the longline gear, considering also additional parameters, such as light transition, prey abundance, physico-chemical characteristics of the marine environment, and the soak time of the gear.

Keywords: swordfish, *Xiphias gladius*, lunar effect, lunar phase, phase of the Moon, catch rates, Aegean Sea, Mediterranean

INTRODUCTION

Swordfish, *Xiphias gladius* Linnaeus, 1758, is a pelagic and highly migratory species and it is distributed in the Atlantic, Indian, and Pacific oceans as well as the Mediterranean Sea. Nakamura (1986) stated that there are two types of migrations for highly migratory species. One that is passive, which is the movement within a habitat in response to local biotic and abiotic conditions, and one that is active, in which the fish move from one habitat to another, following an ontogenetic change resulting from a biological requirement motivated by the need to feed and reproduction. Therefore, swordfish are subjects to horizontal and vertical shifts being this behaviour associated with prey location at a depth range of 0–1500 m (Lerner et al. 2013). Besides, migrating toward temperate or cold waters in the summer and back to warm waters in the fall, having high-temperature tolerance ranging from 5 to 27°C (Tserpes et al. 2003, Dewar et al. 2011, Froese and Pauly 2018).

Swordfish fishing has been carried out in the Mediterranean with longlines, gillnets, harpoons, and traps since the Roman times. Swordfish has been also acquired as bycatch in other fisheries such as longlines and driftnets targeting albacore, purse seines, etc. (Anonymous 2017b). The reported annual catches in the Mediterranean over the last two decades were on average about 13 057 t (Anonymous 2017a). Historically, the main fishing gears

* Correspondence: Dr. Tevfik Ceyhan, Ege Üniversitesi, Su Ürünleri Fakültesi, 35100 Bornova, İzmir, Turkey, phone: +90 232 311 5212, fax: +90 232 388 3685, e-mail: (TC) tevfik.ceyhan@ege.edu.tr, (GT) gtserpes@hcmr.gr, (OA) okan.akyol@ege.edu.tr, (PP) notap@her.hcmr.gr.

used have been surface longlines, representing on average 88% of the annual catch, and gillnets. However, gillnets were completely eliminated in the Mediterranean in 2012 and over the last 25 years the biomass levels of swordfish appear to be rather stable, but representing low levels (Anonymous 2017b). Moreover, the stock is currently 'overfished' and 'suffering overfishing'. According to the objectives of the International Commission for the Conservation of Atlantic Tunas (ICCAT), the stock requires rebuilding and fishing mortality has to be reduced.

Although information is available on the influence of the lunar phases on the CPUEs of the swordfish longline fishery in the Atlantic (Draganik and Cholyst 1987, Moreno et al. 1991, Neves dos Santos and Garcia 2005, Orbesen et al. 2017) and the Pacific oceans (Bigelow et al. 1999), the information concerning the Mediterranean is rather limited (de la Serna et al. 1992, Di Natale and Mangano 1995, Damalas et al. 2007). In Turkey, Akyol (2013) has done the first study about the lunar phase effect on gillnets targeting swordfish.

In this paper, we attempted to determine the lunar phase influence on the swordfish catch per unit effort (CPUE), based on data from Turkish longline fisheries targeting swordfish in the eastern Mediterranean during the 2008–2016 fishing seasons.

MATERIAL AND METHODS

We randomly monitored the daily fishing activity of longliners based at the ports of Fethiye and Özdere during 2008–2016. During those operations, the involved scientists were present on board of the vessels. There were 10–12 vessels in the region, that used longline to target swordfish. Therefore, nine swordfish vessels were randomly selected during the surveys. The surveyed boats ranged from 6 to 14 m (mean 9.8 ± 1.0 m) in length (LOA); 9 to 268 kW (mean 79.7 ± 27.8 kW) in machine power. The number of hooks used in swordfish longlines ranged from 130 to 670 (mean 595 ± 20.85), while the main line was between 1.8 km and 40 km (mean 30.3 ± 1.06 km). A total of 86 surveying operations were carried out between Fethiye and Alanya (79) and Özdere (7) in the southern Aegean coasts along the eastern Mediterranean Sea (Fig. 1). The data collected during each fishing trip included:

- Date, fishing area, and depth
- Fishing gear aspects such as total number of hooks, the total length of the main line, bait type
- The weight of the catch by species

Seven fishing areas and five different bait types were defined (Fig. 1).

The limited number of observations did not allow us to classify the lunar cycle in detailed categories for the subsequent modelling. Thus, the lunar cycle was classified into two periods of light and dark. The demi lunes (first/last quarters), waning gibbous, and full Moon were considered as the light period, while the new Moon and the crescent were incorporated into the dark period. The effect of lunar phase on the swordfish catch rates, expressed in terms of kg · 1000 hooks^{-1}, was examined by means of the Generalized Additive Modelling (GAMs) techniques (Hastie and Tibshirani 1990).

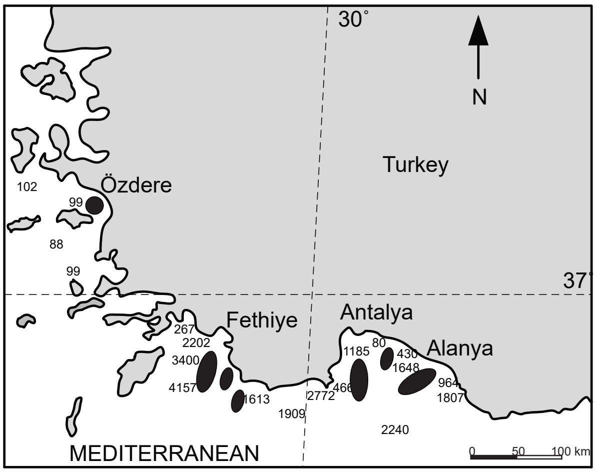

Fig. 1. The sampling areas (black ovals) of swordfish, *Xiphias gladius*, along the south-eastern coasts of Turkey (Mediterranean); the numbers indicate depth in m

The main advantage of GAMs over traditional regression methods was their capability to model non-linear relations between a response variable and multiple explanatory variables using non-parametric smoothers. In the presently reported case, the non-linear predictors included the depth, sea surface temperature (SST), month, and the year of sampling. In addition, bait type and fishing area were considered as factor variables. In this way, other parameters, apart from the lunar phase, that could influence catch rates were also considered.

Given the existence of few zero catches, a Tweedie GAM following a compound Poisson–gamma approach was applied. This avoids multiple-stage modelling of zero-inflated data and allows to model jointly the probability of presence and the non-zero sampled quantity (Shono 2008, Lecomte et al. 2013). The smoother function used was a penalized cubic regression spline and model fitting was accomplished using the "mgcv" library (Wood 2006) under the R language environment (R Core Team 2017). The procedure automatically selects the degree of smoothing based on the Generalized Cross Validation (GCV) score, which is a proxy for the model predictive performance. However, given the limited number of observations, the model was constrained to be at maximum a quartic relation. Hence, the maximum degrees of freedom for each smoothing term, measured as the number of knots (k), was set to 4 (i.e., $k = 5$ in the GAM formulation). A log link function was assumed and deficiencies of the fitted model were diagnosed by means of randomised quantile residual plots (Foster and Branvington 2013).

Thus, the general form of the GAM used was

$$\text{CPUE} \sim a + \text{MP} + A + \text{BT} + s(Y) + s(M) + s(D) + s(\text{SST}) + e$$

where, a is the intercept, MP is moon phase, A is area, BT is bait type, Y is year, M is month, D is depth, SST is sea surface temperature and s indicates the smoother function of the corresponding independent variable and e is a random error term.

Statistical inference was based on the 95% confidence level.

RESULTS

The observed CPUE rates ranged from 0 to 700 kg · 1000 hooks^{-1} and the mean CPUE was 176.09 ± 14.93 kg · 1000 hooks^{-1}. Summary statistics by lunar phase are shown in Table 1. Exploratory analysis revealed large variations between years regarding the median CPUE estimates (Fig. 2) while boxplots of CPUE by lunar phase are highly overlapping (Fig. 3).

Table 1

Summary of catch per unit effort (CPUE) statistics of the longline fishery of swordfish, *Xiphias gladius*, along the south-eastern coasts of Turkey in relation to Moon phases

Moon phase	CPUE [kg · 1000 hooks^{-1}]					
	N	Mean	Range	SD	SE	Median
Dark	24	178.10	40.00–357.14	93.15	19.01	186.50
Light	60	175.27	0–700.00	151.54	19.56	150.00

SD = standard deviation, SE = standard error of the mean, *N* = number of fishing operations.

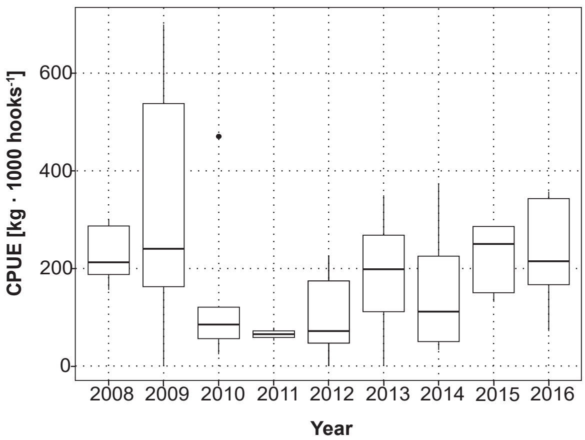

Fig. 2. Catch per unit effort (CPUE) values for of the surface longline fishery of swordfish, *Xiphias gladius*, along the south-eastern coasts of Turkey by year

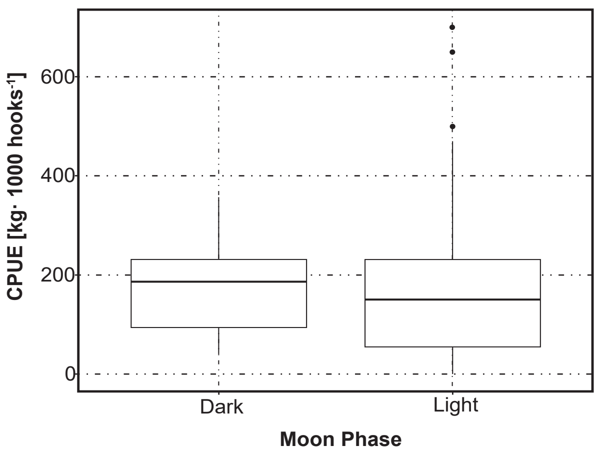

Fig. 3. Catch per unit effort (CPUE) values for of the surface longline fishery of swordfish, *Xiphias gladius*, along the south-eastern coasts of Turkey by Moon phase

The randomized quantile residual plot of the applied GAM model did not show any outstanding feature that would suggest inappropriateness of the fitted model (Fig. 4). The analysis of deviance table indicated that only the effect of year was significant (Table 2) and from the year-effect plot, it appears that CPUE is decreasing up to 2012 remaining rather stable afterwards (Fig. 5).

DISCUSSION

In general, CPUE is used as an index of abundance, meaning that a proportional change in CPUE is expected to represent the same proportional change in stock size (Anonymous 1999). Ideally, an abundance index should be fishery independent. In fact, CPUE is commonly obtained from commercial fishery-dependent data. CPUE rates can be influenced by many factors such as fleet dynamics, schooling behaviour, gear selection, and seasonal and spatial

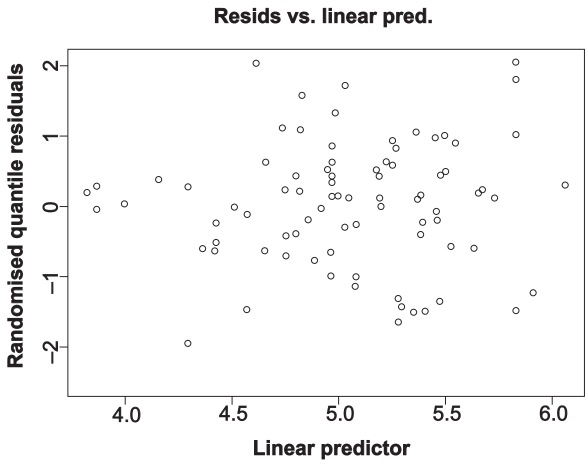

Fig. 4. Randomised quantile residual plot of the GAM model fitted to the catch per unit effort (CPUE) data for of the surface longline fishery of swordfish, *Xiphias gladius*, along the south-eastern coasts of Turkey

Table 2

Analysis of deviance table for the GAM model fitted to the catch per unit effort (CPUE) data of the longline fishery of swordfish, *Xiphias gladius*, along the south-eastern coasts of Turkey in relation to Moon phases

Parameter	GAM		
	df	*F*	*P*
Moon phase	1	0.367	0.547
Bait type	4	0.549	0.700
Area	6	1.586	0.165
s(Year)	2.017	2.966	0.037
s(Month)	1.744	1.729	0.187
s(Depth)	1.815	1.517	0.250
s(SST)	1.000	0.110	0.741

df = degrees of freedom, *F* = *F*-value, *P* = *P*-value, s(x) = smoother function of the corresponding independent variable, SST = sea surface temperature.

allocation of fishing effort (Hilborn and Walters 1992, Harley et al. 2001). Because of this, a pure yearly trend that is representative of the abundance index must be extracted by adjusting various factors (such as lunar phase, SST, area, bait type etc.) that change over the years and bias the raw CPUE trend (Okamura et al. 2018). Zuur et al. (2009) stated that it could be achieved by the use of GLMs (generalized linear models), GLMMs (generalized linear mixed effects models), and GAMs (generalized additive models).

In this study, the CPUE values ranged from 0 to 700 kg · 1000 hooks^{-1}with a mean (±SE) of 176.1 ± 15 kg · 1000 hooks^{-1}. The highest value of 700 kg · 1000 hooks^{-1}was recorded in 2009 during a light period of the Moon. Other authors working in other Mediterranean areas (Di Natale et al. 1995, Relini et al. 2008) have reported mean CPUE values that were generally lower than the current estimate (Table 3). Probably, the ban of the swordfish driftnet fishery, implemented in Turkey in 2011, has favoured catch rate increases of the swordfish longline fishery.

Although the range of depth was between 65 m and 3000 m in this study, the hook position ranged from 5 to 30 m of depth (Akyol and Ceyhan 2010). Regardless of the predicted hook position, hooks fished between 40 and 60 m for most of the time in oceanic studies (Bigelow et al. 2006, Rice et al. 2007). Rice et al. (2007) also stated that some hooks were demersed as deep as 127 m. In this study, the hooks deployed in shallower than those of previous studies and it was usually operated in the same layer of the sea surface in all fishing areas of this study. Thus, there is no statistical difference between fishing areas and between depths of locations where fishing operations were performed.

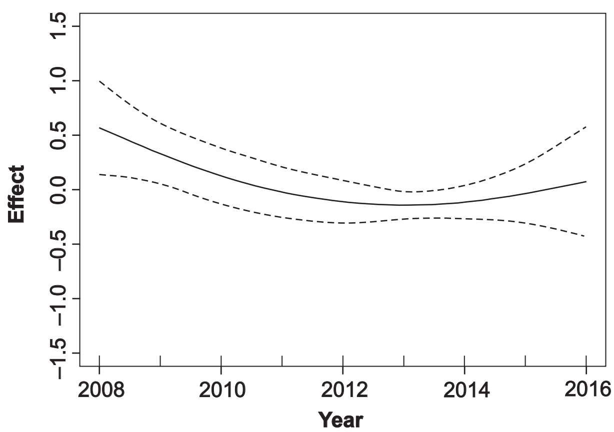

Fig. 5. GAM estimated effect of year on the catch per unit effort (CPUE) rates for of the surface longline fishery of swordfish, *Xiphias gladius*, along the south-eastern coasts of Turkey; dotted lines correspond to the 95% confidence intervals of the estimates

Lerner et al. (2013) reported that the swordfish spent 90% of the time from 8 to 20°C (median temperature: 8.5–13.3°C during day time; 23.6–26.2°C during night time). In this study minimum, maximum and mean SST were 16.0, 27.2, and 18.6 ± 0.32°C, respectively. As it is expected that the narrow SST range in the eastern Aegean Sea did not affect the CPUE because, SST, current, and thermocline are important factors for swordfish shoaling that would be greater in dynamic oceanographic areas such as the equatorial Pacific or western boundary currents (Bigelow et al. 2006).

The following fish species were used as baits: sardines, squids, horse mackerels, round sardinella, and Atlantic chub mackerel although mackerel were the most common ones. Fishermen, however, prefer the use of mixed bait due to higher availability and lower price (especially regarding squids). Thus, the bait did not affect the CPUE in this study. Amorim et al. (2015) reported that there were statistically important differences between mackerel and squid as bait as well as between hook types. On the other hand, the higher catchability of swordfish with hooks baited with squid, might in part be related to its diet. Our results are different from Amorim et al. (2015) due to the baiting hooks with mixed species and choosing mackerel as the main bait.

It has been suggested that the depth distribution of swordfish is altered in response to the percentage of light due to the importance of swordfish vision in feeding (Carey and Robinson 1981). Hence, it is expected that the lunar phase could affect the catches of the swordfish longline fishery.

Table 3

Catch per unit effort (CPUE) values for of the surface longline fishery of swordfish, *Xiphias gladius*, in the Mediterranean

Locality	CPUE		Reference
	Range	Mean	
Gulf of Taranto, Ionian Sea	54.2–98.3	—	De Metrio and Megalofonou 1988
Tyrrhenian Sea and Strait of Sicily	22.10–138.70	101.03	Di Natale et al. 1995
North-western Mediterranean	64.84–169.60	116.46	Relini et al. 2008
Tyrrhenian Sea and Strait of Sicily	90.04–203.21	—	Tserpes et al. 2011
Eastern Mediterranean	77.39–245.18	—	Tserpes et al. 2011
Eastern Mediterranean	15.6–27.8	—	Erdem and Akyol 2005
Eastern Mediterranean	0–700	179.6	Ceyhan and Akyol 2014
Eastern Mediterranean	—	131	Tüzen et al. 2013
Eastern Mediterranean	31.23–479.48	—	Ceyhan et al. 2015
Eastern Mediterranean	0–700	176.1	This study

The presently reported study demonstrated that the lunar effect on swordfish CPUE was not statistically significant, while a series of other studies have provided varying and sometimes contradictory results. Bigelow et al. (1999) postulated that lunar phases might, in fact, affect vulnerability to the fishing gear, since the fish either alter their vertical distribution or have more enhanced visual acuity. In the Atlantic, the most successful catches were observed when the Moonlight intensity was higher (nights with full Moon), followed by nights with first quarter (Neves dos Santos and Garcia 2005). Poisson et al. (2010) have also reported the highest swordfish CPUE rates occurring during the first and last quarters of the lunar cycle. Orbesen et al. (2017) also observed that the night-time swordfish catch rates were the highest during the dark period in the Gulf of Mexico. Conversely, Podestá et al. (1993), similarly to the presently reported study, could not demonstrate significant correlation between CPUE and lunar illumination. Furthermore, Hernandez-Milian et al. (2008) reported weakly significant relations between swordfish catches and both cloud cover, as well as the interaction between lunar phase and cloud cover. In the swordfish gillnet fishery operating in the central Mediterranean Sea, Di Natale and Mangano (1995) showed that the lowest catch rates were occurring during the full Moon. Akyol (2013) reported that the highest CPUE rates of the Turkish swordfish gillnet fishery were observed around the new Moon phase, while the highest rate (300 $kg \cdot km^{-1}$) was observed in May 2009. Poisson et al. (2010) stated that the absence of a consistent catch pattern in association with lunar phases might be related to prey availability. Di Natale and Mangano (1995) discussed that CPUE variations with lunar phase could be related to the behavioural adaptation of swordfish to different ambient light or to changes in the vertical distribution of cephalopods (important swordfish prey) caused by the full Moon. The influence of the lunar cycle on catchability can also be related to changes induced to tides and sea-currents (Omori 1995, Ward and Hindmarsh 2007). In some way, CPUE variations could be also related to changes of fishing intensity based upon preconceived opinions of the fishermen regarding the effect of lunar phase on catch rates.

In conclusion, it seems that the mechanism relating swordfish CPUE variations to the lunar cycle involves several factors, making it difficult to identify direct relations. Further studies are needed to better clarify the impact of the lunar phase on the longline gear, considering also additional parameters, such as light transition, prey abundance, physico-chemical characteristics of the marine environment, and the soak time of the gear.

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