Gillnet fishery – loggerhead turtle interactions in the Gulf of Gabes, Tunisia

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Some gillnets used in the south of Tunisia (Gulf of Gabes) target shark species (*Mustelus* sp., *Carcharhinus plumbeus*) and guitarfish (*Rhinobatos cemiculus*, *Rhinobatos rhinobatos*). These artisanal nets interact with sea turtles. Here we present an analysis of the bycatch of loggerhead sea turtles *Caretta caretta* in these gillnets in the Gulf of Gabes, an important Mediterranean wintering and foraging area for this threatened species. We quantified mean catch per unit effort (CPUE) in three ways to account for uncertainty and found high levels of interaction in each case. The number of turtle captures per km^2 of gillnet per day, the number of turtle captures per km of net and the number of turtle captures per set were 0.527 (0.403–0.649), 0.339 (0.250–0.438) and 0.800 (0.654–0.904), respectively. Captured loggerheads were mainly juveniles (mean = 56.6cm CCL_{n-t}) and direct mortality was estimated as 69.4% (*n*=25). These are the first estimates of sea turtle interactions with artisanal fisheries for northern Africa, and one of very few estimates of turtle mortality in set gillnets in the Mediterranean. Our results indicate a need for research into ways for fishermen to avoid turtle captures and to raise awareness of this problem throughout the Mediterranean Sea. The following specific actions are recommended: 1) management of gillnet fisheries in the Mediterranean Sea, 2) minimizing gear soak time, particularly in foraging and inter-nesting habitats and along the migration pathways of sea turtles, 3) technical modifications of the gear by reducing the number of floats, and 4) carrying out an awareness campaign with fishermen to reduce post-release mortality.

Key words: bycatch, *Caretta caretta*, catch rate, gillnet, mortality

INTRODUCTION

Most sea turtles are globally listed as endangered or critically endangered species (IUCN, 2004). Two sea turtle species nest in the Mediterranean: the loggerhead, *Caretta caretta*, and the green turtle, *Chelonia mydas*. The main nesting concentrations of the loggerhead are found in Greece, Turkey, Cyprus and Libya (Margaritoulis et al., 2003), while those of the green turtle are restricted to Turkey and Cyprus (Kasparek et al., 2001), with minor activity in some other countries such as Syria and Lebanon (Rees et al., 2008). A third species, the leatherback, *Dermochelys coriacea*, is observed at sea year-round throughout the region (Casale et al., 2003). There are also uncommon turtle species in the Mediterranean such as olive ridleys and hawksbills (Laurent & Lescure, 1994).

Sea turtles spend the majority of their life in the sea, during which time they are subject to many threats, such as incidental capture during fishing activities, which is considered one of the most important causes of anthropogenic mortality for sea turtles in the Mediterranean (De Metrio & Megalofonou, 1988; Argano et al., 1992; Clarke et al., 2000; Jribi et al., 2007, 2008; Deflorio et al., 2005; Casale et al., 2004, 2007; Camiñas et al., 2006). Most studies on the bycatch of these species have focused on large-scale commercial fisheries, i.e. longlines and trawls (Deflorio et al., 2005, Jribi et al., 2007, 2008; Casale et al., 2004, 2007). However, the set gillnet fishery is another fishery widely distributed in the Mediterranean, and yet it has largely been ignored in previous studies. This fishery typically uses a single layer of nets, is commonly used in artisanal fisheries, and occurs in all coastal zones around the globe on large and small scales (Lazar & Tvrtkovic, 2003). Within these nets there is a great variety of types and methods used, which makes it difficult to classify this fishery or quantify its impacts (Lazar & Tvrtkovic, 2003).

This study analysed parameters related to the bycatch of loggerhead turtles in coastal gillnets in the south of the Gulf of Gabes, to seek to highlight the importance of this area for *C. caretta* in the Mediterranean context and to stress the conservation implications of the incidental turtle catch by the gillnet fishery in the area.

MATERIALS AND METHODS

The investigation was carried out during the 2007 and 2008 fishing seasons on board artisanal boats connected to the ports of Zarzis, Jerba and El Ketf (Fig. 1). In the study area, gillnets targeting mainly sharks and guitarfish are frequently used in spring and at the beginning of summer (from April to June).

Data were collected by onboard observers during 45 randomly selected fishing sets which took place from April to June in 2007 and during the same period in 2008. In the remaining months, fishermen use other fishing gear

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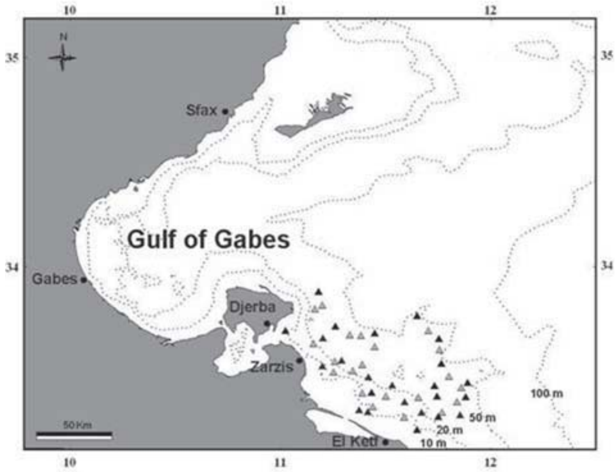

Fig.1. The Gulf of Gabes. Locations of sets with turtles caught (black triangles) and sets without turtles caught (grey triangles).

targeting other species, such as longlines targeting sharks and swordfish (*Xiphias gladius*), and small hooked longlines targeting Sparidae fishes (*Sparus aurata, Diplodus annularis, Sarpa salpa* and *Diplodus pentazzo*).

In this area, set gillnetting consists of several pieces of net (panels) that are tied together to form a single curtain set upright in the water. These nets are fixed to the bottom or at a certain depth by means of anchors or ballast sufficiently heavy to neutralize the buoyancy of the floats. With this type of gear, the fish are gilled, entangled or enmeshed in the net. The gillnet sizes used during this study varied between 2500 and 3000 m in length and 4 to 5.5 m in height. The size of the mesh varied between 14 and 16 cm and the thickness of the thread varied between 4.5 and 6 mm. The net was usually soaked in the late morning. The retrieval began one or two days later and the soak time could reach between three and five days, depending on the weather conditions.

During fishing operations, onboard observers recorded date, geographic coordinates at both the beginning and the end of the hauling of the gear, fishing depth, information on target species and number of turtles captured. Information on turtles caught included the species, the curved carapace length notch to tip (CCL_{n-t}) (Bolten, 1999) and the turtle's physical condition, which was classified as follows: healthy (moving with no observed injuries); injured externally but healthy (head damage, broken flippers and other descriptions were recorded); comatose (dazed, few movements, slight signs of breathing) and dead (no movement, head limp, extended and flopping to the ground, no sign of breathing, eyes not responding to touch).

Extrapolation of catch rates from carefully quantified surveys to a whole fishery or region is difficult because there are several uncertainties (for example, difference in the soak time, length of the net, mesh size). There is no generally recognized standard measure of catch per unit effort (CPUE) for nets. Given this we chose to estimate CPUE taking into account as many parameters as possible. To assess the relative importance of details such as net total area and the soak time for quantifying the interaction of sea turtles with gillnets, we calculated three catch rates (CPUE). First, we estimated the number of turtles captured per km^2 of nets per day ($\hat{R}1$):

$$\hat{R}1 = \frac{n}{S \times d} \quad (1)$$

where n is the total number of turtles caught, S is the total surface area of gillnets used in the fishing operations expressed in km^2 and d is the total duration of soak time expressed in number of days. Next, we made a simpler calculation of the number of turtles captured per km of nets (linear length), $\hat{R}2$:

$$\hat{R}2 = \frac{n}{L} \quad (2)$$

where L is the total length of gillnets used in the fishing operations expressed in km. Finally, we made the simplest calculation, the number of turtles captured per set:

$$\hat{R}3 = \frac{n}{N} \quad (3)$$

where N is the total number of sets.

When it was difficult to estimate the total capture (C_T) from $\hat{R}1$ and $\hat{R}2$ (with these two catch rates, we needed total length or net total area for all nets used in the study zone, which is difficult to obtain), it was estimated using formulae and the total number of fishing sets conducted by the gillnet fishery in the study area, E_T, obtained from the DGPA (General Directorate of Fishing and Aquaculture).

In a fishing set there are two possible conditions with regard to sea turtle bycatch: capture/no capture (0,1). As a consequence, the distribution is exactly binomial and can be easily derived from monitored data. Hence, 95% confidence intervals of catch rates could be calculated with the method for binomial distributions (Zar, 1999), this method was used also to calculate the confidence intervals (95%) of direct mortality p (observed dead) and potential mortality p_1 (comatose state). Total direct mortality and total potential mortality were calculated by applying total captures respectively to p and p_1.

RESULTS

Over the whole study period, 36 loggerhead turtles were incidentally caught during 45 observed fishing sets (17 and 26 sets for 2007 and 2008, respectively). A total of 15 (in 2007) and 21 turtles (in 2008) were captured in 23 sets (51% of the total number of sets). In the majority of cases, one specimen was captured in one fishing set with as many as four specimens captured in a single set. The total length and surface area of gillnets used during the study period were 106 km and 0.627 km^2, respectively. The CPUE and the total catch estimation during the two years of the study are summarized in Table 1.

Table 1. Fishing effort, catch rates and total capture of loggerhead sea turtles estimated in the study area.

	2007	2008	Total
Number of turtles captured	15	21	36
Number of sets	17	28	45
Total surface of gillnets (km^2)	0.181	0.445	0.627
Total duration of soak time (days)	35.94	72.9	108.8
Total length (km)	39	67	106
$\hat{R}1$ (C.I.= 95%)	2.3 (1.65–2.30)	0.647 (0.46–0.81)	0.527 (0.40–0.65)
$\hat{R}2$ (C.I.= 95%)	0.384 (0.23–0.55)	0.384 (0.23–0.55)	0.339 (0.25–0.44)
$\hat{R}3$ (C.I.= 95%)	0.882 (0.64–0.98)	0.75 (0.55–0.89)	0.8 (0.65–0.90)
Total number of sets	613	496	1109
Total captures	540.66 (389.2–603.8)	372 (273.3–442.9)	887.2 (715.3–1002.5)

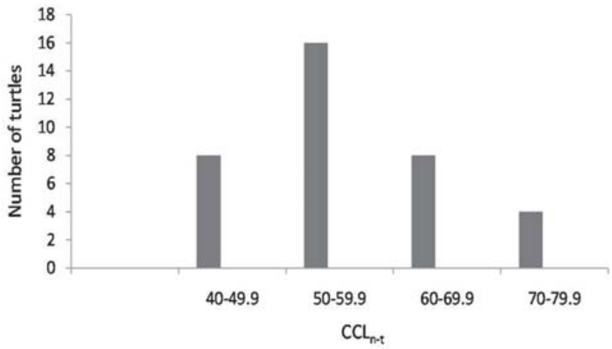

Fig. 2. Distribution of (CCL$_{n-t}$) frequencies of loggerhead turtles caught in the study area (years 2007–2008; *n*=36).

Fishing operations were conducted at depths between 10 and 50 metres. There was no apparent distinguishing feature in terms of location between the sets that did or did not catch turtles (Fig. 1). Turtles were captured in the whole study area and throughout the study period (from April to June).

The mean carapace length (CCL$_{n-t}$) of caught loggerheads was 56.6+/–7.72 cm (range 46–78). Based upon these sizes, most of these turtles were juveniles and five can be assumed to be adult (larger than 70 cm CCL according to Margaritoulis et al., 2003, and Casale et al., 2005a, for Mediterranean loggerheads). One was a female tagged in Kifisia, Greece (Fig. 2). The majority of turtles were dead (*n*=25, 69.44%), five specimens were in a comatose state (13.88 %) and six were in good condition (16.66 %). Extrapolating to the entire area, we estimated the total direct and potential mortalities at 616.07 (496,707–696,160) and 123.14 (99,284–139,232) loggerhead turtles respectively for the entire two years of study.

DISCUSSION

The catch rate of loggerhead turtles suggests that there is a substantial interaction of this species with the gillnet fishery in the south of the Gulf of Gabes, which is one of the most important neritic habitats for loggerhead turtles in the Mediterranean Sea (Margaritoulis et al., 2003). The total captures estimated here are among the highest sea turtle capture rates recorded with set net fisheries in the Mediterranean Sea, and are similar to other rates reported in other countries such as Egypt (Nada & Casale, 2008) and Croatia (Lazar et al., 2006) (Table 2). In Italy, an indirect approach based on tag returns suggested that in the Mediterranean, set nets may capture as many turtles as other fishing gear such as trawling (Casale et al., 2005b). For other countries, captures could not be estimated, even with indirect approaches, due to the lack of information on fishing effort. There are two main reasons for this. First, the gillnet fishery is a dispersed fishery, based on thousands of small vessels situated in numerous ports, thus making it very difficult to assess. Second, besides professional fishermen, there are numerous non-occupational (recreational) fishermen who use gillnets on an irregular basis, so it is difficult to estimate the fishing effort or bycatch rate.

Gillnets in this area primarily affected large juvenile size-classes between 50 and 70 cm CCL$_{n-t}$, with a low number of smaller (<40cm) and larger specimens (>70cm). The importance of juveniles in the area has also been mentioned in previous studies of trawl bycatch (Laurent & Lescure, 1994; Jribi et al., 2007) and longline bycatch (Jribi et al., 2008). The specimens captured are generally in their neritic phase and belong to Mediterranean or Atlantic populations (Carreras et al., 2006; Casale et al., 2008). Margaritoulis et al. (2003) and Broderick et al. (2007) reported that the Gulf of Gabes is a wintering area for

Table 2. Estimate of total turtle captures by set netters in some studies in the Mediterranean Sea.

Study area	Total captures per year	Sources
North of Spain	65	Alvarez de Quevedo et al., 2006
Balearic	196	Carreras et al., 2004
Croatia	393	Lazar et al., 2006
Egypt	754	Nada & Casale, 2008
South of the Gulf of Gabes (Tunisia)	443.6	Present study

Table 3. Mortality rates recorded in other studies with gillnets in the Mediterranean Sea.

Catch mortality rate	Zone	References
94.4% in trammel nets (*n*=18)	Corsica	Delaugerre, 1987
73.7% (*n*=19)	West Mediterranean	Argano et al., 1992
53.7% (*n*=149)	France	Laurent, 1991
54.9 %	North Adriatic	Lazar et al., 2006
69.4% (*n*=36)	Gulf of Gabes	Present study

loggerhead sea turtles. They note that some adult turtles frequenting the gulf of Gabes in winter leave the area during summer to reproduce in other parts of the Mediterranean Sea, thus increasing the proportion of immature turtles in the study area.

The captures reported in this study occurred in waters less than 50 m deep. In fact, the gillnet fishery in the study area, as well as throughout the whole of the Mediterranean, is mostly a small boat-based, traditional fishery, used in shallow water. The use of gillnets at these depths poses a serious threat to foraging loggerhead turtles, which are generally concentrated at depths less than 50 m (Polovina et al., 2003; Godley et al., 2003; Houghton et al., 2002).

Drowning is the main cause of loggerhead mortality in gillnets: the animal, once entangled in the net, cannot reach the surface to breath. The high mortality registered during this study (69.4%) may result from the long soak time. Gillnets in the study area are left at sea for one or many days, which is well beyond the apnoea tolerance range of turtles. This high mortality rate is similar to other rates recorded in other studies in the Mediterranean Sea (Table 3) and exceeds those recorded by trawlers (3.33%) (Jribi et al., 2007), pelagic longline (0.0%) and benthic longline (12.5%) (Jribi et al., 2008). Thus, gillnet fisheries could have a direct mortality level equivalent to or larger than commercial fisheries (Jribi et al., 2007, 2008; Casale et al., 2004, 2007; Casale, 2008).

The gillnet fishery described here poses a serious threat to loggerhead populations for two reasons. First, this gear is generally placed at shallow depths within a high density zone for loggerhead turtles (Casale, 2008). Second, the soak time typically exceeds the apnoea endurance of sea turtles. Moreover, another threat from the gear comes from its location (neritic area). This gear affects specimens in the neritic stage (large juveniles and adults), during which increased mortality rates can have a particularly large effect on loggerhead populations (Laurent et al., 1992).

Considering the scarcity of data concerning the interaction of sea turtles with gillnets, assessing the impact of this gear on these species in the Mediterranean should be a priority because this gear, like other gear types such as benthic trawls, significantly affects Mediterranean and North Atlantic loggerhead populations (Casale et al., 2008).

In the Mediterranean Sea, specific solutions to reduce the impact of set nets have not yet been presented. Management of gillnet fisheries in the Mediterranean is needed and is currently nonexistent. In the meantime, generic solutions can be proposed. These could include spatial and temporal restrictions on fishing (especially in locations and during periods of high concentration of turtles) or the establishment of protected areas in waters adjacent to sea turtle nesting colonies. These measures may effectively reduce turtle bycatch and may be socially and economically acceptable to local communities (Peckham et al., 2008). We also propose some additional approaches to mitigate sea turtle captures and mortality in gillnets: 1) increasing net lift ability by adjusting the anchoring system to allow captured turtles to reach the surface and breathe during the soak time; 2) minimizing gear soak time and time between patrolling gear in order to reduce the time incidentally caught turtles remain in the gear; and 3) modifying float characteristics (especially the colour) and reducing the number of floats, which might reduce turtle attraction and incidence of entanglement in floatlines and the net;

Recently, on the Pacific coast of Baja California, some measures to mitigate sea turtle bycatch have been presented, such as the use of buoy-less nets (without buoys on the float line) (Peckham et al., 2009) and illuminating nets (Wang et al., 2009). These techniques should be tested in the Mediterranean Sea.

Fishermen play a significant role in endangered species conservation efforts, suitable methods for dealing with live-caught turtles in nets may also help to reduce direct mortality. Awareness campaigns should be designed to inform fishermen how to deal with captured turtles and how to apply recovery techniques to comatose turtles. Booklets with specific figures would be very helpful (e.g. Gerosa & Aureggi, 2001). Additionally, injured specimens should be transferred to specialized rescue centres to receive suitable aid for further recovery.

ACKNOWLEDGEMENTS

We wish to thank all the fishermen who allowed us to operate on their boats, all the crews, as well as all the scientists and onboard observers who have participated in this work.

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Accepted: 22 November 2009