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Overview of loggerhead turtles coastal nets interactions in the Mediterranean Sea

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ABSTRACT

1. In the Mediterranean Sea, trawl nets and drifting longlines have been recognized as methods that capture thousands or tens of thousands of turtles. However, the possible impact of other fishing methods has not been adequately addressed, especially for artisanal and amateur fisheries that use coastal nets.

2. Coastal net fisheries, including driftnets and set nets, used at a much shallower depth (<40 m) in the Mediterranean, result in a large bycatch of loggerhead turtles in the neritic zone. The mortality rate with these fisheries seems to be higher than with other commercial fisheries.

3. In the Mediterranean context, additional assessments on fishery characteristics and fishing gear parameters to: (i) develop a simple and unanimous definition of an artisanal fishery; and (ii) standardize units for reporting sea turtle bycatch with coastal nets, are needed to provide an understanding of the current relative degree of risk coastal net fisheries pose to turtle populations.

4. Mitigation measures based on (a) gear-technology approaches, (b) fisheries closures, and (c) increased awareness and education of fishermen, must be considered as priorities and should be implemented without further delay.

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KEY WORDS: loggerhead; turtle; coastal nets; Mediterranean; bycatch; mortality

INTRODUCTION

The Mediterranean Sea is considered a hotspot for marine biodiversity, with about 17000 species listed (Costello *et al*., 2010). In recent years, it has suffered from overexploitation including from bycatch of vulnerable species such as sea turtles (Casale, 2008; Casale and Margaritoulis, 2010).

Most sea turtles are listed as globally endangered or critically endangered species (IUCN, 2009). Two sea turtle species nest in the Mediterranean: the loggerhead, *Caretta caretta*, and the green turtle, *Chelonia mydas* (Figures 1 and 2). The main nesting concentrations of the loggerhead turtle 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 turtle, *Dermochelys coriacea*, is observed at sea year-round throughout the region (Casale *et al*., 2003) but does not nest here. Two other species, the Kemp's ridley (*Lepidochelys kempii*) *and* hawksbill (*Eretnochelys imbricata*) turtles are recorded occasionally within the Mediterranean Sea (Laurent and Lescure, 1994).

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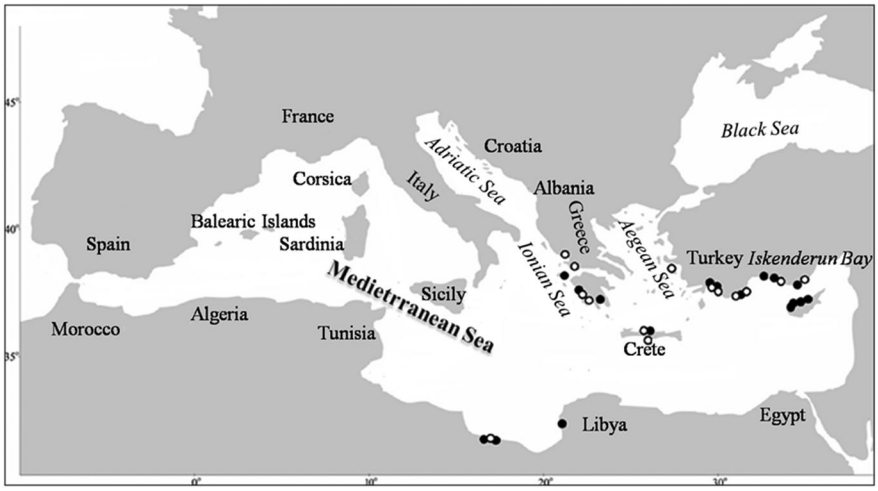

Figure 1. Major nesting sites (≥ 50 nests year^{-1}) of *Caretta caretta* in the Mediterranean (Casale and Margaritoulis, 2010). Closed circles: > 100 nests year^{-1}; Open circles: 50–100 nests year^{-1}

The loggerhead turtle, the most abundant sea turtle in the Mediterranean, frequents oceanic and neritic zones, where they feed on pelagic and benthic prey (McClellan and Read, 2007; Casale *et al.*, 2008a). The important neritic foraging grounds are the south-east coast of Turkey, the Gulf of Gabès (Jribi *et al.*, 2007; Bradai *et al.*, 2009), the north Adriatic Sea (Casale *et al.*, 2004), off the Egyptian coast (Casale, 2008) and off the Spanish coast (Gomez de Segura *et al.*, 2006). Some of these foraging grounds are shared with loggerhead turtles of Atlantic origin, in particular, the western Mediterranean, the Sicily Strait, the Tunisian continental shelf and the Ionian Sea (Laurent *et al.*, 1998; Carreras *et al.*, 2006; Casale *et al.*, 2008b). Loggerhead turtles in the oceanic phase are known to range throughout the Mediterranean, from the Spanish coast to the Ionian Sea and the southern Adriatic Sea (Margaritoulis et *al.*, 2003; Casale *et al.*, 2005a), and possibly also other areas in the eastern part not confirmed yet. Exchanges between the western and eastern basins are well known through genetic and tagging studies (Argano et *al.*, 1992; Carreras *et al.*, 2006; Casale *et al.*, 2008b).

During their life, turtles can be affected by different threats, including bycatch, which is one of the most significant issues affecting fisheries management today (Hall *et al.*, 2000). There is no specific fishery or type of fishing gear that directly targets sea turtles. Although turtle bycatch in trawl and longline fisheries are well studied throughout the Mediterranean Sea (Casale *et al.*, 2004, 2007; Camiñas *et al.*, 2006; Jribi *et al.*, 2007, 2008; Echwikhi *et al.*, 2010a), fishing nets also continue to

Figure 2. Major nesting sites (≥ 40 nests year^{-1}) of *Chelonia mydas* in the Mediterranean (Casale and Margaritoulis, 2010). Closed circles: > 100 nests year^{-1}; Open circles: 40–100 nests year^{-1}

represent a threat for sea turtles, mainly in coastal areas (Argano *et al*., 1992; Bradai, 1993; Lazar *et al*., 2004, 2006; Casale *et al*., 2005b; Casale, 2008; Echwikhi *et al*., 2010b) (Figure 3).

To secure their long-term economic viability and to ensure conformance with international guidelines for the conduct of responsible fisheries, coastal net fisheries need to adopt measures to reduce or eliminate, if possible, the bycatch of sea turtles and other sensitive species (e.g. marine mammals, seabirds, sharks).

Through a review of sea turtle bycatch by coastal nets in the Mediterranean, this study aims to: (i) provide an estimate of total capture, mortality and size of loggerhead turtles affected in many Mediterranean regions; (ii) discuss the importance of the problem of lack of data concerning sea turtle coastal net interactions in the Mediterranean Sea; and (iii) recommend effective and commercially viable solutions which could be implemented to mitigate (avoid, reduce and offset) sea turtle bycatch.

GEAR DESCRIPTION

Fishing nets, including drift nets and set nets, comprise several pieces of net (panels) that are tied together to form a single curtain that hangs upright in the water, suspended by a system of floats and weights, or anchors (Echwikhi *et al*., 2010b). Drift nets, with a relatively large mesh size suitable for catching large pelagic fish, are made of one layer (gillnet) and can be up to 10 km long. These nets, drifting freely with the current or the wind, are kept near the surface by floats on the top line and held vertically by weights at the bottom line. Set nets are smaller (hundreds of metres long and a few metres high (2 to 4 m)), with a relatively small mesh size, suitable for catching small demersal fish in coastal waters. They comprise a single layer (gillnet) or three layers (trammel net), consisting of two external ones with larger mesh size and an internal one with smaller mesh size. These nets are anchored and kept near to the sea bed by weights on the bottom line and are kept vertical by floats on the top line (Nédélec and Prado, 1990; Casale, 2008). Such fishing nets could be considered as passive fishing gears: turtles are caught by chance, as they move from place to place. However, in some cases, these fishing nets could be considered as active fishing gears: turtles try to feed on fish entangled in the nets.

RESULTS

Catch rates and total captures

There are a few studies documenting bycatch of loggerhead turtles with coastal net fisheries (set nets and drift nets) in the Mediterranean (Table 1).

Set nets, including gillnets and trammel nets, represent a threat for loggerhead turtles mainly in coastal areas (Lazar *et al*., 2004; Casale, 2008; Echwikhi *et al*., 2010b; Cambiè, 2011) (Table 2) but the quantification of captures in these widely spread fisheries is very difficult to assess because of the very high number of small boats involved around the entire Mediterranean coast. Turtle bycatch seems to be very high on the North African continental shelf (Tunisia (Echwikhi *et al*., 2010b) and Egypt (Nada

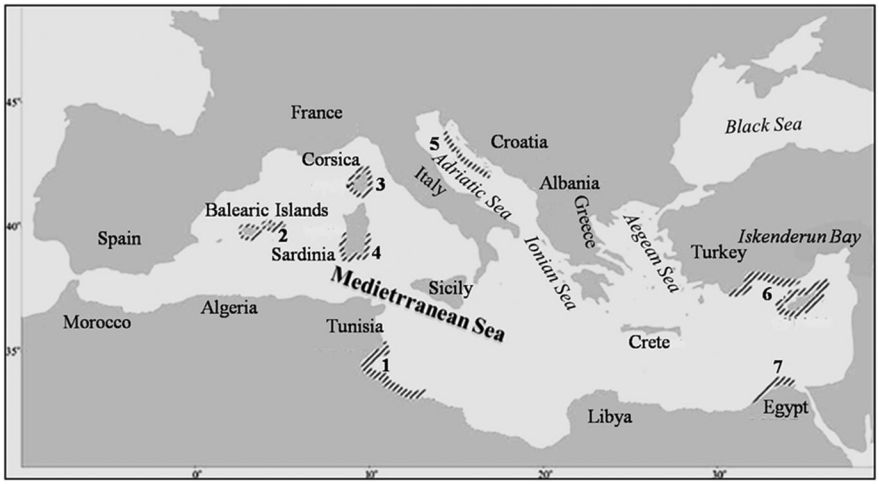

Figure 3. Mediterranean coastal nets fishing areas covered by certain studies: (1) Echwikhi *et al*., 2010b; (2) Carreras *et al*., 2004; (3) Delaugerre, 1987; (4) Cambiè, 2011; (5) Lazar *et al*., 2006; (6) Godley *et al*., 1998; (7) Nada and Casale, 2011.

Table 1. Assessments of loggerhead turtles bycatch in coastal net fisheries in the Mediterranean Sea

Study area	Fishing gear	Monitoring methodology	Findings	Citations
Eastern Adriatic	Set nets	Study occurred from 2000 to 2002. Data on gillnet fishing fleet were obtained from the Directorate of Fisheries and through personal interviews with fishermen in Slovenia.	• In total, 59 loggerhead sea turtles were captured. • The mortality rate was estimated at 54.9%. • Both small juveniles (<50 cm CCL) and large, benthic size-classes (>50 cm CCL loggerhead turtles were affected.	Lazar and Tvrtkovic, 2003
Gulf of Gabès (Tunisia)	Set gillnets	The investigation was carried out from May to June during the 2007 and 2008 fishing seasons on board artisanal boats connected to the ports of Zarzis, Jerba and El Ketf.	• In total, 36 loggerhead turtles were incidentally caught during 45 sets. • The majority of turtles were dead ($n = 25$, 69.44%). • The mean carapace length of caught loggerheads was 56.6+/−7.72 cm (range 46–78).	Echwikhi *et al.*, 2010b
North Adriatic	Trammelnets and set gillnets	Interviews with professional gillnet fishermen in Croatia and Slovenia in 2004, and data on incidental capture of 92 turtles in gillnets in 2000–2005.	• Catch per unit effort (CPUE) is 2.81+/−3.14turtles/vessel/year and 1.11 +/− 1.64 loggerhead turtles/km of gillnet. • From 234 vessels registered, a minimum of 657 loggerhead captures/year was estimated. Total turtle gillnet bycatch was estimated at 4038 captures/year. • A direct mortality of 54.9% was registered.	Lazar *et al.*, 2006
Balearic Islands	Lobster trammelnets	Information was collected from two independent sources: interviews with professional fishermen and data collected by observer's onboard fishing vessels.	• A total of 196 loggerhead turtles were estimated with a CPUE of 0.17 turtles/vessel. • Mortality estimates ranged from 78 to 100%.	Carreras *et al.*, 2004
Corsican waters	Trammelnets	Data were taken from interview and on board observers in two years 1985 and 1986.	• Loggerhead turtles were captured in depth ranging from 8 to 110 m. • Mortality rate was estimated at 94.4%.	Delaugerre, 1987
Gulf of Gabès.	Trammelnets	Interviews of fishermen in numerous ports in the Gulf of Gabès.	• Catch rate was estimated at 0.5–2.1 loggerhead turtles/vessel/year. On the basis of inquiries to fishermen, about 920 turtles/year may be captured by static nets. • Mortality rate was estimated at 5.2% (n = 58).	Bradai, 1993
Northern Cyprus and the Turkish coastline from Antalya to Mersin	Setnets	Fishermen from many harbours were interviewed.	• The estimate catch rates were 4 turtles/year/boat in the northern Cyprus and 2 turtle/year/boat in Turkey. • A bycatch of 2000 loggerheads and green turtles were estimated annually in this region. • The mortality rate was estimated at 10%	Godley *et al.*, 1998
Ionic Coast of Calabria (Italy)	Driftnets	Investigation using onboard observers in the Gulf of Taranto coast.	• Total capture was estimated at 16 000 loggerheads/year. • Turtle mortality rate was estimated from 20 to 30%.	De Metrio and Megalofonou, 1988
Italian coasts	Static nets	Data were collected in the period 1981–2000 in the framework of a sea turtle tagging programme. Turtles were originally incidentally captured by fishing methods, landed, and then tagged and released. Recaptures were reported by fishermen directly to personnel involved in the tagging programme.	• In total, 105 loggerhead turtles were captured or recaptured by static net fishermen from Italy and other Mediterranean countries. • Physical condition was unknown for five specimens and 11 specimens out of the other 100 died as a consequence of the capture.	Casale *et al.*, 2005b

(*Continues*)

Study area	Fishing gear	Monitoring methodology	Findings	Citations
Croatian coasts of the Adriatic Sea	Set nets	Data were collected from 34 recoveries of tagged loggerhead turtles.	• Measured turtles ranged from 21 to 80 $CCL_{n\text{-}t}$ (mean = 45.8; SD = 13.0; $n = 70$). • Nine specimens were caught in fishing nets: six loggerheads were captured in gillnet (five of them were found dead, while only one specimen was recaptured alive and released).	Lazar *et al.*, 2004
Mediterranean coast of Egypt	Set nets	Field surveys in the period June–October 2007 in the 15 most important fishing ports along the Egyptian Mediterranean coast. Fishermen, fishmongers and persons from local communities were interviewed.	• Total capture of loggerhead (*Caretta caretta*) and green turtles (*Chelonia mydas*) were estimated at several thousand per year, possibly over 7000/year, mainly by trawlers, longliners and set netters. • Interviewed fishermen reported that higher turtle mortality was recorded for set nets (which are left at sea from 8 h to 3 days).	Nada and Casale, 2011
Southern coast of Ionian Sea; Calabria	Driftnets	Data were collected from May to September 2007 and from interviews of reliable boat-owners (known and trusted fisherman) and from on board observations.	• No turtle bycatch	Cambiè *et al.*, 2010
Western coast of Sardinia (Italy)	Trammelnets	Ten year study of *Caretta caretta* bycatch off the central west coast of Sardinia Island, Italy. This survey involved 17 small-scale fishing vessels from 1992 to 2001.	• 0.6 loggerhead turtles have been caught by each vessel in the 10-year period. A total of 916 bycatch for the entire small-scale fleet. • Direct mortality rate was estimated at 69%	Cambiè, 2011
Catalonia (Spain)	Trammelnets and set gillnets	The survey, including questionnaires to fishers and observers on board fishing vessels, was conducted from July to August 2005. The questions asked referred to turtle bycatch in the period between June 2003 and July 2004.	• The number of loggerhead turtles caught monthly/vessel was estimated at 0.02 for trammel nets and total capture was estimated at 67 (33–101) specimens	Álvarez de Quevedo *et al.*, 2010

and Casale, 2011)), the Levantine basin (Godley *et al.*, 1998), the western coast of Sardinia (Cambiè, 2011) and the Balearic Islands (Carreras *et al.*, 2004). In Italy, an indirect approach to evaluate turtle bycatch, based on tag returns, suggested that in the Mediterranean, set nets may capture as many turtles as trawling (Casale *et al.*, 2005b).

Few published data are available for drift nets targeting swordfish, which are illegal in most Mediterranean countries. Nevertheless, illegal drift nets are still widely used in some countries such as in Italy (Lucchetti and Sala, 2010). Historically, driftnet fishing in the Mediterranean resulted in the bycatch of large numbers of loggerhead turtles. According to De Metrio and Megalofonou (1988), a total capture of 16,000 turtles was estimated annually with driftnet fishery 'ferretara' in the Ionian Sea. The United Nations established a

Table 2. Catch rates and total capture of loggerhead turtles with fishing net in different areas in the Mediterranean

Study area	Gear	Catch rate	Total capture per year	Reference
Croatia	Set gillnets and trammelnets	2.81 turtles $year^{-1}$ $boat^{-1}$	657–4038	Lazar *et al.*, 2006
Gibraltar Straits	Driftnets	0.24–0.27 turtles day^{-1} km^{-1}	236	Silvani *et al.*, 1999
Gulf of Gabès	Trammelnets	0.92 turtles day^{-1} km^{-1}	2000	Bradai, 1993
Gulf of Gabès	Set gillnets	0.527 (0.403–0.649) turtles $vessel^{-1}$	540.66(389.2–603.8)	Echwikhi *et al.*, 2010b
Italy	Driftnets	-	16,000	De Metrio and Megalofonou, 1988
Egypt	Set nets	-	754	Nada and Casale, 2008
Egypt	Set nets	-	7000	Nada and Casale, 2011
Balearic islands	Trammelnets	0.17 turtles $month^{-1}$ $boat^{-1}$	196	Carreras *et al.*, 2004
Catalonia	Trammelnets and set gillnets	0.019 turtles $month^{-1}$ $vessel^{-1}$	67 (33–101)	Álvarez de Quevedo *et al.*, 2010
Coast of Sardinia	Trammelnets	0.6 turtles $vessel^{-1}$	91.6	Cambiè, 2011

worldwide moratorium on driftnet fishing effective in 1992 but unregulated drift nets continue working in the Mediterranean (Cambiè *et al.*, 2010). There are an estimated 600 illegal driftnet vessels operating in the Mediterranean, including fleets based in Algeria, France, Italy, Morocco, and Turkey (Environmental Justice Foundation, 2007). In particular, the Moroccan fleet, operating in the Alboran Sea and Straits of Gibraltar, comprises the bulk of Mediterranean driftnetting effort, and has been found responsible for high rates of bycatch, including turtles (Environmental Justice Foundation, 2007; Aksissou *et al.*, 2010).

Size classes affected

Loggerhead turtles with sizes between 20.5 and 87 cm CCL are affected, with a particularly high proportion of large juvenile specimens (mean: 48.8 cm CCL; range: 21–80 cm) (Laurent, 1996; Casale *et al.*, 2005b; Echwikhi *et al.*, 2010b) (Table 3). The average size does not differ much among other fishing gears typically deployed in neritic areas, where large turtles are supposed to spend most of their time (Polovina *et al.*, 2003). Catch rates resulting from interactions between coastal nets and loggerhead turtles in some Mediterranean areas reflect a dire situation as the majority of specimens caught seem to be mainly large juveniles approaching sexual maturity and therefore important for the demographic contribution to the population of this species.

Mortality

Taking into account the mortality rates recorded in many Mediterranean areas (Table 4) (Casale *et al.*, 2005b; Echwikhi *et al.*, 2010b; Cambiè, 2011), coastal nets are among the most lethal fishing methods affecting loggerhead turtles in this basin. The mortality rate recorded with fishing nets seemed to be at least 60% of the total capture recorded in the Mediterranean Sea, exceeding those of larger commercial fisheries: trawl (20%), pelagic longline (30%) (Casale, 2008). Mortality induced by these kinds of gears is typically due to forced apnea, because nets are left for many hours or even days at sea, and turtles cannot easily come to the surface to breath, especially when nets are set at depth. Environmental parameters could affect sea turtle mortality: high water temperature (such as in the North Africa countries) associated with high metabolic rates, can strongly reduce their resistance to forced apnea. Considering that the maximum duration of apnea recorded for Mediterranean loggerhead turtles is 120 min (Bentivegna *et al.*, 2003), survival of even the largest turtles is only possible if their incidental capture in set nets occurs shortly before gear retrieval. Moreover, the low predictive power of the survival suggests that additional factors related to the physical conditions of turtles, such as the presence of diseases, infections, previous captures in other fishing gears, stress levels, etc., may determine their ability to

Table 3. Sizes of loggerhead turtles caught with coastal nets in different Mediterranean areas

Study area	Mean size (range)	Reference
France	39.3 (35.5–48.6)	Laurent, 1996
Italy + other Mediterranean	45.8 (21–80)	Casale *et al.*, 2005b
Western coast of Sardinia (Italy)	55 (40–95)	Cambiè, 2011
Gulf of Gabès (Tunisia)	56.6 (46–78)	Echwikhi *et al.*, 2010b

Table 4. Mortality rates of loggerhead turtles with coastal net fisheries from different areas in the Mediterranean

Study area	Gear	Mortality rate	Reference
Croatia	Set gillnets and trammelnets	57.9%	Lazar *et al.*, 2006
Balearic islands (Spain)	Losbster trammelnets	77.7%	Carreras *et al.*, 2004
Italy + other Mediterranean	Set nets	45.5%	Casale *et al.*, 2005b
Gulf of Gabès(Tunisia)	Trammelnets	5.17%	Bradai, 1993
Corsica (France)	Trammelnets	87.5%	Delaugerre, 1987
France	Trammelnets	53.7%	Laurent, 1996
Croatia- Slovenia	Set gillnets and trammelnets	54.9%	Lazar and Tvrtkovic, 2003
Gulf of Gabès (Tunisia)	Set gillnets	69%	Echwikhi *et al.*, 2010b
Western coast of Sardinia (Italy)	Trammelnets	69.4%	Cambiè, 2011
Italy	Driftnets	20–30%	De Metrio and Megalofonou, 1988
Cyprus	Trammelnets	10%	Godley *et al.*, 1998

survive. Turtles may also die if released with pieces of the net attached to the body.

DISCUSSION

Turtle bycatch in coastal nets: the difficulty of assessment and the need for standardization

For many Mediterranean countries, bycatch of turtles with fishing nets could not be estimated, even with indirect approaches, due to the lack of information on fishing effort. The net fishery is widely distributed in the Mediterranean and commonly used in artisanal fisheries. There is no simple and unanimous definition of what is an artisanal fishery, especially in the Mediterranean context. Some of the best criteria to define an artisanal fishery are small boat size and low tonnage (i.e. small scale) (Farrugio *et al*., 1993; Griffiths *et al*., 2007). Unlike the large-scale industry, the artisanal segment relies on small capital investments and is characterized by the use of several and diverse fishing gears (Farrugio *et al*., 1993), targeting a very large variety of species (Maurin, 1962; Quignard and Farrugio, 1982; Fredj *et al*., 1992). Artisanal fishing activities exhibit great variations from one area to another, not only depending on different biological and environmental conditions, but also on the social, economic and historical contexts in which fishermen live (Farrugio *et al*., 1993).

Some categories of information including fishing gear characteristics, fishery characterization (size of the fishery, fishing operations) and catch characteristics (target species and their commercial value) are required to understand the degree of risk a net fishery poses to sea turtles. For example, for gillnets and trammel nets, information recommended for collection includes: where gear is set (i.e. at the sea surface, mid-water or at sea floor), mesh size, twine material, line diameter, line colour, float and float line characteristics, distance between floats, baited or unbaited nets (and if so what species), angle of the net in relation to the coastline and fishing depths. In addition, it would be beneficial to standardize the units for reporting sea turtle catch-per-unit-of-effort (CPUE) in gillnet and trammel net fisheries to enable more meaningful comparisons. Alternative turtle CPUE units for passive net fisheries identified in Gilman (2009) were the number of caught turtles per: (i) trip, (ii) set, (iii) unit length of net, (iv) unit area of net, (v) unit area per soak time, and (vi) the weight of the net. The CPUE chosen must take into account the maximum of parameters affecting turtle bycatch. For example, reporting turtle catch per horizontal length of a net can be a misleading measure for comparisons of different net designs if the net heights are dissimilar, and if turtles are not caught in the same vertical portion of the net. Three catch rates: turtle/set, turtle/km of gillnet, and turtle/km^2 of gillnet/day, were proposed by Echwikhi *et al*. (2010b). These catch rates take into account several parameters affecting turtle bycatch with gillnet such as the surface of the net, the total length of the net and the soak time.

Recommendations for mitigation

Differences in gear designs and materials, turtle species and sizes, turtle abundance at fishing grounds, and other differences between fisheries, may cause sea turtle bycatch reduction approaches to differ in efficacy. Differences in target species and sizes, the local socio-economic context and management framework will determine commercial viability and social acceptability of bycatch mitigation methods, including industry acceptance of any reductions in catch rates of commercially important species.

The mitigation of loggerhead turtle bycatch in the Mediterranean calls for the redesign of fishing gear based essentially on simple alterations to gear configurations. Recent experiments have identified various strategies to reduce turtle bycatch and for increasing the proportion of turtles that survive capture in nets and which facilitate their timely release, such as: (i) regulation of the mesh size to a range that minimizes turtle bycatch but without having an effect on target species; (ii) increasing the hanging ratio and reducing the net profile (height) making it easier to disentangle caught turtles; (iii) making nets more visible to the turtles, through illumination or line material; (iv) placing shark shapes, identified as an effective deterrent for sea turtles, along the gillnet; (v) adjusting the weighting design and/or anchoring design of the nets, such that caught turtles can lift the gear to the surface to breathe during the gear soak.

Measures, other than technical solutions, should also be considered to reduce turtle bycatch, such as restricting fishing effort or capacity, and reinforcing spatial and temporal restrictions on fishing, especially in areas and during periods where the probability of turtle bycatch is high. Identifying such areas/seasons is not an easy task,

because it requires fine-scale spatial stratification and long-term monitoring, respectively. The following fishing restrictions are, however, a reasonable interim solution: (i) near important nesting sites and during the reproductive season (mating, nesting, hatching; May–September) (Margaritoulis, 2005; Schofield *et al*., 2009); (ii) on or near seagrass beds, which are preferred feeding areas for loggerhead turtles (Casale *et al*., 2008a); and (iii) shallow water areas recognized as important foraging grounds for turtles (Casale *et al*., 2010).

In addition, educating fishermen about procedures to reduce post-release mortality should be regarded as a useful conservation tool. Moreover, adequate awareness campaigns directed at fishers are necessary to improve practices for disentangling, handling and releasing captured turtles. For example, developing and using purpose-made line cutters, and selecting a headlamp light colour to reduce turtle stress during handling (using headlamps with red instead of white light) can cause less stress to captured turtles.

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