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An overview of loggerhead sea turtle (*Caretta caretta*) bycatch and technical mitigation measures in the Mediterranean Sea

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Abstract This paper reviews the gear parameters responsible for loggerhead sea turtle (*Caretta caretta*) capture and mortality while taking into account the mitigation measures tested in the Mediterranean Sea. Incidental catch is considered as one of the major threats for turtle survival; however, the loggerhead bycatch estimated in different areas seems to be unrealistic, which highlights the need of a method for homogenising the estimates. Drifting longlines and bottom trawls have the greatest impact on Mediterranean turtle populations, respectively in pelagic and demersal phase, while passive nets (gillnets and trammel nets) seem to be responsible for the highest direct mortality, due to drowning. Most of the experiments available for the Mediterranean are focused on drifting longline. The longline parameters, hook shape and size, bait type, setting position and the reaction to sensory stimuli, strongly affect the sea turtle bycatch and mortality. Circle hooks have the potential to reduce turtle mortality only in certain fisheries and areas; larger hooks are less likely to be swallowed by turtles due to physical constraints of the mouth, reducing the mortality rate and the catch of juveniles; branchlines, once ingested, appear to be one of the major causes of sea turtle mortality; squid bait, which consistently catches more turtles than mackerel, and lightsticks, which strongly attract turtles, should be banned, at least in some areas and seasons. On the contrary only two bottom trawl studies are available from the Mediterranean. Turtle excluder devices have been tested with promising results in Turkey and Italy, even if the loss of large fish should be carefully investigated. For set nets no practical solutions are available at this time. The analysis allows the conclusion that technical parameters affecting turtle bycatch and mortality should only be studied one at a time, in order to avoid inconclusive results, studies on post-release mortality should be implemented and finally fishermen cooperation is paramount in reducing turtle bycatch and mortality.

Keywords Loggerhead · Bycatch · Mitigation measures · Mediterranean

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Introduction

Human activities such as pollution, habitat degradation of the nesting beaches, incidental catch and intentional killing (for blood and meat), represent the major threats to the survival and to the general decline of marine turtle populations in the Mediterranean Sea (Margaritoulis et al. 2003). The Barcelona Convention adopted an Action Plan for the Conservation of Mediterranean Marine Turtles in 1989, revised in 1998–1999 and 2007 (UNEP MAP RAC/SPA, 2007), acknowledging that the impact of fishing activities is one of the most important anthropogenic mortality factors for sea turtles in the Mediterranean Sea and that their conservation deserves special priority (Lutcavage et al. 1997; Tudela 2004). Several countries (22 Mediterranean and 15 non-Mediterranean) regularly fish in this basin and an undefined number of small boats are active in non-EU countries. Therefore, the fishing effort in the Mediterranean is a key factor to take into account in considering the sea turtle conservation. Nevertheless, present knowledge about the interaction of sea turtles with fishing gears and the possible mitigation measures are still insufficiently studied (Casale et al. 2004).

The leatherback- (*Dermochelys coriacea*), the green- (*Chelonia midas*) and the loggerhead-turtle (*Caretta caretta*) are regularly found in the Mediterranean basin (Tudela 2004). The latter two species are listed as Endangered while the leatherback turtle is listed as Critically Endangered on the Red List of Threatened Species of the International Union for Conservation of Nature and Natural Resources (IUCN; Hilton-Taylor 2000). Loggerhead is the most abundant species of marine turtles in the Mediterranean Sea and the knowledge of its biology represents a crucial point to evaluate the impact of different fishing activity in different areas. The loggerhead and the green turtle are known to nest in the Mediterranean, especially on the beaches of the East side (Cyprus, Egypt, Greece, Israel, Italy, Lebanon, Libya, Syria, Turkey and Tunisia; Fig. 1). It is estimated that 2,280–2,787 loggerhead sea turtles (Broderick et al. 2002) and only 300–400 green turtle females annually nest in the Mediterranean. Margaritoulis et al. (2003) have estimated 3,375–7,085 nests per season. The estimates made by Groombridge in 1990 (2,000 loggerhead sea turtles), are similar considering an average of three clutches per season. The number of adults should be even higher considering that most of the individuals do not breed every year. Moreover, additional specimens migrate from Atlantic population to Mediterranean Sea through the strait of Gibraltar during the first half of the year (Camiñas 1997a, b; Fig. 1).

Three main ecological phases characterize the life of loggerhead sea turtle: the pelagic phase, when loggerheads feed on pelagic preys; the demersal phase, when they swim close to the bottom to eat benthic species; and finally an intermediate neritic phase, when loggerheads shift from pelagic–oceanic to benthic–neritic foraging habitats (Tomas et al. 2001; Fig. 1). The greatest density of specimens in demersal phase is found in shallow waters (<100 m). Loggerheads do not dive deep and the maximum recorded depth is 110 m (Lutcavage and Lutz 1997). The bathymetry and environmental characteristics of different areas determine the distribution and abundance of marine turtles. Loggerhead turtles exhibit high fidelity to migratory routes, foraging areas and

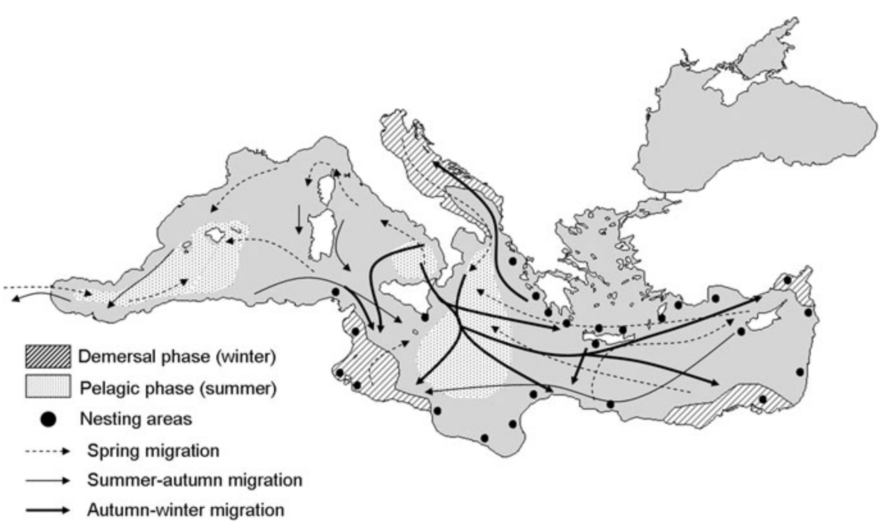

Fig. 1 Loggerhead migrations in the Mediterranean Sea; the main routes, nesting beaches, pelagic and demersal areas are shown (Bentivegna 2002; Broderick et al. 2007; Camiñas 2004; Maffucci et al. 2006)

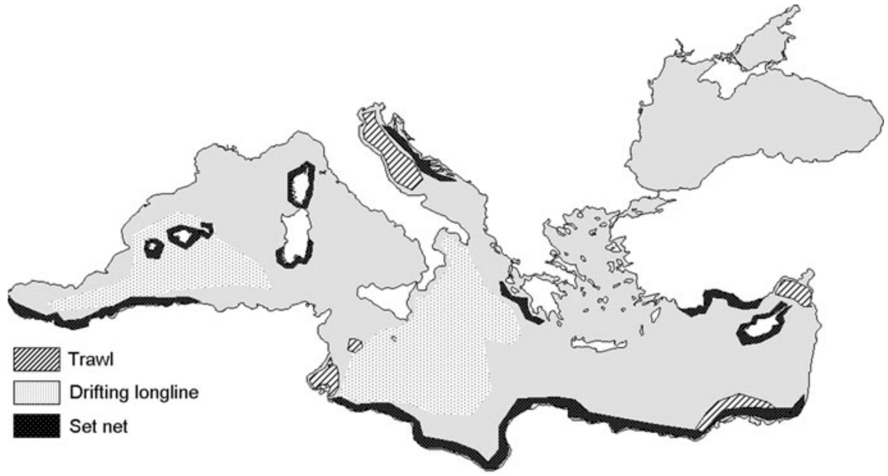

Fig. 2 Turtle bycatch in Mediterranean by gear type and area

wintering sites, between and within years and after successive breeding migrations (Broderick et al. 2007; Fig. 1).

Thus, different types of fishing gear (towed or passive, on the bottom or in the water column) can produce different captures and mortality rates (Gerosa and Casale 1999) and may affect different ecological phases (Fig. 2).

Assessment of loggerhead sea turtle bycatch

In the Mediterranean more than 60,000 turtles per year are estimated to be accidentally caught as a result of fishing practices (Lee and Poland 1998), direct mortality rates ranging from 10 to 50% and even 100% of individuals caught. Moreover, the delayed mortality (after the release at sea) is mostly unknown. On the other hand Casale (2008) highlights an even worse picture suggesting that over 150,000 captures per year may take place in the Mediterranean by trawlers, longliners and set netters, with possibly over 50,000 deaths per year by interaction alone. A more pessimistic scenario is defined considering that official fleet statistics do not include all the existent fishing vessels and that the number of small boats is underestimated. This leads to an estimate of more than 200,000 capture events per year.

Drifting longline

Drifting longline targeting swordfish (*Xiphias gladius*), albacore (*Thunnus alalunga*) and bluefin tuna (*Thunnus thynnus*) deployed over the continental shelf and offshore waters, is considered as the main threat to the marine turtles in the Mediterranean Sea, in terms of catch per year (Gerosa and Casale 1999; Deflorio et al. 2005; Margaritoulis et al. 2003; Table 1). The incidental capture of loggerhead turtles in pelagic phase with longline mainly extends from spring to late autumn, with most captures occurring in the summer (Figs. 1, 2).

Casale (2008) found that over 50,000 specimens are estimated to be caught with pelagic longlines with a mortality of 40% mainly in Spain, Morocco, Italy, Greece, Malta, Libya (Table 1). Lewison et al. (2004) estimated at least 60,000–80,000 captures per year in the Mediterranean while Panou et al. (1992) found an annual catch of about 35,000 specimens only for the Central-Western Mediterranean Sea, which is one of the main areas of concentration for adult loggerheads, as well as for targeted species (swordfish). In fact, Spain is the country with the highest number of turtle captures per year followed by Morocco and Italy (Table 1; Fig. 2). Recent studies on Spanish longline fleet targeting swordfish, suggested that turtle bycatch is drastically high especially around the Balearic Islands (Aguilar et al. 1995; Camiñas 1988; Camiñas et al. 2001; Mayol et al. 1988; Table 1). This is not surprising since it is known that the occurrence of a high concentration of sea turtles in the western basin is due to the Mediterranean population but also to the entrance of specimens from the Atlantic Ocean via Gibraltar (Argano et al. 1992; Camiñas and De la Serna 1995; Fig. 1). Moreover, results indicated that swordfish longline is responsible for more abundant

Table 1 Assessment of turtle bycatch and direct mortality in Mediterranean by gear type

Gear type	Area	Catch/year	Direct mortality	Reference
Drifting longline	Entire Mediterranean	50,000	0–4% (40% potential)	Casale 2008
	Entire Mediterranean	60,000–80,000	Potential mortality 17–42%	Lewison et al. 2004; NMFS 2001
	Western-central Mediterranean	35,000		Panou et al. 1992
	Spain	22,000–35,000	0.36–7.7% (20–30% potential)	Aguilar et al. 1995; Tudela 2000, Carreras et al. 2004
	(Balearic Islands: 15,000–18,000; Aguilar et al. 1995; Camiñas 1988; Camiñas et al. 2001; Mayol et al. 1988)			
	Spain		0.54–4.24%	Camiñas et al. 2006a, b
	South Sicily (Italy)	2,148	>30% potential	Casale et al. 2007a,b
	Lampedusa Island (Italy)	245		Casale et al. 2007a
	Ionian Sea (Italy)	1,084–4,447	0% (potential mortality high)	Deflorio et al. 2005
	Ionian Sea (Greece)	280–3,181		Panou et al. 1999; SGRST-SGFEN 2005
	Aegean and South Ionian seas (Greece)	1,145–5,474		Kapantagakis and Lioudakis 2006
	Cephalonia (Greece)	50		Panou et al. 1992
	Malta	1,500–2,500		Gramentz 1989
	Cyprus	2,000		Godley et al. 1998
	Morocco	3,000		Laurent 1990
	Algeria	250–300		Laurent 1990, Camiñas 2004
	Tunisia	486–4,000	0% (9.1% potential)	Echwikhi et al. 2006; Salter 1995; Demetropoulos 1998; Jribi et al. 2008
Bottom trawl	Entire Mediterranean	30,000	5% (20–25% potential)	Casale et al. 2004; Casale 2008; Laurent et al. 1996; Lazar and Tvrtkovic 1995; Oruç 2001
	Italy	8,000	14% (57% potential)	Casale et al. 2004, 2007a
	Lampedusa Island (Italy)	4,056		Casale et al. 2007a
	North Adriatic (Italy)	4,273	9.4% (43.8% potential)	Casale et al. 2004
	France		3.3–3.7%	Laurent 1991; Delaugerre 1987
	Croatia	2,500	Low	Lazar and Tvrtkovic 1995
	Thracian Sea	0–418		Margaritoulis et al. 2001
	Ionian Sea (Greece)	0–448		Margaritoulis et al. 2001
	Tunisia (whole continetal shelf)	14,000		Jribi and Bradai 2008
	Gulf of Gabes (Tunisia)	2,500–5,500	3.3%	Bradai 1992; Jribi et al. 2004
	Egypt	2,269–high	1–10%	Nada and Casale 2008; Laurent et al. 1996
	Turkey	High	1.6% (13% potential)	Oruç (2001); Oruç et al. 1996

Table 1 continued

Gear type	Area	Catch/year	Direct mortality	Reference
Drift nets	Italy	16,000	20–30%	De Metrio and Megalofonou 1988
	Ligurian and Tyrrhenian Sea (Italy)	Low		Di Natale 1995
	Spain	117–354	3.3%	Aguilar et al. 1995
	Spain	236		Silvani et al. 1999
Bottom longline	Entire Mediterranean	35,000	Potential mortality 40%	Casale 2008
	Lampedusa Island	257		Casale et al. 2007a
	Tunisia	733–2,000	0.53–12.5% (33% potential)	Echwikhi et al. 2006; Jribi et al. 2008; Bradai 1993
	Egypt	2,218		Nada and Casale 2008
Fixed nets	Entire Mediterranean	30,000	>50% (60% potential)	Casale 2008
	Balearic Islands (Spain)	209	50–100%	Carreras et al. 2004
	Corsica (France)	Low	93.3–75%	Laurent 1996; Delaugerre 1987
	France	10–100–low	50–100%	Laurent 1991
	Italy		50%	Argano et al. 1992
	Slovenia–Croatia	657–4,038	50–73%	Lazar et al. 2006
	Cyprus	500	10%	Godley et al. 1998
	Tunisia	920–2,000	5%	Bradai 1993
	Egypt	754		Nada and Casale 2008
	Turkey	1,328	10%	Godley et al. 1998
Pelagic pair trawl	North Adriatic	1,550		GFCM-SAC 2008
	Turkey	High (5 trawlers catch around 100 loggerheads)	Oruç (2001)	
Purse seine	Egypt	37		Nada and Casale 2008
Small scale fishery fixed nets, purse seines, bottom and surface longlines etc.	Tunisia	5,000		Bradai 1995

incidental catch than bluefin tuna and albacore longlines (Camiñas et al. 2001).

Turtles migrating from the Eastern to the Western Mediterranean basin and vice versa through the strait of Messina and the strait of Sicily are very common in Italian waters (Argano and Baldari 1983; Argano et al. 1992; Bentivegna 2002; Margaritoulis 1988; Fig. 1). The two corridors are characterized by high fishing pressure with different gears (Bentivegna 2002) and the drifting longline is the most impacting (Table 1). In this area Cambiè et al. (2008) found that loggerhead sea turtle was the second most abundant fished species after swordfish in longline fishery.

In Greek waters *C. caretta* bycatch seems to be less abundant, even if the situation is not clear due to the year by year high variability on bycatch data (Table 1). Data available for Maltese waters (Gramentz 1989) showed that turtle bycatch in this area is quite similar to the estimates obtained in other areas of the Ionian Sea.

Jribi et al. (2008), recorded that sea turtle catch rate coming from longline fishing activities in Zarzis (Tunisia) is higher than those reported in Greece and Italy (other than Lampedusa) but lower than that reported in the Western Mediterranean Sea, with most of the incidental catches in summer (Jribi and Bradai 2008; Table 1). Morocco shows a very similar amount of sea turtle capture (Laurent 1990) while the bycatch data available for Algeria (Camiñas 2004) seem to be underestimated (Table 1).

Bycatch due to foreign industrial longline fleets operating in the Medieterranean waters (Japanese, flag of convenience) could lead to an even worse situation. Data on annual catches are available for other non-EU countries but in some cases there is a little concern on their validity.

Bottom trawl

Bottom trawl has been considered as the second most impacting fishing gears for sea turtle populations in terms of number of catch per year (Table 1). Bottom trawl mainly impacts turtles in demersal phase since they prefer coastal shallow waters less than 50 m or even 20 m deep, where they feed (Hare 1991; Caillouet et al. 1991; Bradai 1994; Epperly et al. 1995); most of them are juveniles and sub-adults usually far from their hatching ground (Bolten et al. 1998). Usually Mediterranean continental shelf, which constitutes the feeding habitats for several turtles, is really narrow in most areas. Nevertheless, in some places (Gulf of Gabés, Northern Adriatic Sea, Southern Turkey and Egypt), the continental shelf is large and turtles in demersal phase are used to spend winter time in these areas. Mediterranean bottom trawlers are estimated to catch around 30,000 specimens per year altogether (Table 1), with a mortality of 25%, mainly in Italy, Tunisia, Croatia, Greece, Turkey, Egypt, and Libya (Casale et al. 2004; Casale 2008; Laurent et al. 1996; Lazar and Tvrtkovic 1995; Oruç 2001; Fig. 2). Moreover it is well known that the same turtle can be caught more than one time, for this reason Casale (2008) has estimated more than 40,000 "capture events" for the Italian waters alone.

North Adriatic Sea with its shallow waters (<100 m) and rich benthic communities is considered as one of the most important feeding habitat in the whole Mediterranean, mainly for the population nesting in Greece (Fig. 1) and the bycatch estimates for this area are high (Casale et al. 2004; Lazar et al. 2004; Lazar and Tvrtkovic 1995). A study carried out in the shallow waters of the continental shelf south of Lampedusa Island showed considerable catch rates of loggerhead turtle, due to the high fishing pressure by bottom trawlers coming in this area from other Italian harbours (Table 1; Casale et al. 2007a).

In the Gulf of Gabès (Tunisia) Jribi et al. 2004 estimated that the total accidental catch of loggerhead sea turtle is comparable with that reported for the North Adriatic (Table 1), although the estimates for the whole continental shelf of Tunisia (captures made by Tunisian and Italian fleets) gave an even worse picture (Jribi and Bradai 2008). Sea turtle bycatch estimated by Nada and Casale (2008) in Egypt was slightly lower than that observed in the Gulf of Gabès.

The Eastern Mediterranean coast of Turkey represents an important area for marine turtle nesting and feeding (Baran and Kasparek 1989). Oruç (2001) observed that for this area green turtle is more important than loggerhead turtle bycatch. Moreover, turtles captured were mostly juveniles (81%) and most turtles were alive when taken from the trawls. In Greece bottom trawl seems to have a minor impact on sea turtle population (Margaritoulis et al. 2001).

Other gears

Few official and published data are available for drift nets targeting swordfish, which are illegal in most of Mediterranean countries. Nevertheless, illegal drift nets are still widely used in some countries, and the amount of bycatch is hypotized to be very high. According to De Metrio and Megalofonou (1988), Italian drift nets in the Ionian Sea are estimated to catch around 16,000 turtle/year. In recent years the use of legal drift net called "Ferrettara", similar for its characteristics to the illegal "spadara" (used to catch swordfish), has been causing several problems for fisheries inspectors in Italian waters. For this reason illegal drift nets (masked as legal "Ferrettara") are still being used. Moreover several drift nets of EU countries were probably sold to non-EU countries, mainly Moroccan fleets, shifting the bycatch problems from the North to the South basins.

As it concerns bottom longlines they are generally used at a depth of 200–700 m which not arouse concern (Bolten et al. 1994), however, there are some fishing grounds where this method is used at a much shallower depth, causing numerous captures of marine turtles, mainly juveniles. Demersal longlines seem to be responsible for about 35,000 capture events, the most affected marine areas being the north African continental shelf (Tunisia, Libya, Egypt), the Alboran Sea (Morocco), the Levantine basin (Turkey) and the Aegean (Greece; Casale 2008).

Studies concerning fixed nets in the Mediterranean are rare. Fixed nets represent a threat for sea turtles mainly in coastal areas (Lazar et al. 1998, 2004; Argano et al. 1992; Fig. 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 disseminated along all the Mediterranean coasts. Over 30,000 captures per year are estimated mainly in Tunisia, Libya, Greece, Turkey, Cyprus, Croatia, Italy, Morocco, Egypt, France (Casale 2008; Fig. 2). Turtle captures seem to be very high in certain areas, such as Croatia, Slovenia and Tunisia. (Lazar et al. 2006; Bradai 1993). Juveniles are frequently caught nearby nesting areas in Greece, Turkey and Cyprus (Godley et al. 1998; Suggett and Houghton 1998). Lescure (1987) reported that in Mediterranean French coast loggerhead sea turtles are mainly captured with trammel nets and bottom trawl. Thus, some authors (Casale et al. 2005) stated that in the Mediterranean Sea the interaction of sea turtles with the static net fishery could be very important and comparable to other fisheries.

Very little information is still available for pelagic pair trawl, even if in the North Adriatic an annual estimate reports that about 1,550 turtles per year are caught accidentally (GFCM-SAC 2008) with all turtles released alive. The purse seines seem to represent a minor problem since the annual catches are probably very low and turtles are released alive.

Main fishing gear parameters affecting marine turtle bycatch and mortality

The capture of loggerhead sea turtle strongly depends on different parameters. The most important factor is the fishing effort: number of vessels, engine power (KW, HP), Gross Tonnage (GT, TSL), time at sea (hours per day, days per year, etc.) are parameters essential to be taken under control. Nevertheless, the mortality rate is variable and it largely depends on gear type, practices on board and on capability of surviving to the forced apnoea.

Three main processes must be considered in longline turtle bycatch: attraction of the turtle by bait, hooking and finally escapement during hauling of the gear.

The hooks can be identified by several parameters as the general shape ('J' or 'G'), dimensions (total length, length diameter, gap between point and shank, length shank, width, throat, barb size, etc.), material (steel, inox), point (with barb or not), shape of eye flat or twisted (generally the shank and the point are not on the same plain, but on plains with a difference of 10–25°, degree offset, with the aim of enhancing the catch efficiency). In the hooking process, the most important parameters are: the overall hook width, which can be correlated with turtle mouth dimension, its gap, which ensures deeper penetration of the point and better holding power of the fish, its shape which can influence the hooking position.

The direct mortality induced by longlines appears to be low (Table 1) but the delayed mortality is a cause of concern because it is widely unknown and it is suspected to be very high (Camiñas and Valeiras 2001; National Marine Fisheries Service 2001; Lewison et al. 2004; Deflorio et al. 2005; Kapantagakis and Lioudakis 2006). The low direct mortality can be justified by the fact that the hooked loggerhead sea turtles maintain enough power to raise the lines to the surface and to breathe. About the 80% of the hooked turtles is released alive but the post-release mortality strongly depends on the hooks position in different parts of the digestive tract (mouth, oesophagus, stomach, intestine, etc.; Camiñas and Valeiras 2001). In particular, if the hook is swallowed in the lower oesophagus or in the stomach the turtle has a very low chance of surviving. On the contrary the mortality of turtles with a hook in the mouth or higher oesophagus seems to be less important even if a hook in the mouth could compromise the feeding performance, especially if it impedes closure of the mouth (Casale et al. 2007b). Studies made by rescue centres showed a high post-release mortality, both in the short- and in the long-term. A capture in a line with hook timer showed that a turtle was able to survive for 18 h and 9 min. The estimates of potential mortality caused by drifting longline obtained in various areas by different authors (Aguilar et al. 1993; Casale et al. 2007b; Lewison et al. 2004; Table 1) are similar and ranged from 17–20 to 30–40%. The parameters barb size and hook length can affect the capacity of the turtle to disengage. Some studies showed that the use of barbless hooks implied a small reduction in unhooking time, leading to an improvement of survival rate (Alós et al. 2008).

Nevertheless in addition to the hook, the secondary lines of a longline (the so called branchlines which is the piece of line attached to the hook) can easily cause turtle death, especially if it is long enough to be affected by intestinal peristalsis (Bjorndal et al. 1994; Casale et al. 2007b; Oros et al. 2004). In these cases death typically occurs after many days. Unfortunately as a common practice fishermen are used to cut the branchline from the deck while the captured turtle is still in the water (they gain time because turtle are often very heavy) so leaving most turtles released with potentially lethal branchlines longer than 1 m (Guglielmi et al. 2000). Thus it appears that the hooks cause death in the short term and the branchlines in the long term (Casale et al. 2007b).

Nevertheless, other parameters affect sea turtle catch and mortality. Albacore and bluefin tuna longlines generally produce higher direct mortality in the hooked turtles than swordfish longlines. This is probably because of the gear structure and hook size but it could be also due to the fishing depth or to the distance from the coast or to the higher catch amount that could sink the gears affecting turtle mortality by reducing breathing possibilities. Turtle mortality in longline could be strongly affected by the depth of the main line setting. Loggerhead sea turtles spend most of their time at less than 40 m and they do not dive deeper than 100 m (Polovina et al. 2003). Juveniles of loggerhead sea turtles are capable of diving to depths below 200 m, but generally they stay in the upper 30 m (Dellinger 2000; Dellinger and Ferreira 2005). Thus the main interaction depth with longline is the upper 20 m of the water column (Dellinger and Ferreira 2005). Several studies confirmed the very low direct mortality rate due to shallow-set longline gear activities (Deflorio et al. 2005; Gilman et al. 2007; Jribi et al. 2008; Pinedo and Polacheck 2004; Piovano et al. 2009). The mortality rate in bottom longlines seems to be concentrated on juveniles particularly, since bigger specimens are able to drag the main line with its weights up to the surface to breathe. Therefore, demersal longlines seem to be responsible for a potential mortality (delayed) of about 40%, because hooked turtles, especially juveniles, cannot reach the surface to breathe (Casale 2008). Finally turtle mortality seems to be correlated to the time setting: the longer the set time, the more turtles captured die (Camiñas et al. 2006a, b).

In bottom trawl incidental catch of loggerhead sea turtle probably occur during towing operations when turtles are foraging on the bottom. When captured by a trawl, loggerhead sea turtles may drown, becoming first comatose and eventually dying. Mortality by trawling is due to forced apnoea, thus longer or faster tows are responsible of higher mortality rates. Therefore, towing time is one of the main factors affecting the mortality rate (Henwood and Stuntz 1987) but, especially in the bottom trawl, additional factors might occur (Stabenau et al. 1991). Sasso and Epperly (2006) found that turtle mortality was different depending on seasons, mortality being higher in the winter than in summer. They also found that tows of short duration (<10 min) have negligible effect on mortality. Thus it may not be a reasonable solution to allow the longer fishing times 60 min in winter and 40 min in summer as recommended by the US National Research Council (1990). The observed direct mortality in Turkish waters was really low (0.3%), while some specimens (4.6%)

were figured comatose or weak when released from the nets (Oruç 2001).

As it concerns passive nets it is realistic to consider that this fishing gear has the potential to be more harmful than pelagic longlines and bottom trawl. The mortality rate associated with this fishing gear is estimated to be around 50% and even more (Table 1). Studies on gillnets and trammel nets found that these gears are responsible of high turtle direct mortality (from 50 to 100%). Drowning is the main reason for the sea turtle mortality since turtles get entangled in nets when trying to feed on fish previously captured and are forced underwater for an unsustainable period of time (Laurent 1991, 1996; Table 1). To this, 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 the resistance to forced apnoea.

Mitigation measures

The identification of methods to reduce or prevent sea turtle bycatch is a high priority for fishery managers and a necessary component of conservation efforts. The most obvious and simplest approach to solve the bycatch problems is the reduction of the fishing effort, even if this is often not a practical or viable option for economic, social and sustenance reasons. A summary of the main mitigation measures tested in the Mediterranean Sea is shown in Table 2.

Drifting longline

Several studies have been carried out into mitigation measures to reduce turtle bycatch in longline fisheries focusing efforts within a number of different longline fisheries around the world but, few of them have been performed in the Mediterranean Sea. Drifting longline in the Mediterranean Sea targets large pelagic fish such as albacore (*T. alalunga*), bluefin tuna (*T. thynnus*) and swordfish (*X. Gladius*). Several measures have recently been proposed to reduce sea turtle capture and mortality in pelagic longline (see for a review Gilman et al. 2006): (1) using small circle hooks ($\leq$4.6 cm narrowest width) in place of smaller J and Japan tuna hooks; (2) setting gear below turtle-abundant depths; (3) single hooking fish bait vs. multiple hook threading; (4) reducing gear soak time and retrieval during daytime; (5) avoiding bycatch hotspots through fleet communication programmes and area and seasonal closures. Among these solutions three are particularly promising: reducing the hook size, setting the hooks deeper in the water column and changing the hook shape.

Hook size

The hook size influences the probability that the hook is swallowed and the turtle becomes hooked internally, increasing the delayed mortality after the release. Some studies on captivity showed that loggerhead sea turtles had a much lower tendency to ingest hooks larger than 51 mm in width, than smaller hooks (Løkkeborg 2004). The reduction in the hook size from “18/0 J” to “9/0 J” is the easiest solution because larger hooks are less likely to be swallowed by turtles due to physical constraints of the mouth (Watson et al. 2003). Larger loggerheads are probably more likely to ingest hooks than smaller loggerheads. In the Balearic Islands Alós et al. (2008) found that the hook size is the most important cause for the deep-hooking, which is reduced by the use of large hooks. Moreover large turtle tend to be caught in deep-hooking locations. Finally they found that large hooks reduce the incidence of hooking injuries, with a small reduction in catch rate. Similar results were obtained by Jribi et al. (2008) in Tunisia, where the smaller hooks of bottom longlines seemed to be more easily swallowed in the digestive tract in comparison with hooks of surface longlines, which remained in the mouth. In the Ionian Sea the hook used for albacore fishing (4 cm long) is notably smaller than the one used for swordfish (10 cm long) and it is baited using small bait which makes the biting easier for small marine turtles (Deflorio et al. 2005).

During the *GFCM-SAC Transversal Working Group on bycatch/incidental catches* (2008) participants stressed the point that bottom longlines catch a bigger number of juvenile loggerheads, due to the smaller hook size.

Hook shape

The shape greatly affects the hook position in the mouth and the capacity of a turtle to disengage from

Table 2 Principal bycatch mitigation measures tested in the Mediterranean Sea

Gear type	Mitigation measure	Area	Action	Reference
Drifting longline	Hook size	Mediterranean	Smaller turtles are caught by BLL (smaller hooks)	GFCM-SAC (2008)
		Ionian Sea (Italy)	Larger turtles are caught by SWO-LL (larger hooks)	Deflorio et al. (2005)
		Balearic Islands (Spain)	Smaller hooks caused deep-hooking	Alós et al. (2008)
		Tunisia	Smaller hooks (BLL) caused deep-hooking	Jribi et al. (2008)
	Hook shape: J vs circle hook	Atlantic–Mediterranean	Results do not support move from J to circle hook	Project UE-FISH/2005/28-A
		Italy	Circle hooks reduced turtle bycatch; circle hooks were not easily swallowed	Piovano et al. (2009)
		Spain	Hook type is not the main factor for turtle bycatch reduction	De La Serna et al. (2008)
		Spain	Inconclusive results	Parga (2008)
		Spain	Circle hook can shift the problem from turtle to cetaceans or sharks	Camiñas and Valeiras (2001)
		Western Mediterranean	No evident differences	Rueda and Sagarminaga (2008)
			Circle hook only reduce leatherback turtle bycatch	Casale 2005 (review of Watson et al. 2003, 2004)
			Circle hook effective in reducing turtle bycatch in several countries, circle hooks reduce the rate of hook ingestion	Several authors (i.e. Watson et al. 2004; NGO websites etc)
		Bait type	Spain	Mackerel bait instead of squid bait reduce turtle bycatch Rueda and Sagarminaga (2008)
			Atlantic–Mediterranean	Mackerel bait instead of squid bait reduce turtle bycatch project UE-FISH/2005/28-A
				Mackerel bait instead of squid bait reduce turtle bycatch GFCM-SAC 2008
	Depth setting	Atlantic–Mediterranean	Deep longline: reduction in turtle bycatch, reduction in target species	Rueda and Sagarminaga (2008)
		Ionian Sea (Italy)	Most of turtle bycatch between 10–15 m depth	Project Life Nature 2003-NAT/IT/000163
		Mediterranean	SWO-LL catch turtle at a depth <60 m; ALB-LL catch turtle at a depth <20 m	Laurent et al. (2001)
	Sensory stimuli	Italy (tank tests)	Floats presence or absence does not influence turtle behaviour	Piovano et al. (2002)
		Italy (tank tests)	Odour play a key role in the bite-no bite decision	Piovano et al. (2004)
		Spain	Lightsticks attract sea turtle	Rueda and Sagarminaga (2008)
		Italy (tank tests)	Acoustic tests: inconclusive results	Piovano et al. (2002)
Bottom trawl	TED (Turtle excluder device)	Italy	Effective in reducing turtle bycatch, discard and debris; possible problems with loss of large fish	Lucchetti et al. (2008)
		Turkey	Effective in reducing turtle bycatch	Atabey and Taskavak (2001)

SWO-LL Swordfish longline, *ALB-LL* albacore longline, *BLL* bottom longline the hook. The hook location plays a fundamental role in the post-release survivorship of sea turtles, especially when hooks remain lodged in the body with trailing fishing line. As it concerns the Mediterranean, one of the most important mitigation measures tested in order to reduce turtle bycatch is the change in hook shape from traditional "J" shape to a "circular" one. Different manufacturers produce hooks in many different sizes and designs. In the case of J hooks the point is parallel to the shank, while in circle hooks the point is perpendicular to the shank. There is growing evidence that circle hooks tend to be located mostly externally in the jaw or mouth as opposed to deeper hooking (Watson et al. 2005; Gilman et al. 2006, 2007; Read 2007). Nevertheless, the efficacy of circular hooks in reducing turtle bycatch and throat hooking is clearly demonstrated only in certain fishing grounds.

Piovano et al. (2009) tested hooks with a different shape but a similar gap (about 2.6 cm width; circle hook size 16/0 vs J hook size 2) in order to determine the potential effectiveness of the hook design to both reduce sea turtle capture as well as to maintain acceptable levels of target species capture rates in a shallow-set longline swordfish fishery. They found that circle hooks can effectively reduce the number of immature loggerhead sea turtles accidentally captured by up to 70% without affecting the capture rate of target species (swordfish). Piovano et al. (2009) also found that all hooked turtles were brought on board and released alive, irrespective of the type of hook. This seems to confirm the very low direct mortality rate due to shallow-set longline gear activities. They also showed that 81% of the hooking occurred in the mouth, while 19% were swallowed, all of which were on J hooks (zero swallowed with circle hooks).

On the contrary the results obtained in a project carried out in the Atlantic and Mediterranean areas (UE-FISH/2005/28-A) do not support the promotion of shifting from J hooks to either of the two circle hooks (16/0 0° offset and 18/0 10° offset), as these hooks did not consistently reduce turtle catch rates (although there was an indication that 18/0 circle hooks were less likely to be swallowed than J hooks or 16/0 circle hooks) and had negative impacts on swordfish catches. De La Serna et al. (2008) found that the type of hook was not a valuable solution in reducing sea turtle bycatch and probably factors other than hook type were observed to be more important. Moreover circular hooks, especially in combination with squid bait, generally decrease the catch rates of the most important fish target species.

In the western Mediterranean, turtle catch rate of circle hooks was slightly lower than on J hooks. Rueda and Sagarminaga (2008) compared 12/0 circle hooks and J shape hooks having similar dimensions in Spanish longline vessels but they did not find any significant difference in turtle bycatch and in tuna catches. Moreover Camiñas and Valeiras (2001) noticed that circular hooks seemed to shift the bycatch problem from turtles to cetaceans and sharks. Casale (2005) in reviewing Watson et al. (2003, 2004), strengthen the fact that the overall effect of the circle hooks in reducing turtle bycatch is limited to the soft-shelled leatherback turtle. Moreover, for the loggerhead sea turtle the studies carried out by NOAA in the Atlantic suggest that catch rate of these species is affected by hook size and bait rather than by hook shape. Parga (2008) tested small circle hooks instead of traditional J hook in Spanish surface longline targeting *T. alalunga*. Results were inconclusive except for a significant reduction of immature *T. thynnus*.

Some differences on fishermen judgment were also observed: circular hooks are not well accepted by Spanish fishermen (Báez et al. 2006) as their use is considered to diminish yields of target species (Gilman et al. 2006). On the contrary Italian fishermen did not find any appreciable difference (project Life Nature 2003-NAT/IT/000163). For this, Piovano et al. (2009) support the enforcement of circle hooks in the Mediterranean swordfish longline fishery because it can represent a simple and inexpensive technical solution to decrease the capture of turtles.

Bait types

Bait type is considered as one of the main factors affecting longlines efficiency. In non Mediterranean experiments (U.S. and Pacific data) mackerel bait reduced turtle bycatch compared to squid bait (82% of all loggerheads caught were caught with squid bait) and increased the catch of swordfish compared to squid bait (Watson et al. 2005). This was probably due to the fact that fish bait (mackerel) tends to come free of the hook while the turtle takes small bites from it. On the contrary squid remains more firmly attached, requiring the turtle to take larger bites in order to swallow the bait increasing the chances of becoming hooked (Gilman et al. 2006). Moreover, the CPUE of swordfish was reduced by using circle hooks with squid bait in Atlantic waters. In captivity studies carried out in Italy Piovano et al. (2005) found that mackerel (*Scomber* spp.) bait smell was an important component for the detection of bait by turtles while smell-less artificial baits were generally unattractive for turtles. Experiments performed onboard Spanish Mediterranean swordfish longliners (Rueda et al. 2006, Rueda and Sagarminaga 2008) showed that turtle bycatch was lower with mackerel baits, whereas the target species (swordfish) had no important difference. Spanish experiments allowed to conclude that the shift in bait type to mackerel during the summer periods, when the incidence of turtles in the fishing grounds of EU vessels is at its highest, may provide the greatest benefits to loggerhead sea turtle conservation, even if bluefin tuna catches were lower on mackerel compared to squid bait. Results obtained in the EU project UE-FISH/2005/28-A showed that the combination of hook and bait type that resulted in the lowest bycatch of turtles and the highest catches of swordfish was J hooks with mackerel bait.

The participants of the *GFCM-SAC Transversal Working Group on bycatch/incidental catches* (2008) concluded that the most successful measure to reduce turtle bycatch in swordfish longline is the change of bait from squid to mackerel, which decreased the incidental catch of turtles by 80%, without affecting the catch of swordfish.

Depth setting

Rueda and Sagarminaga (2008) in the Balearic Islands carried out tests with longlines positioned at a different depth. They found a reduction in turtle bycatch in the deeper longline but, on the other hand, they also found a reduction in target species catches. In the Ionian Sea preliminary results of project Life Nature-2003-NAT/IT/000163 seem to indicate that most sea turtle bycatch happened when hooks are set between 10 and 15 m deep, however, more data are needed to confirm this. Other studies (Laurent et al. 2001) showed that the maximum depth at which the marine turtles were caught was 60 m for swordfish longline and 20 m for albacore longline.

Báez et al. (2007) in a research project carried out in the Balearic Islands (Western Mediterranean), observed that probability of catching at least one loggerhead was related not only to the setting depth but also to the distance of the fishing-ground to the coast.

Jribi and Bradai (2008) stated bottom longline has the potential to be more harmful than pelagic longlines, given the fact that the caught animals do not have any chance to reach the surface to breath.

One approach to reduce sea turtle interactions with longline fisheries can also take into account the behaviour of sea turtles and the factors that lead them to interact with fishing gear. An overview of sound, chemical, and light detection in sea turtles is provided by Southwood et al. (2008).

Fishermen have often suggested that hooks set closer to the floats have a higher probability of catching turtles accidentally. Experiments carried out at the "Delphynursery"of "Fondazione Cetacea" in Cattolica (Italy) as well as at the Centro Recupero Tartarughe Marine in Linosa (Italy) aimed at evaluating the floats attractiveness (Piovano et al. 2002). They tested sea turtle behaviour with respect to lit as well as unlit white floats. The results of the study seemed to indicate that the distribution of the turtles in the tanks was not affected by the presence of floats either lit or unlit. Therefore, the floats presence or absence does not influence turtle behaviour. Moreover, the effect of bait colours (yellow, red and blue) and bait odour was tested with experiments carried out with 27 loggerheads (22 immature and 5 adults) in open tanks. Colour attractiveness demonstrated to be partially age dependent. Juveniles react to bait colours differently with respect to sub-adults and furthermore, sub-adults show sharp individual differences. Young specimens never attacked a red-coloured sheath, whereas sub-adults apparently prefer this colour. Some other studies (Swimmer et al. 2002, 2005; Watson et al. 2002) showed that blue bait was not effective in reducing sea turtle capture rate than untreated bait.

Swimmer and Brill (2006) highlighted the importance of olfactory and acoustic stimulus in turtle reaction.

Chemical cues can play a key role in the sea turtle bite/no bite decision once a food item has been visually located. Piovano et al. (2004) demonstrated that loggerheads had an ability to distinguish between fishing lures based on odour. In the experiment two identical squid-shaped plastic lures were used one of which with a hidden small piece of fish. The lures containing the fish showed greater frequency suggesting that olfactory cues are involved in prey recognition mechanisms.

Recent behavioural experiments indicate that lightsticks used in many longline fisheries attract sea turtles and Rueda and Sagarminaga (2008) observed that most turtles were caught on hooks after sunrise. In non-Mediterranean experiments Wang et al. (2006) found that lightsticks which flash intermittently, or have wavelengths between 540 and 600 nm, or project only downward may be potential strategies that limit the attractiveness of lightsticks to juvenile turtles. The participants to the Working Group on bycatch/incidental catches (Rome, Italy, 15–16 September 2008) recommended to seriously considering the opportunity of banning lightsticks and any light source in pelagic longline fishery.

Considering the acoustic stimulus, deterrent experiments were carried out on 4 juveniles and 7 subadults of loggerhead sea turtles in open round tank having a 10 m diameter at the Cattolica (Italy) “Delphynursery”. At frequencies between 50 and 400 Hz, some avoidance behaviour was observed with the maximum level of avoidance at 50 Hz (20%). A “neutral” behaviour (turtles reacting to the sound but not moving towards or away from its source) was observed between 50 and 700 Hz with highest levels (40%) between 50 and 100 Hz. At frequencies above 700 Hz, no response was always observed. In any case during the experiments the most frequent behaviour at all frequencies was “no response” and this results, even if based on a small sample, together with the increased level of acoustic pollution in the Mediterranean did not encourage continuation of this type of experiments.

Bottom trawl

Mortality by trawling is mainly due to the forced apnoea during towing activity. The recovery of turtles after submergence takes several hours (Stabenau and Vietti 2003), sometimes as long as 20 h (Lutz and Dunbar-Cooper 1987). The long recovery time is one of the main problems as turtles that experience multiple captures are likely to be even more susceptible to lethal acidosis (Lutcavage and Lutz 1997). In order to reduce the time of submergence and than the turtle mortality, a specific technical modification was proposed in the early 1980s: the *Turtle Excluder Device* (TED). TED is a sort of grid, which diverts large objects or animals like turtles towards a special exit positioned before the codend (Epperly 2003). TEDs have demonstrated to be very effective mainly in prawn trawl fisheries; for this reason several countries adopted TEDs as mandatory management measure and bottom trawlers of South-east-Asia, South-America and Africa are obliged to use TEDs in their nets in order to export prawns to USA.

Some authors (see for a review Casale et al. 2004) believe that TEDs available at present are probably not a realistic solution for reducing turtle bycatch in Mediterranean mixed bottom trawl fisheries, because they are designed for the shrimp trawl fishery and they would exclude the larger commercial specimens too. Conversely in two recent experiments, carried out in the Mediterranean trawl fisheries by Atabey and Taskavak (2001) and Lucchetti et al. (2008), the authors found that TEDs can be properly proposed as management tool for the conservation of marine turtle population in the Mediterranean Sea, at least in certain periods and areas. Atabey and Taskavak (2001) tested the Supershooter TED in the shrimp fishery of Turkey. They obtained very good results because both loggerhead- and green sea turtle were excluded by the modified Supershooter, and unwanted incidental catches, such as jellyfish, sharks, and rays, were also excluded. They found that most catches occur at the depths between 11 and 30 m and that the proportion of dead and comatose turtles resulting from trawls increases with towing time. Lucchetti et al. (2008) investigated the effect of different TED designs and materials on loggerhead turtle bycatch of bottom trawl fisheries, frequently captured in the Adriatic fisheries. The best results were obtained by the TED called Supershooter, which reduced the debris and improved fish quality in the catch. This might imply a reduction of additional sorting operations on board, increasing time and costs. Authors, in agreement with the doubts expressed by Casale et al. (2004) and Laurent and Lescure (1994) stressed the fact that additional tests should be conducted in order to evaluate the loss of large fish.

Discussion

The review of papers and grey literature on loggerhead turtles bycatch available for the Mediterranean Sea allows to conclude that surface longlines, bottom trawls and illegal driftnets are the major threats to the survival of this species, even if the impact of fixed nets (gillnets and trammel nets), due to their high direct mortality, should be carefully considered. Nevertheless, in our opinion turtle bycatch estimates reported in several papers seem to be unreal. This is mainly due to the methods applied for the data standardization. Authors often assumed that CPUE was homogeneous by area, season and boat, which is not exactly so; the periods, the locations and the boats chosen for samplings at sea can affect the final estimates. We believe it is incorrect to extrapolate the results of a fraction of one season and fleet and applied them to all boats and all year. In any case we think the turtle bycatch is an unsustainable problem which deserves to be a priority of fisheries management.

Paper results allowed the conclusion that bottom trawls mainly impact turtle population during winter time while longlines and fixed nets have their main influence from spring to autumn with most captures occurring in the summer. Thus, a method for homogenising the data collection through the calibration of the procedures for the bycatch estimation would be very useful in the Mediterranean Sea, in order to provide fishing managers with reliable data. Finally the assessment of turtle bycatch in some non-EU countries, mainly in those countries where nesting beaches are observed, such as Syria, would be essential for the conservation of the sea turtle population.

The following recommendations and remarks can be summarized for the Mediterranean, on the basis of analysis of the results attained in several papers.

Regarding the longline, the efficacy of circle hooks in reducing the turtle bycatch is widely investigated but contrasting results have been obtained in Mediterranean fisheries. Further investigation of post-hooking mortality in loggerhead sea turtles would be very useful to determine the real effects of J and circle hook types on the overall impact of these fisheries on turtle populations. Fishermen stated that it is more difficult to release turtles from circle hooks than J hooks, which could also affect turtle survival and requires further investigation. Thus, it is possible to conclude that circle hooks have the potential to reduce the turtle mortality only in certain fisheries and areas, but rigorous field tests should be conducted before requiring circle hooks as a mandatory measure in longline fisheries.

In combination with hooks the branchlines appear to be the major source of sea turtle mortality. A relatively short piece of branchline left in the mouth of a released turtle can easily cause death if ingested and further research on branchline characteristics (material, length, thickness etc.) should be carried out in order to reduce turtle mortality.

The type of bait seems to be one of the main factors affecting turtle bycatch in the longline. Changing the bait from squid to mackerel has been demonstrated to be effective in reducing incidental capture of loggerhead sea turtles and no valuable differences are observed on target species catch. Results obtained in different areas seem to suggest that the greatest reduction in turtle bycatch rates, with the least effect on target species catch, would be achieved by using only mackerel bait instead of squid bait and continuing to use J hooks instead of circle hooks. We believe that a very simple, relatively cheap and effective method to reducing incidental catches would be using mackerel bait at least during those periods when turtles are most abundant. It has also been suggested that using larger bait might deter or prevent turtles from swallowing it and therefore the attached hook, but this remains to be tested (Gilman et al. 2006).

Moreover, we strongly suggest taking into consideration the possibility of banning the lightsticks and any light source in pelagic longline fishery which can strongly attract loggerhead sea turtles. Obviously this extreme solution should be carefully field tested.

As it concerns dyeing baits (tests carried out in non-Mediterranean countries), although effective in laboratory settings with captive turtles, they appear not to be effective as a mitigation measure in reducing sea turtle bycatch in longline fisheries. As the reaction to different colours strongly depends on individual age as well as other factors, such as smell, we suppose it does not seem worthwhile to continue these kinds of tests. Furthermore, the importance of physical factors (i.e. light penetration and colour absorbance with the depth, currents, oceanographic factors, temperature etc.) makes it very difficult to adopt different bait colours as a mitigation measure. Finally the experiments described in this current paper were conducted within the confines of shallow pools where there was very little light attenuation, thus the at-sea conditions should be seriously taken into consideration in reading the in-pool results, particularly those on colour and odour. Another important factor is the isolation of a single turtle in a captive environment. In the light of these problems we believe that tank tests should be considered with caution.

Studies concerning odour bait influence on turtle bycatch highlight the importance of an integrated approach towards sensory deterrents, as both visual and chemical cues are likely to attract sea turtles to longline gear and contribute to potentially harmful interactions (Piovano et al. 2004).

Experiments with acoustic deterrent demonstrate that habituation to acoustic signals is an important issue with respect to the feasibility and long-term effectiveness of an acoustic deterrent (Moein et al. 1994). Results obtained in the Mediterranean Sea (but more generally worldwide) taking into account the problems and difficulties associated with the use of acoustic deterrents, found that there is a low possibility that an acoustic signal could selectively deter sea turtles from interacting with longline gear without affecting commercial species. This does not encourage continuing these types of experiments.

Nevertheless, some discrepancies concerning fishing practices and scientific strategies were observed in several experiments carried out in various countries and fleets. The lack of standardization (i.e. types of hooks-baits tested in the different experiments, protocols or schemes used to perform the respective experiments at sea, different areas-times investigated etc.) might explain the discrepancies obtained among fleet-authors. We believe that technical parameters affecting turtle bycatch and mortality should only be studied one at a time (hook size, hook shape, set depth, distance from the coast etc.) to avoid inconclusive results: i.g. in order to study the efficacy of different hook shapes, the parameters of hook size, depth, bait, distance from the coast etc. should be fixed first, and only than can the hook shape be changed.

As it concerns bottom and mid-water trawl we think TEDs could probably represent a suitable solution in these fisheries but only when properly matched to fishing conditions (i.e. TED angle, construction materials, floatation, position and size of the exit hole, webbing flap etc.). The introduction of TEDs may reduce turtle mortality by avoiding the multiple submergences of a turtle, allowing an adequate rest interval at the surface where the animal might be able to recover from the acidosis by hyperventilating (Stabenau et al. 1991; Stabenau and Vietti 2003). Additionally, TEDs could reduce the amount of discard in the codend catch leading to an improvement of fish quality and to a reduction of the sorting time. However, there might be a risk in increasing the losses of large commercial flat species such as turbot (*Psetta maxima*), flounder (*Scophthalmus rhombus*) and angler fish (*Lophius* spp). Towing time is one of the main factors affecting mortality rate. Towing time would probably need to be to 10 min or less in order to achieve the negligible mortality of $<1\%$. Obviously in our opinion this is not a practical solution. In the light of bycatch estimates we recommend to assess the impact of pelagic trawl on turtle population more in depth; moreover, we suggest trying TEDs in particular fishing areas and fisheries such as "sea cucumber grounds" of the middle Adriatic Sea and the prawn fisheries in Sicilian, Turkish and Tunisian waters.

Concerning passive nets Casale et al. (2005) stated that fixed nets may have the same impact as the bottom trawl nets. On the other hand, the direct mortality associated with these types of gears seems to be very high in comparison with other fishing gears but no practical solutions other than changing mesh size or twine thickness are available at this time in the Mediterranean Sea for set nets. Nevertheless, we consider the use of high hanging ratio, which makes the nets tighter, and the use of gillnets instead of trammel nets, could reduce turtle entanglements. Further studies to develop excluder devices in set nets would be necessary. However, measures other than technical solutions should be considered to reduce interactions with this gear, such as spatial and temporal measures. For example some regions, such as the coastal areas of Turkey and Greece, are characterised, in certain seasons (i.e after nesting), by high abundance of young turtles. Avoiding these areas where turtle occurrence is seasonally linked could be good practice. Finally, we strongly support the banning of driftnets in all countries of the

Mediterranean due to the very high hypothesized bycatch rate of these nets.

As a general result the direct mortality observed at gear retrieval is often very low for most fishing practices except for fixed nets. However, the post-release mortality is suspected to be very high. We believe that further studies with video-camera, satellite tags etc. focused on the delayed mortality would be very useful in order to understand the efficacy of the mitigation measures. For this reason, specifically regarding the question of turtle damage and the behaviour after escape or release, we think that international cooperation is important for achieving efficient management that would ensure the survival of sea turtles while sustaining the economic benefits provided by fisheries.

Furthermore, some simple modification to common fishing practices would be useful in reducing *C. caretta* bycatch. The increase of setting depth for longlines has been found to decrease the overall catch rates of turtles. In the meantime it has led to increase mortality of turtles that are still hooked because they cannot reach the surface to breathe and die through drowning. Moreover, on the deeper longlines it is possible to observe a reduction in turtle bycatch but also a reduction in the catches of target species. The distance from the coast is a parameter that fisheries managers should take into account for the conservation of sea turtle population. We suggest limiting the drifting longline effort to within 35 international nautical miles from the coast, at least in certain regions, could reduce loggerhead bycatch substantially without affecting swordfish captures and with little resistance from fishermen. As it concerns the bottom trawl the reduction of haul duration would be an effective operational measure for reducing direct mortality and occurrence of injured as well as weak and comatose individuals.

Fishermen agree on the importance of economic loss due to turtle interactions with fishing gear. Loss of hooks, bait, branch lines and other components of the gear and loss of time are economic concerns needing to be solved. The capture of sea turtles also produces a decrease in the fishing effort and yields on drift longlines, as a consequence of the reduction in the number of hooks and the time necessary to repair or replace the gear. In any case fishermen cooperation is essential for the survival of sea turtles after catch. Comatose specimens can survive or die, depending on the circumstances; turtles caught are generally hauled on board in a very weak or comatose state and should not be released immediately because they cannot swim to the surface to breathe and in these cases the probability of drowning is very high. Therefore, it is fundamental to inform fishermen on the procedure to identify comatose turtles and release them only when they are healthy. Thus this problem can be substantially reduced by simply keeping the turtles onboard and allowing them to recover. Fishermen cooperation is also essential in removing the hooks from the turtle's mouth. Hooks that are lodged externally (i.e. jaw) are easily detected by fishermen and should be removed with the correct de-hooking device and actions. Fishermen interventition at this time can greatly affect the probability of surviving (Piovano et al. 2009). Mediterranean guidelines for fishermen strongly suggest that fishermen cut the fishing line as close to the hook eye as possible (Gerosa and Aureggi 2001). However, this is probably more likely for superficial hooking. Awareness campaigns (handling practices) and tools (dehooking devices) given to fishermen so that they can cut branchlines and remove hooks whenever possible are valuable as mitigating measures (Casale 2008).

In summary, reducing loggerhead bycatch in the Mediterranean Sea will only be successful through a multidisciplinary approach of taking into consideration changes to fishing gear and practices, management policies (closed areas and seasons), turtle reaction behaviour to different stimuli and the continual education and updating for fishermen. Therefore, a binding cooperation between the fishing industry, management bodies and research Institutions is paramount in protecting this species especially for its survival after the catch.

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