Amphibia-Reptilia 32 (2011): 493-502

Effect of bait on sea turtles bycatch rates in pelagic longlines: An overview

Khaled Echwikhi[1,*], Imed Jribi[2], Mohamed Nejmeddine Bradai[1], Abderrahmen Bouain[2]

Abstract. Pelagic longline fishing has been identified as a significant threat to endangered sea turtle populations. Reducing sea turtle bycatch in pelagic longline fisheries, in concert with activities to reduce other anthropogenic mortality sources, may halt and reverse population declines. Here, we examine the effect of bait manipulation as a simple mitigation method that could reduce sea turtle interactions with longline fishing gear. We analyzed laboratory experiments and field trials conducted in the Mediterranean, the northeast Distant Area in the Atlantic and the Western North Pacific. Studies showed that turtles are more likely to feed on squid than on mackerel when both are used simultaneously as bait. The stingray, *Dasyatis pastinaca*, used as bait, was more effective than mackerel; this ray was vulnerable and stimulated much thought about other species to use as alternative bait. Effective in laboratory conditions with captive turtles, dyed and artificial bait did not seemed to be effective in reducing turtle bycatch in field conditions. Optimal mitigation measure must reduce incidence of hooking of threatened sea turtles to acceptable levels and also offer an economic advantage to fisheries. Studies concerning the effect of bait modification to reduce 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. Further research on the development of sensory-based deterrents can contribute to reduced sea turtle bait interactions and maintain catch rates of target species.

Keywords: capture, deterrent, fisheries, fishing gear, mitigation measure.

Introduction

Fisheries bycatch has been implicated in the population decline of numerous species of marine megafauna such as sea turtles (Lewison et al., 2004; Wallace et al., 2010). As a result, six of the seven recognized sea turtle species are endangered (three of those are listed as critically endangered), while there is insufficient information to determine the conservation status of the seventh sea turtle species (IUCN, 2003).

Sea turtles are taken in many fisheries, but considerable attention has been focused recently on their bycatch in longline fisheries which has been identified as a significant threat to endangered sea turtle populations (Camiñas et al., 2001; Lewison et al., 2004; Carranza et al., 2006; Casale et al., 2007; Jribi et al., 2008; Soykan et al., 2008; Alfaro-Shigueto et al., 2010a, b; Casale, 2011).

The types and frequency of interactions between fishing gear and protected species depend not only on the extent of spatio-temporal overlap of fishing activities and critical habitat for a given species, but also on fishing methods and gear characteristics (Wallace et al., 2008). Effective management strategies to improve selectivity of catch and to reduce bycatch must integrate fisheries operations and protected species biology (Kraus et al., 1997; Epperly et al., 2002; Heppell et al., 2005).

Several measures to avoid and minimize interactions of pelagic longlines with sea turtles and other sensitive species, such as seabirds, are being proactively developed by industries and scientists and implemented in some fisheries (Brothers et al., 1999; Watson et al., 2005). An ideal mitigation measure would be one that accomplishes all of the following: (1) reduces captures of sea turtles to negligible levels; (2) has minimal reductions or increases capture of target species, if not overexploited; (3) has minimal or beneficial effects on other threatened

1 - National Institute of Sea Sciences and Technologies, P.O. Box 1035, 3018 Sfax, Tunisia
2 - Sfax Faculty of Sciences, P.O. Box 1171, 3000 Sfax, Tunisia
*Corresponding author; e-mail: chouikhikhaled@yahoo.fr

 DOI:10.1163/156853811X601924

bycatch species (e.g. albatross, billfish, some sharks); (4) provides operational benefits; (5) has low costs of implementation (especially important in developing countries); and (6) does not increase safety hazards (Sales et al., 2010).

Strategies to abate turtle bycatch in longline fisheries include (i): regulatory controls in fishing effort, season bycatch levels, fishing area and fishing season (NMFS, 2000; Pradhan and Leung, 2006); (ii): changes in fishing practices and gear modification (Bolten and Bjorndal, 2003; Watson et al., 2004, 2005; Gilman et al., 2007), (iii): voluntary fleet communication programs to avoid bycatch hotspots (Gilman et al., 2006a; Lee Lum, 2006) and (iv): handling and release practices to increase the survival prospects of the captured turtles (Gerosa and Aureggi, 2001).

Bait type is considered as one of the main factors affecting longlines efficiency (Swimmer et al., 2005; Yokota et al., 2009). In fact, evaluation of the potential impacts of bait modifications on the catch efficiency for target and non-target species is necessary (Swimmer et al., 2005; Gilman et al., 2006b; Yokota et al., 2009; Echwikhi et al., 2010).

Through an extensive knowledge of mitigation measures tested to reduce the interaction of sea turtle with fisheries, we present a review in recent experiments testing the effect of (i) bait species, and (ii) dyed and artificial baits on turtle pelagic longline bycatch. We discuss the importance of the sensory cues that attract sea turtles to bait as food sources and that influence their 'bite/no bite' response to refine longline fishing techniques and to develop economically viable gear modifications to reduce sea turtle bycatch without impacting the catch rates of targeted species.

Pelagic longline – sea turtle interactions

Pelagic longline fishing has been used worldwide since the 19th century and ranges from small-scale domestic artisanal fisheries to modern mechanized industrialized fleets from distant water fishing nations. Targeted species include bigeye (*Thunnus obesus*), albacore (*T. alalunga*), yellowfin (*T. albacares*) and bluefin tuna (*T. thynnus*), as well as swordfish (*Xiphias gladius*). Compared to the target fish, sea turtles seem to be particularly attracted by the bait which is almost always bitten and/or swallowed so that the hook ends up in the mouth, tongue or esophagus (Aguilar et al., 1995). In few cases, captures are made because turtles get entangled in the main lines (Gerrior, 1996; Witzell, 1996), this means that the animal is not interested in nibbling at the hook, the bait probably stimulates the turtle's curiosity and so it gets caught up in the longline.

The sea turtles taken most frequently in pelagic longlines are loggerheads (*Caretta caretta*) and leatherbacks (*Dermochelys coriacea*). Lewison et al. (2004) estimated that more than 200 000 loggerheads and 50 000 leatherbacks were taken as bycatch in the pelagic longline fisheries in the year 2000.

Due to problematic turtle bycatch levels, many fishing areas were closed. Instituting a closure for one longline fleet may result in an increase in effort by the longline fleet of another nation with fewer possibilities to manage turtle bycatch (Gilman et al., 2006b). For example, during the 4 years closure of the Hawaiian longline fleet swordfish fishery, the swordfish supply to the US marketplace traditionally met by the Hawaiian fleet, was replaced by imports from other longline fleets, including those from Mexico, Panama, Costa Rica and South Africa, which lack measures to manage turtle interactions and have substantially higher ratios of sea turtle captures to unit weight of swordfish catch (Bartram and Kaneko, 2004; Sarmiento, 2004).

The importance of understanding and minimizing the bycatch of sea turtles by the pelagic longline fisheries has been well documented in many studies (Lewison et al., 2004; Gilman et al., 2007; Lewison and Crowder, 2007; Alfaro-Shigueto et al., 2008, 2010a; Crognale et al., 2008; Gardner et al., 2008; Gless et al., 2008; Howell et al., 2008; Jribi et al., 2008; Peckam et al., 2008; Soykan et al., 2008; Tomás et al., 2008; Casale, 2011). The FAO guidelines require longline fisheries to develop and implement modifications in hook design, bait species, depth, gear specifications and fishing practices in order to minimize sea turtle incidental bycatch and mortality (FAO, 2005). Recently, trials using different types of bait have been used as a mitigation method to reduce sea turtle bycatch in longline fisheries (Swimmer et al., 2005; Watson et al., 2005; Yokota et al., 2009; Echwikhi et al., 2010).

Experimental bait treatments and findings

Bait species

Many bait species have been used in pelagic longline fisheries. To be considered good bait, this must be: a prey preferred by the target species, able to stay fresh for a long time in the open sea, available in large quantities, not expensive and providing the best economic return for fishermen. Species such as the flying squid (*Todarodes* sp.), scomber (*Scomber scombrus* and *Scomber japonicus*) and the gilt sardine (*Sardinella aurita*) were generally the baits used in pelagic longline fisheries (Piovano et al., 2004).

The effect of bait species and especially the comparison between squid and fish baits were tested in many fishing experimental sets conducted in the western part of the Mediterranean Sea (Rueda et al., 2006; Baez et al., 2010) where high bycatch of loggerhead turtles has been recorded (Aguilar et al., 1995; Camiñas and De la Serna, 1995; Camiñas et al., 2006). Results of these experiments demonstrated that the number of turtles captured using fish bait were significantly lower than those recorded with squid without a significant reduction of target species (tables 1 and 2). These results were supported by Yokota et al. (2009) for fishing experiments conducted in the Western North Pacific (a major fishing ground for swordfish and pelagic sharks) in 2002 and 2003: "the use of fish bait reduces the loggerhead turtle bycatch by 75% compared to squid" (Yokota et al., 2009).

Table 1. Number of fishing operations, estimated weight (in tons) of target species, and turtle bycatch hooking (number of individuals). Data were taken from Báez et al. (2010).

Bait	Fishing operations	Target species (tons)	Turtle bycatch
Squid + fish	619	235.7	1759
Fish-only	176	33.4	142

Table 2. Number of fishing sets and turtles captured with mackerel and squid baits. Data were taken from Rueda et al. (2006).

No. of sets	No. of turtles captured with squid bait	No. of turtles captured with mackerel bait
15	27	11

In the Northeast Distant Area in the Atlantic, in both 2002 and 2003, experiments focused on hook style and bait type were conducted (Watson et al., 2005). Two baits species were evaluated: squid (*Illex* spp.) and mackerel (*Scomber scombrus*). Experimental treatments of bait and hook type were compared against a control set that consisted of a standard 9/0 J-hook with a 20°25 offset, baited with squid. Results showed that circle hooks combined with mackerel reduced loggerhead bycatch rate by 90%, whilst catch rates of swordfish increased slightly, but tuna catch rates dropped precipitously (table 3) (Watson et al., 2005).

The combination of hook and bait was also tested in the Western North Pacific off the coast of Japan (Yokota et al., 2007), in which mackerel (*Scomber japonicus*) and squid (*Todarodes pacificus*) baits were combined with tuna and circle hooks. Results showed that 54 loggerhead sea turtles were caught in 76 operations (approximately 74 000 hooks). For bait type, the incidental captures with mackerel were fewer than those with squid in both hook types in 2003 and 2004 (table 4).

The difference between catch rates of sea turtles using both fish and squid baits can be explained by the hooking mechanism related to the bait texture; sea turtles, specifically logger-

Table 3. Reduction in capture rate (turtles per thousand hooks) of sea turtles and change in swordfish and bigeye tuna catch per unit effort (kg retained per 1000 hooks) in the NED experimental fishery. Data were taken from Watson et al. (2003, 2004, 2005) and Shah et al. (2004).

Treatment	Loggerhead			Leatherback			Swordfish			Bigeye tuna		
	2002	2003	Both	2002	2003	Both	2002	2003	Both	2002	2003	Both
Non-offset 18/0 circle hook with squid	0.88	0.65	0.74	0.64	0.90	0.75	−0.33	−0.29	−30	0.29	0.20	0.24
10° offset 18/0 circle hook with squid	0.85			0.50			−0.29			0.22		
Combined 18/0 circle hook with squid	0.86			0.57		0.63				0.26		
10° offset 18/0 circle hook with mackerel	0.90	0.86	0.88	0.65	0.56		0.30	0.09	0.19	−0.81	0.88	0.80
9/0 J hook with mackerel	0.71			0.66			0.63		–	−0.90		
10° offset 20/0 circle hook with mackerel		0.91			0.72			0.08			0.90	

Table 4. Total numbers of hooks and loggerhead sea turtle catches, and mean loggerhead sea turtle catch rate for each hook and bait type. Data were taken from Yokota et al. (2007).

Year	Hook type	Bait type	No. of hooks	No. of turtles captured
2002	Tuna hook	Squid	7260	1
	Circle hook	Squid	1800	0
	Tuna hook	Mackerel	7260	0
	Circle hook	Mackerel	1800	0
2003	Tuna hook	Squid	10 498	22
	Circle hook	Squid	5400	13
	Tuna hook	Mackerel	7982	3
	Circle hook	Mackerel	4200	2
2004	Tuna hook	Squid	6912	7
	Circle hook	Squid	3401	0
	Circle hook	Squid	3574	4
	Tuna hook	Mackerel	6976	1
	Circle hook	Mackerel	3401	0
	Circle hook	Mackerel	3574	1

heads, were most likely to swallow the entire squid (flexible and tough muscle texture) but they bit and cut the fish bait and ingested small pieces of fish muscle. According to Yokota et al. (2009), catch rates would also be affected by the bait loss (i.e., bait that is loss from the hook) differences between bait species. Bait with a low loss-rate resulting in a longer soak time has the potential to increase catch rates. In this context, Ward and Myers (2007) used a model analysis to demonstrate that the squid bait *L. opalescens*, which has a firmer body, resulted in a lower rate of bait loss than soft-bodied fish bait such as herring *Clupea pallasii* and sardine. Variations in the number of vacant hooks (i.e., bait loss) might affect bait performance. However, there is little information about bait species effect and their bait loss and catch rate in regard of target and non-target fish species.

In the Gulf of Gabes, a neritic habitat for the loggerhead turtle in the Mediterranean sea (Margaritoulis et al., 2003; Bradai et al., 2005; Broderick et al., 2007; Casale et al., 2008; Zbinden et al., 2008), Echwikhi et al. (2010) go beyond the use of mackerel instead of squid to demonstrate that other baits such as pieces of stingray (*Dasyatis pastinaca*) can reduce the bycatch rate of loggerhead turtles (table 5). The difference between the two bycatch rates of sea turtles when mackerel or stingray were used may, on the one hand, be related to both the colour and the unusual form of pieces of stingrays, which is unknown for the turtle (Echwikhi et al., 2010). On the other hand, the mackerel (*Scomber* spp.) smell may attract the loggerhead turtles (Piovano et al., 2004). In the Mediterranean Sea, the Common Stingray, *Dasyatis pastinaca*, is threatened by the small-scale inshore fisheries (Morey et al., 2006) and is classified as a Near Threatened Species (Cavanagh and Gibson, 2007). Further research is necessary to identify a less threatened species to be used as alternative bait (Echwikhi et al., 2010).

Dyed and artificial baits

To reduce the interaction of sea turtles with pelagic longlines, simple manipulation and treatment of bait can be a mitigation method without affecting target capture. In this context, blue-dyed squid was considered effective in the

Table 5. Number and catch rates of sea turtles and target species using mackerel and stingrays. Data were taken from Echwikhi et al. (2010).

	No. of hooks	No. of sets	No. of sea turtles captured	Target species (*Carcharhinus plumbeus*)	Turtle/1000 hooks	Target species/1000 hooks
Hooks baited with mackerels	22 150	29	26	291	1.173 (1.173-0.086)	13.137 ± 2.234
Hooks baited with stingrays	13 800	19	3	256	0.217 (0.210-0.224)	18.550 ± 0.168
Total	35 950	48	29	547	0.806 (0.802-0.810)	15.215 ± 1.769

experiments of Swimmer et al. (2005). They reported that "in captivity, both Kemp's ridley, *Lepidochelys kempi*, and loggerhead turtles preferred untreated squid over squid that had been dyed dark blue". These results were not confirmed in two field trials conducted in the same period in the Gulf of Papagayo, Costa Rica, (where the incidental catch of olive ridley turtles, *Lepidochelys olivacea*, is generally high). During both trips, there were no differences in rates of turtle interactions when using untreated and blue-dyed baits (8.4 and 8.1 turtles per 1000 hooks) (Swimmer et al., 2005). The use of blue-dyed bait was considered ineffective in reducing turtle bycatch in other experiments such as those conducted in the Northeast Distant waters between September and October 2001 (Watson et al., 2002) and also in experiments conducted in the western North Pacific from May to June 2002 and 2003 (Yokota et al., 2009). Although effective in laboratory conditions with captive turtles, dying baits appear not to be effective as a mitigation measure in reducing sea turtle bycatch in longline fisheries. The reaction to different colours strongly depends on individual age as well as other factors, such as smell (Gless et al., 2008; Lucchetti and Sala, 2009). 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 baits colours as a mitigation measure (Southwood et al., 2008; Lucchetti and Sala, 2009).

Artificial bait has been tested to find out what attracts turtles to the hook. Piovano et al. (2004) investigated the importance of olfactory stimulation in bycatch of loggerhead turtles in the Italian swordfish fishery. The results clearly showed that scomber odor was important for discriminating between lures. Further research is required to test odorless lures, as a potential bycatch mitigation technique if they can be shown to be effective in catching swordfish.

Discussion and conclusion

Experiments and studies reviewed here demonstrate that in addition to the use of circle hooks instead of 'J' shape hooks (Watson et al., 2005; Read, 2007; Piovano et al., 2009) and the deployment of hooks at depths below those where the turtles are most often found (Beverly and Robinson, 2004), the use of fish instead of squid as bait has been considered effective in reducing turtle bycatch without an adverse effect on the catch of target species (Gilman et al., 2006b; Yokota et al., 2009). It is a simple, relatively affordable and effective method to reduce incidental catches of sea turtles, at least during periods when turtles are most abundant (Casale, 2011). Even when fish bait resulted in lower catch of target species, an overall economic disadvantage may not arise when we considered all variables (e.g., bait cost vs target species landing; squid bait prices have recently increased) (Yokota et al., 2009). In Tunisia, for example, the price of squid is about 8 U.S. dollars/kg while the cost of mackerel ranged from 1 to 2 U.S. dollars/kg. Unfortunately, mackerel is already used by many Mediterranean longliners, and to reduce turtle bycatch the mackerel should be of large size, while several reasons including the cost and the size of the individuals of the target species may make fishermen may prefer small mackerels as bait (Guglielmi et al., 2000). Gilman et al. (2003) observe that 'the longline industry is expected to respond most strongly to economic incentives and disincentives', but do not elaborate on what these incentives might be and how they might function within the fishery. Gilman et al. (2006a) make similar assumptions about the balance of economic costs and benefits of a fleet communication program to abate bycatch.

Consideration of sea turtle behavior and the nature of interactions between sea turtles and fishing gear may lead to innovative solutions to the bycatch problem. The factors that attract sea turtles to longline gear and bait are not yet well understood. According to Southwood et al. (2008), both visual and chemical cues attract sea turtles to baited fishing gear and contribute to potentially harmful interactions. Visual cues play important roles in sea turtle foraging behavior (Constantino and Salmon, 2003; Moein-Bartol and Musick, 2003) and most likely influence sea turtles interaction with fishing gear (Swimmer et al., 2005; Swimmer and Brill, 2006; Wang et al., 2007; Southwood et al., 2008). The chemosensory abilities of sea turtles have been an object of study for many years, as there is a great interest in the role that chemical cues play in navigation, migration, and natal homing for these species (Carr, 1967). It is clear that sea turtles are capable of detecting and responding to chemical cues at their aquatic life stages. The aspect of chemoreception most relevant to interactions with longline fisheries is the role of chemical cues in food detection, recognition, and location in sea turtles (Southwood et al., 2008). This is a particularly important issue for species of sea turtles that ingest longline bait, such as pelagic stage loggerhead turtles interactions with longline gear are the result of foul-hooking in the flippers or carapace rather than attempts to ingest the bait. Laboratory trials show that loggerhead turtles are able to detect chemicals emanating from bait and associate those chemicals with a food source (Grassman and Owens, 1982; Southwood et al., 2007).

Experiments conducted by Southwood et al. (2007) support the idea that sea turtles are primarily visual predators, as juvenile loggerhead turtles showed a low success rate locating food in the absence of visual cues. For this reason, it seems likely that the use of a visual deterrent would be more effective in preventing sea turtle interactions with longline gear. Altering the visual environment associated with baits or hooks may be an effective strategy to reduce the incidental capture of sea turtles in both pelagic and coastal fisheries. Factors that affect the aquatic vision are complex and include the marine organisms own visual capabilities, the depth and angle of the viewed object, as well as the optical properties of the water (Johnsen, 2002). In the open ocean and at various depths, the exact light conditions and wavelength discrimination abilities by sea turtles are currently unknown, thus we assume that objects in turtle tanks do not appear the same as in the open ocean (Swimmer et al., 2005). The effectiveness of a visual deterrent will depend largely on whether or not the turtle's aversion response overrides the feeding response, which is fueled in part by chemical cues. The use of chemical additives to make longline bait less attractive or to make it more difficult for sea turtles to locate is appealing from both an economic and enforcement perspective (Southwood et al., 2008). Chemical modifications would be relatively easy to implement in longline fisheries, as bait could be chemically treated prior to packaging and distribution. Studies investigating the efficacy of various methods for repelling birds show that a combination of both visual and chemical deterrents is more effective than either cues on their own (Mason and Clark, 1996), and this may also be the most appropriate approach for deterring sea turtles from interacting with longline gear.

The efficiency of sensory-based deterrents may be strongly influenced by numerous factors, and techniques that are useful in reducing sea turtle bycatch in one fishery, may not work as well in another fishery. Factors to consider when evaluating the feasibility of incorporating a sensory-based deterrent in a longline fishery would include the oceanographic region where fishing occurs, time of day when gear is set, target species, age and size class of sea turtles interacting with fishing gear, and diurnal and seasonal variations in sensory capabilities.

Modifications to the lightsticks (used as lures in longline fisheries) that exploit differences in visual capabilities or behavior of sea turtles could be effective at reducing bycatch of sea turtles. Alterations of the spectral output of lightsticks provide a promising means of deterring turtles from interacting with longline gear (Southwood et al., 2008). Another option for lightstick modification is to make simple changes in physical design such that light is emitted predominately downwards rather than in all directions (Lohmann and Wang, 2007). This could be accomplished by shading the upper portion of the lightstick. Downward-directed lights would presumably be more difficult to detect from above. Given that loggerhead turtles typically utilize the top 50 m of the water column, this modification may render lights undetectable to loggerheads but still visible to deepwater target species such as swordfish and bigeye tuna. The efficacy of this approach for preventing detection of lightsticks by leatherback turtles is debatable, given this species' propensity for deep dives.

Gear modifications to reduce sea turtle bycatch in longline fisheries must be economically viable and relatively easy to implement if they are to be readily adopted by the fishing industry. Identification of differences in sensory capacities of pelagic fishes and sea turtles has stimulated much thought and discussion on innovative yet simple gear modifications for higher selectivity of target fish species.

Further research on innovative types of bait and bait modification provides possible solutions to reduce bycatch of sea turtles based on differences in sensory behaviour of turtles and target species. Identification of differences in sensory capabilities of sea turtles and target species, as well as potential sensory attractants or deterrents for these animals, could guide efforts to refine fishing techniques to target the commercial species and to reduce the bycatch of sea turtles.

Acknowledgements. We thank all the scientists that have participated in this project and to persons who help us in collecting fishery data and other information about turtle bycatch. We thank also Mr. Steven C. Anderson for his help in English revision and the two anonymous referees for their valuable comments on a first version of this article.

References

Aguilar, R., Mas, J., Pastor, X. (1995): Impact of Spanish swordfish longline fisheries on the loggerhead sea turtle *Caretta caretta* population in the western Mediterranean. In: Proceedings of the 12th Annual Workshop on Sea Turtles Biology and Conservation, p. 1-6. Richardson, J.I., Richardson, T.H., Eds, NOAA Technical Memorandum NMFS-SEFSC-361.

Alfaro-Shigueto, J., Mangel, J.C., Seminoff, J.A., Dutton, P.H. (2008): Demography of loggerhead turtles *Caretta caretta* in the southeastern Pacific Ocean: fisheries-based observations and implications for management. Endang. Species Res. **5**: 129-135.

Alfaro-Shigueto, J., Mangel, J.C., Bernedo, F., Dutton, P.H., Seminoff, J.A., Godley, B.J. (2010a): Small-scale fisheries of Peru: a major sink for marine turtles in the Pacific. J. Appl. Ecol. DOI:10.1111/j.1365-2664.2011.02040.x.

Alfaro-Shigueto, J., Mangel, J.C., Pajuelo, M., Duttonc, P.H., Seminoff, J.A., Godley, B.J. (2010b): Where small can have a large impact: Structure and characterization of small-scale fisheries in Peru. Fisher. Res. DOI:10.1016/j.fishres.2010.06.004.

Báez, J.C., Real, R., Macias, D., De La Serna, J.M., Bellido, J.J., Camiñas, J.A. (2010): Captures of swordfish *Xiphias gladius* (Linnaeus 1758) and loggerhead sea turtles *Caretta caretta* (Linnaeus 1758) associated with different bait combinations in the Western Mediterranean surface longline fishery. J. Appl. Ichthyol. **26**: 126-127.

Bartram, P.K., Kaneko, J.J. (2004): Catch to bycatch ratios: Comparing Hawaii's longline fisheries with others. SOEST 04-05, JIMAR Contribution 04-352, 40 pp.

Beverly, S., Robinson, E. (2004): New deep setting longline technique for bycatch mitigation. AFMA Report No. R03/1398, Secretariat of the Pacific Community, Noumea, New Caledonia.

Bolten, A., Bjorndal, K. (2003): Experiment to evaluate gear modification on rates of sea turtle bycatch in the swordfish longline fishery in the Azores – Phase 2. Final Project Report submitted to the US National Marine

Fisheries Service, Archie Carr Center for Sea Turtle Research, University of Florida, Gainesville, Florida, USA.

Bradai, M.N., Bentivegna, F., Jribi, I., El Ouaer, A., Maatoug, K., El Abed, A. (2005): Monitoring of loggerhead sea turtle *Caretta caretta*, in the central Mediterranean via satellite telemetry. In: Proceedings of the Second Mediterranean Conference on Marine Turtles, p. 54-57. Demetropoulos, A., Turkozan, O., Eds, Kemer, Antalya, Turkey.

Broderick, A.C., Coyne, M.S., Fuller, W.J., Glen, F., Godley, B.J. (2007): Fidelity and overwintering of sea turtles. Proc. Royal Soc. B **274**: 1533-1538.

Brothers, N.P., Cooper, J., Lokkeborg, S. (1999): The incidental catch of seabirds by longline fisheries: worldwide review and technical guidelines for mitigation. FAO Fisheries Circular No. 937, Rome, FAO, 100 pp.

Camiñas, J.A., De la Serna, J.M. (1995): The loggerhead distribution in the western Mediterranean Sea as deduced from captures by the Spanish longline fishery. Sci. Herpet. **1995**: 316-323.

Camiñas, J.A., Valeiras, J., De La Serna, J.M. (2001): Spanish surface longline gear types and effects on marine turtles in the western Mediterranean Sea. In: Proceedings of the First Mediterranean Conference on Marine Turtles, p. 88-93. Rome.

Camiñas, J.A., Baez, J.C., Valeiras, J., Real, R. (2006): Differential loggerhead by-catch and direct mortality due to surface longlines according to boat strata and gear type. Sci. Mar. **70** (4): 661-665.

Carr, A. (1967): So Excellent a Fish. Natural History Press, New York.

Carranza, A., Domingo, A., Estrades, A. (2006): Pelagic longlines: A threat to sea turtles in the Equatorial Eastern Atlantic. Biol. Conserv. **131**: 52-57.

Casale, P. (2011): Sea turtle by-catch in the Mediterranean. Fish Fisher. DOI:10.1111/j.1467-2979.2010.00394.

Casale, P., Catturino, L., Freggi, D., Rocco, M., Argano, R. (2007): Incidental catch of marine turtles by Italian trawlers and longliners in the central Mediterranean. Aquatic Conserv.: Mar. Freshw. Ecosyst. **18**: 945-954.

Casale, P., Freggi, D., Gratton, P., Argano, R., Oliverio, M. (2008): Mitochondrial DNA reveals regional and interregional importance of the central Mediterranean African shelf for loggerhead sea turtles (*Caretta caretta*). Sci. Mar. **72** (3): 541-548.

Cavanagh, R., Gibson, C. (2007): Overview of the Conservation Status of Cartilaginous Fishes (Chondrichthyans) in the Mediterranean Sea. IUCN, Gland, Switzerland and Malaga, Spain.

Constantino, M.A., Salmon, M. (2003): Role of chemical and visual cues in food recognition by leatherback post hatchlings (*Dermochelys coriacea*). Zool. **106**: 173-181.

Crognale, M.A., Eckert, S.A., Levenson, D.H., Harms, C.A. (2008): Leatherback sea turtle *Dermochelys coriacea* visual capacities and potential reduction of bycatch by pelagic longline fisheries. Endang. Species Res. **5**: 249-256.

Echwikhi, K., Jribi, I., Bradai, M.N., Bouain, A. (2010): Effect of type of bait on pelagic longline fishery-loggerhead interactions in the Gulf of Gabes, south of Tunisia. Aquatic. Conserv.: Mar. Freshw. Ecosyst. **20**: 525-530.

Epperly, S., Avens, L., Garrison, L., Henwood, T., Hoggard, W., Mitchell, J., Nance, J., Poffenberger, J., Sasso, C., Scott-Denton, E., Yeung, C. (2002): Analysis of sea turtle bycatch in the commercial shrimp fisheries of southeast U.S. waters and the Gulf of Mexico. NOAA Technical Memorandum NMFS-SEFSC-490, US Department of Commerce.

FAO (2005): Report of the technical consultation on sea turtles conservation and fisheries. FAO Fisheries Report No. 765, Food and Agriculture Organization of the United Nations, Rome.

Gardner, B., Sullivan, P.J., Epperly, S., Morreale, S.J. (2008): Hierarchical modeling of bycatch rates of sea turtles in the western North Atlantic. Endang. Species Res. **5**: 279-289.

Gerosa, G., Aureggi, M. (2001): Sea Turtle Handling Guidebook for Fishermen. UNEP/MAP, RAC/SPA, Tunis.

Gerrior, P. (1996): Incidental take of sea turtles in northeast U.S. waters. In: Pelagic Longline Fishery – Sea Turtle Interactions: Proceedings of an Industry, Academic and Government Experts, and Stakeholders Workshop Held in Silver Spring, p. 14-31. Williams, P., Anninos, P.J., Plotkin, P.T., Salvini, K.L., Eds, NOAA Technical Memorandum NMFS-OPR-7, Washington, DC.

Gilman, E., Brother, N., Koboyachi, D., et al. (2003): Performance assessement of underwater setting chutes, side setting and blue dyed bait to minimize sea bird mortality in Hawaii pelagic longline and swordfish fisheries. Final report, Westen Pacific Regional Fishery Management Council, Honolulu, HI, USA, 49 pp.

Gilman, E., Dalzell, P., Martin, S. (2006a): Fleet communication to abate fisheries bycatch. Mar. Policy **30** (4): 360-366.

Gilman, E., Zollett, E., Beverly, S., Nakano, H., Davis, K., Shiode, D., Dalzell, P., Kinan, I. (2006b): Reducing sea turtle bycatch in pelagic longline fisheries. Fish Fisher. **7**: 1-22.

Gilman, E., Kobayashi, D., Swenarton, T., Brothers, N., Dalzell, P., Kinan, I. (2007): Reducing sea turtle interactions in the Hawaii-based longline swordfish fishery. Biol. Conserv. **139**: 19-28.

Gless, J.M., Salmon, M., Wyneken, J. (2008): Behavioral responses of juvenile leatherbacks *Dermochelys coriacea* to lights used in the longline fishery. Endang. Species Res. **5**: 239-247.

Grassman, M.A., Owens, D.W. (1982): Development and extinction of food preferences in the loggerhead sea turtle, *Caretta caretta*. Copeia **1982**: 965-969.

Guglielmi, P., Di Natale, A., Pelusi, P. (2000): Effetti della pesca col palangaro derivante sui grandi pelagici e sulle specie accessorie nel Mediterraneo centrale.

Heppell, S.S., Heppell, S.A., Read, A.J., Crowder, L.B. (2005): Effects of fishing on long-lived marine organisms. In: Marine Conservation Biology: The Science of Maintaining the Sea's Biodiversity, p. 211-231. Norse, E.A., Crowder, L.B., Eds, Island Press, Washington, DC.

Howell, E.A., Kobayashi, D.R., Parker, D.M., Balazs, G.H., Polovina, J. (2008): Turtle Watch: a tool to aid in the bycatch reduction of loggerhead turtles *Caretta caretta* in the Hawaii-based pelagic longline fishery. Endang. Species Res. **5**: 267-278.

IUCN (2003): Red List of Threatened Species. Red List Programme, International Union for the Conservation of Nature and Natural Resources, Species Survival Commission, Cambridge, UK and Gland, Switzerland.

Johnsen, S. (2002): Cryptic and conspicuous coloration in the pelagic environment. Proc. R. Soc. Lond. (Biol.) **269**: 243-256.

Jribi, I., Echwikhi, K., Bradai, M.N., Bouain, A. (2008): Incidental capture of sea turtles by longlines in the Gulf of Gabe's (South Tunisia): a comparative study between bottom and surface longlines. Sci. Mar. **72** (2): 337-342.

Kraus, S.D., Read, A.J., Solow, A., Baldwin, K., Spradlin, T., Anderson, E., Williamson, J. (1997): Acoustic alarms reduce porpoise mortality. Nature **388**: 525.

Lee Lum, L. (2006): Assessment of incidental sea turtle catch in the artisanal gillnet fishery in Trinidad and Tobago, West Indies. Appl. Herpetol. **3**: 357-368.

Lewison, R.L., Crowder, L.B. (2007): Putting longline bycatch of sea turtles into perspective. Conserv. Biol. **21**: 79-86.

Lewison, R.L., Freeman, S.A., Crowder, L.B. (2004): Quantifying the effects of fisheries on threatened species: the impact of pelagic longlines on loggerhead and leatherback sea turtles. Ecol. Lett. **7** (3): 221-231.

Lohmann, K.J., Wang, J.H. (2007): Behavioral responses of sea turtles to prototype experimental lightsticks. In: Sea Turtle and Pelagic Fish Sensory Workshop, p. 15-17. Swimmer, Y., Wang, J.H., Eds, NOAA Technical Memorandum NMFS-PIFSC-12.

Lucchetti, A., Sala, A. (2009): An overview of loggerhead sea turtle (*Caretta caretta*) bycatch and technical mitigation measures in the Mediterranean Sea. Rev. Fish Biol. Fisher. **20**: 141-161.

Margaritoulis, D., Argano, R., Baran, I., Bentivegna, F., Bradai, M.N., Camiñas, J.A., Casale, P., De Metrio, G., Demetropoulos, A., Gerosa, G., Godley, B., Houghton, J., Laurent, L., Lazar, B. (2003): Loggerhead sea turtles in the Mediterranean: present knowledge and conservation perspectives. In: Ecology and Conservation of Loggerhead Sea Turtles, p. 175-198. Bolten, A.B., Witherington, B.E., Eds, Smithsonian Institution Press, Washington, DC.

Mason, J.R., Clark, L. (1996): Grazing repellency of methyl anthranilate to snow geese is enhanced by a visual cue. Crop Prot. **15**: 97-100.

Moein Bartol, S., Musick, J.A. (2003): Sensory biology of sea turtles. In: The Biology of Sea Turtles, p. 79-102. Lutz, P.L., Musick, J.A., Wyneken, J., Eds, CRC Press, Boca Raton, FL.

Morey, G., Moranta, J., Riera, F., Grau, A.M., Morales-Nin, B. (2006): Elasmobranchs in trammel net fishery associated to marine reserves in the Balearic Islands (NW Mediterranean). Cyb. **30**: 125-132.

NMFS (2000): Fisheries off west coast states and in the Western Pacific; Western Pacific pelagic fisheries; Hawaii-based pelagic longline area closure. 230, Fed. Reg. **65** (166): 51991-51996. US Department of Commerce, Washington, DC.

Peckham, S.H., Maldonado Diaz, D., Koch, V., Mancini, A., Gaos, A., Tinker, M.T., Nichols, W.J. (2008): High mortality of loggerhead turtles due to bycatch, human consumption and strandings at Baja California Sur, Mexico, 2003 to 2007. Endang. Species Res. **5**: 171-183.

Piovano, S., Balletto, E., Di Marco, S., Dominici, A., Giacoma, C., Zannetti, A. (2004): Loggerhead sea turtle (*Caretta caretta*) by catches on longlines: the importance of olfactory stimuli. Ital. J. Zool. **2**: 213-216.

Piovano, S., Swimmer, Y., Giacoma, C. (2009): Are circle hooks effective in reducing incidental captures of loggerhead sea turtles in a Mediterranean longline fishery? Aquatic Conserv.: Mar. Freshw. Ecosyst. **19**: 779-785.

Pradhan, N.C., Leung, P. (2006): Incorporating sea turtle interactions in a multi-objective programming model for Hawaii's longline fishery. Ecol. Econ. **60**: 216-227.

Read, A.J. (2007): Do circle hooks reduce the mortality of sea turtles in pelagic longlines? A review of recent experiments. Biol. Conserv. **135**: 155-169.

Rueda, L., Sagarminaga, R.J., Baez, J.C., Camiñas, J.A., Eckert, S.A., Boggs, C. (2006): Testing mackerel bait as a possible bycatch mitigation measure for the Spanish Mediterranean swordfish longlining fleet. In: Book of Abstracts of the 26th Annual Symposium on Sea Turtle Biology and Conservation, p. 262. Frick, M., Panagopoulou, A., Rees, A., Williams, K., Eds, Island of Crete, Greece, 3-8 April 2006.

Sales, G., Giffoni, B.B., Fiedler, F.N., Azevedo, V.G., Kotas, J.E., Swimmer, Y., Bugoni, L. (2010): Circle hook effectiveness for the mitigation of sea turtle bycatch and capture of target species in a Brazilian pelagic longline fishery. Aquatic Conserv.: Mar. Freshw. Ecosyst. DOI:10.1002/aqc.1106.

Sarmiento, C. (2004): Assessing Market Transfer Effects Generated by Court Rulings in the Hawaii Longline Fishery. Western Pacific Regional Fishery Management Council, Honolulu, HI, USA.

Shah, A., Watson, J., Foster, D., Epperly, S. (2004): Experiments in the Western Atlantic Northeast Distant Waters to Evaluate Sea Turtle Mitigation Measures in the Pelagic Longline Fishery Summary of Statistical Analysis. National Marine Fisheries Service, Pascagoula, MS, USA.

Southwood, A., Higgins, B., Brill, R., Swimmer, Y. (2007): Chemoreception in loggerhead sea turtles: an assessment of the feasibility of using chemical deterrents to prevent sea turtle interactions with longline fishing gear. NOAA Technical Memorandum NMFS-PIFSC NOAA-10.

Southwood, A., Fritsches, K., Brill, R., Swimmer, Y. (2008): Sound, chemical, and light detection in sea turtles and pelagic fishes: sensory-based approaches to bycatch reduction in longline fisheries. Endang. Species Res. **5**: 225-238.

Soykan, C.U., Moore, J.E., Zydelis, R., Crowder, L.B., Safina, C., Lewison, R.L. (2008): Why study bycatch? An introduction to the Theme Section on fisheries bycatch. Endang. Species Res. **5**: 91-102.

Swimmer, Y., Brill, R. (2006): Sea turtle and pelagic fish sensory biology: developing techniques to reduce sea turtle bycatch in longline fisheries. NOAA Technical Memorandum NOAA-TM-NMFS-PIFSC-7, US Department of Commerce.

Swimmer, Y., Arauz, R., Higgins, B., McNaughton, L., McCracken, M., Ballestero, J., Brill, R. (2005): Food color and marine turtle feeding behaviour: Can blue bait reduce turtle bycatch in commercial fisheries? Mar. Ecol. Prog. Ser. **295**: 273-278.

Tomás, J., Gozalbes, P., Raga, J.A., Godley, B.J. (2008): Bycatch of loggerhead sea turtles: insights from 14 years of stranding data. Endang. Species Res. **5**: 161-169.

Wallace, B.P., Heppell, S., Lewison, R., Kelez, S., Crowder, L.B. (2008): Impacts of fisheries bycatch on loggerhead turtles worldwide inferred from reproductive value analyses. J. Appl. Ecol. **45**: 1076-1085.

Wallace, B.P., Lewison, R.L., McDonald, S.L., McDonald, R.K., Yot, C.K., Kelez, S., Bjorkland, R.K., Finkbeiner, E.M., Helmbrecht, S., Crowder, L.B. (2010): Global patterns of marine turtle bycatch. Conserv. Lett. **3**: 1-12.

Ward, P., Myers, R.A. (2007): Bait loss and its potential effects on fishing power in pelagic longline fisheries. Fisher. Res. **6**: 69-76.

Watson, J.W., Foster, D.G., Epperly, S., Shah, A. (2002): Experiments in the Western Atlantic Northeast Distant Waters to Evaluate Sea Turtle Mitigation Measures in the Pelagic Longline Fishery. Report on Experiments Conducted in 2001. US National Marine Fisheries Service, Pascagoula, MS, USA.

Watson, J.W., Foster, D.G., Epperly, S., Shah, A. (2003): Experiments in the Western Atlantic Northeast Distant Waters to Evaluate Sea Turtle Mitigation Measures in the Pelagic Longline Fishery. Report on Experiments Conducted in 2001 and 2002. US National Marine Fisheries Service, Pascagoula, MS, USA.

Watson, J.W., Foster, D.G., Epperly, S., Shah, A. (2004): Experiments in the Western Atlantic Northeast Distant Waters to Evaluate Sea Turtle Mitigation Measures in the Pelagic Longline Fishery. Report on Experiments Conducted in 2001. 135 pp.

Watson, J.W., Epperly, S.P., Shah, A.K., Foster, D.G. (2005): Fishing methods to reduce sea turtle mortality associated with pelagic longlines. Can. J. Fisher. Aquat. Sci. **62**: 965-981.

Witzell, W.N. (1996): The incidental capture of sea turtles by the U.S. pelagic longline fleet in the western Atlantic Ocean. In: Pelagic Longline Fishery – Sea Turtle Interactions: Proceedings of an Industry, Academic and Government Experts, and Stakeholders Workshop Held in Silver Spring, Maryland, 24-25 May 1994, p. 32-38. Williams, P., Anninos, P.J., Plotkin, P.T., Salvini, K.L., Eds, NOAA Technical Memorandum NMFS-OPR-7, US Deptartment of Commerce.

Yokota, K., Minami, H., Nobetsu, T. (2007): Research on mitigation of the interaction of sea turtle with pelagic longline fishery in the western North Pacific. In: Proceedings of the Third International Symposium on SEASTAR 2000 and Asian Bio-logging Science (The 7th SEASTAR 2000 Workshop), p. 3-8.

Yokota, K., Kiyota, M., Okamura, H. (2009): Effect of bait species and color on sea turtle bycatch and fish catch in a pelagic longline fishery. Fisher. Res. **9**: 53-58.

Zbinden, J.A., Aebischer, A., Margaritoulis, D., Arlettaz, R. (2008): Important areas at sea for adult loggerhead marine turtles in the Mediterranean Sea: satellite tracking corroborates findings from potentially biased sources. Mar. Biol. **153**: 899-906.

Received: April 28, 2011. Accepted: September 6, 2011.