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INTERACTIONS BETWEEN SEA TURTLES AND PELAGIC LONGLINE FISHERIES

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1. Background information on longline fishing and sea turtle bycatch

Longlines are a specific type of fishing gear, characterised by having multiple baited hooks attached individually to a mainline. Longlining is the term used to describe the use of longline gear. Generally, there are two longline fishing methods: demersal, and pelagic. Good descriptions of longline fishing and fishing gear can be found in (Bjordal and Lokkeborg 1996, and Brothers et al. 1999). This report will deal only with pelagic longlining, as it is the longline fishing method most often implicated in the incidental take or interacting with sea turtles. However, there are some recent reports of sea turtle interactions with demersal longline gear, and these are included in this section just for completeness, but will not be discussed further in this report.

1.1 Demersal or bottom longlining

Demersal or bottom longline gear (Figure 1) has the mainline anchored to the bottom and the target species are demersal, in other words they are fish that live at or near the bottom, sometimes called groundfish. Until recently there has not been much information on turtle bycatch in bottom longline fisheries; Oravetz (1999) says that evidence on the incidental take of sea turtles on bottom longlines is sparse, but they have the potential to take reef dwelling turtles such as loggerheads and hawksbills. According to Bolten et al. (1994), the fisheries (in the Azores) that target demersal fish species apparently do not capture sea turtles because of the depths (200–700 m) at which the lines are set; and a study based on interviews of 169 Spanish (Andalusian) fishermen (Baéz et al. 2006) fishing with a variety of gear types found that 14 bottom longline fishermen in the study reported to have never caught a sea turtle, while 32 of the surface longline fishermen interviewed reported frequent turtle captures.

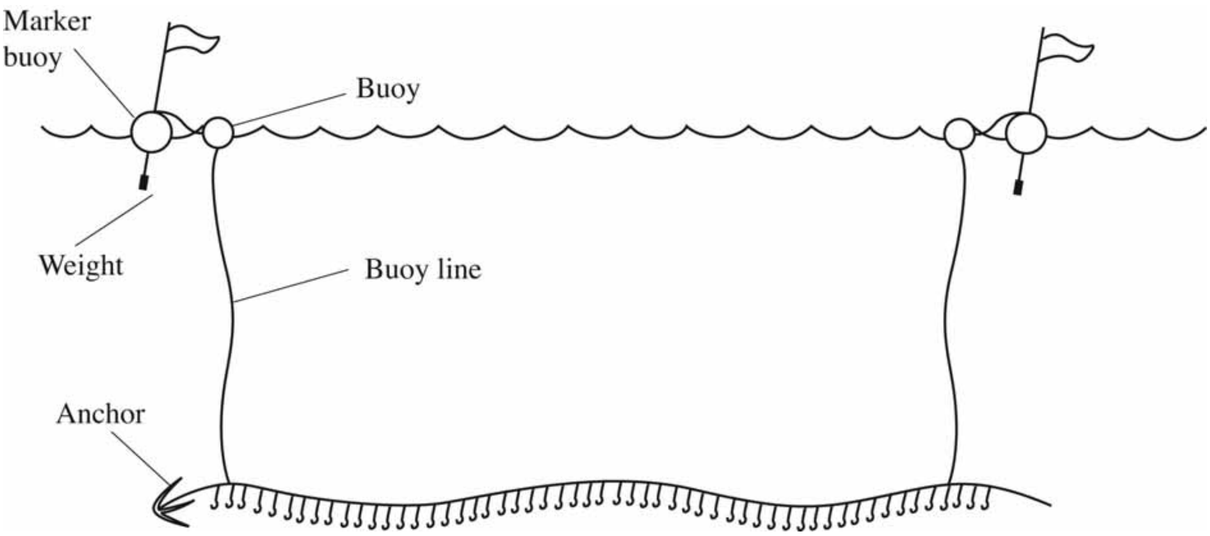

Figure 1: Bottom longline (adapted from Bjordal and Lokkeborg 1996)

The lack of turtle bycatch data from bottom longline fisheries may be partially an artefact caused by the lack of observer coverage in those fisheries, especially in artisanal bottom longline fisheries. There is some recent evidence that there may in fact be fairly significant turtle bycatch in some

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bottom fishing fisheries. Peckham et al. (2006) describe an artisanal bottom longline fishery in the Gulf of California, Mexico that has very high turtle bycatch and mortality rates. In seven one-day trips from 7 to 26 September, 2005, one olive ridley and 26 loggerhead turtles were caught on a total of 1200 hooks set, resulting in a bycatch rate of 21.67 loggerheads per 1000 hooks, or 3.86 turtles per trip. 22 of the 27 turtles were retrieved dead and two died in the boats, resulting in a bycatch mortality rate of 89 per cent. With the exception of the olive ridley, which was released in apparently good condition, turtles caught alive were moribund. Similarly, Echwikhi et al. (2006) describe a bottom longline fishery (Figure 2) in the Region of Zarzis (Gulf of Gabes, Tunisia) that fishes for grouper species. The fishery set 86,000 hooks during the 2004–2005 season, mostly at depths less than 50 m, and caught 732 turtles, resulting in a bycatch rate of 0.278 turtles per 1000 hooks. Mortality was 12 per cent.

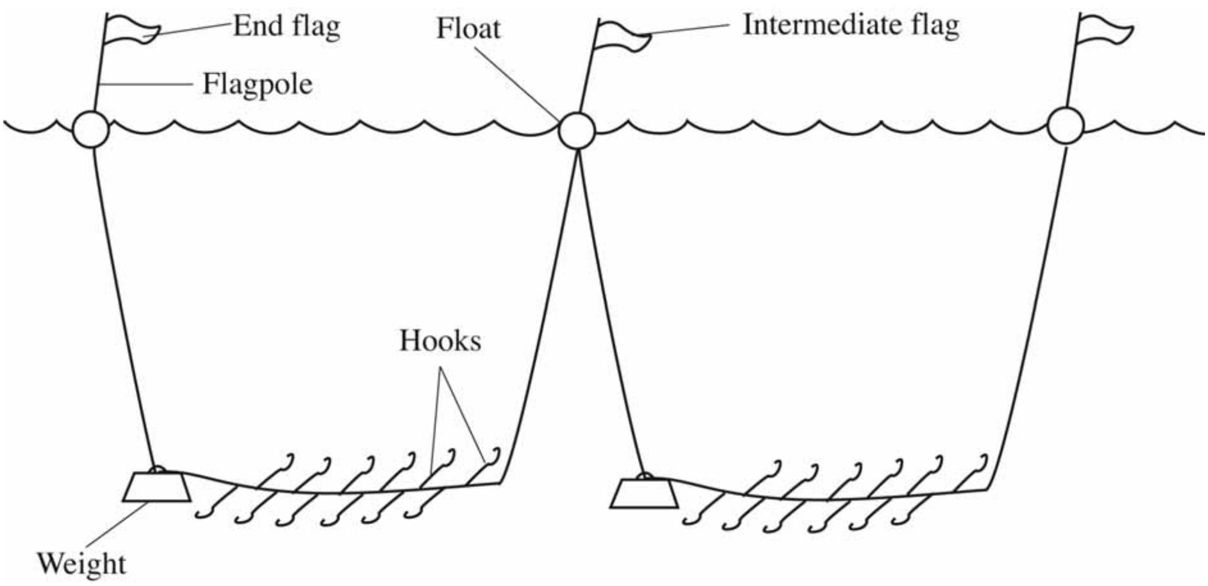


Figure 2: Bottom longline (adapted from Echwikhi et al. 2006)

1.2 Pelagic or horizontal longline gear and fishing method

Pelagic longlines, in contrast to bottom longlines, drift freely near the surface in the high seas and target pelagic fishes, or fish that live in the open sea, and are not usually associated with the bottom. The pelagic environment is also where most sea turtles spend a majority of their time. Good descriptions of pelagic longline fishing can be found in (Yamaguchi 1989, OFCF 1993, Hoey and Moore 1999, SPC 2001, Beverly et al. 2003, and at the FIGIS website: http://www.fao.org/figis/servlet/fishtech?fid=1010). A pelagic longline is made up of units or sections of line that are called baskets. They are called baskets because, on the early Japanese vessels, longline sections were stored on the deck in baskets. A basket of longline gear is the amount of mainline and branchlines in between two floats (Figure 3). This is true for traditional basket gear, which is typically made of three-strand tarred polyester mainline, and for monofilament gear, which is made from single-strand nylon mainline that is stored as a unit on a hydraulic reel (Figure 4). A basket may contain as few as four or five branchlines or as many as thirty or forty (Figure 3). A branchline, or gangion, is a single line with a snap, or clip, at one end and a hook at the other. It may also have a swivel, weighted or un-weighted, between the snap and the hook (Figure 5). The entire longline might contain anywhere from 20 to 200 baskets, and consist of a mainline 15 to 150 km long. The mainline is suspended in the water by a series of floats, or buoys, that are attached to the mainline by floatlines, or droppers. The floats are usually attached to the floatlines with snaps (Figure 6), and the floatlines are attached to the mainline by snaps.

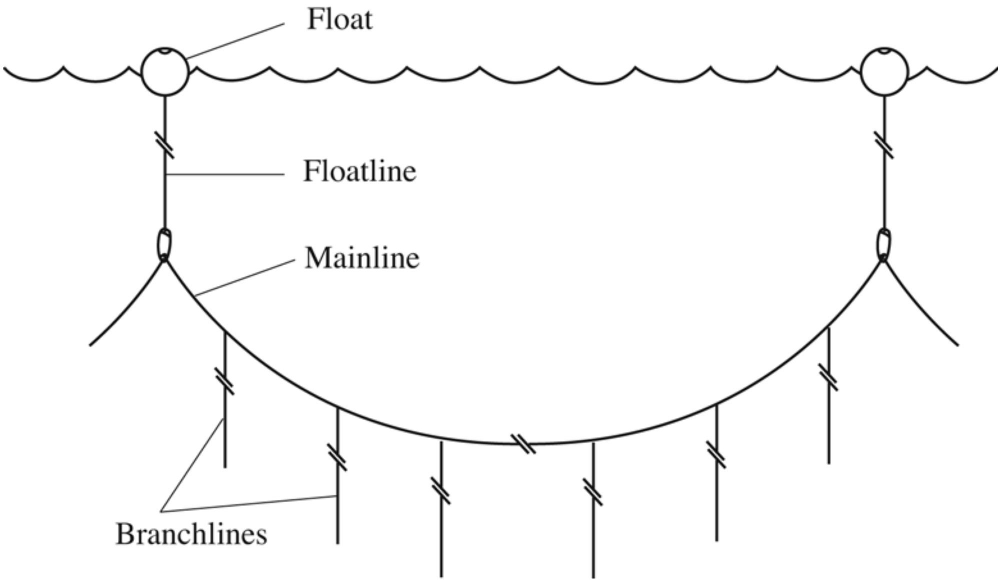


Figure 3: Basic longline gear configuration – one basket (Beverly et al. 2003)

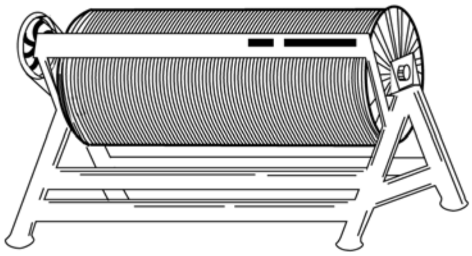


Figure 4: Hydraulic longline reel (Beverly et al. 2003)

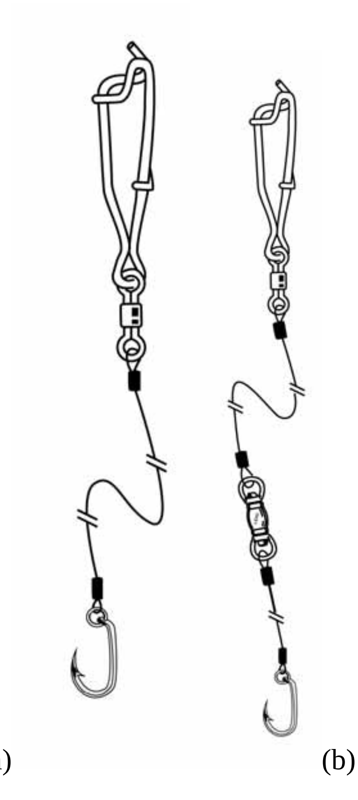


Figure 5: Branchlines; without leaded swivel (a) and with leaded swivel (b) (Beverly et al. 2003)

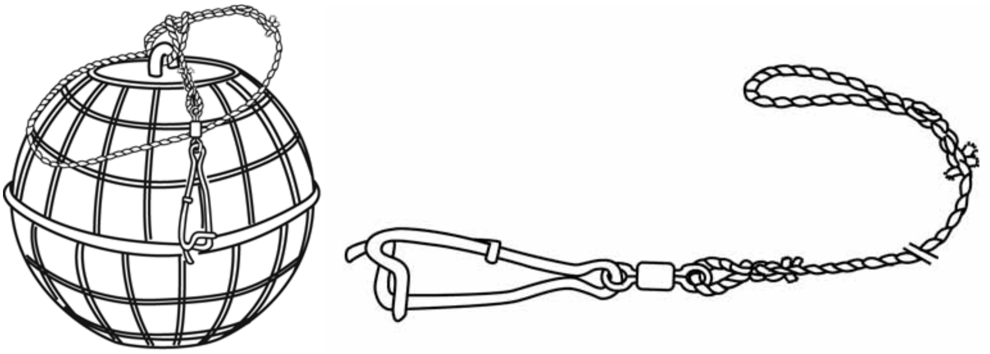


Figure 6: Hard plastic float with snap, and floatline with snap (Beverly et al. (2003)

The line is set and hauled once a day from a moving vessel, but is allowed to drift, or soak, on its own in between setting and hauling for six to fifteen hours (Figures 7 and 8). A typical tuna longline set from a small to medium-scale longliner (< 100 GRT) would be about 60 to 120 km long and have from 1200 to 2400 hooks. A typical longline trip would last one to three weeks and the line would be set 6 to 12 times, once each fishing day. Small to medium-scale longliners target bigeye tuna and yellowfin tuna in the tropics, albacore tuna in the subtropics, or broadbill swordfish in temperate zones and usually deliver the catch as fresh chilled fish. Large industrial longliners (> 250 GRT) usually target bigeye and yellowfin in the tropics or albacore tuna in the subtropics and temperate zones and deliver the catch as frozen product. Unlike the small to medium-scale longliners, the large longliners stay at sea for months at a time.

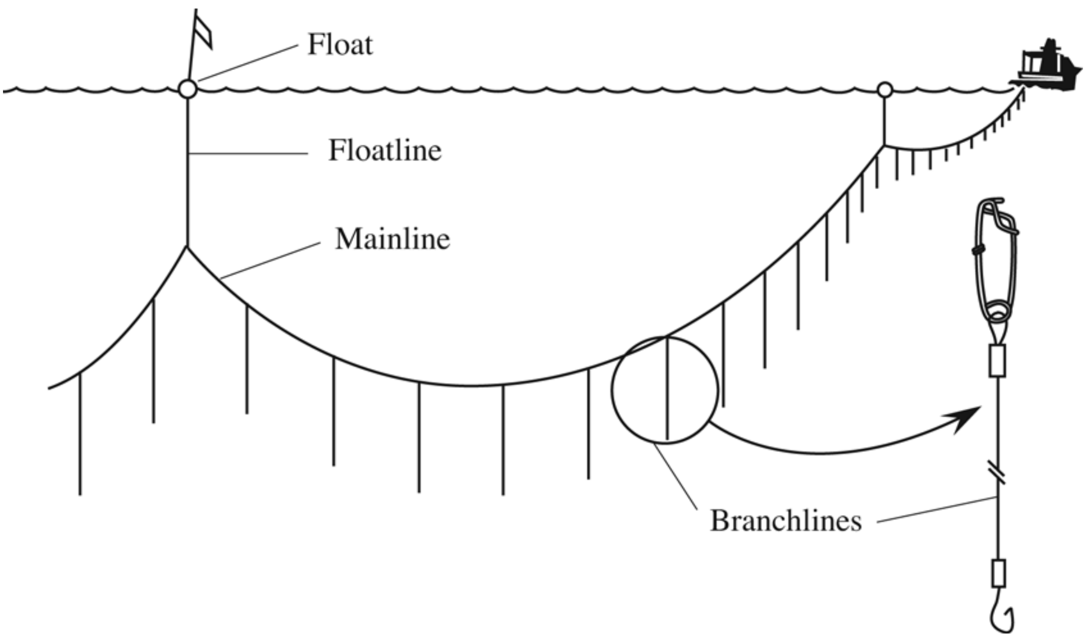


Figure 7: Longline being set from small to medium-scale longliner (Beverly et al. 2003)

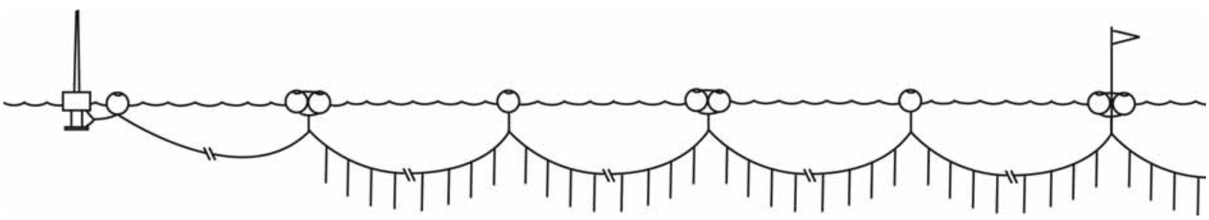


Figure 8: Pelagic longline showing one end and four baskets (Beverly et al. 2003)

1.3 Trends in pelagic longline fishing

Longline fisheries have grown rapidly and then levelled off at relatively high levels during the last half century. For example, longline fishing effort has increased four-fold from 113 million hooks to 680 million hooks annually during the fifty year period from 1952 to 2002 (Molony 2004) in the western central Pacific Ocean (WCPO). The combined catch of bigeye and yellowfin doubled from 100,000 mt to 200,000 mt annually in the same fifty year period. Since the 1980s, 50 per cent of the fleet fishing in the WCPO has been Japanese, Taiwanese, or Korean flagged. The Japanese fleet has since declined but has stabilised to where they set around 125 million hooks annually, accounting for about 20–25 per cent of the total effort in the WCPO. Other fleets fishing in the WCPO have grown since the 1980s including the US fleet, the mainland Chinese (PRC) fleet, and smaller domestic fleets in several Pacific Island countries and territories (PICTs). The growth in catch from pelagic longline fishing on a global scale has shown even more striking trends (Figure 9). In 1952, the combined fleets operating in the WCPO and the Indian Ocean (the global fleet at the time) caught a total of only 68,000 mt of albacore, bigeye and yellowfin (SPC-WCPFC 2006). By 2002 the combined fleets fishing in the WCPO, Indian Ocean, eastern Pacific and the Atlantic Ocean caught 643,000 mt of the same three species, an almost ten-fold increase in catch over fifty years. The 2002 catch consisted of 138,000 mt of albacore, 303,000 mt of bigeye, and 202,000 mt of yellowfin.

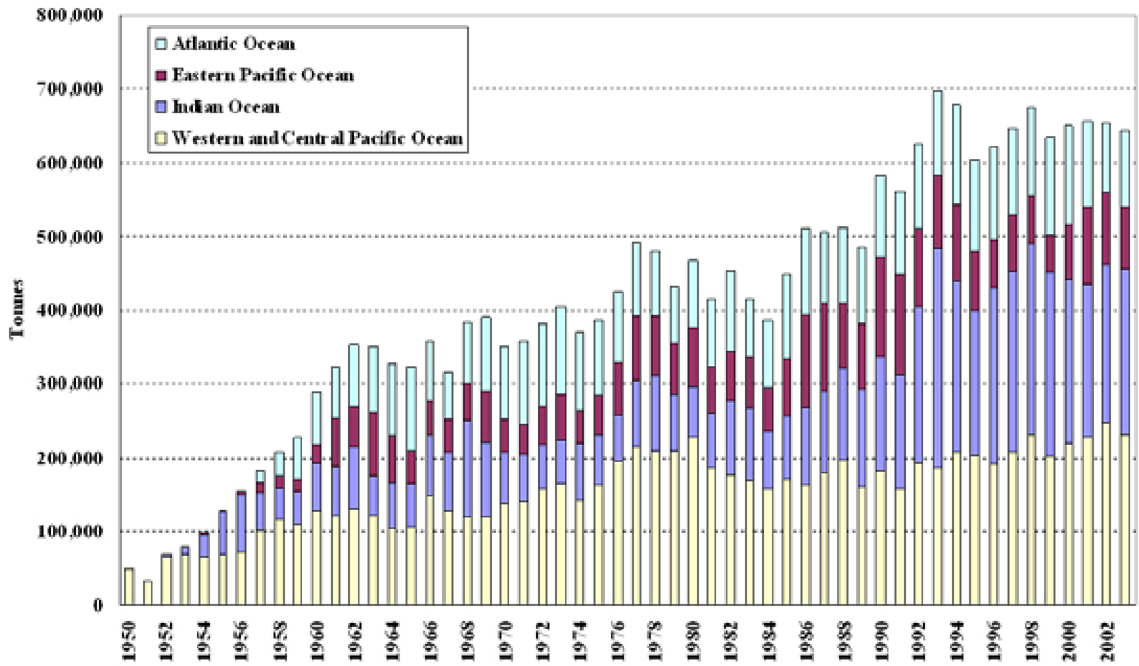


Figure 9: Global trend of total pelagic longline catch in metric tonnes from three oceans from 1952 to 2002 (SPC-WCPFC 2006)

1.4 Pelagic longline fishing categories and/or strategies

Pelagic longline fishing can roughly be divided into two categories: shallow-set and deep-set gear (Suzuki et al. 1977 and SPC 2001). Shallow-set gear targets either broadbill swordfish or night swimming bigeye tuna (and occasionally sharks). Both bigeye tuna and swordfish are targeted with night sets in a two week period, one week on either side of the full moon. Fishermen set four to six hooks in each basket and use relatively short floatlines of 5 to 10 m, and, until recently, used squid bait in combination with chemical or electric light sticks (Figure 10) to attract the target fish. Until recently swordfish sets used 8/0 or 9/0 ‘J’ hooks (similar to big game trolling hooks) almost exclusively while tuna sets used either Japan tuna hooks or tuna circle hooks (see section 4.2 for a description of various longline hooks). Shallow-set gear is usually set at night, just around dusk, and hauled the following day, just after sunrise. Line setters, or shooters (Figure 11), are not usually used in this style of fishing. The depths reached by the baited hooks in a shallow-set range from near the surface down to about 100 m (Figure 12).

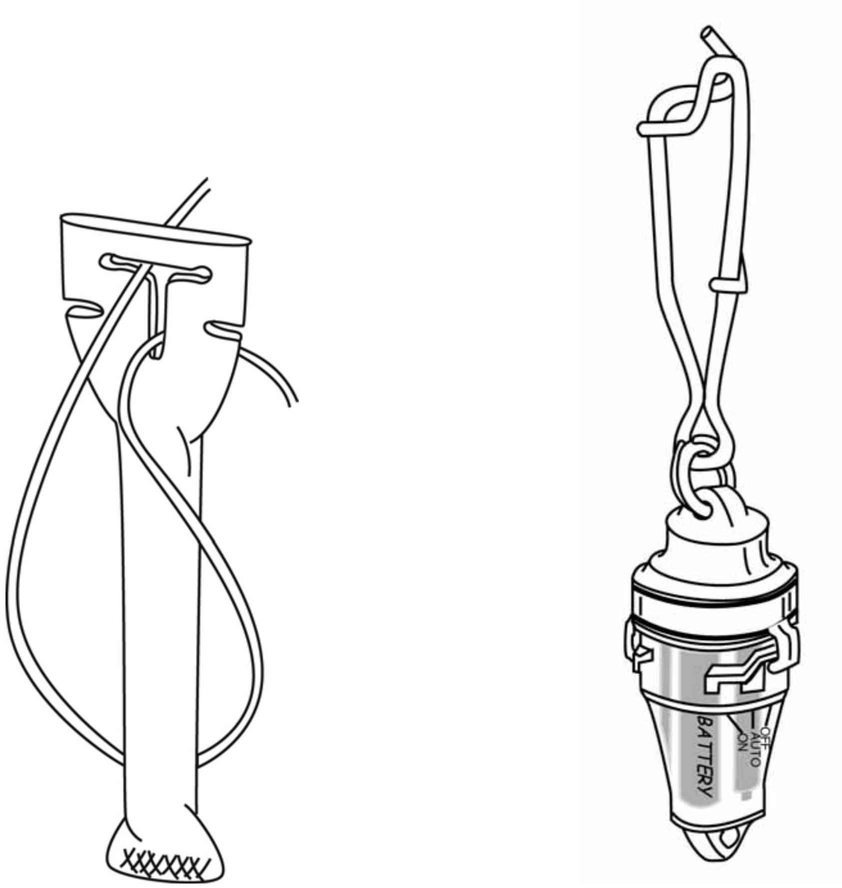


Figure 10: Chemical and electric lightsticks (Beverly et al. 2003)

Figure 11: Hydraulic line setter (Beverly et al. 2003)

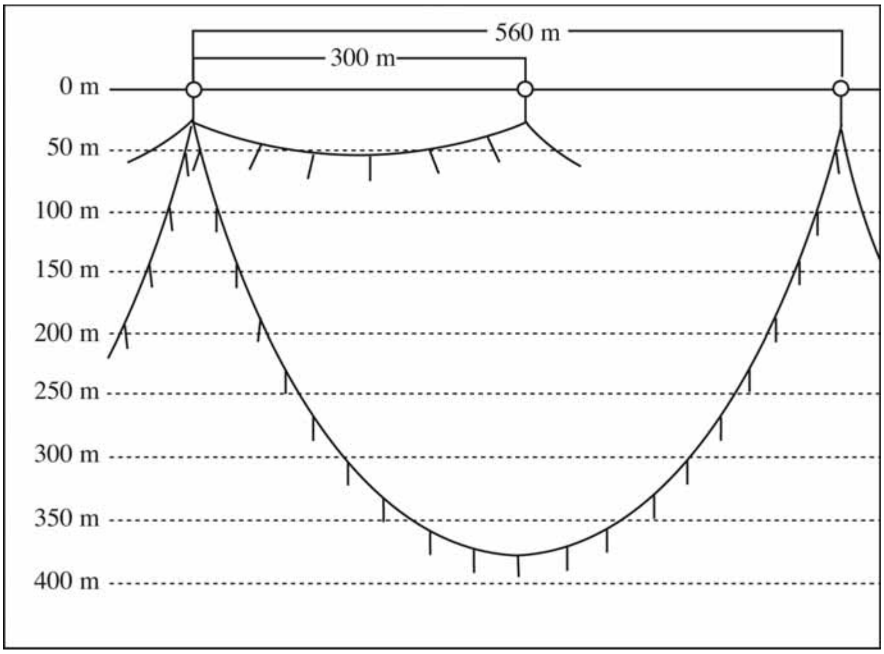


Figure 12: Shallow-set and deep-set longlines (Beverly et al. 2003)

By contrast, deep-set gear targets day swimming albacore tuna and bigeye tuna, use longer floatlines of 20 to 30 m, and more hooks in a basket — ten to forty. Hooks are usually Japan tuna hooks or circle hooks, bait can be squid or finfish such as mackerel or saury, lightsticks are usually not employed, and the gear is set in the morning and hauled starting in the afternoon or evening. Hydraulic line setters (Figure 11) are used to produce a sag in the line by throwing line out at a rate faster than the boat is moving (Beverly et al. 2003, SPC 2005), allowing it to sink to greater depths. Depths reached by this type of gear can range from 40 m down to 400 m or more (Figure 12), beyond the mixed layer, down through the intermediate layer to the thermocline (Figure 13). The depth at which different species are captured is important to understanding the impacts of longline fisheries on both target and bycatch species. Turtles and many other longline bycatch species spend the majority of their time in the mixed layer — the upper 100 m of the water column. A recent study in Hawaii (Bigelow et al. 2005) showed the observed median depth of the deepest hooks on 333 swordfish sets (shallow-sets) to be 60 m while the observed median deepest hooks on 266 tuna sets (deep-sets) was 248 m.

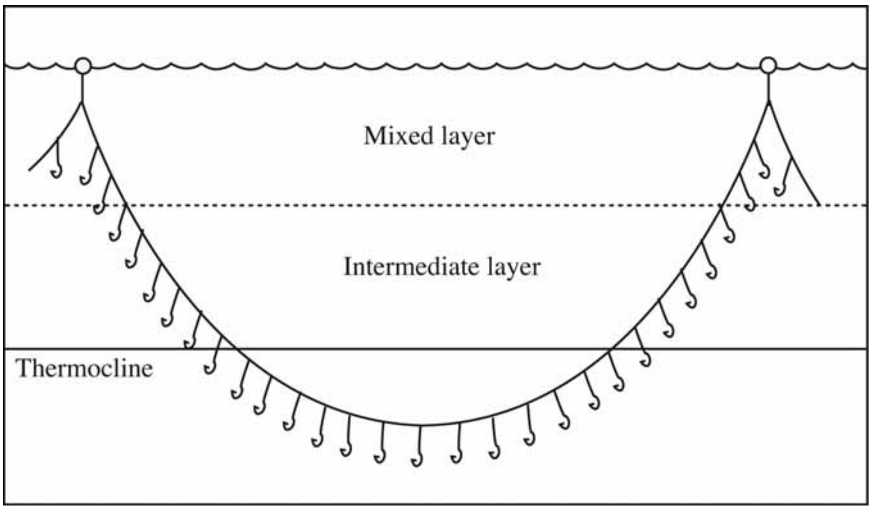


Figure 13: Deep-set longline gear in relation to mixed layer, intermediate layer, and thermocline (Beverly et al. 2003)

Both types of pelagic longline gear — shallow-set and deep-set — occasionally interact with turtles as well as other bycatch species (Witzell 1984; Dollar 1991, Bolten et al. 1994, Ogren 1994, Thoulag 1994, Aguilar et al. 1995, Segura and Arauz 1995, Witzell and Cramer 1995, Arauz et al. 1999, Kleiber 1998, Skilman and Kleiber 1998, Witzell 1996, Hoey and Moore 1999, Yeung 1999, Dalzell 2000, Ito and Machado 2001, SPC 2001, Crowder and Myers 2001, Yeung 2001, Robins et al. 2002, Javitech 2002, Javitech 2003, Garrison 2003a&b, Garrison and Richards 2004, Lewison et al. 2004a, Garrison 2005, Molony 2005). Pelagic longline sets of both types are often deployed near temperature breaks (thermal fronts) or eddies that are revealed by sea surface temperature (SST) charts, sea surface height (SSH) charts, or colour charts showing phytoplankton concentrations (Beverly et al. 2003). These charts are produced from remote sensing data obtained by satellite and are available to longline fishing enterprises on the Internet or by subscription. They can be downloaded in near real-time from satellites using on-board electronic equipment. Longline fishermen search for fronts and eddies using electronic charts and onboard temperature sensing equipment. Turtles, it turns out, are apparently attracted to these same fronts and eddies. For example, nine juvenile loggerhead turtles bearing transmitters were tracked by satellite in the North Pacific (Polovina et al. 2000) and were found to be associated with the 17ºC and 20ºC temperature fronts. These fronts were also areas of high chlorophyll concentration and were probably good forage areas for the turtles.

1.5 Sea turtle/longline interactions, and the way forward

Observer and logbook data show that shallow-set night longline gear is roughly ten times more likely to have turtle bycatch encounters than deep-set gear (SPC 2001, Ito and Machado 2001). This is probably because sea turtles such as loggerheads and olive ridleys spend the majority of their time in the top 100 m of the water column (Polovina et al. 2003). Loggerhead sea turtles have also been found to feed predominately at the surface (Parker et al. 2005). Few deep-water prey items were found in 52 loggerheads that were examined. Leatherback turtles have also been found to spend the majority of their time near the surface (Eckert et al. 1989). Typically, when setting deep, even if targeting depths beyond the normal range of sea turtles, a good proportion of the hooks in a deep-set longline – as many as 30 per cent – will still be in the top 100 m where they can encounter sea turtles (Beverly and Robinson 2004). When deep-set gear has encounters with sea turtles, it is usually with the shallowest hooks in the set, the ones nearest the floats (SPC 2001).

Most sea turtle encounters in the pelagic longline fishery, whether hooking or entanglement occurs, happen on swordfish type sets, in other words shallow night sets, setting around the full moon, using squid bait accompanied by lightsticks, setting without using a line setter, and fishing near thermal fronts (temperature breaks) or eddies (SPC 2001, Crowder and Myers 2001, Molony 2005).

Some campaigns have been mounted by NGOs against commercial longline fishing in the Atlantic and Pacific Oceans (Kinan and Dalzell 2005, Ovetz 2005) based on sea turtle/longline interactions. Others groups however, are working with scientists and fishermen to come up with workable solutions to reduce sea turtle/longline interactions, and allow fishing operations to continue, as longline fishing is just one of many sources of sea turtle mortality (Kinan and Dalzell 2005). Longline caught fish also contribute significantly to the economies of some small island states. In the WCPO, for example, longline fishing accounts for only one tenth of the tonnage of tuna taken by purse seining, but in terms of revenue, the two fisheries are about the same because of the higher relative value of longline caught tuna; and longlining has so far proven to be the only way in which Pacific Island developing states can get a significant share of the Pacific Islands tuna fishery (Adams 2003). In some Pacific Island states, revenues from tuna longlining are one of the biggest components of their gross domestic product.

The approach that has been taken in the late 1990s to the present time is to develop gear, techniques and regulations that reduce bycatch and longline fisheries impacts on sea turtles without affecting the economic sustainability of the fisheries. This is the problem now being faced by fishermen and fisheries managers — reducing sea turtle bycatch in pelagic longline fisheries without closing the fisheries or rendering them economically unsustainable. As emergency measures, the commercial fisheries for swordfish were closed in Hawaii and on parts of the Atlantic coast of the mainland US by court orders until solutions could be found (NOAA 2004a). As a result of these closures several fishing enterprises suffered economic hardship (Dalzell 2000, Ito and Machado 2001, Hogan 2004). During this time fishermen and researchers worked on developing alternate gear to reduce turtle bycatch while keeping the fisheries sustainable (Swimmer and Brill 2001; Boggs 2002b; Bolten and Bjorndal 2003; Bolten and Bjorndal 2004; Watson, et al 2002, 2003a, 2004a). Eventually the two US swordfish fisheries were re-opened, but with many new restrictions (Federal Register 2004a, Federal Register 2004b), after experimental work in the Atlantic showed that 18/0 circle hooks used in conjunction with mackerel bait greatly reduces sea turtle catch and, in some cases, increases target catch (Watson et al. 2005). Furthermore, when turtles were caught on the experimental gear with circle hooks, injury was reduced and post-capture survival rates were likely increased.

While circle hooks were being tested, methods and gear were also being developed to properly handle caught turtles to reduce injury and to further increase chances of post-capture survival (Balazs and Pooley 1994, Javitech 2002, Epperly et al. 2004). Turtle de-hookers, line cutters, and various other pieces of equipment have been developed and are now mandatory items on longline boats in some fisheries (NOAA 2005a — refer section 5.2). In addition to having this array of equipment on their boats, longline captains must also attend annual protected species workshops. Experimental work on circle hooks is continuing and has spread to many regions where there is a well developed pelagic longline fishery including Hawaii, Latin America, Japan, and Australia.

In addition to circle hook experiments, three promising strategies have been developed to reduce shallow hooks in deep-set gear (refer section 4.3.13), one using lead weights and paired floats to get the entire fishing portion of the line out of range of turtles (Beverly 2003, Beverly and Robinson 2004, SPC 2005), the second using a combination of lead weights and mid-water floats to standardize the depth of branchlines (Beverly et al. 2004), and a third using mid-water floats to accomplish the same thing (Shiode et al. 2005).

Others have directed their work towards determining why and how turtles react to longline gear. Experiments have been conducted on captive sea turtles to see how they respond to gear including longlines and floats, and to assess avoidance devices designed to prevent turtles from swallowing baited hooks, from getting snagged on baited hooks, and from getting entangled in branchlines (Hataway and Mitchell 2002). Blue dyed baits and camouflaged fishing gear have been tested to determine whether or not turtles could be fooled into avoiding the gear (Boggs 2002b, Watson et al. 2002). Artificial bait, both odourless and with fish odours, have been tested to find out what attracts turtles to the hook (Swimmer and Brill 2001, Piovano et al. 2004). Work on all of these mitigation techniques (hook designs, deep setting, modified bait) need to be validated with robust data sets. This can only be accomplished by having good observer programs in place.

Good observer coverage of pelagic longline fisheries is not only essential for management requirements, it is also necessary to understand turtle longline interactions in terms of when and where they occur, to understand where problem areas or seasonality exist, to determine take rates so total take estimates can be made, and to verify longline logbook data. Past logbook derived estimates of turtle takes account for only about 9 per cent of total take. In other words, in the Hawaii longline fishery, there were about 11 times more turtles being taken than logbook data indicated (DiNardo 1993). In the early 1990s, when turtle bycatch became an issue in pelagic longline fisheries, observer coverage was scant (< 5%) or non-existent. Even when observer programs did exist their focus was on recording target species effort and catch for stock analysis, not on recording turtle interactions (Ogren 1994). Another problem was that, even when turtle interactions were recorded, turtles were often misidentified or not identified at all. In the last few years observer programs have generally changed their emphasis to focus on endangered or threatened species as well as on target species effort and catch, and observers are being trained in turtle identification and handling, and in protocols and data reporting (Bjorndal and Bolten 1999; McCoy 2004a, 2004b, 2005; NOAA 2005c). The level of observer coverage has also improved so that, in some fisheries, coverage is up to 20 or 25 per cent. In fact, coverage in the shallow-set longline fishery in Hawaii has been at 100 per cent since 2004 (Federal Register 2004b). Overall coverage for the Hawaii-based pelagic longline fishery from 2000 to 2003 has been 20.4 per cent (Kobayashi and Polovina 2005). This is up from 4.6 per cent during the period from 1994 to 1999. Prior to 1994 there was zero coverage.

In the last decade there have been a multitude of workshops and meetings, bringing researchers, fisheries managers, and longline fishermen together to work on bycatch solutions (Balazs and Pooley 1994; Balazs et al. 1995; Williams et al. 1996; Bolten et al. 2000; Kleiber and Boggs 2000; Parks 2002; Anon 2003; Anon 2004a; Boggs 2004a; FAO 2004a, 2004b; Long and Schroeder 2004; Anon 2005; Kinan 2005; NOAA 2005f). In addition, booklets and brochures outlining turtle bycatch issues and solutions have been printed and distributed (SPC 2002a, SPC 2003, Ocean Watch Australia 2003, King 2004, Gilman 2005, NOAA 2005d, SPC 2005); videos and DVDs demonstrating proper post-capture handling of turtles have been produced (Anon 2004b, NOAA 2004b, Hataway and Epperly 2004, Canin et al. 2005); and educational programs have been developed to promote awareness and to educate fishermen, fisheries observers, and fisheries managers on the turtle bycatch problem and solutions (McCoy 2004a, 2004b, 2005).

The current direction of effort in research into sea turtle bycatch mitigation in pelagic longline fisheries can roughly be categorised as: describing and quantifying the problem; studying behaviour of sea turtles in relation to longline fishing gear; developing and modifying fishing gear, bait, and setting characteristics to mitigate sea turtle interactions; developing equipment and methods to release turtles and to enhance post-capture survival; and developing management measures to implement best practices for reducing interactions and post-capture mortality.

2. Description and quantification of the problem

Pelagic longlining targets tuna and billfish species but also catches other species that may or may not be marketable (Beverly et al. 2003). Target species include bigeye tuna (*Thunnus obesus*), yellowfin tuna (*T. albacares*), albacore tuna (*T. alalunga*), broadbill swordfish (*Xiphias gladius*), striped marlin (*Tetrapturus audax*), and sometimes shark species. There are two groups of non-target species caught by longliners: byproduct (retained bycatch) and bycatch (discards). For good discussions of the various terms related to bycatch see Alverson et al. (1994), Hoey and Moore (1999), and Chapman (2001). Byproduct, or retained bycatch, includes those species that are not targeted but are retained because they have commercial value. These include species such as mahi mahi or dolphin fish (*Coryphaena hippurus*), wahoo (*Acanthocybium solandri*), opah or moonfish (*Lampris guttatus*), and some billfish and shark species, among many others.

Some longline bycatch species are discarded because they either have no commercial value or because they are endangered and are protected by law. Discarded bycatch species that have no commercial value include species such as lancetfish (*Alepisaurus* spp), snake mackerel (*Gempylus serpens*), pelagic rays (*Dasyatis violacea*), some sharks, and undersized tunas and billfish, among many others. Discarded bycatch species that are endangered and are protected by law include sea turtles, seabirds, marine mammals, some shark species, and, in some areas, billfish.

2.1 Main sea turtle species encountered

The bycatch of sea turtles is of particular concern in pelagic longline fisheries as with some other fisheries because some turtle species are considered vulnerable to local and even global extinction because of declining numbers (Williams et al. 1996, Spotila et al. 2000, Hall et al. 2000), and the incidental capture of turtles in longline fishing gear is generally accepted to be a significant factor contributing to their decline in both the Pacific and Atlantic Oceans (Eckert et al. 1989, Williams et al. 1996, Robins et al. 2002, Lewison et al. 2004a, WWF 2004). The two species caught most frequently on pelagic longlines are loggerheads and leatherbacks (Lewison et al. 2004a), although olive ridley and green turtles are caught as well in the Hawaii-based longline fishery (Ito and

Machado 2001) and almost exclusively in the Costa Rican longline fishery (Arauz 2001). The predominate turtle caught in the western and central Pacific Ocean longline fishery is the olive ridley (Molony 2005). Turtles can be lightly hooked in the mouth (Figure 14), deeply hooked in the mouth (hook is swallowed), externally hooked on the neck or flipper, or entangled on the line.

Figure 14: Turtle caught on pelagic longline (photo courtesy J. Manieva)

Pelagic-stage juvenile hard-shelled turtles such as loggerheads are generally hooked in the mouth as a result of biting the bait (SPC 2001), while leatherbacks are mostly reported as being entangled in the fishing line or externally hooked in the shoulder or flipper (Witzell 1984, Witzell and Cramer 1995, Garrison 2003b, Garrison and Richards 2004, Garrison 2005, Javitech 2002, Javitech 2003). Most turtles interacting with longline gear are eventually released alive — they are often released with hooks in their mouths, throats, stomachs, or flippers (Aguilar et al. 1995, Oravetz 1999). The effect of these hooks and the stress of being captured are largely unknown although attempts have been made to quantify post-release mortality using pop-up satellite tags (Parker et al. 2001, Swimmer et al. 2002a, Epperly et al. 2002, Chaloupka et al. 2004); and a comparison has been made between hook types and post-hooking mortality (Epperly and Boggs 2004). Estimates have been made of both immediate and post-capture mortality (NMFS 2001b).

2.2 Different terminologies used

One of the problems in the literature is the profusion of terms concerning what happens between turtles and longline fishing gear. Some reports talk of *interactions* while others talk of *encounters*, some mention *capture* or *capture events* while others say *incidental catch* or *incidental encounters*, and still others say *take*. Sometimes there is a distinction made between turtles that were encountered and released alive and uninjured, alive and injured, or were put back into the sea dead — other times there is no distinction. When distinctions are made they are based on whether the turtle was lightly hooked (mouth), deeply hooked (swallowed the hook), externally hooked in the flipper, or entangled in the gear; and whether or not the hook and any line attached to it were removed or cut.

Another problem in the literature is that bycatch and bycatch rates are expressed in a variety of ways, making it difficult to make comparisons. Some reports give a raw number of turtle captures with no mention of effort while others give raw numbers for both effort and catch. Other reports express nominal CPUEs as turtles caught per one hundred hooks, per one thousand hooks, per ten thousand hooks, or per set. Other reports show CPUE graphically. Some reports extrapolate catch rates to the whole fishery to get an estimated total catch, others do not. Some reports give confidence intervals for estimated bycatch, others do not. Some reports provide additional information on effort including area fished, depth of set, bait, set characteristics, oceanographic features, etc, while some do not include this information.

Total estimated bycatch is usually obtained by multiplying the observed rate by total effort (Witzell 1984), but this is a simplistic approach that makes a lot of broad assumptions. Most estimates are derived using statistical methods or models that attempt to account for the assumptions. For example, Kleiber (1998) tested 27 different independent variables for statistical significance in affecting the probability of longline-turtle interactions including elements of the following: spatial-temporal, gear, environment, catch of other species, and vessel characteristics. Probably the most confounding thing about bycatch rates and total bycatch estimates is that there is a danger that data could be gleaned from observer coverage of a fishery with high bycatch rates (the swordfish fishery) and extrapolated to obtain a rate and total estimated catch for the entire fishery (swordfish plus tuna) or components of the fishery that actually have very low bycatch rates (tuna fishery). Some reports separate the fisheries (Witzell and Cramer 1995, SPC 2001, Molony 2005), while others lump them together (Yeung 1999, 2001). Lewison et al. (2004b) in attempting to explain the impacts of fisheries bycatch on marine megafauna, describe the limitations on bycatch data. In contrast to statistics collected for target species once they are landed, bycatch data are based on logbooks or observer records. Logbook data cannot be verified and research suggests that logbooks underreport bycatch. Several nations employ independent observers but the effort is low compared to total fishing effort. Worldwide 40 nations are engaged in longline fishing but only 15 of those have observer programmes. The main consequence of these data limitations is the introduction of uncertainty.

2.3 Catch rates for sea turtles

Bycatch of turtles in longline fisheries has been reported from all major oceans (Balazs and Pooley 1994). Sea turtle bycatch estimates have been made for several longline fisheries including: the Australian fleet (Miller 1994, Robins et al. 2002), Canada (Javitech 2002, Javitech 2003), European fleets fishing in the Mediterranean Sea (Aguilar et al. 1995, Laurent et al. 2001, Camiñas 2004), the Hawaii-based longline fleet (Price in Balazs et al. 1995, Kleiber 1998, McCracken 2000, Ito and Machado 2001), the Japanese fleet fishing in the Atlantic (Witzell 1984), the Japanese fleet in the western Pacific and South China Sea (Nishemura and Nakahigashi 1990), the US Atlantic pelagic longline fleet (Witzell and Cramer 1995; Witzell 1999; Yueng 1999, 2001; Garrison 2003b, 2005; Garrison and Richards 2004), the US fleet in the Gulf of Mexico (Ogren 1994), and various fleets, including distant water fishing nations (DWFN) fishing in the western and central Pacific Ocean (SPC 2001, Molony 2005). The global impact of longline fisheries has been examined and some extraordinary assessments of the impact of this fishery on loggerhead and leatherback sea turtles have been made (Lewison et al. 2004a).

Estimates of turtle *interactions* in longline fisheries around the world range from zero to infrequent to very high. The range of differences coincides with areas, seasons, and fishing strategies, amongst other factors. For example, during the period from 1996 until the end of 2004 a total of 45 observer trips were completed for New Caledonia's longline fleet (30 vessels), covering 316 deep-sets and over 600,000 hooks. During this time there were no turtle *takes* reported (pers. comm. from SPC Fisheries Database Supervisor Peter Williams). With no observed turtle catches there is no way to estimate total turtle bycatch for the New Caledonia fleet except to combine it with other fleets. In a similar timeframe, for example, logbook data from the Australian longline fleet, a portion of which fishes adjacent to the New Caledonia EEZ, showed a total of 272 reported turtle *interactions* from 1997 to 2001 (Robins et al. 2002), which equates to one turtle for every 250,000 hooks set, or a catch per unit effort (CPUE) of 0.004 turtles per 1000 hooks. A study of observer data from the western central Pacific Ocean (SPC 2001) estimated different rates for turtle *encounters* based on setting strategies, bait used, and fleet characteristics. Nominal CPUEs ranged from 0.0069 turtles per 1000 hooks for deep-sets to 0.061 turtles per 1000 hooks for shallow-sets, with most encounters occurring in the western tropical Pacific (WTP). Applying estimates of *mortality* to estimates of *encounters* suggested that 500–600 marine turtle mortalities may occur in the WTP longline fishery per year (SPC 2001).

A study of the Japanese longline fleet fishing in US Atlantic waters (Witzell 1984) reported *incidental captures* of loggerheads and leatherbacks to be two-and-a-half times greater in the Gulf of Mexico (0.018 turtles per 1000 hooks) than in the Atlantic (0.0073 turtles per 1000 hooks). By contrast, the

Spanish fleet fishing in the western Mediterranean in the early 1990s had a very high *capture rate* of 9.8 loggerhead turtles per day per vessel (Aguilar et al. 1995). This possibly equates to 20,000 *capture events* every year (with an estimated 20% mortality). Very high *incidental catch* rates were also reported from Costa Rica (Arauz et al. 1999) where observer data from one longline fishing trip on an industrial vessel showed *incidental capture* of 34 turtles on 1750 hooks giving a combined CPUE for olive ridley and green sea turtles of 19.4 turtles per 1000 hooks with an estimated mortality of 8.8 per cent. Turtle catch rates differ between various longline fisheries for two reasons — fishing strategies change temporally and spatially depending on target species, and there are changes in sea turtle distribution and abundance (Witzell 1995). Mortality rates differ because, although immediate mortality is known, little is known about post-capture, or delayed, mortality.

In the following Table (1), attempts will be made to summarize documented sea turtle interactions in the pelagic longline fishery by area — nominal catch per unit effort (CPUE) where given, will be noted, but will be referred to as bycatch per unit effort (BPUE). If CPUE figures are not provided as such in a particular report, an attempt will be made to determine BPUE from the information provided. For standardisation, nominal BPUEs will be in turtles per 1000 hooks. Note that various statistical methods were used to produce the estimates of total catch, where given, and that most estimates have wide confidence intervals, but these details have been omitted for simplicity; and hook numbers and BPUEs, where given, have been rounded off in many cases. Other relevant data, such as mortality, is recorded in the comments/other information column of Table 1. To understand the data from the Atlantic Ocean, Figure 15 provided the statistical fishing areas.

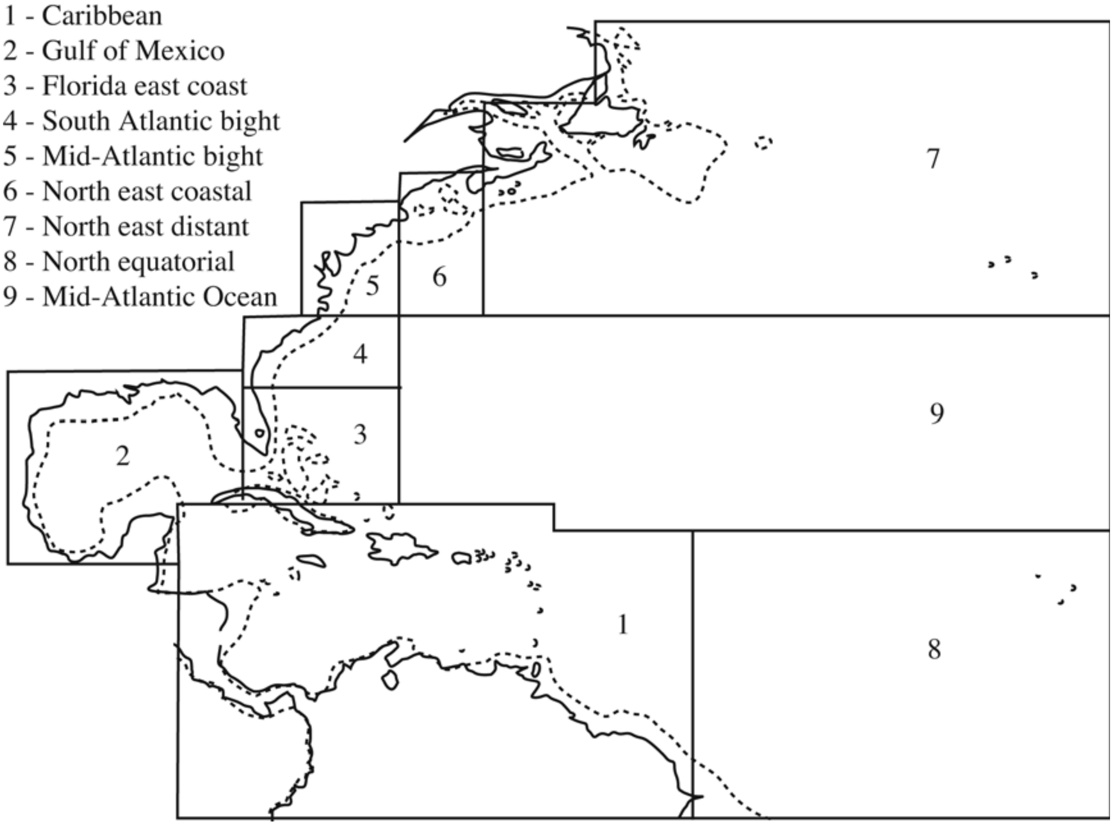


Figure 15: Statistical fishing areas in the western Atlantic US pelagic longline fishery from Witzell (1999). Area 7 is the northeast distant, or NED, statistical area.

Table 1: Summary of sea turtle catch and interaction information by location and author, with BPUE (bycatch per unit effort) provided as *BPUE per 1000 hooks as a standard unit of effort

Location and Reference	Year of study	Number of hooks	Loggerhead turtles		Leatherback turtles		Olive Ridley turtles		Other turtles		Total – all turtle species		Comments/other information
			No.	BPUE*	No.	BPUE*	No.	BPUE*	No.	BPUE*	No.	BPUE*	
Atlantic Ocean Japan Witzell 1984	1978 to 1981	3,651,434							126	0.0073	126	0.0073	Turtle catch estimates derived by multiplying observed CPUE by logbook effort. 30% of turtles were dead on retrieval.
Gulf of Mexico Witzell 1984	1978 to 1981	1,662,273							204	0.018	204	0.018	Turtle catch estimates derived by multiplying observed CPUE by logbook effort. Most turtles were identified as leatherback, at 8% of all turtles were dead on retrieval.
Ogren 1994	1979 1980	451,902 294,297			2 7	0.0044 0.0238			10 1	0.0221 0.0034	12 8	0.0266 0.0272	Foreign fishery data, with mortality of turtles in 1979 estimated at 30%, with zero mortality in 1980. Turtles reported to aggregate on current fronts, foraging on accumulated jellyfish. Longliners working the same area.
Azores Bolten et al. 1994		Not given	28		5						33		Reported catch by one fisherman from swordfishing activities, with 1 dead, 8 hooked in the oesophagus and 19 hooked in the mouth.
Bjorndal and Bolten 1999	1998	Not given	60	0.3–0.4 (estimate from graph)							60	0.3–0.4 (estimate from graph)	Interactions recorded over 151 sets on the same vessel. All sets were at night, no lightsticks used, and fishing depth was 15–50 m. Turtles were hooked: 54 in mouth, 3 swallowed the hook, 1 in the eye, 1 in the flipper, and 1 undetermined. One turtle was dead and 1 was weak and resuscitated.
Prieto et al. 2000	May to August, year not given	Not given							27	0.036 (May) to 0.753 (July)	27	0.036 (May) to 0.753 (July)	Study conducted from 1 boat from May to August. 27 turtles hooked in the mouth, 1 in the eye and 1 in the flipper. Only 1 of the 27 turtles was dead on capture.
US Atlantic fleet Witzell and Cramer 1995	1992–93	15,800,000	243	Lightsticks 0.0238 No l-sticks 0.0051	598	Lightsticks 0.0469 No l-sticks 0.0279					841	0.053	Only 1 leatherback and 3 loggerheads dead. One turtle hooked twice and another 3 times, indicating turtles can continue feeding and be counted multiple times.

Location and Reference	Year of study	Number of hooks	Loggerhead turtles		Leatherback turtles		Olive Ridley turtles		Other turtles		Total – all turtle species		Comments/other information
			No.	BPUE*	No.	BPUE*	No.	BPUE*	No.	BPUE*	No.	BPUE*	
													CPUE doubled on sets using lightsticks. Most leatherbacks hooked externally or entangled. Most loggerheads hooked in mouth.
Witzell 1996	1992 1992–93	7,411,544 436,799										0.0593 0.1442	1992 data from logbooks, with catch rate much lower than the combined 1992/93 observer data. Observers noted some turtles were caught several times, increasing numbers of interactions.
Witzell 1999	1992–95	17,798,150	1337	Lightsticks 0.11 No l-sticks 0.021	1264	Lightsticks 0.093 No l-sticks 0.031					2601	0.146	June to November main season in areas 5-7 (Fig ??). Area 7 accounted for 46.8% of leatherback and 70% of loggerhead captures. Average fishing depth was 54 m and with most effort directed at the 200 m isobath of the shelf, or south eastern edge of the Grand Banks.
Yeung 1999	1998	181,000 6,340,000	15	0.0829	4	0.0221			1	0.0055	20 728	0.1105 0.1148	Effort of 181,000 hooks was observer data, and all turtles were released alive, although all but one was presumed to have died. Total turtle take is an extrapolation of the observer data to the total effort in the fishery in 1998.
Yeung 2001	1999 2000	291,200 7,240,000 329,730 7,530,000	64 50	0.22 0.152	45 32	0.1545 0.097			3 5	0.0103 0.0152	112 1016 87 769	0.3846 0.14 0.2639 0.10	Effort of 291,200 and 329,730 hooks was from observer data, with only one turtle dead in 1999, while estimated mortality was for 23 turtles, or 36% of the interactions in this year. This percentage was used to calculate the total mortality from the fishery in 1999 and 2000.
Garrison 2003b	2001 2002	Not given 6,760,000 Not given 6,020,000	 312 575	 0.0462 0.0955	 1208 962	 0.1787 0.103					273 1520 335 1537	 0.2249 0.2553	From observer data, only one dead loggerhead was recorded in 2001 and one dead leatherback in 2002. The estimated encounters for the US Atlantic fleet is a raised figure based on the encounters reported during observed sets.
Garrison and Richards 2004	2003	Not given 7,000,000	151 819	 0.117	150 1191	 0.1701			3 1	 0.0001	304 2011	 0.2873	Only one dead leatherback reported from observer data. Total encounters is based on a raising observer records plus adding in the encounters from experimental fishing, which had 100% observer coverage.
Garrison 2005	2004	7,200,000	734	0.102	1362	0.189					2096	0.291	No reported turtle deaths from observer data for the US Atlantic fleet in this year.

Location and Reference	Year of study	Number of hooks	Loggerhead turtles		Leatherback turtles		Olive Ridley turtles		Other turtles		Total – all turtle species		Comments/other information
			No.	BPUE*	No.	BPUE*	No.	BPUE*	No.	BPUE*	No.	BPUE*	
Canada Javiteck 2002	2001	283,057	196	0.6924	28	0.099			3	0.0106	227	0.802	Figures based on observer data from the Canadian Atlantic fleet. No leatherbacks dead and most released alive and uninjured (78%). 2 hard shell turtles dead (2%), but most released alive and uninjured (76%).
Javiteck 2003	2002	Not given		0.557		0.131						0.688	Figures based on observer data, from shallow set night fishery; average fishing depth of 10–20 m, with most captures at <10 m. 77% of hard shell turtles released alive and uninjured, with around 80% of leatherbacks released in the same condition.
Mediterranean Sea Spanish fleet Aguilar et al. 1995	1991–92	343,200	1098	3.1993	2	0.0058					1100	3.205	Figures based on observer data from the Spanish longline fishery, with an estimated catch of 20,000 sub-adult loggerheads annually. Fishing depth of gear was 25 m and mortality estimated at 20%.
Camiñas 2004, Laurent et al. 2001	1990	Not given									35,627		1990 and 1991 data based on estimates for the whole fleet, with 0.4% mortality and a catch range of 22,000 to 23,637 turtles in 1991. 1999/00 based on observer data for the two years. 2000 data based on extrapolating the observer data to the total effort. Some turtles were reported to be hooked multiple times. Immediate mortality rate was estimated at 2.6% in 2000.
	1991	Not given									22,819		
	1999–00	Not given	2125		2						2127		
	2000	1,615,652									1858	1.15	
Italian fleet Camiñas 2004, Laurent et al. 2001		Not given									550		Unknown year data based on estimates for the whole fleet, with unknown mortality and a catch range of 100 to 1000 turtles. 1999/00 based on observer data for the two years. 2000 data based on extrapolating the observer data to the total effort. Immediate mortality rate was estimated at 0% in 2000.
	1999–00	Not given	218						2		220		
	2000	187,096									174	0.93	

Location and Reference	Year of study	Number of hooks	Loggerhead turtles		Leatherback turtles		Olive Ridley turtles		Other turtles		Total – all turtle species		Comments/other information
			No.	BPUE*	No.	BPUE*	No.	BPUE*	No.	BPUE*	No.	BPUE*	
Greek fleet Camiñas 2004, Laurent et al. 2001	 1999–00 2000	Not given Not given 9,776,190	 22		 1						50 23 6159	 0.63	Unknown year data based on estimates for the whole fleet, with unknown mortality. 1999/00 based on observer data for the two years. 2000 data based on extrapolating the observer data to the total effort. Immediate mortality rate was estimated at 4.3% in 2000.
Malta fleet Camiñas 2004		Not given									2000		Unknown year data based on estimates for the whole fleet, with unknown mortality and a catch range of 1500 to 2500 turtles.
Morocco fleet Camiñas 2004		Not given									3000		Unknown year data based on estimates for the whole fleet, with unknown mortality.
Algeria fleet Camiñas 2004		Not given									300		Unknown year data based on estimates for the whole fleet, with unknown mortality.
South Spain Baez et al. 2006		Not given											Survey of 169 southern Spanish fishermen, particularly the Andalusian region, revealed that 32 surface longline fishermen reported they caught >10 turtles annually.
Pacific Ocean **Australia** Miller 1994	1993	47,432							1	0.0211	1	0.0211	Catch is based on observer data from 57 observer cruises off the east coast.
Robins et al. 2002	1997 to 2001	68,000,000							272	0.004	272	0.004	Figures are for the Australian longline fleet during these years. The immediate mortality was calculated to be 4%.
Costa Rica Segura and Arauz 1995	1991 and 1992	28,273 12,879					83 31	2.936 2.407	1 2	0.0354 0.1553	84 33	2.971 2.562	Observer data from a surface longline fishery for mahi mahi (28,273 hooks) and a deeper set tuna (down to 80 m) fishery (12,879 hooks). Turtle mortality was 1.2% in surface fishery, and 10.1% in deeper fishery.
Arauz et al. 1999	1997 1998	1750 1804							34 26	19.429 14.412	34 26	19.429 14.412	1997 data based on 1 longliner with a fishing depth of 25–50 m, with a mortality of 8.8%. 1998 data based on an experimental longline set at depths of 72–90 m, with no mortality.
Arauz 2001	1999 and 2000	39,284					250	6.364	12	0.3055	262	6.6694	All sets were shallow, with a fishing depth of <27 m. No mortality reported, with turtles released alive but injured.
FSM Thoulag 1994	1992–93	280,110			2	0.0071	3	0.0107	2	0.0071	7	0.025	Observer data from foreign and locally flagged longliners working in FSM. No

Location and Reference	Year of study	Number of hooks	Loggerhead turtles		Leatherback turtles		Olive Ridley turtles		Other turtles		Total – all turtle species		Comments/other information
			No.	BPUE*	No.	BPUE*	No.	BPUE*	No.	BPUE*	No.	BPUE*	
													mortality rates given.
Heberer 1997	1990 to 2000	1,272,000	1	0.0008			8	0.0063	38	0.0299	47	0.037	Figures based on FSM observer data, with coverage of 1–3%. Immediate mortality was reported at 44.6%.
Hawaii (Pacific) Price (in Balazs et al. 1995)	1994–95	599,700							38	0.0634	38	0.0634	Figures based on observer data from Feb 1994 to Feb 1995. Swordfish (shallow) sets accounted for 79% of encounters, with another 8% on mixed swordfish and tuna sets. All encounters except 1 were on night sets, with 71% of encounters on the hooks adjacent to floats (shallowest hook).
Skillman and Kleiber 1998	1994–95	11,800,000	442	0.0375	178	0.0151	88	0.0075	44	0.0037	752	0.0637	Extrapolated figures based on 4.4% observer coverage. Estimated mortality; 56 loggerhead 16 olive ridley, 21 leatherback, 5 green, and 8 unidentified, with 14.4% mortality overall.
McCracken 2000	1994 to 1996	Not given	418 annual		112 annual		146 annual		40 annual		716 annual		Estimated number of interactions by turtle species. Mortality estimates; 17% loggerhead 8% leatherback, 33% olive ridley, 13% green
Ito and Machado 2001	2000	764,078	15	0.0196	7	0.0092	9	0.0118	15	0.0196	46	0.0602	Figures based on observer data for 751 sets. 72% were reported as alive, 13% as released injured, and 15 % were dead on retrieval.
Kobayashi and Polovina 2005	1994 to 1999 2000 to 2002	Not given Not given	418 T 168 K 94 T 40 K		112 T 37 K 49 T 17 K		146 T 73 K 60 T 40 K		40 T 18 K 26 T 15 K		716 T 296 K 229 T 112 K		The period 1994–99 is the pre-management era in the Hawaii longline fishery; 2000–02 is the post-management era. Annual turtle takes (T) and kills (K) for all turtle species have greatly reduced with the introduction of management to this fishery.
W-Pacific & S-China Sea Nishemura and Nakahigashi 1990	1988–89	Not given							21,200	0.10	21,200	0.10	Figures based on logbooks, data from research vessels, and responses to questionnaires. Mortality was estimated at 42% (12,300 turtles) for this area.

Location and Reference	Year of study	Number of hooks	Loggerhead turtles		Leatherback turtles		Olive Ridley turtles		Other turtles		Total – all turtle species		Comments/other information
			No.	**BPUE***	**No.**	**BPUE***	**No.**	**BPUE***	**No.**	**BPUE***	**No.**	**BPUE***	
Pacific Ocean SPC 2001	1990 to 2000											WTP 0.026 WSP 0.0022 WTeP 0.0005	Figures based on observer data, with tropical areas having a higher incidence of encounters, mainly with green and olive ridley turtles. Data presented in 3 zones, western tropical Pacific (WTP), western south Pacific (WSP), and western temperate Pacific (WTeP). This data was further broken down by fishing strategy for the WTP: shallow night set 0.066; shallow day set 0.047; and deep day set 0.0066.
Molony 2005	1993 to 2004 1991 to 2004 1990 to 2004											TSS 0.1424 TDS 0.0162 TA 0.00236	Figures based on raised observer data covering 481 turtle interactions, mainly olive ridley, over 3 fisheries. Highest catches were in the tropical shallow-set (TSS) fishery, with 4.2% mortality, followed by the tropical deep-set (TDS) fishery, with 71% mortality and 16% mortality in the temperate albacore (TA) fishery. Raised data estimated 4000 to 15,000 interactions annually, with mortality being 500 to 3000 turtles.
Kaplan 2005		Not given				Tuna 0.0048 Swordfish 0.0246							Figures based on observer data over several years for leatherbacks. Mortality estimated to be 5% and 12% for the eastern and western Pacific. Mortality for harvesting eggs and females on nesting beaches was estimated at 28% and 13% for the eastern and western Pacific. Mortality in the eastern Pacific 5 time higher for egg and female harvesting than for longlining.
Global Lewison et al. 2004a	2000 Pacific 2000	1.4 billion 728 million	200,000		50,000 20,000	 0.0275							Compilation of data from 40 nations with bycatch data from 13 observer programmes. Longline effort was in two categories; 1.2 billion hooks for tuna fishing and 200 million for swordfish fishing. Worldwide catch rates were estimated at 0–14 for loggerhead and 0–2.4 for leatherback/1000 hooks.

As can be seen from Table 1, there is a wide and varied BPUE for sea turtles depending on location and style (deep-set or shallow-set) of pelagic longlining used. Data from several other reports where no BPUE data was given, also are relevant in their assessment of the issue. Bailey et al. (1996) report that there were no records of longline turtle catch in the Regional Tuna Fishery Database (RTFD) for the SPC western and central Pacific Ocean statistical area (for years prior to 1996). However, based on observer reports, marine turtles were occasionally taken in the longline fishery in tropical waters of the WCPO but that there were insufficient data to determine the extent of exploitation. In the observer reports, for the western tropical Pacific green, hawksbill, olive ridley, and unidentified turtles were listed as seldom caught; for the western south Pacific unidentified turtles were listed as seldom caught; and for the western temperate Pacific unidentified turtles were listed as rarely caught.

Bartram and Kaneko (2004) compare the bycatch (BPUE) to catch (CPUE) ratios in Hawaii's longline fishery to other longline fisheries. The ecological impacts of pelagic longline fisheries vary with when, where and how longlines are set. Setting characteristics influence target and bycatch catch rates, especially depth of set. Hawaii pelagic longline fisheries have been characterised as having high bycatch rates. The study done by Bartram and Kaneko sought to compare the Hawaii longline fishery with other fisheries that supply or have the potential to supply the same US markets as the Hawaii fishery. Indices of BPUE and CPUE were calculated based on incidental catch of bycatch species and catch of target species. Catch to bycatch ratios were calculated by dividing CPUE by BPUE. This provided a standard index that allowed scaling of BPUEs from low to high and comparing Hawaii's fishery with others. The major finding of the study was that Hawaii's longline fishery has a lower CPUE/BPUE ratio of sea turtles and finfish (except for lancetfish) compared to most competing pelagic longline fisheries.

Lewison et al. (2004a) integrate catch data from over 40 nations with bycatch data from 13 international observer programmes and estimate that, despite infrequent encounters, more than 200,000 loggerheads and 50,000 leatherbacks were likely taken as pelagic longline bycatch in 2000. Global longline fishing effort was estimated at 1.4 billion hooks annually, with six times more effort targeting tuna (1.2 billion hooks) than swordfish (200 million hooks). Four hotspots were identified: south of Kiribati in the central Pacific Ocean, the region between Indonesia and the Philippines, the Mediterranean Sea, and the central southern Atlantic Ocean. BPUE from swordfish and tuna vessels worldwide ranged from 0 to 14 loggerheads and from 0 to 2.4 leatherbacks per 1000 hooks. The Pacific-wide BPUE for leatherbacks was 0.0275 turtles per 1000 hooks based on 20,000 leatherbacks caught on 728 million hooks. However, Kaplan (2005) states that the catch rate for leatherbacks given by Lewison et al. (2004a), is likely biased upward because of their reliance on questionnaires and observer coverage that is less extensive than that from SPC (2001).

2.4 Sea turtle mortality estimates

Estimates of turtle mortality are very important to understand the effect of longline fisheries on sea turtle populations (Laurent et al. 2001). Estimates of mortality reflect the sum of immediate mortality (dead when retrieved) and delayed or assumed mortality (presumed dead after release due to injuries). Kleiber (1998), for example, estimated kill rates for the Hawaii-based longline fishery for the years 1991–97, based largely on Aguilar et al. (1995), who assumed 29 per cent mortality for all turtles that ingested the hook (internally hooked). Kleiber (1998) made other assumptions of mortality for different condition codes from observer data including: externally hooked, unknown hook position, condition not recorded, alive and uninjured at release, and dead upon retrieval. Combining all of the mortality rates from the different condition codes gave the following overall kill rates for the four species involved: loggerheads 17.5 per cent, olive ridleys 25.4 per cent, leatherbacks 4.2 per cent, and green turtles 1.6 per cent. In a similar vein but with somewhat different results, McCracken (2000) gave the following estimated mortality rates for the Hawaii-based longline fishery: loggerheads 17 per cent, leatherbacks 8 per cent, olive ridleys 33 per cent, and greens 13 per cent.

A different set of mortality rates was given by NMFS (2001b) in a Decision Memorandum that was based on interactions, responses, and injuries. For example, entangled turtles that were disentangled with no injury had a zero mortality rate, while entangled turtles with an external hook that were disentangled with no trailing gear but with minor injuries had a 27 per cent mortality rate. Mouth hooked turtles with the hook left in but with no trailing gear and moderate injuries had a 27 per cent mortality rate, while mouth hooked turtles with the hook left in and trailing gear with serious injury had a 42 per cent mortality rate. Turtles that swallowed the hook, regardless of response or injury, had a 42 per cent mortality rate. Dead turtles had a 100 per cent mortality rate.

Immediate mortality is generally higher for deep-sets than for shallow-sets (Camiñas 2004, Molony 2005), even though catch rates are lower for deep-set gear. Mortality estimates for the deep-set component of the Hawaii-based longline fishery (Boggs 2005), for example, are as follows: green turtles 86 per cent, leatherbacks 34 per cent, loggerheads 44 per cent, and olive ridleys 96 per cent. It should be noted, however, that although these rates are high there is very little turtle bycatch in the deep-set fishery. In fact, the most recent Biological Opinion (NMFS 2005a, WPRFMC 2006b) for the Hawaii longline fishery has concluded that the continued existence of all sea turtle species, including leatherbacks, is not jeopardized by the continued operation of the deep-set component of the fishery.

It should be kept in mind that there are many different ways of calculating delayed mortality rates, all based on a variety of assumptions; and it should also be noted that with recent gear innovations and post-capture protocols, mortality rates have likely decreased, so older rates and estimates may not necessary apply to fisheries that are employing bycatch mitigation measures. In the Hawaii-based longline fishery, for example, estimated loggerhead takes dropped from an annual average of 418 during 1994–1999 when there were no management restrictions in place to an annual average of 94 during 2000–2002 when there were management restrictions and post-capture handling protocols in place (Kobayashi and Polovina 2005). During the same time periods annual mortality estimates for loggerheads went from 168 to 40.

2.5 Understanding post-capture mortality

Swimmer et al. (2002a) report on the use of pop-up satellite archival tags (PSATs) to quantify mortality of marine turtles incidentally caught in longline fishing gear. The assessment of turtle mortality caused by hooking or entanglement in longline gear is difficult. Estimates have been based on a combination of recorded immediate mortality, cessation of transmissions from satellite tags, and captive studies where turtles caught on longlines were placed in tanks and observed over time. The range of mortality estimates is variable, from 8 to 95 per cent for loggerheads and leatherbacks, making it difficult to define a reasonable overall mortality rate. PSATs were used to quantify mortality and morbidity rates in turtles released from longline gear by recording data on swimming depth, water temperatures, and a daily estimation of geolocation. PSATs can be programmed to release after durations of up to two years after deployment, thereby providing long term movement patterns. They will also release and begin transmitting stored data if the turtle either dies or sinks below a certain depth, or the tag is shed. An olive ridley was fitted with a PSAT after being caught by a Hawaii-based longliner in 2001. The turtle had been mouth hooked but the hook was not recovered. The turtle was at liberty for 82 days before the tag was shed. It travelled in a south-westerly direction and covered a straight line course of 1874 nm. More importantly though, is the fact that the turtle was still functioning normally for three months despite the presence of a longline hook in its mouth.

Swimmer et al. (2004) report on turtles tagged with PSATs in the Gulf of Papagayo, Costa Rica, between November 2001 and June 2003. PSATs were deployed on nine olive ridley turtles and one green turtle that were caught on longline gear. PSATs were also deployed on five hand-caught olive ridleys which served as controls. The results of the study indicated that olive ridleys can survive an encounter with longline gear for at least two months after release. Longline caught turtles all survived at least 3.5 weeks and most survived a minimum of six weeks post-release before the tag was shed.

Epperly et al. (2002) report on the development of an experimental design and research plan to estimate post-hooking survival of sea turtles captured in longline fisheries in the North Atlantic. Although the number of turtles captured by longline fisheries has been estimated, the actual number of turtles removed from the populations due to post-capture mortality is unknown and estimates are hotly contested. Most turtles are alive when boated but some die as a result of injuries after being released. There is general agreement that post-hooking mortality occurs over a period of time and could be caused by tissue damage, infection, and digestive track blocking. Hooks can cause lesions that can become infected, or they may penetrate an organ or blood vessel, or become encapsulated or be expelled. Fishing line may stick to the digestive tract and cause death. The only feasible way to conduct post-hooking mortality studies on a large number of (turtles) in the open ocean over a long period of time is to use technology that transmits data remotely to a central location (PSATs). In autumn 2001 twenty-three PSATs were deployed on the Grand Banks in the North Atlantic in a pilot study to prove the validity of the technology. They were programmed to pop-up during July and August 2002. Tags were deployed on turtles that had been hooked in the beak, that had ingested the hook, that were entangled, that had been hooked in the flipper, hooked in the mouth, or swallowed the hook. Most hooks had been removed. At the time the report was written eight of the 23 tags had transmitted data. The minimum time at large was 106 days. One concern was the performance of the tags. Poor data from the tags made it impossible to determine if the turtles died or not.

Parker et al. (2001) report on post-hooking survival of sea turtles taken by pelagic longliners fishing in the North Pacific. A total of 54 transmitters were deployed from 1997 to 2000. As of February 2001 four of these were still transmitting to satellites. Of the remaining 50 transmitters, 35 were attached to loggerheads, 12 to olive ridleys, three on green turtles. Fifteen transmitters functioned poorly or not at all. Eleven of these were on deeply hooked turtles and four on lightly hooked turtles. Thirty-five turtles had successful tracks of which 22 were loggerheads, 10 were olive ridleys, and three were greens. Of these 35 turtles with successful tracks, 15 were lightly hooked and 20 had ingested the hooks. For all species combined the average duration of tracking was 4.2 months for lightly hooked turtles and 3.7 months for deeply hooked turtles. The lightly hooked turtles travelled 2500 km while the deeply hooked turtles travelled 2600 km on average. There were no significant differences between the lightly hooked and deeply hooked turtles in duration and distance travelled. Overall, this study suggested a 20 to 40 per cent mortality rate depending on hooking status (based on the 15 transmitters that failed, although some of these were probably due to actual transmitter failure and not turtle mortality).

2.6 Discussion

So how many turtles are caught and how many turtles die as a result of being caught in pelagic longline fisheries worldwide? Is the total annual catch of loggerheads and leatherbacks really in the hundreds of thousands and the total annual mortality in the tens of thousands? If we take the estimated global longline fishing effort from Lewison et al. (2004a) and the bycatch rates from Molony (2005) and apply the simple formula given by Witzell (1984) of multiplying observer data by total effort to get an estimate of total catch, we arrive at quite different estimates for total turtle encounters than those given by Lewison et al. (2004a) 1,200,000,000 hooks fishing in the tuna (deep-set) longline fishery annually and catching turtles at a rate of 0.0162 turtles per 1000 hooks would produce an estimated catch of 19,440 turtles. 200,000,000 hooks fishing in the swordfish (shallow-set) longline fishery annually and catching turtles at a rate of 0.1424 turtles per 1000 hooks would produce an estimated catch of 28,480 turtles. The total annual estimated catch from all longline fisheries worldwide would then be 47,920 turtles, much less than the 250,000 turtle takes estimated by Lewison et al. (2004a). However, if you base the estimate on the total number of hooks fished worldwide, 1,400,000,000, and use Molony's catch rate from just the shallow-set fishery, 0.1424 turtles per 1000 hooks, then you arrive at a number close to the estimate given by Lewison, et al (2004a): 199,360 turtles.

Interestingly, Lewison et al. (2004a) identified several turtle bycatch hotspots, one of which was south of Kiribati, which happens to be within the area covered by Molony (2005), so maybe the global estimate of 47,920 turtles is not so farfetched. Some provisos to this bit of guesswork though: it should be noted that the shallow-set fishery Molony (2005) refers to is probably not swordfish sets but shallow night sets for bigeye tuna, and that Molony's estimates were derived from data for all turtle species caught on longline gear while Lewison et al. (2004a) looked at loggerheads and leatherbacks only. The set characteristics for the two fisheries are almost identical, however, and loggerheads and leatherbacks are the two species implicated in most interactions.

One other thing, if the total global catch is about 47,000 turtles how does one explain the very high catches in just the Mediterranean of over 25,000 turtles annually? That would account for over half of the global catch. The answer may lie in the fact that a lot of these turtles are caught multiple times and that they may be able to survive ingesting the hook. A study of the Italian swordfish fishery in the Mediterranean (Piovano 2005) revealed that 92 per cent of loggerheads (n=277) caught in that fishery had one or more hooks either external or lodged internally (revealed by x-ray analysis). Some turtles had as many as three hooks encysted in their stomachs. Similarly, a report from the Atlantic on turtle bycatch in the US longline fishery (Witzell 1996) stated that observer records indicate that some turtles were caught two and three times, raising the number of interactions. Aguilar et al. (1995) recording post-hooking survival of loggerheads in the Spanish swordfish fishery documented that some turtles with deep ingested hooks (some ingested more than one hook) could take as long as 285 days in captivity to expel the hook(s). Many turtles survived after four months without expelling the hook(s) with no observable side effects. The implications from these findings are that the number of turtles caught in the longline fishery may actually be much less than the number of turtle interactions, and that turtles apparently can survive interactions even when the hooks have been swallowed. The estimate of 25,000 turtles caught annually in the Mediterranean may translate into about 12,500 turtles, each caught twice resulting in 25,000 encounters. This has implications on mortality rates as well. Many estimates of mortality have been based on the estimate from Aguilar et al. (1995) of 29 per cent mortality for any turtles swallowing hooks in the Mediterranean fishery. One turtle swallowing two hooks in two separate encounters would halve this number. The fact that some turtles have multiple hooks encysted in their stomachs from previous encounters puts most assumptions about post-capture mortality in real doubt. More work is obviously needed to understand the problem.

3. Turtle behaviour in relation to longline fishing interactions

Turtle behaviour relates to longline fishing interactions in a number ways. There are obvious spatial and temporal overlaps of turtle habitat and longline fishing activity. Most sea turtles follow sometimes narrow migratory paths from nesting beaches to foraging grounds, traversing several thousand kilometres. Turtles may follow routes that take them to highly productive areas (Polovina et al. 2000, Polovina et al. 2004, Ferraroli et al. 2004, Hays et al. 2004). They have been tracked to frontal zones and eddies that are high in chlorophyll and plankton productivity. These same fronts and eddies, sometimes called hotspots, are also sought out by longline fishermen so there are opportunities for interactions between fishing gear and turtles. There is an overlap of turtle foraging grounds and longline fishing grounds and possibly an overlap of seasons as well. Turtles and fishermen may show up in the same place at the same time, and perhaps they both do this by sensing temperature, as turtles and longline fishermen seem to have similar temperature preferences, be it for foraging or fishing. Watson et al. (2002), for example, found increased loggerhead catch at temperatures above 22.2ºC and increased leatherback catch at temperatures above 20.0ºC; and Polovina et al. (2000) found that juvenile loggerhead turtles were associated with the 17ºC and 20ºC temperature fronts in the North Pacific.

Turtles are basically surface dwellers, even though they can dive to great depths. For the most part loggerhead and olive ridley turtle diving behaviour is restricted to the upper 100 m of the water column (Polovina et al. 2003). Leatherbacks can dive much deeper — 900 m, but a good proportion of their time is still spent in the upper 200 m (Sale et al. 2005). Eckert et al. (1989) found that the average dive depth of leatherbacks to be 61.6 m, and that they forage at night on the deep scattering layer (plankton layer), when it is nearer to the surface. Longline fishing gear, especially for swordfish, is concentrated in the upper 100 m of the water column, so there is an overlap of turtles and longline fishing gear in the water column. Swordfish gear also fishes at night, when turtles are feeding. Turtles forage on a variety of organisms found in the mixed layer, which may include the same species of baitfish that longline fishermen use to attract target species. Loggerhead turtles have been described as opportunistic feeders that ingest items floating at or near the surface; and, although fish is not a large part of their diet, it is likely that, when they do eat fish, they ingest only dead or debilitated fish rather than actively hunting or chasing such species (Parker et al. 2005). Some longline fishermen use live bait, but almost all fish with dead squid or fish bait (Beverly et al. 2003) so this bait becomes easy prey for turtles.

Turtles may also be attracted to lightsticks that are a significant component in most swordfish fishing gear; and to luminous beads or loop protectors that are often used on swordfish and tuna gear. Witzell (1999), for example, reports that the highest CPUE for leatherbacks in the Atlantic longline fishery was on sets with lightsticks; and Javitech (2003) reports that the highest CPUE for loggerheads in the Canadian longline fishery was on sets with luminous protectors. Olfactory stimulation, or smell, also plays a role in attracting turtles to bait (Piovano et al. 2004). Turtles have been shown to be interested in artificial lures with fish smell but not in lures without fish smell. Colour of bait, on the other hand, probably does not make much difference. Laboratory trials showed that undyed bait was preferred by Kemp's ridley and loggerhead turtles but field trials showed no difference in preference (Watson et al. 2002, Swimmer et al. 2005). Lastly, swimming behaviour undoubtedly plays a role in entanglement of sea turtles. The leatherback turtle, for example, has never developed the ability to swim backwards (Fisheries and Oceans Canada 2004). This poses some difficulty when leatherbacks encounter floatlines in the ocean because they are not able to back away from them. They keep moving forward with the line caught in the notch formed by their neck and front flipper, eventually resulting in entanglement and possible drowning. The following paragraphs will attempt to summarize information on turtle behaviour in relation to pelagic longline fishing.

3.1 Turtle movements and foraging in relation to oceanographic features

Oravetz (1999) states that swordfish, a major target species in longline fisheries, tend to concentrate along frontal zones with high topographic relief and high biological productivity, and that these are often the same areas where sea turtles concentrate, creating a scenario for interactions with longline fisheries.

Nichols (2001) reports that new technologies allow scientists to answer questions regarding the life history of Pacific loggerhead turtles. Mark and recapture data (tagging studies) combined with results from satellite telemetry, remote sensing, oceanography, and genetic studies have provided a better understanding of loggerhead movements and distributions. Pacific loggerheads are hatched on nesting beaches primarily in Japan. Juveniles are then transported into the North Pacific by the Kuroshio Current. Loggerheads were tracked using satellite telemetry and these results were combined with tagging data, diet analysis, and oceanographic patterns. The results showed a pattern of movement over the course of two to six years that had them moving from west to east, feeding along convergence and frontal zones. At maturity loggerheads begin returning to nesting beaches in Japan, which may take a year to reach. As they cross the Pacific from east to west they traverse an area known as the "garbage patch" where there is an abundance of marine debris. Mature loggerheads appear to remain in the west Pacific after making this journey. Upwellings and convergence zones are important as pelagic feeding areas and migratory corridors for loggerhead turtles.

Polovina et al. (2000) report on a study that tracked nine juvenile loggerhead turtles during 1997 and 1998 in the central North Pacific using satellite telemetry. The turtles all travelled westward against prevailing currents, along two convergent fronts that were identified by remote sensing data monitoring sea surface temperature (SST), chlorophyll, and geostrophic currents. Six of the turtles were associated with a 17ºC front that had relatively high chlorophyll concentrations and an eastward current. Three other turtles were associated with a 20ºC front that had lower concentrations of chlorophyll but a faster moving eastward current. The results of this study appear to explain why incidental catch rates of loggerheads in the Hawaii-based longline fishery are highest when gear is set on SST fronts of 17ºC and 20ºC. From the seasonal distribution of longline effort relative to these two fronts it appears that the fishing ground lies between these two fronts during the first quarter and well to the south of the 17ºC front, but close to the 20ºC front, in the second quarter. These findings suggest that seasonal or area closures of the longline fishery could be tested to reduce incidental catch of loggerheads.

Polovina et al. (2004) report on forage and migration habitat of loggerhead and olive ridley turtles in the central North Pacific using satellite telemetry. Twenty-six loggerhead and 10 olive ridley turtles that were captured and released from the pelagic longline fishery provided information on position and movement. These data were combined with environmental data from remote sensing to get a description of the turtles' habitat. Loggerheads travelled westward, moved seasonally north and south between 28º and 40º N latitude, and stayed in waters with SSTs of 15–25ºC. They were found in association with temperature and chlorophyll fronts, eddies associated with sea surface height (SSH) anomalies, and geostrophic currents (Figure 16). The Transition Zone Chlorophyll Front (TZCF) and the southern edge of the Kuroshio Extension Current (KEC) appear to be important forage and migration habitats. In fact, one loggerhead spent three months along the edge of a meander and eddy at 170ºE longitude which represents a surface convergence zone with likely high concentrations of prey for the turtles.

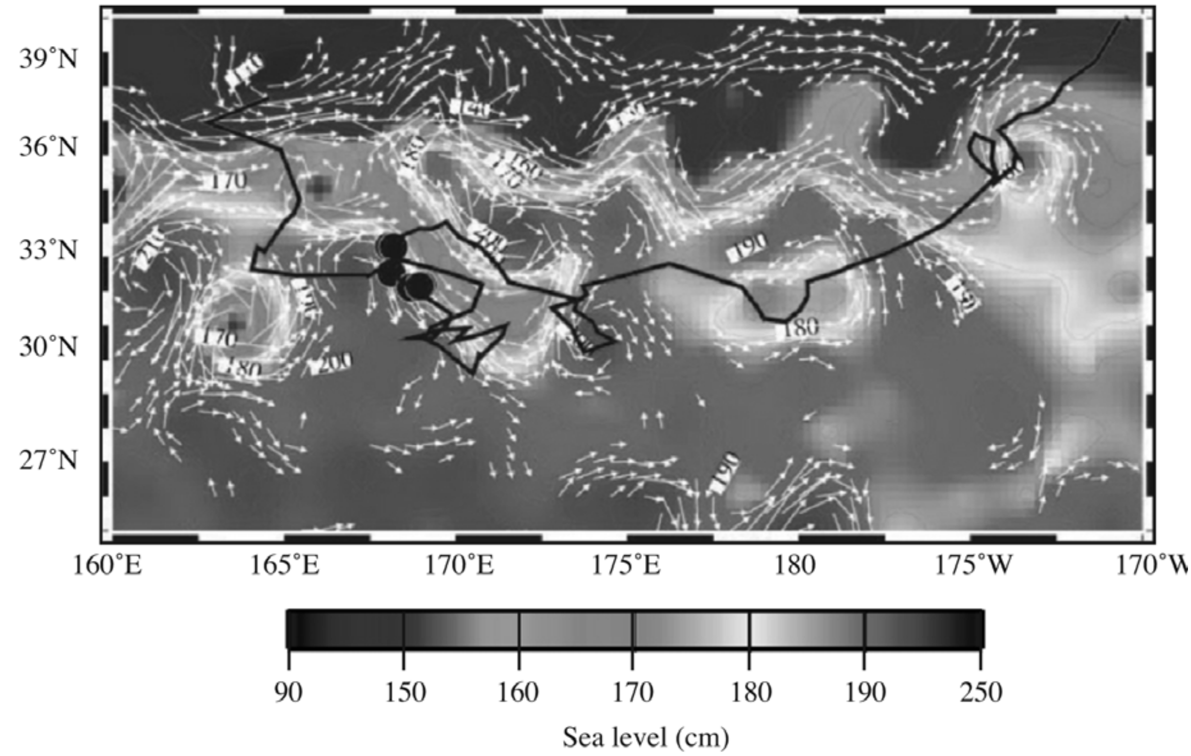


Figure 16: Geostrophic currents and SSH along with loggerhead track line — black line, and positions — black dots (Polovina et al. 2004). The dots indicating turtle positions at about 33º N and 170º W, that lie right along the edge of a meander and eddy. This is the area where the turtle spent the most time. The Kuroshio Extension Current (KEC) can be seen as the strong eastward flow at 35ºN.

By contrast, the olive ridleys were found south of the loggerhead habitat between 8º and 28º N latitude in SSTs of 23ºC to 28ºC (Polovina et al. 2004). Loggerheads and olive ridleys occupy habitats with different physical and biological characteristics (Figure 17). Loggerheads occupy the northern edge of the Subtropical Gyre and the Transition Zone, where there is a shallow thermocline, strong SST and chlorophyll gradients, and surface current convergences. Olive ridleys inhabit two different oceanic regions. Most stayed in the centre of the Subtropical Gyre where there is a deeper thermocline and strong SST and chlorophyll gradients. Other olive ridleys followed major ocean currents. One travelled along the edge of the KEC while two travelled in the equatorial region south of the Subtropical Gyre using the North Equatorial Current (NEC) and the Equatorial Counter Current (ECC). The equatorial region, in addition to being characterised by these strong geostrophic currents, is associated with wind induced upwellings and a shoaling of the thermocline, both of which may provide shallow foraging grounds for the olive ridleys. The turtles can also use the east and west currents to travel back and forth. In conclusion, Polovina et al. (2004) states that the findings that the TZCF, the southern edge of the KEC, the NEC, and the EEC represent important habitat for loggerheads and olive ridleys suggest that reducing longline fishing effort in those areas will also reduce the incidental take of those turtles.

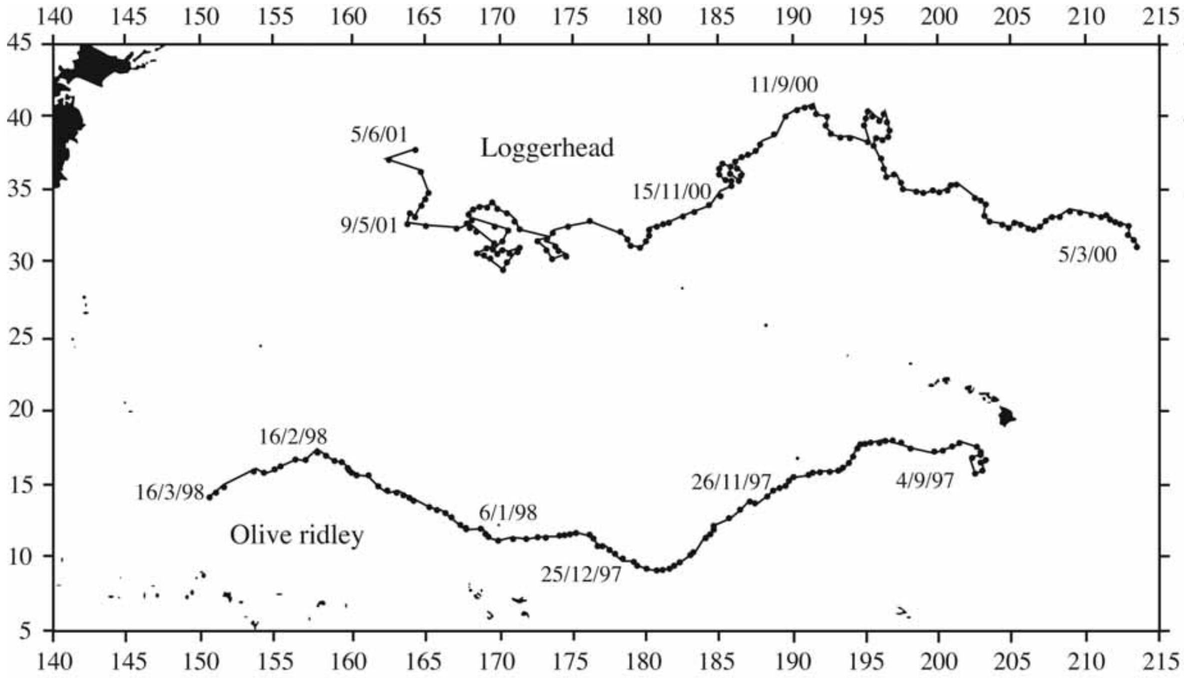


Figure 17: Track lines for loggerhead and olive ridley turtles that travelled the greatest distance (Polovina et al. 2004). The Hawaiian Islands can be seen near the start of the olive ridley track.

Ferraroli et al. (2004) report on leatherback turtle movements in the Atlantic. Apparently there are no equivalent narrow migrations corridors for Atlantic leatherbacks as there are for Pacific leatherbacks. However, there are a few hotspots in the Atlantic. Argos satellite transmitters were deployed on 29 leatherbacks from nesting sites in French Guiana and three from Surinam. Migration trajectories indicate that, unlike in the Pacific, leatherbacks are widely dispersed in the North Atlantic. They follow two main patterns: some go north following the Gulf Stream, while others go east and stay in the tropics. Some of the turtles that followed the Gulf Stream crossed it and eventually veered to the east into the plankton rich transition zone between the Sub-tropic and Sub-polar Gyres. Then their movements became closely related to oceanic fronts. The turtles following the oceanic fronts slowed down as they were foraging for their main prey, gelatinous plankton. This is also where pelagic longline boats aggregate.

Hays et al. (2004) report on Pan-Atlantic leatherback movements that were monitored by the use of long-term satellite telemetry. Initial findings were that turtles ranged throughout the Atlantic, so closing limited areas to longline fishing would probably have only partial success. Two turtles that were tracked from the Caribbean in 2002 traversed the Atlantic moving eastward. Other turtles tracked from the Caribbean in 2003 travelled northwest toward Cape Cod in America. Five travelled northeast and reached the area between the Azores and United Kingdom. Six entered the Northeast Distant area (where the NMFS circle hook experiments took place — Watson et al. 2005) and travelled extensively within the area. The reasons for these broad individual differences in travel are unknown. It was concluded that wide ranging movements of leatherback turtles means that future conservation measures need to operate across the Atlantic basin to be successful; and that Pan-oceanic movements along with shallow diving (see below) are doubly disadvantageous in that they both increase the chance of interactions with longline fishing gear.

James et al. (2005) report on a study that equipped 38 leatherback turtles with satellite tags at sea off Nova Scotia, Canada during the summers of 1999–2003. Observations were collected for 8288 tracking days. Eleven turtles were tracked for longer than one year. The animals tagged came from various southerly nesting sights. The turtles concentrated their movements in waters off eastern Canada and northeastern United States, spending up to four months in northern waters before heading south to South America, the Antilles, Panama, and Costa Rica. Twelve tags transmitted long enough to show a return to the northwest Atlantic, north of 38º in the summer of the following year after being tagged. These were the first tags to confirm annual round-trip migration in leatherbacks. The turtles did not follow set migration patterns along narrow corridors. More importantly, however, the tagging study showed that leatherbacks spend a good deal of time, up to four months, in high-use shelf and slope waters where they are vulnerable to interactions with fixed fishing gear (gear that is anchored to the bottom) before heading south. The study collected 83 records of leatherbacks interacting with fixed gear in shelf waters off eastern Canada between 1997 and 2003. Of these, 95 per cent were entanglements with floatlines resulting in 18 per cent mortality. The report suggested that, for leatherbacks, entanglement in pelagic longline gear does not necessarily lead to mortality. In fact, observer data reveals that very few leatherbacks are discovered dead on pelagic longlines. In contrast, fishing gear anchored to the bottom in shelf waters may lead to higher mortality per interaction because entangled turtles at depth or at the surface during low tide will almost certainly drown. Fixed fishing gear receives very little observer coverage so the magnitude of the problem is not well known.

Baéz et al. (2006) report that Spanish longline fishermen (interviewed in a study) noted that it is almost impossible to solve the problem of incidental capture of sea turtles in surface longline fisheries in the Mediterranean because captures take place in the summer when bluefin tuna and swordfish enter the Mediterranean from the Atlantic to spawn. Turtles, which are more abundant in the region at this time, have similar distribution and migratory routes to bluefin and swordfish.

Work and Balazs (2002) report on necropsy findings on eleven dead sea turtles that were taken as bycatch in the North Pacific longline fishery. Necropsies were performed on seven olive ridley, two green, and two leatherback turtles. Sanma bait (*Cololabis sairi*, a commonly used longline bait) was found in the oesophagi of four olive ridley turtles. One turtle contained three fish, indicating ingestion from more than one hook. Other items included cowfish, pyrosomas (tunicates), pelagic snails, bird feathers, and bits of plastic. The leatherbacks and one green turtle contained pyrosomas exclusively.

Parker et al. (2005) report on the diet of 52 loggerhead turtles collected as bycatch in the North Pacific high seas driftnet fishery in the early 1990s. The study revealed that loggerheads may be opportunistic feeders, feeding on items floating at or near the surface. Included in their diet are mesopelagic fish such as lanternfish and hatchetfish. Because these fish were found in low numbers it was suggested that loggerheads ingest only dead or debilitated fish rather than actively hunting and chasing these species.

3.2 Turtle diving behaviour

Eckert et al. (1989) report on diving and foraging behaviour of leatherback turtles in the Caribbean (St. Croix, Virgin Islands). Temperature depth recorders (TDRs) were placed on six gravid leatherbacks and dive behaviour was monitored continuously during inter-nesting for periods from 9 to 11 days. Average dive duration was 9.9 minutes and average dive depth was 61.6 m. One turtle dived twice to depths beyond the scale of the TDRs (>1000 m). Night dives were shallower and more frequent than day dives, suggesting nocturnal foraging.

Sakamoto et al. (1993) report that loggerhead turtles dive fairly shallow during inter-nesting periods off Japan. Two loggerheads were monitored and it was found that virtually all of their dives were shallower than 30 m.

Seminoff et al. (2001) report on diving behaviour of green turtles in the Gulf of California, Mexico. Between 1999 and 2000, TDRs were deployed on nine green turtles. The maximum dive depth was 48.5 m and mean dive duration was greater during night hours.

Swimmer et al. (2002a) report on an olive ridley turtle that was fitted with a Pop-up Satellite Tag (PSAT) after being captured in the Hawaii-based longline fishery. The turtle travelled for 82 days covering 1874 nm. During the day the turtle spent nearly 60 per cent of its time in the top 50 m, and only rarely dove to depths of 250 m. At night the turtle spent 45 per cent of its time between 10 and 100 m. The maximum dive was 544 m.

Polovina et al. (2003, 2004) report on dive depth distribution of loggerhead and olive ridley sea turtles in the central North Pacific Ocean. Two loggerheads and two olive ridleys were fitted with depth recorders and monitored with satellite telemetry. Results showed that 40 per cent of the loggerheads' time was spent at the surface and 90 per cent of their time was spent at depths shallower than 40 m. On only 5 per cent of the days did loggerheads dive deeper than 100 m. Olive ridleys have a different diving pattern than loggerheads. They spent only 20 per cent of their total time at the surface and 40 per cent of their time deeper than 40 m, and they dove deeper than 150 m at least once a day during 25 per cent of their days. The report notes that observer data from the Hawaii longline fishery, with 5 per cent coverage, found that all of the incidental catch of loggerheads occurred on shallow-sets. The depth-frequency distribution for loggerheads provides evidence that the elimination of shallow-sets will substantially reduce the incidental catches of loggerheads. However, when deep-sets are made or retrieved, or when current shears prevent the line from sinking to its expected depth, some hooks on a deep-set will be present in relatively shallow depths and this could result in incidental catches of turtles. The 2004 report noted that beginning in April 2001, shallow sets were prohibited in the Hawaii-based longline fishery. Observer data following this prohibition, with 20 per cent coverage, showed that no loggerheads and only two olive ridleys were caught from April through December 2001.

Hays et al. (2004) report on Pan-Atlantic leatherback turtle movements including diving behaviour. Although leatherbacks dive very deeply on occasion (one dove to 1230 m, which is a record dive for a reptile), they generally restrict their dives to less than 250 m. Normally, more than half of a turtle's time was spent diving to depths below 10 m. Dives were generally within the (mixed) layer and over 99 per cent of all dives were shallower than 250 m, the same depth range targeted by longline fishermen.

Sale et al. (2006) report on long term monitoring of leatherback diving behaviour off the coast of South Africa spanning both the Indian and Atlantic Oceans. Four leatherbacks were monitored for periods ranging from two weeks to 8 months during their post-nesting movements. The turtles traversed 1569 to 18,994 km. Dive data were obtained by satellite telemetry. Most dives were shallower than 200 m and dive durations were 30 to 40 minutes. Night dives were generally longer than day dives. Day dives were generally short but there were cases of day dives reaching over 900 m and lasting 70 minutes or more. Deep and long duration dives ceased after a while for the three turtles that were tracked the longest. This change in behaviour appeared to have been related to water temperature, suggesting that there was an abundance of seasonal prey. (In other words, the turtles possibly found what they were looking for and stopped looking).

3.3 Discussion

Turtle foraging behaviour and longline fisheries follow similar patterns. Turtles forage in the same places that longline fishermen seek out for optimal target species catch. In other words, turtles and man are both looking for the same productive fishing grounds or hotspots when they are on the move. Turtles are found near temperature and chlorophyll fronts and in the same depth strata where longline fishing gear is typically found. The problem of turtle habitat and fishing grounds overlapping increases by an order of magnitude for shallow-set gear because turtles, for the most part, stay in the upper 100 m of the water column where shallow-set gear is deployed. This is undoubtedly compounded by the fact that swordfish gear fishes at night when turtles are feeding. Both shallow-set gear and deep-set gear types are deployed along temperature fronts, eddies produced by Sea Surface Height (SSH) anomalies, along chlorophyll fronts, and near other oceanographic features known to be productive fishing areas. In fact, when looking at a track of turtle movements superimposed over a chart generated from remote sensing data that shows SSHs (Figure 16), one could almost imagine he is looking at a plot of a longline vessel's activities. The features on the chart corresponding to where the turtle spent most of its time (black dots) look just like the kind of features that longline fishermen look for on the same kind of remote sensing charts.

SSH charts similar to the one shown in Figure 16 above, along with SST, surface current, and sea colour indicating chlorophyll levels, are all readily available to longline fishermen in near real-time from a variety of Internet sites. Turtles also show up seasonally in some areas at the same time that bait and target species show up, such as in the Mediterranean Sea during swordfish and bluefin tuna seasons, and in the Atlantic and Gulf of Mexico during swordfish seasons. To exacerbate the situation even further, turtles often feed on small dead fish, similar to the kind of small dead fish that longline fishermen use for bait. Just based on what is known about turtle migrating, foraging, and diving behaviour, it is no wonder that there are interactions between turtles and longline fishing gear. Parker et al. (2005) suggest that one possible way to decrease fisheries interactions with (loggerhead) turtles might be to identify specific foraging areas for protection, such as around Baja, California (Mexico) and in the central North Pacific west of the Emperor Seamounts. Reduction of fishing effort or other fishery mitigation techniques in these areas may greatly decrease the number of fisheries interactions with turtles.

4. Developing and modifying fishing gear, bait, and setting characteristics to mitigate sea turtle interactions

Oravetz (1999), in a report on reducing incidental catch in fisheries, was almost prophetic when he discussed pelagic longlines and possible bycatch mitigation measures, "*Research on gear types can also be undertaken to reduce potential interactions with sea turtles. Alternate gear placement, bait, and hook types and materials can be developed to reduce interaction with turtles*"

4.1 General

The majority of the experimental gear work to mitigate turtle bycatch has been fishery dependent. That is to say, experiments carried out on fishing vessels actually involved in the fishery. A smaller percentage of experiments have been done in laboratories using captive turtles. This type of testing is called fishery independent. Aside from that, fishing gear solutions to turtle interactions on pelagic longline gear fall roughly into three broad categories: changing hook designs to decrease catch rates and post-capture injury, changing or altering the bait or gear to make them either less attractive to turtles or to make hooking or entanglements less likely, and changing setting characteristics to avoid turtles altogether. Of the three, changing hook designs has shown the most promise so far. Changing to 18/0 circle hooks has proved to be so successful at mitigating turtle bycatch and enhancing target species catch that two formerly closed fisheries have been re-opened. Changing bait from squid to mackerel has also had some success, especially at enhancing target species catch. The use of artificial bait needs more testing. Dyeing bait blue and camouflaging all of the fishing gear by dyeing it blue-grey have not been very successful but still need more testing. Devices that avoid deep hooking and entanglements have been developed but need more testing. And while the first attempt at targeting swordfish deep during the day to avoid turtle bycatch was not very productive, new techniques that land all of the hooks out of reach of turtles show some promise, at least for catching tuna and avoiding fishing in the "turtle zone". These deep-setting techniques may prove useful in targeting swordfish during the day as well.

Lokkeborg (2004) reviewed existing and potential longline gear modifications to reduce sea turtle mortality for the FAO Expert Consultation on Interactions between Sea Turtles and Fisheries within an Ecosystem Context. The work to develop solutions to reduce sea turtle bycatch in longlines has begun, the report says, and some promising mitigation measures have been identified, tested, and implemented. The report reviews and evaluates these measures and discusses areas where further research is needed. The most comprehensive work on development of bycatch mitigation, according to the author, is the three-year long study done in the Atlantic (Watson et al. 2005). Circle hooks baited with mackerel bait gave a 90 per cent reduction in the bycatch of loggerhead turtles and a 75 per cent reduction in the bycatch of leatherbacks compared to J hooks baited with squid. Alternate types of mitigation measures are discussed including blue-dyed bait, stealth gear, deep-set versus shallow-set gear, and deep day sets for swordfish, among others. The review recommended that bycatch reduction techniques that have shown promise should be tested and evaluated by nations having longline fisheries where sea turtles are incidentally caught.

NOAA (2005b) summarizes international activities related to reduction of bycatch of sea turtles in longline fisheries developed or fostered by one of the several NMFS offices. The living document, which can be found on NOAA's website, is divided into six sections: technology transfer, gear experiments (field), possible future gear experiments, gear experiments (laboratory), bi- and multi-lateral efforts, and non US activities. Most of the gear experiments listed deal with the efficacy of circle hooks.

Gilman et al. (2006) provide a good review of strategies for reducing sea turtle bycatch in pelagic longline fisheries including: regulatory controls on fishing effort, seasonal bycatch levels, fishing areas, and fishing seasons; changes in fishing gear and methods; voluntary industry fleet communication programmes to avoid bycatch hotspots; and handling and release practices to increase the survival prospects of captured turtles. The paper discusses all practices but concentrates on reviewing results of research involving changes in fishing gear and methods. Strategies to reduce turtle bycatch must be effective as well as economically viable. Many results to date from experiments have not been peer reviewed, have small sample sizes, have been conducted over only a few seasons in a small number of fisheries, and do not consider effects on other bycatch species. Many studies preclude drawing conclusions about the independent effect of single factors on turtle bycatch and target species catch rates (was it the bait, the hook, the depth, or the time of day?). It is a priority to conduct trials in longline fleets that set gear shallow, that overlap threatened turtle populations, and that overlap high densities of turtles such as those in breeding colonies. In addition, because there is no current standard protocol for measuring sizes and categorizing shapes of longline hooks, this should be a priority.

The following section will discuss some of the trials that have been conducted to date on all these methods. Different hook designs will also be discussed, because hooks so far have been the single most important parameter in turtle bycatch mitigation.

4.2 Hookology

A fish hook is a seemingly simple thing but it does have discernable parts. Mustad (undated) describes a typical hook as having an eye, shank, bend, bite/throat, a point and barb, and a gape (sometimes called gap). Four different dimensions are given in the illustration (Figure 18): total length, front length, gape, and bite/throat. Mustad (undated) states that the most important of these are the size of the gape and the size of the bite/throat. Nothing, however, in the Mustad hook size numbering system readily appears to correspond to these dimensions. In fact, they say that there is no uniform system of hook measurements. Mustad hooks, as well as most hooks manufactured in Europe or America, come in a range of sizes from 22 (the smallest) to 20/0 (the largest). Small hooks are numbered in a descending order so a #21 is bigger than a #22, and a #20 is bigger than a #21, and so on right up to a #1 which is the biggest small hook. Large hooks are numbered in an ascending order starting with the smallest, 1/0, and going to the largest, 20/0. Not every hook style is available in the full range of sizes from 22 to 20/0. Furthermore, there is little consistency in methods for applying this ranking system in the profusion of fishing gear catalogues. A 10/0 hook made by one company may not correspond in actual size to a 10/0 hook made by another. Generally, the 22 to 20/0 system is just a ranking system and has little to do with actual hook dimensions. There are exceptions to this, however (see discussion below on circle hooks).

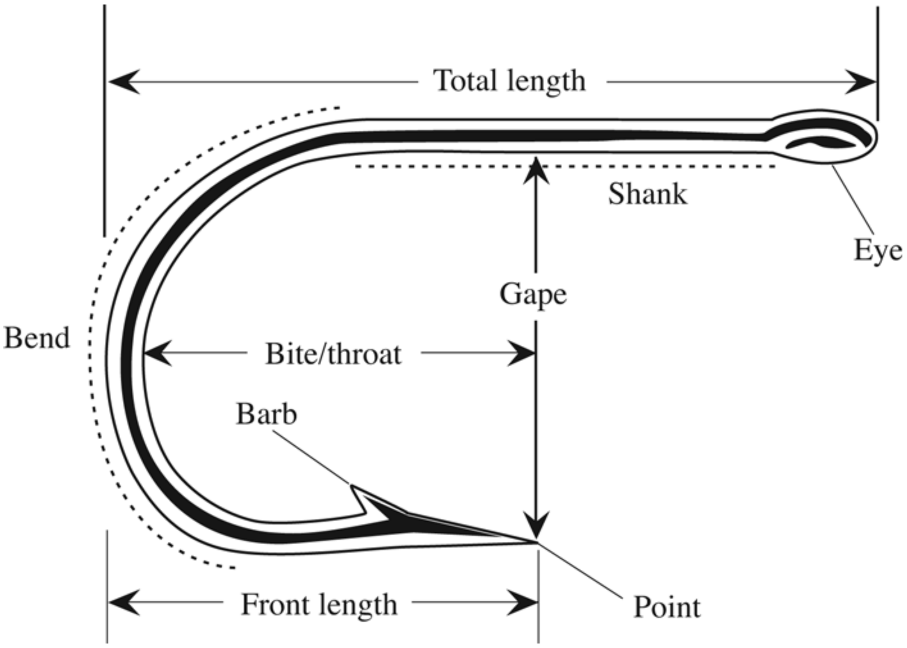


Figure 18: Hook anatomy adapted from Mustad (undated)

Basically there are three kinds of hooks used in pelagic longline fishing: Japan tuna hooks, circle hooks, and J hooks (Beverly et al. 2003). Japan tuna hooks (Figure 19) have been the most popular for years, especially with tuna longliners. They come in a variety of sizes but are usually described by a Japanese measurement called "*sun*", which is about 3.3 cm (OFCF 1993) and is used to measure the length of the hook. A 3.4 *sun* hook, for example, is 3.4 *sun* x 3.3 cm/*sun* long. In other words, a 3.4 *sun* hook is 11.2 cm long. This is the entire length of the wire making up the hook from the eye to the tip of the point (not to be confused with total length in Figure 18). However, this measurement says nothing about the shape of the hook or the size of the bite/throat or gape. The most popular sizes of Japan tuna hooks for longlining are 3.4, 3.6, and 3.8 *sun*. Japan tuna hooks come either with a ring or without a ring in the eye. The most popular hook for tuna longlining is a 3.6 *sun* stainless steel Japan tuna hook with ring.

Figure 19: Japan tuna hooks with ring from Hi-fishing Tackle Company website (http://www.hi-fishing.com/tuna_fr.htm). Not to scale.

Circle hooks (Figure 20) are also called G hooks or tuna circle hooks, and are generally measured the same way that Japan tuna hooks are measured. Japanese-made circle hooks used in longline fishing generally come in sizes ranging from 4.2 *sun* to 5.5 *sun*. Again, the number refers to the entire length of wire making up the hook from the eye to the point, just as with the Japan tuna hook. Most Western-made circle hooks are numbered and measured in a similar way. The difference is that the numbers refer to centimetres, not *sun*. Thus an 18/0 circle hook measures 18 cm from the eye to the tip of the point. This is equal to a 5.5 *sun* Japanese made circle hook (conversely, a 3.4 *sun* Japan tuna hook would be an 11/0 in the Western system). Some manufacturers, however, use a completely different numbering system for circle hooks. Tankichi and Maruto brand hooks, for example, are numbered from 28 to 44 (POP 2004). Table 2 compares Western to Japanese circle hook sizes. Circle hooks are commonly used for fisheries other than pelagic longline such as deep water snapper fishing. They are popular because of their rotating effect which makes them self setting. In fact, circle hooks are also called rotating hooks. When a fish bites and applies pressure, the circle hook rotates and sets itself. Sizes for circle hooks generally range from 8/0 to 16/0 but lately larger sizes such as 18/0 and even 20/0 have been available. The most popular sizes for longline fishing range from 14/0 to 18/0. Circle hooks do not usually come with rings. A good discussion of circle hooks can be found in ASMFC (2003).

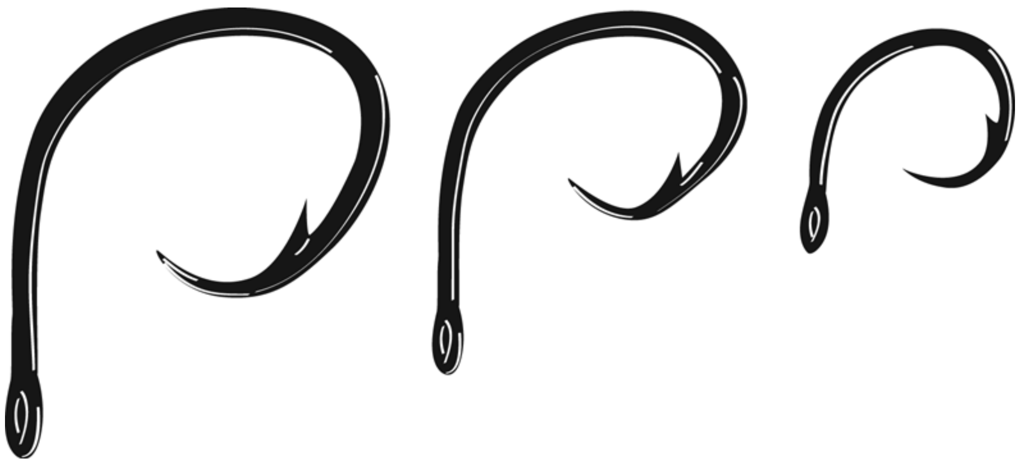


Figure 20: Circle hooks adapted from Mustad (undated), not to scale

Table 2: Comparison of Western circle hook sizes to Japanese circle hook sizes.

Western circle hook (cm)	Japanese circle hook (*sun*)	Tankichi and Maruto circle hook
12/0	3.6	28
14/0	4.2	36
16/0	4.8	44
18/0	5.5	na

J hooks (Figure 21) are very similar to big game trolling hooks used to catch marlin and other big game species. They come in sizes ranging from 1/0 to 12/0, and are usually associated with longline fishing for swordfish. The most common sizes of J hooks used for swordfish are 8/0 and 9/0. A 9/0 J hook measures 15 cm from the eye to the point so it is not easy to compare numbers for J hooks with the other hook designs. A 9/0 J hook, in fact, is similar in size to a 16/0 circle hook. Swordfish fishermen prefer J hooks because swordfish have a soft lower jaw that can be easily torn, in which case the fish is lost. J hooks tend to hold better than other hooks in a swordfish mouth (Beverly et al. 2003). They also have a better chance of hooking the hard bill of the swordfish because of their straight shape. The main feature of a J hook that makes it different from Japan hooks or circle hooks is that the barbed point is almost parallel to the shank of the hook. With Japan tuna hooks the shank is bent towards the tip of the hook while circle hooks have a point that is bent until it almost points directly at the shank at a 90º angle. What this means is, of the three hook designs, the J hook has the largest gape. This could be one of the reasons that J hooks are implicated in higher turtle bycatch rates than the other hook designs.

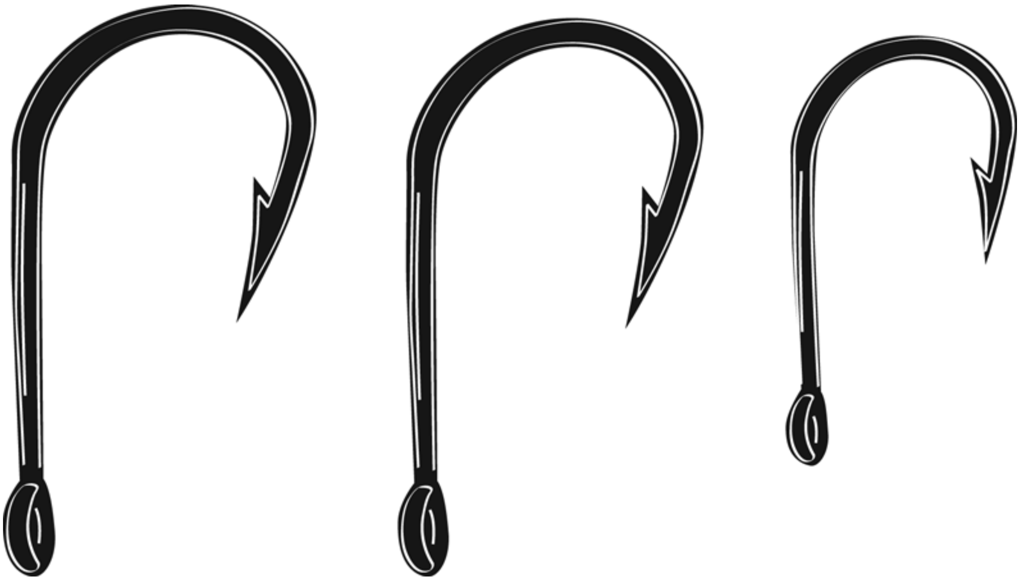


Figure 21: J hooks adapted from Mustad (undated), not to scale

Notwithstanding all that has been said about hook parts and dimensions, the most important hook dimension in regards to turtle bycatch is probably none of the above. NOAA Fisheries (Watson et al. 2003b) have determined, in a study using captive loggerheads, that the overall (narrowest) width of the hook is the most important measurement because that determines whether or not a turtle can swallow the baited hook. The study concluded that using hooks larger than 51 mm in width has the potential to significantly reduce post-capture mortality of loggerheads incidentally captured on longlines. A 16/0 circle hook, for example, has a width of 51 mm while a 9/0 J hook (which is similar in size to 16/0 circle hook) has a width of only 41 mm. Just based on this one reference point the 16/0 circle hook would be preferable to the 9/0 J hook for reducing post-capture mortality.

Another confounding factor with hooks is the fact that they can be either off-set or non-offset (Figure 22). With non-offset, or straight hooks, the point lies in the same plane as the shank of the hook. With offset hooks the point is bent away from the plane of the shank by anywhere from 5–25º. If the point is offset to the left the hook is kirbed. If the point is offset to the right the hook is reversed (Figure 22). Japan tuna hooks, for example, typically have a 10–20º (kirbed) offset. Circle hooks and J hooks, however, can be either offset or non-offset. Both offset and non-offset hooks have been tested in regards to turtle bycatch rates in pelagic longline fishing, and some issues have been raised. There are implications for acceptability by fishermen. For example, fishermen found it difficult to thread bait on non-offset circle hooks in one study (Watson, et al 2005). There are also possible implications on the effects on target species and bycatch species catch rates, and on post-capture injury and mortality rates of turtles. Another complication is that before about 1995, longline hooks were available only in galvanised high carbon steel. Now they are available in stainless steel as well. This means that they last longer, especially when coming into contact during storage with other fishing gear such as the stainless steel snaps used on the branchlines (with two similar metals there is no galvanic reaction and, thus, less corrosion); but this also has implications for bycatch post-capture mortality. Stainless steel may last longer than galvanised steel in a turtle's mouth or oesophagus. In fact, stainless steel hooks are not allowed in the re-opened US Atlantic swordfish fishery (Federal Register 2004b).

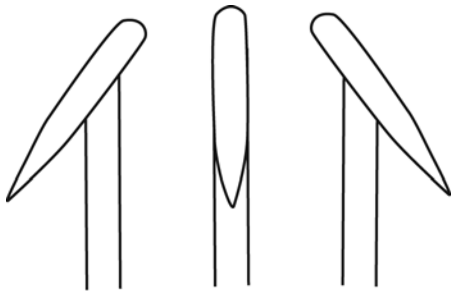


Figure 22: Offset (kirbed and reversed) and non-offset hook points, from In-Fisherman website (http://www.in-fisherman.com/magazine/exclusives/IFM0502_AboutHooks/).

There are management issues in regards to wholesale changing of hooks in a fishery. Longline fishermen who are use to the fishing performance of one type of hook need to be convinced that their catch rates for target species will not be negatively affected by switching to another style of hook. Another consideration is expense. Hooks are an expendable item in the sense that they are replaced regularly as they are lost, for example to shark bite, and this is usually budgeted into the operational expenses of a fishing trip and is not substantial. However, replacement of 2000–3000 hooks as a single event would most likely be beyond the operational budget of most longliners. An important bycatch mitigation project was conducted in Ecuador by a coalition consisting of NGOs, government fisheries offices, and fisheries management organisations (Largacha et al. 2005). They got around the concerns of fishermen by exchanging circle hooks for the fishermen's J hooks. Over 15,000 circle hooks were freely exchanged for J hooks on 115 participating vessels in the Ecuadorian artisanal longline fishery (results of this experiment are discussed in Section 6).

4.3 Hook, bait, and gear modification experiments

Experiments with gear modifications to existing longline gear, including the types of hooks and bait used, have been conducted in many locations around the Pacific and Atlantic Oceans. This section summarises these experiments by modification, and highlights the outcomes of these experiments.

4.3.1 Hook and bait type experiments

Skomal et al. (2002) report on a study of recreational catch of bluefin tuna in the Atlantic. The study found that 94 per cent of the bluefin tuna caught on circle hooks were hooked in the jaw and only 4 per cent were hooked in the pharynx or oesophagus (n=51), compared to 52 per cent jaw hooked and 34 per cent oesophagus or pharynx hooked with J hooks (n=50). The estimated mortality for J hooks was seven times greater than for circle hooks. It was concluded that circle hooks cause less damage than J hooks and can be a valuable conservation tool in recreational (tag and release) fisheries.

Watson et al. (2003a; 2004a) report on experiments conducted in 2001, 2002 and 2003 in the western Atlantic Northeast Distant (NED or Area 7 in Figure 15) waters to evaluate sea turtle mitigation measures in the pelagic longline fishery. It was found that 18/0 circle hooks and mackerel bait reduced both loggerhead and leatherback turtle interactions significantly in comparison to J hooks with squid bait. Circle hooks also reduced the rate of hook ingestion by loggerheads, reducing post-capture mortality. The combination of 18/0 circle hooks with mackerel bait was found to be the most efficient mitigation measure for both loggerheads and leatherbacks. Research also found that 20/0 circle hooks were effective in reducing loggerhead and leatherback interactions. Experiments conducted in the western North Atlantic Ocean and reported by Watson et al. (2005) and NOAA (2005e) found that circle hooks baited with mackerel significantly reduced both loggerhead and leatherback bycatch. Circle hooks also reduced the rate of hook ingestion by loggerheads, potentially reducing post-capture mortality.

From July to October 2002, thirteen commercial longline vessels made 489 research sets in the western North Atlantic, fishing a total of 427,382 hooks: approximately 142,000 for control (J hooks with squid bait) and 71,000 for each treatment (Watson et al. 2005). Four experimental hook and bait combinations were tested: 0º offset 18/0 circle hook with squid bait, 10º offset 18/0 circle hook with squid bait, 20-25º offset 9/0 J hook with mackerel bait, and 10º offset 18/0 circle hook with mackerel bait. The offset circle hooks were used because it was difficult to thread mackerel bait on a 0º offset circle hook. The target species, swordfish and bigeye tuna, along with blue shark, were the species most caught (Watson et al. 2005). In addition, 96 loggerheads and 148 leatherbacks were captured and released alive. The highest reduction rates for loggerhead interactions were achieved with 18/0 circle hooks with mackerel bait. Circle hooks with mackerel bait reduced loggerhead catch by 90 per cent, while circle hooks with squid bait reduced loggerhead catch by 86 per cent. J hooks with mackerel bait reduced loggerhead catch by 71 per cent.

Circle hooks also resulted in a significant change in hooking location. The majority of loggerheads (68.8 per cent) caught on J hooks swallowed the hook while only 27.3 per cent of the loggerheads caught on circle hooks swallowed the hook — most were hooked in the mouth were it is easier to remove the hook. The largest reduction in leatherback interaction was achieved with mackerel bait (Watson et al. 2005). The J hooks with mackerel bait reduced leatherback catch by 66 per cent and circle hooks with mackerel bait reduced leatherback catch by 65 per cent. Circle hooks with squid bait reduced leatherback catch by 57 per cent. The leatherback catch rate on the control hooks was 2.0 to 2.9 times that of the experimental hooks. Leatherbacks were most often hooked externally or entangled in the lines; often they were both hooked and entangled. They were most often hooked in the shoulder, armpit, or front flipper.

Watson et al. (2005) concluded that employing 18/0 circle hooks or by using mackerel bait can significantly reduce sea turtle interactions. When the two are used together the reduction in turtle interactions is 90 per cent for loggerheads and 65 per cent for leatherbacks and this is without impacting swordfish catch. This approach used in conjunction with tools and techniques developed to remove hooks and line from turtles, significantly reduced the capture rate of turtles and potentially reduced post-capture mortality while not negatively impacting the target species catch rate.

Garrison (2003a) summarised target species and turtle catch rates by hook and bait type in the pelagic longline fishery in the Gulf of Mexico for 1992–2002. The study was carried out to determine if results from the circle hook experiments in the northeast distant fishery (Watson et al. 2003a) could be extrapolated to the entire fishery. Data from a total of 4209 pelagic longline sets were examined. Hooks used were 16/0 circle hooks or 7/0 or 8/0 J hooks. Sets using J hooks primarily used squid bait while sets using circle hooks used fish bait, mostly sardines. Sets using J hooks had higher average catch rates of marine turtles, swordfish, bigeye tuna, and bluefin tuna while sets using circle hooks had higher average catch rates of yellowfin and other tuna species. The report concluded that, in general, the observed patterns in the Gulf of Mexico were consistent with those in the Atlantic experiments, and that the results from the Atlantic experiments and the Gulf of Mexico analysis support the argument that the increased catch rates of turtles is related to the increase in the use of J hooks and squid bait in the Gulf of Mexico fishery.

Bolten and Bjorndal (2002) report on the evaluation of the effects of hook type on sea turtle bycatch in the swordfish fishery in the Azores. A total of 93 sets were made in 2000 during the swordfish season (July to December) from a 25 m commercial longline vessel. All hooks were baited with squid. The experiments used three hook types: non-offset J, offset J, and circle hooks. The three types of hooks were alternated all along the line (A,B,C,A,B,C…) so their position varied. 237 turtles were captured, with the number of turtles caught by each hook type being similar, but the location of the hook was not — 57 per cent of the loggerheads caught on J hooks were hooked in the throat while 81 per cent of the loggerheads caught on circle hooks were hooked in the mouth. The report concluded that circle hooks significantly reduced throat hooking in loggerheads and this has important implications for reduced turtle mortality.

Bolten and Bjorndal (2003) report on Phase 2 of the experiment to evaluate gear modification on rates of sea turtle bycatch in the swordfish longline fishery in the Azores. A total of 60 sets were made from a 25 m commercial swordfish longline vessel between 2 September and 6 December 2001. The same three hook types were used: non-offset J hooks, offset J hooks, and circle hooks, with the same alternating pattern of hooks along the line and squid bait used exclusively. A total of 45 turtles were captured. There was no significant difference among the three hook types in the number of sea turtles caught. Sixty per cent of the loggerheads caught on J hooks were caught in the throat while only nine per cent of the loggerheads caught on circle hooks were caught in the throat. Conclusions from Phase 2 were basically the same as from the previous study (Bolten and Bjorndal 2002).

Bolten and Bjorndal (2004) report on Phase 3 of the experiment in the Azores. Forty-eight sets were made from a 25 m commercial longline vessel between 25 September and 15 December 2002. This was a continuation of the project reported in Bolten and Bjorndal (2002 and 2003), however, different hooks were trialled. The three hook types used were 16/0 circle hooks, 16/0 circle hooks with offset, and 18/0 circle hooks with offset. Hooks were set alternately along the set (A,B,C,A,B,C…). The bait for all sets was squid. There were no significant differences among the three hook types in the number of sea turtles caught. However, there was a significant difference in the number of blue sharks (*Prionace glauca*) caught on the three hook types. Conclusions were that the use of circle hooks significantly reduced the rate of throat hooking in loggerheads, and the increase in blue shark bycatch with circle hooks needs further investigation.

Nakano (2004) reports on mitigation experiments being conducted in Japan. The Fisheries Research Agency in collaboration with Hokkaido University are conducting experiments using circle hooks in the hopes of reducing incidental interactions with turtles and longline gear. In some experiments, bycatch rates using circle hooks compared to bycatch rates with conventional Japan tuna hooks did not decline; but the circle hooks were effective in reducing the proportion of throat-hooked turtles, thus improving their chance of post-capture survival.

4.3.2 Circle hook modification

Most of the current experiments on hooks are based on a comparison of circle hooks, Japan tuna hooks and J hooks used in swordfish fisheries, the catch rates of sea turtles and the position of hooking. An alternative approach is being taken in work undertaken and supported by the Inter-American Tropical Tuna Commission (IATTC) in projects underway in Ecuador and Peru (Martin Hall personal comments). In these experiments, a short stiff piece of wire is attached near the eye of the circle hook (Figure 23), pointing down at an angle of 45 degrees to the shank of the hook. The idea of this is to reduce the chance that the hook will be swallowed by a sea turtle, and therefore increase post-hooking survival. The idea was taken from Barnes et al. (2004), who used this approach in the snapper fishery in New Zealand to try to reduce the gut-hooking of snapper. The experiments off Ecuador and Peru are in the early stages, with some promising results coming from the coastal mahi mahi fishery.

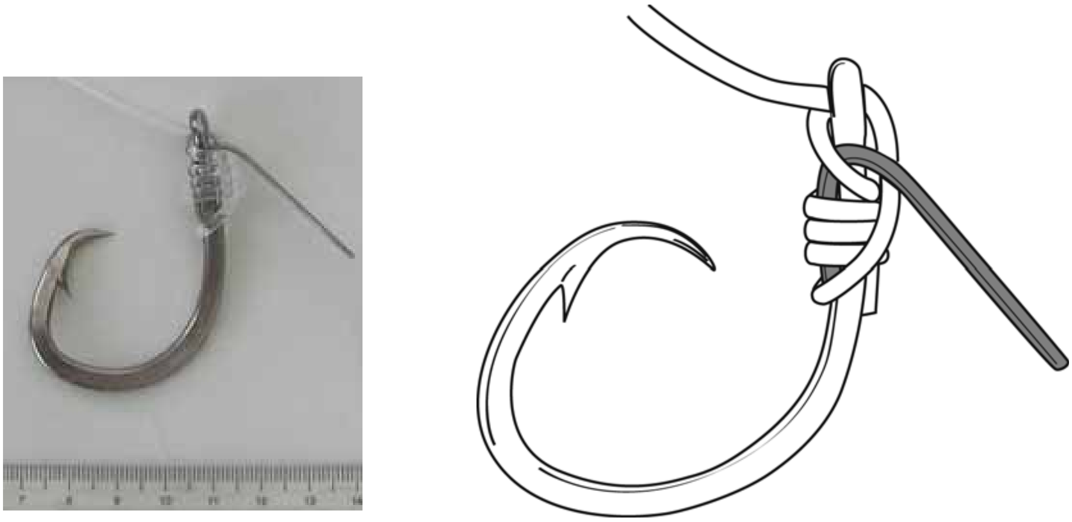


Figure 23: Circle hook with wire attached near the eye (photo provided by Martin Hall, IATTC)

4.3.3 Dyed and artificial bait experiments

Swimmer and Brill (2001) report on fishery independent experiments to identify a method to repel marine turtles from longline fishing gear, even though sensory mechanisms that attract turtles to longline gear were unknown at the time of the study. Captive sub-adult green turtles were presented with both treated and untreated food on a simulated longline. In other words, bait on hooks was lowered into the water in a tank so turtles would have a choice of baits. The first treated bait to be tested was blue dyed squid. Blue squid was initially rejected by all turtles. For turtles that had just been fed untreated squid prior to being offered blue dyed squid, however, blue dyed squid was not rejected. Squid was also marinated in a variety of chemical compositions to determine the importance of olfaction (smell) in the bite/no bite decision made by the turtles. Squid was soaked in garlic, citric acid, lactic acid, capsicum, wasabi oil, etc. Turtles were willing to eat squid soaked in all of these substances. In order to isolate the effects of vision from olfaction, artificial baits were also being developed. Fish and squid-based baits were hardened using gelatine and algenic acid, and were dyed and given the same shape. The only difference was the taste. The conclusion was that turtles use a combination of vision and olfaction in making the decision to bite something or not.

Watson et al. (2002) report on experiments conducted in 2001 in the western Atlantic Northeast Distant (NED or Area 7 in Figure 15) waters to evaluate sea turtle mitigation measures in the pelagic longline fishery. Eight vessels made 186 sets, with a total of 164,429 hooks set. There were no statistically significant differences between loggerhead catch rates on blue dyed bait and natural bait. Blue dyed bait experiments were subsequently terminated.

Nakano (2004) reports on experiments being conducted in Japan, where a comparison was made between squid and mackerel baits, and a comparison was made between blue-dyed and normal mackerel. There was no difference between the blue-dyed and normal mackerel baits.

Piovano et al. (2004) report on investigations into the importance of olfactory (smell) stimulation in bycatch of loggerhead turtles in the Italian swordfish fishery in the Mediterranean. Tests were carried out on 27 captive turtles (that had accidentally been caught in the fishery) using squid shaped plastic lures with and without scomber (*Scomber scombrus*) fish odour. Scomber is the main bait used in the fishery. One concern was to find an artificial lure type that would be suitable for reducing turtle bycatch but would not negatively affect the fishery. Behaviours of the turtles were grouped into four categories: acknowledging the lure, attraction to the lure, identification of the lure as prey, and, finally, biting the lure. Scomber odour nearly tripled the biting behaviour on lures. The results clearly showed that scomber smell was important for selecting between lures. Odourless lures, therefore, may have some promise as a bycatch mitigation technique if they can be shown to be effective in catching swordfish.

Swimmer et al. (2005) report on experiments conducted in Costa Rica using whole squid dyed different colours to investigate bait modifications that could reduce the interaction of turtles with longline fishing gear. In captivity, both Kemp's ridley and loggerhead turtles preferred untreated squid over squid that had been dyed dark blue. Loggerheads also preferred untreated squid over squid dyed red. Kemp's ridley turtles showed the opposite response. Field trials using blue dyed squid were conducted on commercial boats in the Gulf of Papagayo where the incidental catch of olive ridley turtles is high. There were no differences in rates of turtle interactions (8.4 and 8.1 turtles per 1000 hooks) when using untreated and blue dyed baits. It was concluded that dyeing bait blue seems to work in a laboratory setting but does not appear to have potential as an effective mitigation measure to reduce turtle bycatch in longline fisheries.

4.3.4 Soak time

During experiments conducted in 2001 in the western Atlantic (Watson et al. 2002), it was found that for loggerheads there was a 200 per cent increase in catch between the first and second half of the haul — the longer the soak, the more chance of catching a turtle. Further experiments conducted in the same area in 2002 (Watson et al. 2003a) indicated that a significant reduction in loggerhead catch may be achieved by reducing daylight soak time.

In the Azores, Bolten and Bjorndal (2002) concluded from their experiments in 2000 that the rate of turtles caught increased with line retrievals later in the day, while the rate of fish caught stayed the same, and that sea turtle bycatch can be reduced by hauling earlier in the day. A continuation of experiments in the Azores in 2001 (Bolten and Bjorndal 2003) resulted in the same conclusions. Bolton and Bjorndal (2004) continued with their experiments in 2002, using a similar approach, although only circle hooks of different sizes were used. Again, the conclusion was that retrieval of the line earlier in the day and reducing soak time would reduce sea turtle bycatch.

4.3.5 Float designs

Hataway and Mitchell (2002) summarize work done in 2001 by NMFS Harvesting Systems Branch in Pascagoula, Louisiana on 180 captive loggerhead sea turtles. The aim of the research was to learn as much as possible about sea turtle behaviour around longline gear in order to lesson interactions. During the experiments, three types of floats were evaluated: orange bullet, white bullet, and orange poly (Figure 24). These are the most predominately used floats in the swordfish fishery. Holding pens were divided into side A and side B and a float was placed in either side by random selection. Turtles were monitored to see if they spent more time on one side or the other. Preliminary results were that turtles spent about twice as much time on the side with the orange bullet float than on the control side. With the white bullet float and the orange poly float there was no difference. In other tests, some turtles were conditioned by being fed under floats. These were tested against non-conditioned turtles. Results showed that conditioned and non-conditioned turtles spent the same amount of time on the side with the float as on the control side. Head to head tests were also done to see if either float type attracted turtles more than another. This was done with conditioned and non-conditioned turtles. Conditioned turtles seemed to prefer the orange float side over the white float side while non-conditioned turtles favoured the white float side over the orange float side. White floats with and without snaps were also evaluated. There didn't seem to be any difference.

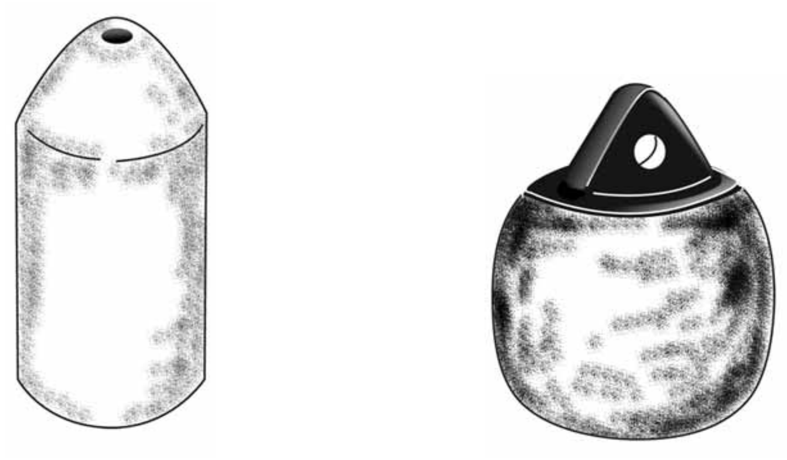


Figure 24: Bullet float and poly float (Beverly et al. 2003).

In conclusion, Hataway and Mitchell (2002) stated the preliminary tests showed the turtles were attracted to orange floats but not white floats. However, in later tests this was not evident. Additional testing is required to determine if other components of the float attract turtles, such as the snap or the floatline. It could be that movement of the floats or the occurrence of bait around the floats attracts turtles. The captive reared turtles had no open ocean experience so possibly did not have a natural attraction to floating objects.

4.3.6 Deep hooking avoidance devices

Deep hooking avoidance devices (Figure 25) were reported on in Hataway and Mitchell (2002), as part of work done in 2001 by NMFS Harvesting Systems Branch in Pascagoula, Louisiana on 180 captive loggerhead sea turtles. The devices consisted of various sized discs, a football shape object, a plastic drink bottle with the bottom cut out, and a plastic funnel. All of these devices were designed to prevent the turtles from swallowing the hook deeply (no hooks were used in the experiments, however). The devices were crimped onto baited mono leaders and offered to the captive sea turtles. Results were that all of the discs prevented the turtles from swallowing the bait. The football shape and the funnel both worked as well. The plastic drink bottle test did not work very well because the bottle poked the turtle in the face and he gave up trying to take the bait. The deep hooking avoidance devices showed great promise in reducing deep hooking, but tests are needed to see if they will still allow for capture of target species.

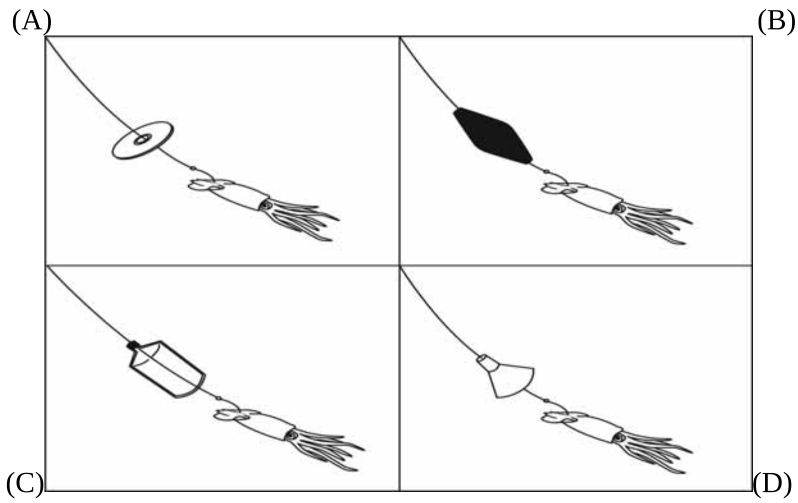


Figure 25: Deep hooking avoidance devices (re-drawn from Hataway and Mitchell 2002). A- disk, B- football shape, C- plastic drink bottle, and D- funnel.

4.3.7 Visibility of different diameter, stiffness and coloured branchlines and mainline

Visibility of different diameter, stiffness and coloured branchlines and mainline were reported on in Hataway and Mitchell (2002), as part of work done in 2001 by NMFS Harvesting Systems Branch in Pascagoula, Louisiana on 180 captive loggerhead sea turtles. It was determined that grey, clear, or dark blue branchlines are the least visible, and that smoke-blue, black, or dark blue mainlines are the least visible. Larger diameter lines were more visible than smaller lines. In another test a simulated longline with several branchlines of different diameters (and stiffness) was positioned in a tank with individual turtles for 30 minute periods. The results showed that encounters with stiffer branchlines resulted in fewer entanglements. Weighted versus non-weighted branchlines were also tested. Results showed that there were fewer entanglements with weighted branchlines. Figure 26 shows a typical encounter between a turtle and a branchline that could result in entanglement or flipper hooking.

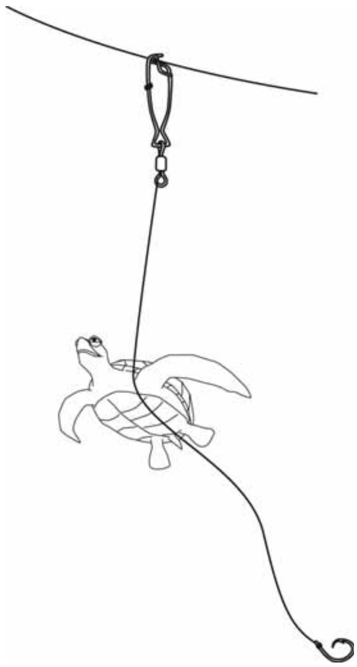


Figure 26: Typical encounter between turtle and branchline (re-drawn from Hataway and Mitchell 2002).

There are many uncertainties about why turtles are attracted to monofilament lines. It has been suggested that they see the lines and then follow them to the baited hooks (Hataway and Mitchell 2002). If this is so then lines that are less visible may be beneficial. The colour of the line may be important. However, leatherback turtles tend to get entangled in lines (by chance encounter) so lines that are more visible may be better for reducing leatherback interactions. Stiffer branchlines are less likely to entangle turtles.

4.3.8 Hook deflectors or guards

Hook deflectors (Figure 27) or guards were reported on in Hataway and Mitchell (2002), as part of work done in 2001 by NMFS Harvesting Systems Branch in Pascagoula, Louisiana on 180 captive loggerhead sea turtles. The deflector consisted of a funnel device attached to the branchline just above the hook, oriented with the funnel mouth facing either towards or away from the hook. Its purpose was to bounce the hook away from a passing turtle and prevent flipper hooking. Funnel deflectors attached to the branchlines reduced the incidence of entanglement and flipper hooking. Funnels with the mouth oriented toward the snap resulted in more deflections. Funnel hook deflectors could also double as deep hooking avoidance devices. Hook guards made from stainless steel leader material were also tested. They worked well for deflecting the hook off the flipper.

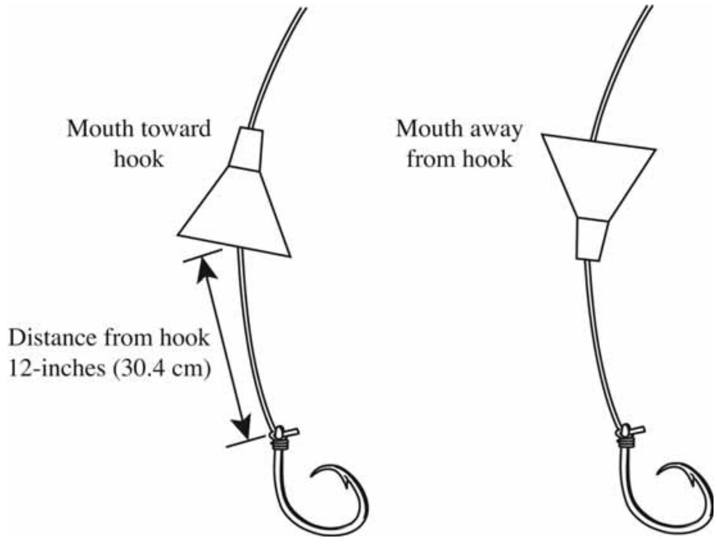


Figure 27: Funnel hook deflectors (re-drawn from Hataway and Mitchell 2002).

4.3.9 Use of decoys

Hataway and Mitchell (2002) summarize work done in 2001 by NMFS Harvesting Systems Branch in Pascagoula, Louisiana on 180 captive loggerhead sea turtles. Some experiments were undertaken using shark models (decoys) to see if sea turtles would avoid them. Initially the decoys worked, but the turtles became acclimated to them after 45 minutes. The exception to this was when a decoy of a great white shark was used. Turtles would turn sideways to expose their full carapace whenever they encountered the great white model. Further investigation needs to be done on predator shapes (shark decoys). A next step would be to experiment with silhouettes constructed from flexible material that could be easily attached and removed from the longline. Lastly, observations indicated that turtles are attracted to shiny objects such as snaps, swivels, and hooks. Further investigation into dark coloured snaps, swivels, and hooks is needed. Flat black snaps are already available commercially.

4.3.10 Stealth (camouflaged) gear

Stealth fishing gear was designed to reduce the visibility of longline gear to sea turtles in the Hawaii-based pelagic longline fishery. Boggs (2002b; 2004a) reports on the results of these experiments that took place between March and May 2002. To economize on control operations and avoid unnecessary turtle takes, the stealth experiments were conducted simultaneously alongside deep day set experiments, as well as one control vessel that fished with regular swordfish gear. Dark blue-grey monofilament was used for the mainline, floatlines, and branchlines on the stealth gear. Battery powered yellow light emitting diode (LED) lights were used on the stealth gear while regular chemical lightsticks were used on the control gear. All stainless steel snaps on the stealth gear were painted dull blue and the squid bait was dyed blue as well. Boggs (2004a) reports that the stealth gear caught 30 per cent fewer swordfish than the control gear and that the vessel received 39 per cent less revenue overall for its catch compared to the control vessel. It was concluded that the reduced performance of the stealth gear was gear related. Because of that, and the fact that there were no turtle takes on the stealth gear, it was concluded that more testing was needed.

4.3.11 Deep daytime setting of gear

Boggs (2002b; 2004a) reports on deep daytime gear experiments conducted from March to May 2002, to reduce bycatch and mortality of sea turtles in the Hawaii-based pelagic longline. The deep daytime gear was normal swordfish style gear that was set deep during the day instead of shallow at night. Deep daytime fishing operations for swordfish used the same target depths as tuna gear uses. A line setter was used, setting more mainline and a greater number of hooks between floats than for a typical swordfish set. Total number of hooks set, however, was similar to a normal swordfish set. Fishing depth was monitored with temperature depth recorders (TDRs).

Boggs (2004a) reports that the deep daytime fishing trials for swordfish did not do well. The swordfish catch was 85 per cent less than for the control gear. The catch of tuna was not reduced by as much. However, overall revenue was reduced by 71 per cent for the vessel doing deep daytime fishing compared to the control vessel. The deep daytime sets fished on average at a depth of 244 m while the stealth gear fished at 19 m. The deep daytime gear fished deep enough for tuna, it was concluded, but probably not deep enough for daytime swordfish as tracked swordfish reach depths of 400 m during the day. The contract vessels had some difficulty fishing deeper than 300 m, in any case, and this may have affected the trials. No turtles were caught on the deep daytime gear. One loggerhead was taken on the control vessel.

4.3.12 Hook timer and circle hook experiments

Boggs (2004a) also gave results for the hook timer and 18/0 circle hook experiments, which began in April 2002. A total of 95 sets were made. A single leatherback was captured giving the only hook timer data. The turtle was hooked at 0738 HST, 35 minutes before it was sighted on the line. It threw the hook itself and escaped. One loggerhead was also captured but the hook timer malfunctioned. About 20 per cent of the branchlines in the hook timer study were equipped with 18/0 circle hooks for comparison with the J hooks. Circle hooks were found to be only 40 per cent as effective as J hooks in catching swordfish, but were 94 per cent as effective in catching tuna.

4.3.13 Deep-sets versus shallow-sets

Beverly (2003), Beverly and Robinson (2004), Beverly et al. (2004), Bazilchuk (2005), and SPC (2005) report on a new deep-setting longline technique that sets all of the baited hooks at a prescribed range of depths, somewhere in the intermediate layer and down to the thermocline depth, avoiding having any baited hooks in the critical top 100 m where most turtle encounters occur. The new setting technique involves weighting the mainline in such a manner that the entire basket fishes below this critical depth. In order to set the entire line deep the mainline was used as supplementary floatline. In other words, the fishing portion of the line was suspended by long sections of mainline, weighted down by 3 kg lead weights at one end and suspended by floats on normal floatlines at the other. To avoid tangles, floats were set in pairs separated by 50 m of blank mainline (Figure 28). All parameters were simple to change and the only new gear needed was lead weights with lines and snaps and TDRs to determine actual depth of the line. All other fishing gear remained the same as the boats usually used.

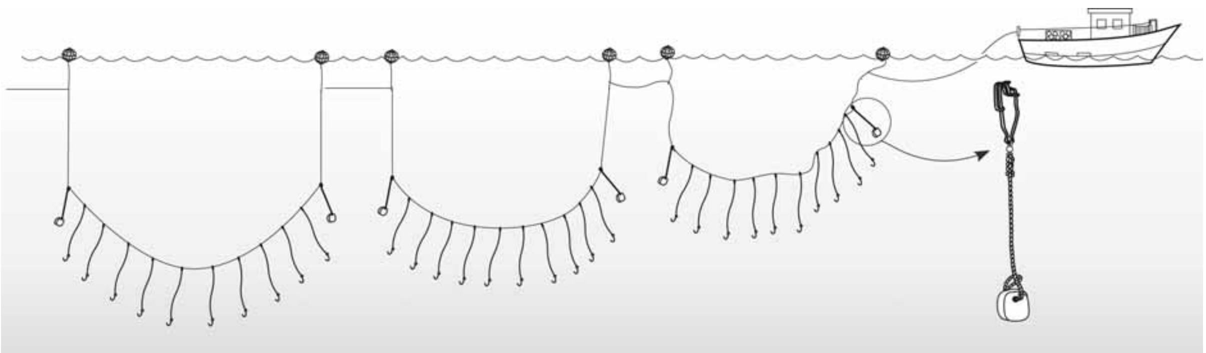


Figure 28: Boat setting new deep-set gear (SPC 2005)

Three trips were made to test this new technique, two in Australia and one in New Caledonia (Beverly and Robinson 2004). Data was collected on depths and catch and effort to compare the deep setting technique with the boat's normal fishing practices. Normal gear on the commercial vessel fished a range of depths from 40 to 200 m while the weighted gear fished a range of depths from 120 to 340 m — when the target depth of shallowest hook was 100 m (Figure 29). In all, 6000 hooks were set on the second trip, 2420 using weighted gear while 3580 hooks were set using the boat's normal configuration. The deep-setting technique proved to be successful in depth targeting, but not without a cost: more gear was needed, more time was spent on deck, and fewer valuable byproduct species were caught (Beverly and Robinson 2004). However, it was concluded that the trials were successful as longlines were set at prescribed depths below a minimum target depth. No turtles were caught but the data set was too small to draw any conclusions from this (Robins et al. 2002).

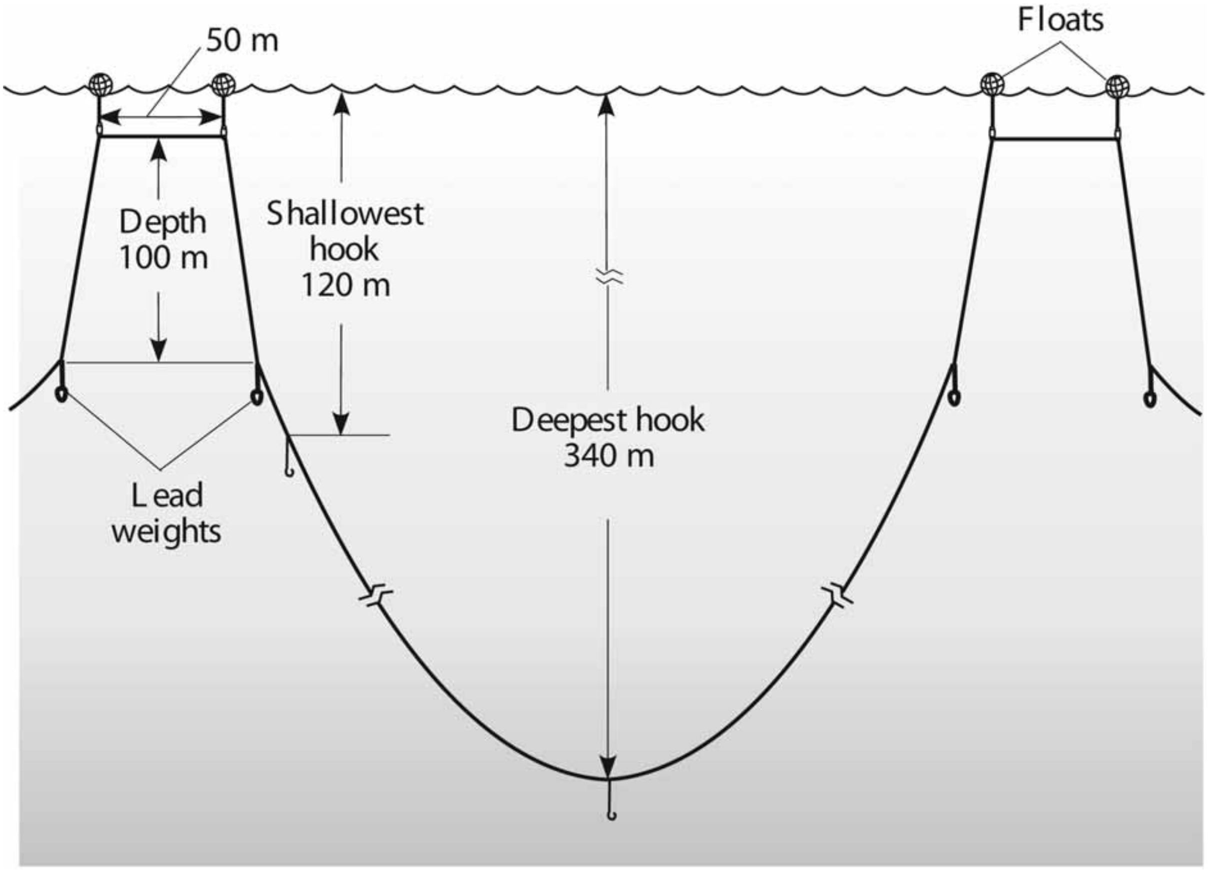


Figure 29: One basket of longline gear using deep-setting technique (Beverly and Robinson 2004)

A deep-setting technique has been developed in Hawaii for fishing for bigeye tuna and pomfrets (*Taractichthy steinachneri*) on seamounts (Beverly et al. 2004). The technique is similar to that described above and in Beverly and Robinson (2004), except that the mainline is very short — only one basket with 100 branchlines (for bigeye tuna, Figure 30), or one basket with 200 branchlines (for pomfrets, Figure 31) is set at a time; and floats are attached mid-basket to maintain a horizontal shape to the line. From January to July 2004, 23,370 hooks were fished using this technique and no turtles were reported caught during this time.

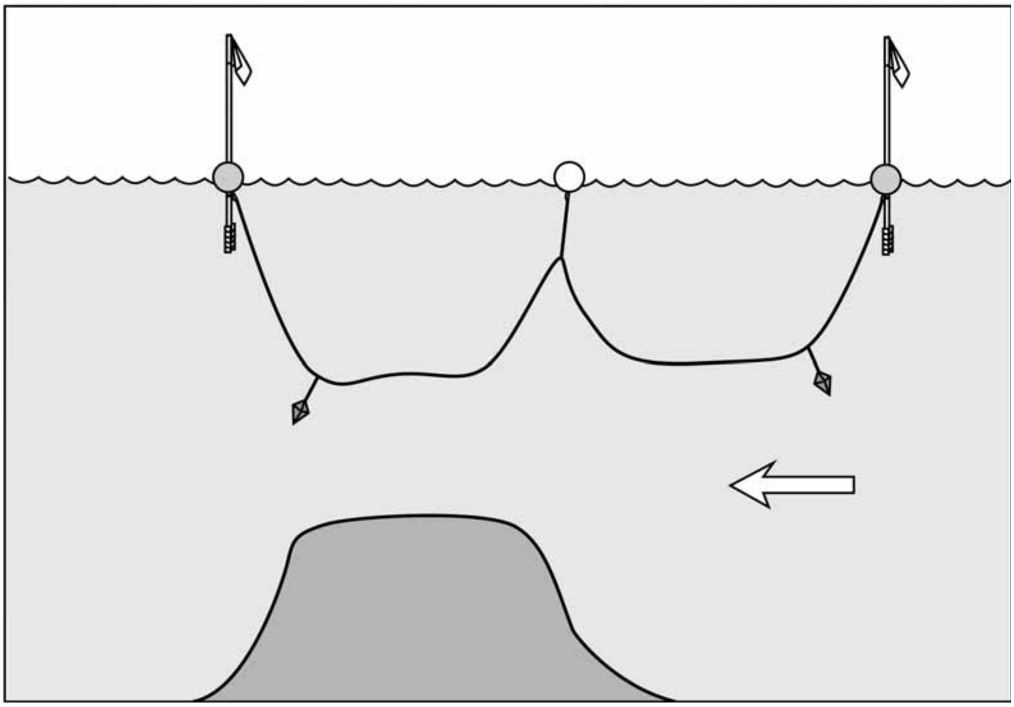


Figure 30: Hawaii-style deep-set basket targeting bigeye on seamount (Beverly et al. 2004)

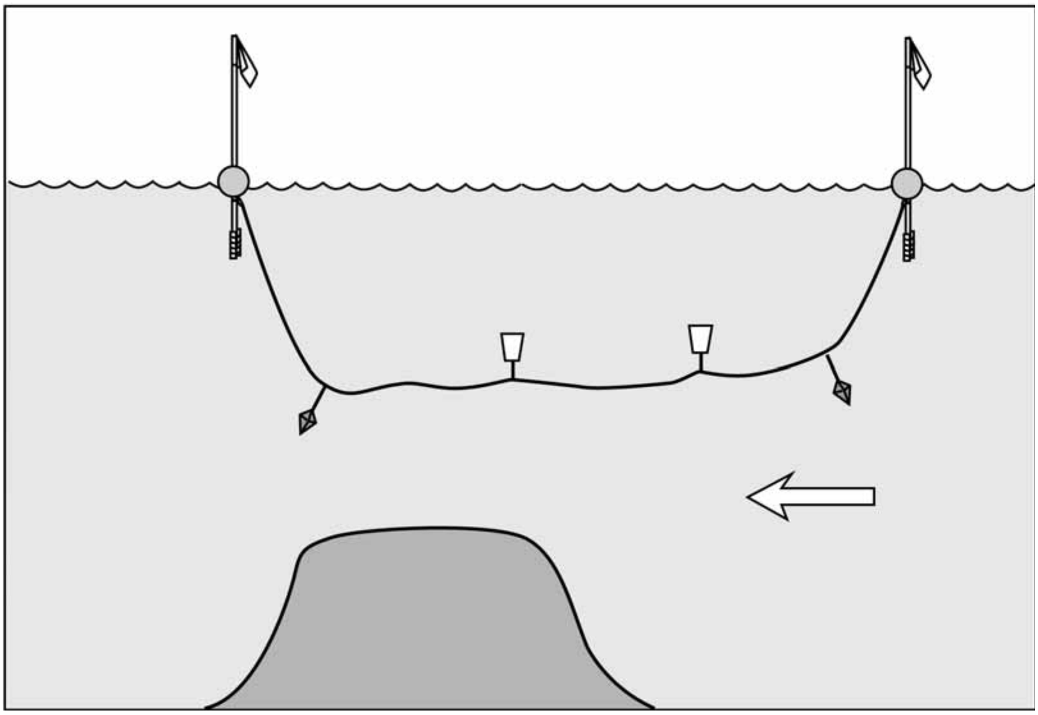


Figure 31: Hawaii-style deep-set basket targeting pomfret on seamount (Beverly et al. 2004)

Shiode et al. (2005) report on a Japanese mid-water float system for standardising hook depths on tuna longlines to reduce turtle bycatch. The method is similar to the method outlined above (Beverly et al. 2004) for targeting pomfret on seamounts except that lead weights are not used. One or two mid-water floats are placed in the middle of each basket to raise the middle branchlines up to the depth of the end branchlines in the basket, in other words, to maintain the fishing portion of the line in a more-or-less horizontal shape (Figure 32). In trials comparing this technique to conventional gear, the distance between the deepest hooks and the shallowest hooks was reduced from 55 m to 5 m, so the technique seemed to work technically although depths below 100 were not reached by the test gear with two mid-water floats. Depths were monitored by TDRs. No fishing effort and catch data were reported.

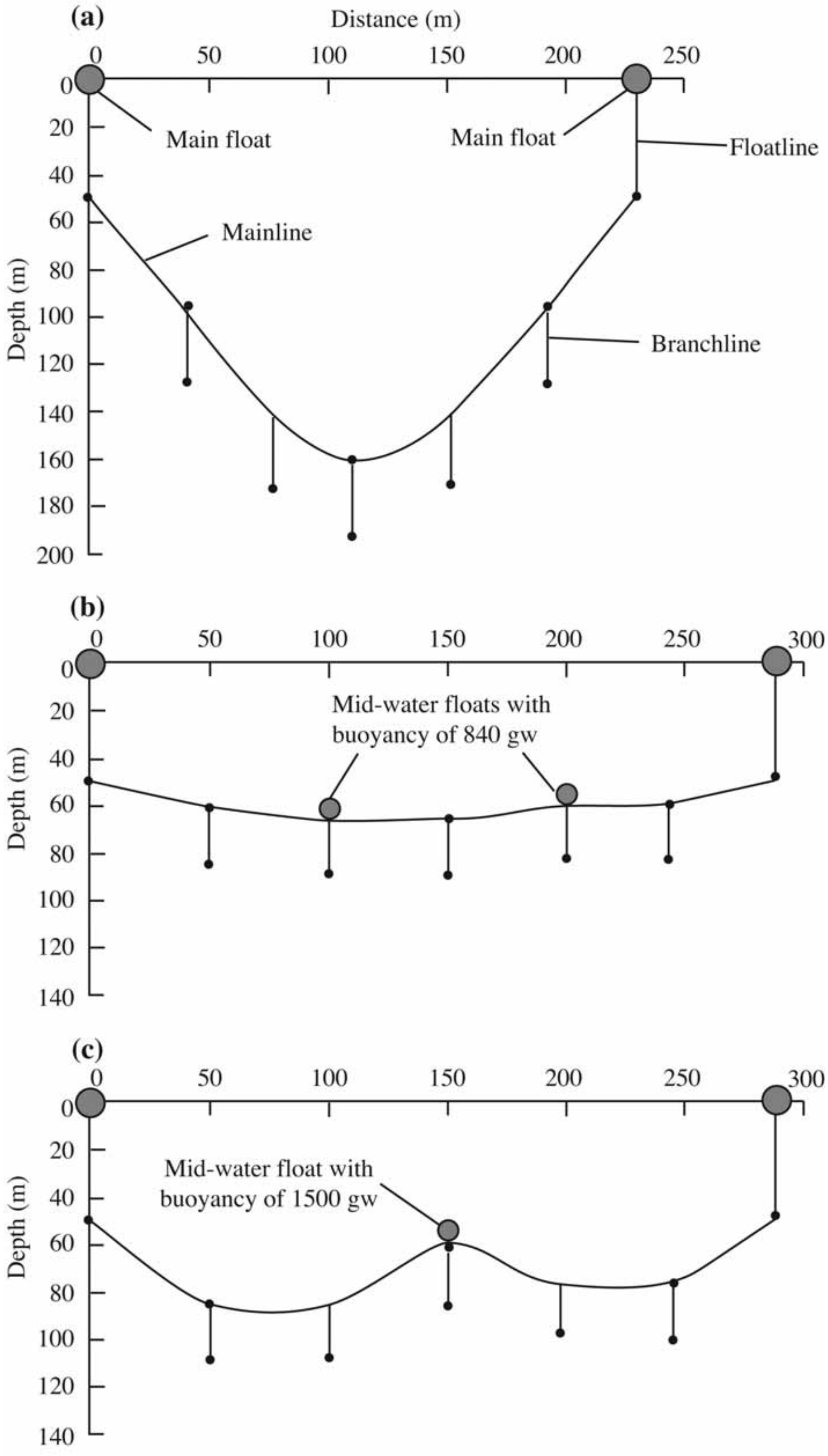


Figure 32: Japanese mid-water float system, with (a) normal basket configuration, (b) basket with two mid-water floats, and (c) basket with one mid-water float (re-drawn from Shiode et al. 2005)

4.3.14 Tangle-proof floatline

Beverly (unpublished) has developed a tangle-proof floatline (Figure 33) for shallow-set (swordfish) longline fisheries that prevents entanglements by leatherback turtles. The new design, which has yet to be field tested, may also mitigate entanglements with other turtle species in other fisheries where floatlines form part of the gear. The tangle-free floatline is made from the same material as a normal floatline with an eye at the top end for attaching a float and a longline snap at the other end for attachment to the mainline. Two things are added to the normal floatline; a string of small pressure resistant cylindrical hard plastic net floats and a 2 kg lead weight. The upward pressure exerted by their floatation keeps the floatline rigid. The lead weight at the bottom end keeps the line straight and vertical in the water column. The cylindrical floats roll on the line like little wheels. It is expected that the combination of a rigid line and rolling floats will prevent or reduce sea turtle entanglements.

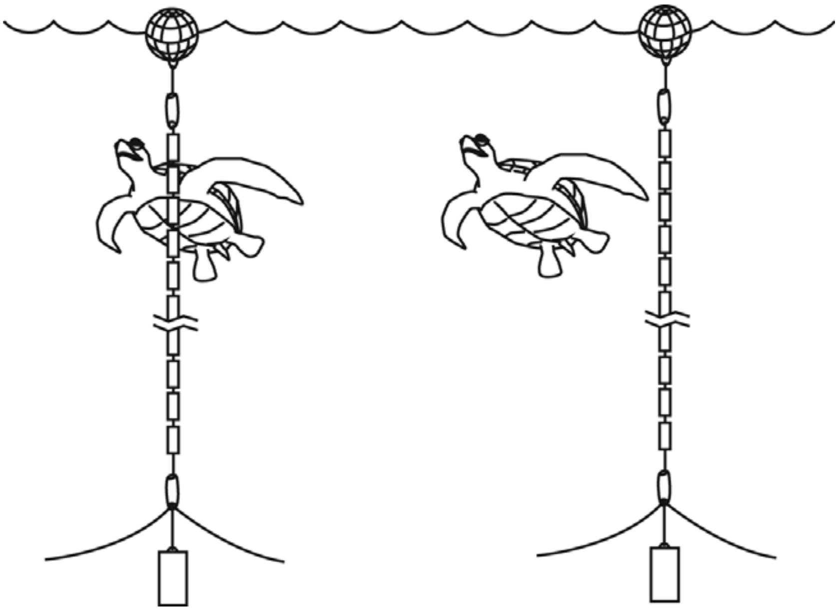


Figure 33: Tangle-proof floatline arrangement: on the left the turtle strikes the floatline; on the right the line has rolled off the turtle allowing it to escape entanglement (Beverly unpublished)

4.3.15 Self releasing hook design

Shelton Products (http://www.sheltonproducts.com/) have produced a self releasing hook (Figure 34) that may have applications to longline fishing, although no testing has been done to date using this hook on tuna longline gear. The self release hook was designed for catch and release game fisheries such as sport salmon fishing. However, it may work as a way to release longline captured turtles (and other bycatch species) without having to boat the turtles. The quick release hook would also undoubtedly do much less damage to the turtles' mouths than de-hooking devices because, rather than being torn out of the mouth, the hook is rotated out. The way it works is very simple — the eye of the hook is not at the end of the shank but is located on the bend. The leader, which is tied to the eye, is secured to the shank by a locking device. This is pulled free when the fish is alongside the boat. The leader is then pulled, rotating the hook and pulling it out bend first, releasing the fish unharmed.

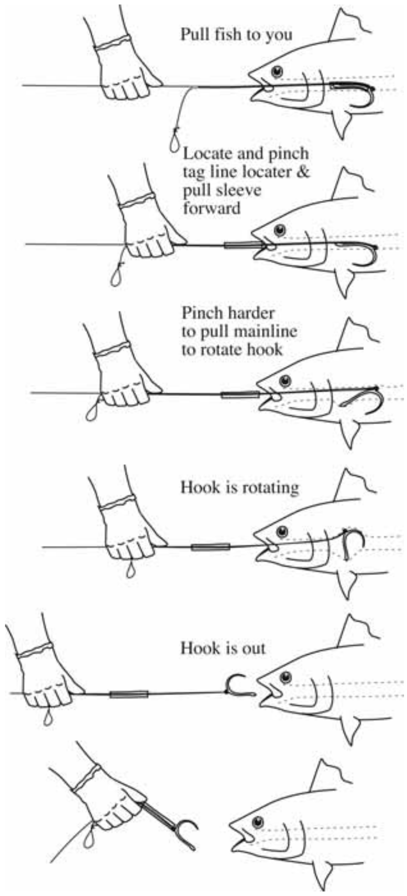


Figure 34: Shelton Products self releasing hook (re-drawn and adapted from their website)

4.4 Effects of gear modifications on catch rates for tuna and swordfish

An important consideration of gear modifications is the effect they will have on the catch rates of tunas and swordfish, the target species. This was considered during many of the experiments undertaken, as a reduction in target species catch rates will affect the viability of fishing operations.

Experiments conducted in the western Atlantic in 2001 and 2002 (Watson et al. 2003a) found that mackerel bait was more efficient for swordfish catches than squid bait, and circle hooks were more efficient for tuna catches than J hooks. Further experiments undertaken in the same area in 2003 and reported by Watson et al. (2004a) found that 20/0 circle hooks were effective in reducing loggerhead and leatherback interactions but did not increase swordfish catch rates compared to 18/0 circle hooks. Mackerel bait was found to be more effective for swordfish than squid but only in cooler waters (<17.7ºC). Circle hooks with squid bait were more efficient for tuna than J hooks, but mackerel bait was less efficient for tuna than squid.

Watson et al. (2004b) report on an evaluation of circle hooks in the Gulf of Mexico tuna fishery. NOAA Fisheries conducted research from February to April 2004 to compare non-offset 18/0 circle hooks with non-offset 16/0 circle hooks on the catch rates of yellowfin tuna using sardines for bait. Three commercial pelagic longline vessels made 61 sets setting 29,570 hooks. Three leatherbacks were caught, two on the 18/0 hooks and one on the 16/0 hooks. No loggerheads were caught. There was a 26.5 per cent reduction in total yellowfin caught by the 18/0 circle hooks compared to the 16/0 circle hooks, indicating that use of the 18/0 circle hooks in the fishery could result in economic loss when compared to the 16/0 circle hooks.

Watson et al. (2005) and NOAA (2005e) describe research carried out in the western North Atlantic Ocean. Specifically, the effectiveness of 18/0 circle hooks with mackerel (*Scomber scombrus*) bait was evaluated with respect to reducing sea turtle interactions while maintaining swordfish and tuna catch rates. Swordfish catch rate was increased 30 per cent by circle hooks with mackerel bait and 63 per cent by J hooks with mackerel bait (Watson et al. 2005). The catch rate of swordfish, however, was reduced by 33 per cent by 0º offset circle hooks with squid bait and 29 per cent by 10º offset circle hooks with squid bait. Circle hooks baited with squid increased the catch rate for bigeye tuna by 26 per cent while mackerel bait significantly decreased the catch rate for bigeye — by 81 per cent with 18/0 circle hooks and by 58 per cent with J hooks. The combination of circle hooks and mackerel bait had no negative effect on swordfish catch rates.

Watson et al. (2005) concluded that employing 18/0 circle hooks or by using mackerel bait can significantly reduce the capture rate of turtles and potentially reduced post-capture mortality while not negatively impacting the target species catch rate. The 18/0 circle hooks maintained catch efficiency for bigeye when baited with squid and for swordfish when baited with mackerel.

Ward et al. (2005) report on the effect of circle hooks on target and non-target catch rates (and economic performance) in Australia's longline fisheries. During July and September 2005 the feasibility of measuring the effects of circle and tuna hooks on catch rates on three longliners off eastern Australia was investigated. Preliminary results of the study were not statistically significant due to the small sample size, but indications were that circle hooks caught fewer bigeye tuna and striped marlin than tuna hooks. Fish caught on the circle hooks were generally larger than those caught on tuna hooks, however. Conclusions were that 16/0 circle hooks can be used by longliners that deploy dead squid and fish baits, but smaller (13/0) circle hooks are better for boats that use live bait.

Boggs (2002b; 2004a) reports on a variety of fishing experiments to reduce bycatch and mortality of sea turtles in the Hawaii-based pelagic longline fishery including the testing of stealth (camouflaged) gear, deep daytime gear, and using a hook timer and 18/0 circle hooks. Boggs (2004a) reports that the stealth gear caught 30 per cent fewer swordfish than the control gear and that the vessel received 39 per cent less revenue overall for its catch compared to the control vessel. It was concluded that the reduced performance of the stealth gear was gear related. Results from the deep daytime gear trials showed the swordfish catch was 85 per cent less than for the control gear. The catch of tuna was not reduced by as much. However, overall revenue was reduced by 71 per cent for the vessel doing deep daytime fishing compared to the control vessel. Boggs (2004a) also reported that about 20 per cent of the branchlines in the hook timer study were equipped with 18/0 circle hooks for comparison with the J hooks. Circle hooks were found to be only 40 per cent as effective as J hooks in catching swordfish, but were 94 per cent as effective in catching tuna. Overall, all three experiments resulted in lower catch rates of target species, and lower economic returns to the boats.

Results from deep setting experiments conducted off Australia and New Caledonia showed that the nominal CPUE of target species was slightly better for the weighted gear overall — 17 per cent more fish of all target species were caught — but was much better for the main target species (Beverly and Robinson 2004). Forty-two per cent more bigeye tuna were caught using weighted gear. Swordfish CPUEs were practically identical for weighted and normal gear configurations. A number of swordfish were caught during daylight hours at depths greater than 100 m. Beverly et al. 2004 reported that during fishing trials using similar gear in the Hawaii seamount fishery, CPUE for the main target species was quite high, although the size of the bigeye caught was below the average size for longline caught bigeye (fish averaged 12.2 kg). CPUE for bigeye for a six month period from January to July 2004 (23,370 hooks fished) was 9.1 fish per 100 hooks, or 111 kg per 100 hooks.

4.5 Discussion

The development of alternate fishing gear and setting techniques to avoid sea turtle interactions in longline fisheries is just beginning. The most promising new development so far has been the adoption of the circle hook. The successful experiments using circle hooks with mackerel type bait have allowed two shallow-set swordfish fisheries, which had been closed because of turtle interactions, to reopen. There have also been good successes in the Atlantic and in the Ecuadorian fisheries based on the use of circle hooks and mackerel bait. More experimental fishing using circle hook gear with mackerel bait is needed, and this is being done, for example in Australia (Ward et al. 2005). In addition, the modified circle hook with attached wire for reducing the chance sea turtles ingesting the hook is also looking promising.

Alternate fishing methods that avoid the top 100 m where most turtle encounters occur are promising and may be applicable to the swordfish fishery. Deep-setting techniques need to be vigorously tested during the day on swordfish fishing grounds to see if a day fishery is possible for this species. Perhaps the lines need to be set even deeper than they are for bigeye tuna. Eliminating all shallow-set night sets in longline fisheries, both for tuna and for swordfish, would eliminate most turtle interactions. Other types of gear designed to avoid turtles being hooked, swallowing the hook, getting entangled, or being attracted to the gear in the first place, need more testing as well.

The experiments that have looked at changes in catch rate of the target species as a result of hook, bait and gear modifications also reveal that some modifications will not be acceptable to industry, due to the decline in catch rates. Deep setting and the use of circle hooks with mackerel baits again seem to be the most successful experiments to date, having no negative impact for the most part. However, more experimentation is needed to test these methods fully and the affect the gear changes will have on catch rates for the target species.

Finally, there was one perceived negative impact as a result of the use of circle hooks in some of the trials. The use of circle hooks increases the catch of blue sharks in the fishery, and this may have management implications for shark species in the future.

5. Developing equipment and methods to release sea turtles and enhance post-capture survival

Balazs et al. (1995) report on an expert workshop held in Hawaii in 1995 on developing guidelines for handling turtles hooked or entangled in the Hawaii longline fishery. At the time of the workshop, the actual numbers of turtles captured on longline gear, the level of injury and mortality caused by these interactions, and the resulting impacts on stocks were largely unknown. Turtles taken by longline gear may be alive or dead, or appear dead and be comatose, when hauled aboard or alongside during gear retrieval. Additional injury may result from the hauling process and death or damage can occur from forced submergence, or from the hook penetrating an internal organ or major blood vessel, or from subsequent infection. Live turtles may be cut free with hooks in their throats and varying lengths of line trailing behind them. Later, this line could be ingested causing further damage, or it could cause entanglements or even death by strangulation. The expert workshop was convened to answer this question: “What are the most important steps which can be taken to improve the survivability of turtles hooked or entangled in the Hawaii longline fishery?” The responses to the question were separated into those activities that captains would be expected to do and those that observers would do if they were aboard the vessel. Recommendations were made based on the findings of working groups that looked at different phases of longline fishing and turtle handling.

These recommendations included the following guidelines for retrieval of hooked or entangled sea turtles (without notations on advantages and disadvantages):

- Equip all vessels with cut out doors;
- Scan mainline as far ahead as possible to sight turtles;
- Effort should be made not to get ahead of the mainline while hauling;
- Upon sighting a turtle, slow the vessel and line hauling speed and adjust the direction towards the turtle while keeping minimum tension on the line;

- Once the snap of the branchline with the turtle is in hand continue moving towards the turtle at a slow speed — if this is not possible take the boat out of gear, stop the vessel, and retrieve the turtle;
- Retrieve the branchline slowly, avoid tugging or yanking, and do not use gaffs;
- Ensure that there is slack in the line to keep the turtle in the water while it is alongside the vessel;
- Assess the turtle's condition and size — is it dead or alive, is it hooked or entangled, is the hook ingested;
- If the turtle is small bring it onboard using a dip net;
- If the turtle is too large to safely board without causing it damage, use clippers to cut away line on entangled turtles — remove hook if possible if the hook is external — if this is not possible cut the line at the eye of the hook — if the hook is internal cut the branchline as close to the eye of the hook as possible;
- Do not use the branchline or gaff to board a turtle — lift it on board by the carapace, flippers, or with assistance of a dip net; and
- The vessel should be stopped and in neutral when releasing a turtle — ease it gently into the water head first and observe that it is well away from the vessel before engaging the propeller.

The recommendations of the expert workshop (Balazs et al. 1995) also included the following guidelines for treatment of hooked or entangled sea turtles by fishermen:

- Determine if the turtle is alive or dead;
- If there is no visible movement touch the eye and pinch the tail;
- If the turtle is dead remove line and hook and return the turtle to the sea immediately;
- If it is unsure whether the turtle is dead or not, touch the eye and pinch the tail periodically for up to 24 hours to see if there is a response;
- If the turtle is responsive, it should be placed in a shaded, protected area and covered with a moist cloth and checked periodically for up to 24 hours at which time it should be returned to the sea;
- If the turtle is active remove line, restrain the turtle (depending on circumstances), remove hooks that are external or visible in the mouth by using a wood object such as a broom handle — if the hook is not visible cut the line as short as possible; and
- Release the turtle as gently as possible in a direction away from the vessel with the engine in neutral.

Finally, the expert workshop (Balazs et al. 1995) had the following recommendations for treatment of hooked or entangled sea turtles by observers:

- Determine if the turtle is dead or alive;
- If it is alive, remove hook using a hook extractor — prop the mouth open with wooden object such as a broom handle and grasp the hook with plier-like tool, then touch the eye and pinch the tail periodically for 24 hours to see if there is a response — collect life history data — place the turtle in a shaded, protected area and cover with a moist cloth with the head in a down position and elevate the hindquarter several inches, and attempt to resuscitate comatose turtles — check periodically for 24 hours and if the turtle is dead after 24 hours, tag and store on ice or in a freezer;
- If the turtle is retrieved dead, leave any entangled line or hook in place and cut all but two feet of line and tape it to the turtle — collect life history — write collection identification information on the tag and attach the tag securely then store the turtle on ice or in a freezer;
- If the turtle is active, remove entangled line or hook, collect life history data, and release the turtle as gently as possible in a direction away from the vessel with the engine in neutral.

5.1 Techniques and tools used for handling caught sea turtles

The Secretariat of the Pacific Community has produced a poster (SPC 2002b) detailing methods for releasing live sea turtles caught on pelagic longlines. It is available in both English and French and was prepared especially for Pacific Island fishermen. It was subsequently reproduced in SPC's longline fishing manual (Figure 35). In addition, the poster was reproduced in a laminated A4 size and A4 size sticker, so that these could be used on deck by fishermen when a sea turtle was encountered.

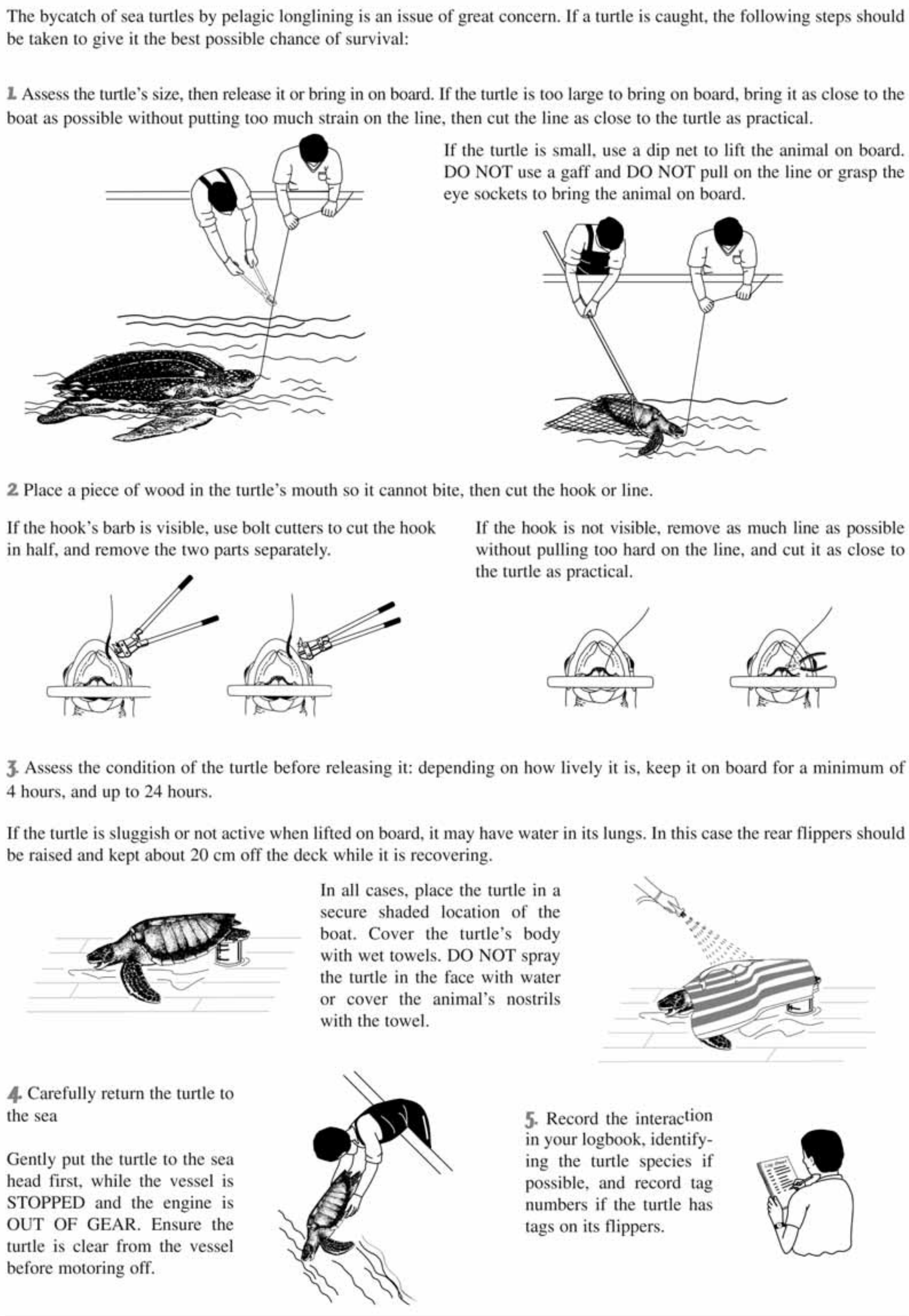


Figure 35: Methods for releasing live hooked sea turtles caught on longline gear (Beverly et al. 2003)

Epperly et al. (2004), in a NOAA-NMFS document, describe in detail the tools and techniques for removing fishing gear from incidentally captured sea turtles and other bycatch species. The required equipment and techniques described are intended to reduce sea turtle injury and promote post-release survival. A demonstration of the tools and techniques can be seen on the video "*Removing Fishing Gear from Longline Caught Sea Turtles*" (Hataway and Epperly 2004). Captains and observers who participated in the sea turtle mitigation experiments in the Atlantic in 2001–2003 (Watson et al. 2004a) were interviewed after each trip to discuss the efficacy of various tools provided to remove gear from sea turtles. Based on field testing and user feedback the tools were updated and revised (see list below). This equipment is now mandatory on all US vessels in the Atlantic that fish with longline gear, and must be used in accordance with the careful release protocols. A copy of these protocols must be kept in the wheelhouse of every vessel fishing in the US Atlantic longline fishery. The document describing these protocols is divided into three parts: Part 1 — Vessel's Responsibilities Upon Sighting a Sea Turtle, Part 2 — Sea Turtles Not Boated, and Part 3 — Sea Turtles Boated. An attempt will be made to briefly paraphrase the contents of these three parts.

Part 1 — Vessel's Responsibilities Upon Sighting a Sea Turtle:

- Scan the line far ahead;
- Avoid getting ahead of the mainline;
- Upon sighting a turtle slow vessel and line drum speed;
- If slow speed is not possible, stop the vessel;
- Take engine out of gear;
- Pull branchline slowly;
- Do not use sharp objects to retrieve or control turtle;
- Assess turtle's condition and size and whether it is hook or entangled;
- There are three possible interactions — entangled but not hooked, hooked but not entangled, and hooked and entangled;
- If hooked, assess the location of the hook;
- Vessel must be stopped for assessment and boating of turtle;
- Turtles 3 feet (about 90 cm) in straight carapace length can be boated safely if sea conditions permit, larger turtles should be boated when conditions and equipment permit;
- If the turtle cannot be boated follow Part 2 of the protocols;
- Whenever possible turtles should be boated and Part 3 of the protocols should be followed; and;
- The vessel is responsible for the turtle's safety from the first sighting until release.

Part 2 — Sea Turtles Not boated

- The turtle should be brought as close as possible, but it may need a short time to calm down;
- Gear removal must be done quickly;
- A turtle tether (a line on a pole that is looped over one flipper) can be used to help control the animal — it takes pressure off of the branchline;
- Long-handled line cutter is used to cut monofilament line from entangled turtles;
- Monofilament cutter is used to cut line if the turtle is close to the boat;
- Long-handled de-hooker for internal hooks is used to remove internal hooks from sea turtles that cannot be boated;
- Long-handled J shaped de-hooker for external hooks is used for removing hooks from flippers; and
- Long-handled device to pull an inverted V during entanglement is used to assist in cutting away line — a gaff or boat hook can be used for this.

Detailed instructions are given in the document for using all of the above tools under various scenarios.

Part 3 — Sea Turtles Boated

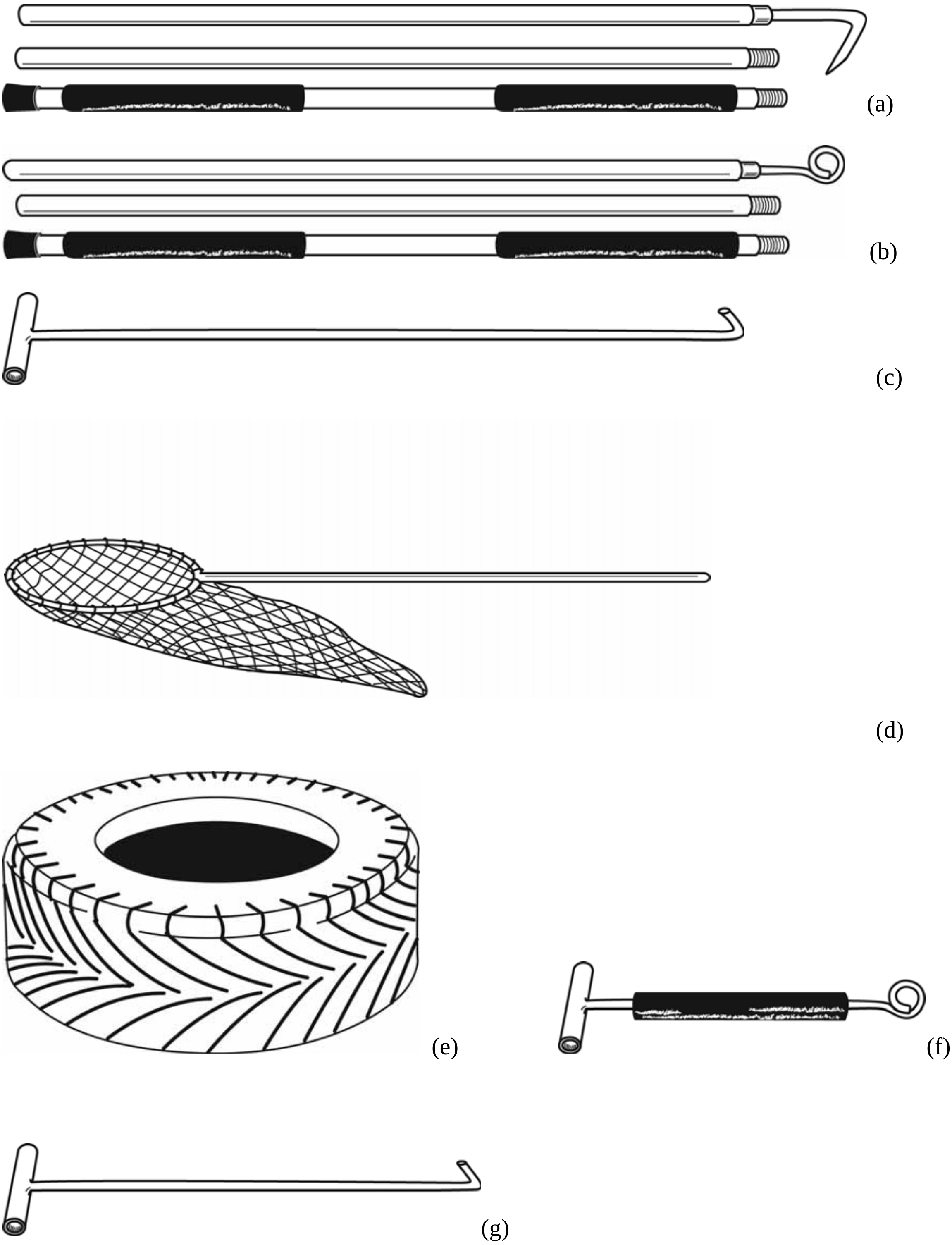
- It is important that the turtle is never pulled out of the water using the branchline;
- If the turtle is small enough, a dip net can be used to carefully boat the turtle;
- For larger turtles that cannot be boated with a dip net, a hoist can be used — the hoist is a large basket-like device that is lowered and raised by a hydraulic crane or boom;
- While onboard, the turtle must be kept moist and in the shade, maintaining its body temperature above 60ºF (15.5ºC) or similar to the water temperature at capture;
- It must be isolated and immobilised on a cushioned surface — the hoist will do for larger turtles, and an automobile tire will do for smaller turtles;
- Comatose turtles should be revived before being released — comatose turtles can be kept on deck for 24 hours without a permit, for resuscitation;
- A turtle kept on deck for 24 hours without sign of life may be considered dead and should be returned to the water;
- If it is unsure whether hook removal will cause more damage, then the hook should not be removed;
- All external hooks should be removed;
- Hooks in the mouth should be removed;
- Hooks that have been swallowed should not be removed when the insertion point is not visible;
- When a hook cannot be removed the line should be cut as close as possible to the eye of the hook;
- If part of the hook is visible it should be cut with bolt cutters and removed;
- If the turtle is hooked internally its mouth needs to be opened — block the nostrils, tickle the throat, or cover the nostrils and apply light pressure to the front corner of the eye with one hand and firm pressure to the throat with the other;
- Otherwise use rope loops covered with protective tubing, or the avian mouth speculum to open the mouth and then use mouth gags (block of wood, canine mouth gags, hank of rope, PVC pipe couplings) to keep it open;
- To get a better view after the mouth is open, insert a pair of needle-nosed pliers in the closed position into the upper oesophagus and then open the pliers;
- Use pliers, bolt cutters, or short-handled de-hooker to remove internal hooks;
- Use a short-handled J-style de-hooker or a Scotty's de-hooker to remove external hooks;
- Once gear is removed and the turtle recovered, boated turtles should be released in water of similar temperature as at capture, preferably in a non-fishing area;
- Release the turtle by lowering it over the aft portion of the vessel, close to the surface, when gear is not in use and the engine is in neutral; and
- The turtle's swimming behaviour and diving ability should be monitored after release and recorded in the daily logbook

5.2 Specific equipment used to release hooked or entangled sea turtles

NMFS (Federal Register 2004b) has listed required equipment needed for the careful release of sea turtles caught in (US Atlantic) hook and line fisheries. The list of approved models of release equipment is available at (http://www.nmfs.noaa.gov/sfa/hms). The required equipment includes the following:

- Long-handled line cutter (Figure 36 (a)),
- Long-handled de-hooker for ingested hooks (Figure 36 (b)),
- Long-handled de-hooker for external hooks (Figure 36 (c)),
- Long-handled device to pull an inverted Vee (Figure 36 (c)),
- Dip net (Figure 36 (d)),
- Standard automobile tire (Figure 36 (e)),
- Short-handled de-hooker for ingested hooks (Figure 36 (f)),
- Short-handles de-hooker for external hooks (Figure 36 (g)),

- Long-nose needle-nose pliers (Figure 36 (h)),
- Bolt cutter (Figure 36 (i)),
- Monofilament line cutter (Figure 36 (j)), and
- Two different types of mouth openers and mouth gags (including either a block of wood, a set of three canine mouth gags, a set of two sturdy dog chew bones, a set of two rope loops covered with hose, a hank of rope, a set of four PVC splice couplings, or a large avian oral speculum — Figure 36 (k)).



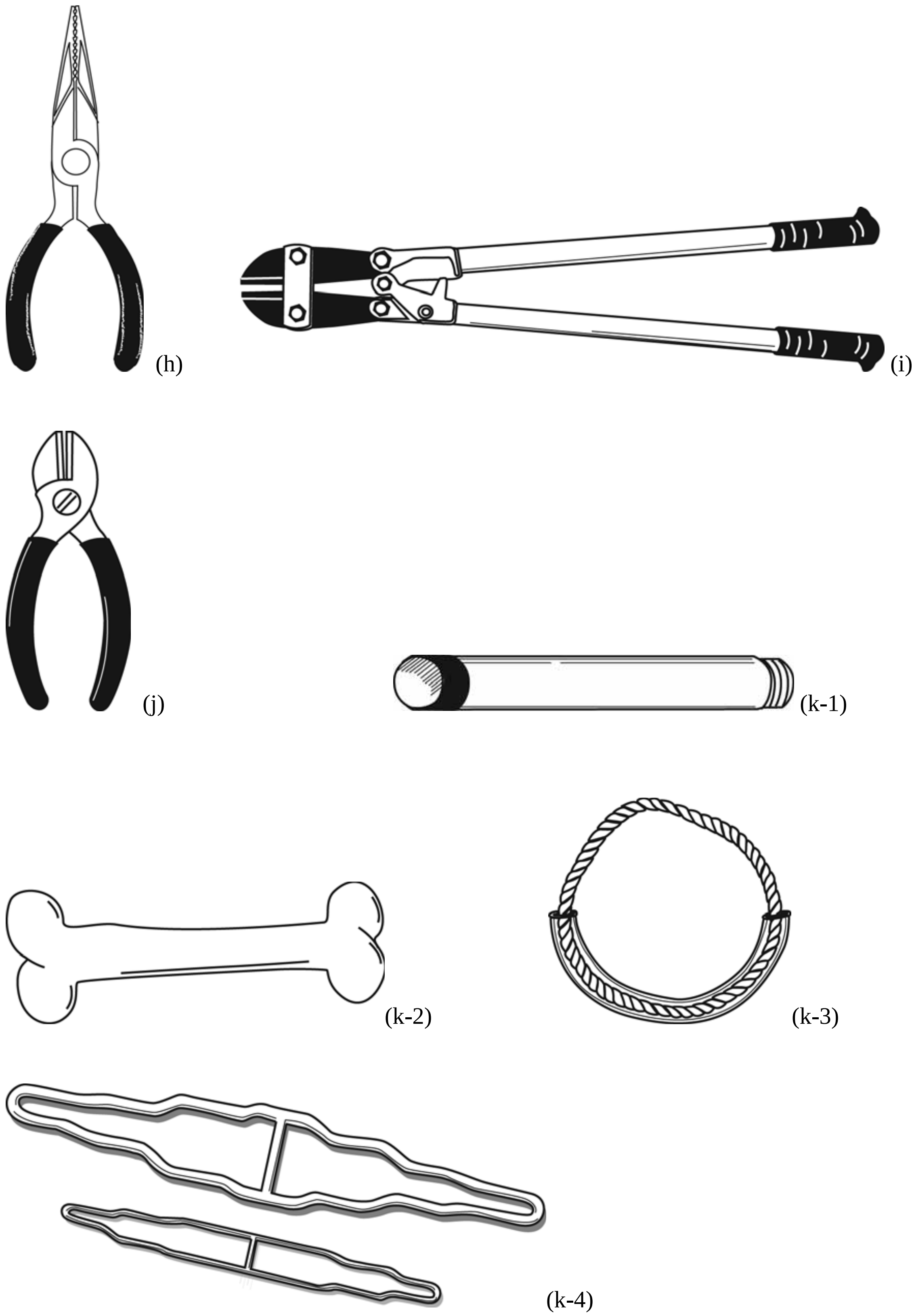


Figure 36: Equipment required by law to be carried on US Atlantic longline vessels for handling and releasing sea turtles

5.3 Discussion

Tools and techniques have been developed and tested for disentangling and de-hooking turtles captured in longline gear to increase the chances of post-capture survival. In order to be effective the tools need to be available to all fishermen and the techniques and protocols need to be learned by captains, crews, and observers. Management regimes can require that the tools are onboard every longline vessel in the fleet and they can require that captains attend protected species workshops where they will learn to use the tools and techniques correctly. In addition, there are several videos and DVDs that demonstrate how to use line cutters, de-hookers, and how to properly resuscitate and release a turtle after capture. The following is a list of video and DVD productions outlining proper turtle handling techniques:

- *Handling Hooked & Entangled Sea Turtles*. NOAA Fisheries/PIRO.
- *Hooks Out and Cut the Line*. A DVD produced by SeaNet – Oceanwatch, Australia.
- *Crossing the Line: Sea turtle handling guidelines for the longline fishing industry*. Produced by Hatchling Productions and Beldi Consultancy, Australia.
- *Removing Fishing Gear from Longline Caught Sea Turtles*. National Marine Fisheries Service, Southeast Fisheries Science Center, Miami, Florida.

Every responsible longline fishing boat should carry the release tools (minimum should be line cutter, de-hooker, dip net, and mouth gags) listed above and should have a copy of at least one of the videos or DVDs listed above available for all crew to watch. They should also carry printed versions of release protocols in the wheelhouse.

6. Management solutions to reduce the incidental catch of sea turtles in longline fisheries and to decrease post-capture mortality.

Management solutions to reduce the incidental catch of sea turtles in longline fisheries and to decrease post-capture mortality can roughly be divided into pre- and post-circle hook experiment measures. Before the findings that circle hooks and mackerel bait can reduce interactions and mortality and maintain target species catch rates, management measures were for the most part emergency measures to close or curtail the fisheries until solutions could be found. Time/area closures or complete closures were probably the only quick fix available. However, they came at a price. In Hawaii, for example, many of the boats affected by the closure of the swordfish fishery relocated to California, essentially fishing in the same fishery (Dalzell 2000). The closure probably had more of an effect on fishermen than it did on turtles. Likewise, closing the NED in the western Atlantic (refer Figure 15) would likely have increased interactions in other areas where pelagic longlining took place, if effort had been redirected there (James et al. 2005). In any case, after sustainable mitigation devices and practices were developed, fisheries that were closed could be reopened by implementing gear and bait restrictions, restrictions on setting characteristics, restrictions on total allowable bycatch, and implementation of quick release protocols including the mandatory use of new gear and methods. Time/area closures have been retained as options, however, if total allowable bycatch levels are reached. Other management initiatives have been developed as well including enhancement of observer programmes, hook exchange programmes, fleet communication schemes to avoid hotspots, voluntary contribution to nesting beach restoration projects, convening of workshops, and the production and distribution of educational materials.

Oravetz (1999) suggests that mitigating measures to reduce sea turtle take should include additional research on the distribution and abundance of sea turtles, as well as a reduction of fishing effort when sea turtles occur in concentrations. Alternatives include limiting new entrants to longline fisheries, changing fishing quotas, setting seasonal limits based on sea turtle distribution and abundance, and pulling longlines more frequently (set and haul twice daily).

Hogan (2004) describes management experiences in implementing turtle avoidance and mitigations measures in commercial fisheries including pelagic longline fisheries. The report singles out experiences in the United States longline fisheries in both the Atlantic and the Pacific. Given that longline fisheries conducted both in the EEZs and the adjoining high seas areas had impacts on turtles, steps were required to address the problem over a wide geographic area. The status of sea turtles that interacted with longline fleets differed by ocean, however. Populations of leatherbacks in the Pacific were considered to be critically endangered and so required immediate and comprehensive management measures to reduce interactions. One difference between trawl and longline bycatch issues was that the trawl fisheries had the turtle exclusion device (TED), which was an alternative to closing the fishery. Pelagic longline fisheries had no equivalent device or gear that would allow the fishery to continue. The problem was that little was known about turtle interactions with longline fisheries, and specifically what could be done to reduce them. As a result, NOAA Fisheries implemented temporary time/area closures in 1999 for the Hawaii-based longline fishery to reduce the bycatch of endangered and threatened turtles. In June 2002, NOAA Fisheries implemented permanent regulations prohibiting fishing for swordfish in the Pacific by US vessels north of the equator, and prohibiting all longline fishing during April and May in waters south of Hawaii to the equator. These time/area closures were based on observer data that identified areas of high interaction. Prior to the closures, the Hawaii-based longline fleet was estimated to take 850 turtles annually. With the closures in place, the estimated annual take was reduced nine-fold, down to approximately 100 turtles. These time/area closures had serious impacts on the industry in Hawaii. About 20 vessels gave up their Hawaii permits and shifted their operations to California where they continued to interact with turtles. Some vessels switched to tuna fishing while others remained inactive. The whole scenario led to lawsuits and litigation by the industry and environmental groups to challenge the measures put in place by fisheries management authorities.

Hogan (2004) also reports that NOAA Fisheries implemented seasonal time/area closures for the US Atlantic longline fishery beginning in 2000. In July 2002 a final rule was implemented which prohibited fishing with longline gear in an area of over 2,600,000 square nautical miles in the Northwest Atlantic. Prior to this closure the US Atlantic fleet was estimated to take over 3000 turtles annually. With the closure in place, the estimated take was reduced four-fold, down to 875 turtles annually. While the Atlantic time/area closure was in place NOAA Fisheries was exploring longer term solutions based on gear modifications that could lead to reopening the fisheries. Two studies were conducted, one in the eastern Atlantic around the Azores and one in the northwestern Atlantic (see Section 4 above). These studies were successful in identifying gear modifications that can help reduce sea turtle bycatch in longline fisheries.

Hogan (2004) concludes by saying that the experiences (to date) in the introduction and implementation of new gear modifications and management actions to reduce the impact of fisheries on sea turtle populations demonstrate the difficulties to the challenge of reconciling economic activities with conservation activities. Not all approaches or options were accepted by all user groups. Some of the important lessons learned were:

- Voluntary acceptance of gear modifications may be difficult and may not provide the conservation goal established by management;
- Methods that result in increased costs or decrease in target catch will likely be resisted;
- User groups should be active participants in planning, development, and evaluation of new technologies and management measures;
- Mandatory use of new sustainable technologies requires effective enforcement commitment;
- Technical training of enforcement personnel can be a cost-effective technology transfer technique and may help to maintain rapport between managers, enforcement officials, and user groups;
- Planning for new technology should include commitments for technology transfer;
- Regulations implementing new mitigation techniques should be flexible and easily modified to allow for different conditions during commercial operations, and to allow for improvements; and
- Successful development and acceptance of sustainable technologies requires effective communication and cooperation between researchers, management, and the public.

6.1 Management out of Hawaii

The Western Pacific Regional Fishery Management Council (WPRFMC), based in Hawaii, has been very active in working with the Hawaii-based longline industry to develop new sea turtle mitigation measures and develop and implement appropriate management measures to ensure the survival of the fishery, while addressing and reducing sea turtle interactions. WPRFMC (2004) has produced a very comprehensive document on management measures to implement new technologies for the Western Pacific pelagic longline fishery. The document is an amendment to the fishery management plan for the pelagic fisheries of the Western Pacific Region and includes a final supplemental environmental impact statement. The regulatory aspects of the amendment provide for a multitude of management measures to mitigate turtle interactions in the Hawaii-based longline fishery including the following:

- Establish an annual limit on the amount of shallow-set effort north of the equator to 2120 sets;
- Divide and distribute the shallow-set effort each calendar year in equal portions (in the form of transferable single-set certificates valid for one year) to all Hawaii permit holders;
- Prohibit Hawaii permit holders from making more shallow-sets north of the equator during a trip than he has certificates for;
- Require Hawaii permit holders to submit one certificate per trip for each shallow-set made north of the equator within 72 hours of each landing;
- Require that Hawaii-based vessels, when making shallow-sets north of the equator, use only 18/0 or larger circle hooks with a 10º offset;
- Require that Hawaii-based vessels , when making shallow-sets north of the equator, use only mackerel-type bait;
- Establish annual limits on the numbers of interactions between leatherback (16) and loggerhead (17) turtles while engaged in shallow-setting;
- Establish a procedure for closing the shallow-setting component of the Hawaii-based longline fishery for the remainder of the calendar year when either of the two limits is reached, after giving one week notice to all permit holders (see below);
- Require that operators notify NMFS in advance of every trip whether the sets involved in the trip will be shallow or deep-sets, and require that operators make only sets of the type declared;
- Require that operators of Hawaii-based longline vessels carry and use NMFS-approved de-hooking devices; and
- Require that Hawaii-based longline vessels, when making shallow-sets north of 23º N start and complete the line setting during the night time (no earlier than one hour after local sunset and no later than local sunrise).

WPRFMC (2005c) has taken an integrated management approach to the conservation of protected species, including sea turtles, in longline fisheries that sums up the best possible approach so far. They have produced a brochure that outlines the integrated approach. First, the issues must be recognized: the incidental catch of protected species in pelagic longline fisheries is of primary concern; most longline interactions occur on shallow-sets; longline fishing has increased globally since the 1950s with 30 nations operating 6000 vessels in the Pacific alone; pelagic longline is the most economically important fishery in the Pacific; and successful mitigation measures must reduce or eliminate bycatch without making fishing operations difficult or unprofitable so that they can be exported to other fisheries. The above management measures were reinforced. WPRFMC recognises that effective solutions must encompass a species' entire life history, and address both terrestrial and oceanic impacts. Promoting internationally-based conservation measures at nesting beaches and coastal foraging grounds may provide greater benefits than fishery measures that are focused only on the pelagic environment. WPRFMC has supported and implemented a number of sea turtle conservation projects since 2004 in Indonesia, Papua New Guinea, Japan, and Baja California, Mexico to bolster recovery of North Pacific loggerheads and West Pacific leatherbacks (Kinan 2005). WPRFMC also supports international and domestic partnerships among government, industry, and non-government organisations to develop effective fishery management solutions. Mitigation measures must not only be practical and convenient, but cost-effective and provide crew with incentives to employ them consistently and effectively. Collaboration provides a way to disseminate tools and strategies that have been developed and implemented in US longline fisheries. These approaches can then be refined for use by foreign fleets.

In March 2006 the WPRFMC (2006a) voted to request that the US Department of Commerce close the Hawaii shallow-set longline fishery targeting swordfish because they were near to reaching the annual limit on turtle interactions. The fishery operated during all of 2005 without reaching the limits on leatherback and loggerhead takes. In the first two months of 2006, however, the fishery had already interacted with 15 loggerheads and one leatherback turtle. The probable explanation for this was that the 17º and 20º isotherms were tightly compressed, reducing the turtles' habitat resulting in an increased likelihood of interactions. BPUE rate in the first quarter of 2005 was 0.016 turtles per set compared to 0.034 turtles per set during the first quarter of 2006.

Recently (WPRFMC 2006b) some of the regulations covering Hawaii-based longline permit holders have been extended to include all vessels that target tuna, billfish, mahi mahi, wahoo, and other pelagic species fishing within the 200 mile EEZ managed by the WPRFMC. As of 15 December 2005, trollers, handliners, and operators of non-longline vessels must follow specific release protocols for captured turtles. All owners and operators of permitted longline vessels operating in the Western Pacific Region must carry line clippers and bolt cutters; must abide by prescribed safe handling, resuscitation, and release requirements for incidentally hooked or entangled sea turtles (larger vessels must carry dip nets); and must attend protected species workshops annually. In addition, all permitted longline vessels (not just the Hawaii-based vessels) that employ shallow-sets north of the equator must use 18/0 or larger circle hooks and only mackerel-type bait. In other words, turtle bycatch mitigation management measures implemented by WPRFMC will apply to American Samoa, Guam, and the Northern Marianas Islands in addition to Hawaii.

Kobayashi and Polovina (2005) report on an evaluation of time-area closures to reduce incidental sea turtle take in the Hawaii-based longline fishery using a generalised additive model (GAM). GAMs of sea turtle take in the fishery were developed at NMFS Pacific Islands Fishery Science Center (PIFSC), using observer data, to identify time-area closures that would effectively reduce interactions with sea turtles while minimizing hardships to longline fishermen. The GAMs were then used to predict total take using logbook data. Computer simulations were used to assess the impact of seasonal and spatial closures. Leatherback turtles were the primary concern in the study. Impacts to the fishery were measured by predicting the fraction of the fleet that would be displaced by time-area closures, and long term financial impacts were estimated. Due to the widespread patterns of leatherback takes spatially and temporally it was difficult to define the best scenario for reducing takes with minimal impact on the fishery. April and May accounted for the highest monthly leatherback takes, with a widespread spatial distribution. By contrast, olive ridleys were taken more in southerly regions (with no seasonal trend) and loggerheads more in northerly regions (January and February had the highest takes). In was concluded that, generally, combinations of seasonal and spatial closures provide the best solutions when targeting a particular level of turtle take reduction with least disruption of fishery effort; and that time-area closures are a viable option even in complex situations with multiple species, but that further work in modelling pelagic movement of turtles and fishing gear characteristics would be useful.

6.2 Management in the Atlantic

NOAA (2005a) has produced a guide for complying with the regulations for Atlantic tuna, swordfish, sharks, and billfish fishermen that includes pelagic longline gear restrictions. To fish with pelagic longline gear in the Atlantic Ocean and adjacent waters fishermen must possess three permits: swordfish, shark, and tuna. There are a number of time/area closures that apply to these permit holders: the Northeastern United States area is closed during the month of June (the coordinates are 39 to 40ºN latitude and 68 to 74ºW longitude); the Charleston Bump area off the state of Georgia is closed from 1 February to 30 April; the Florida east coast is closed year-round; the DeSoto Canyon offshore of the west coast of Florida is closed year-round; and the Northeast Distant (NED, where the circle hook experiments took place) is closed year-round except to vessels fishing with specific gear and bait, and complying with other conditions. The gear restrictions for fishing in the NED state that pelagic longline vessels, when fishing in the NED, are limited to using only 18/0 or larger circle hooks with an offset not to exceed 10º, and are limited to using only whole Atlantic mackerel and/or squid baits. In addition, the vessels must possess and use sea turtle handling and release gear in compliance with NMFS's release protocols (see below). Outside the NED vessels can use either 18/0 circle hooks with an offset not exceeding 10º, or 16/0 or larger non-offset circle hooks. In additional, all hooks must be corrodible, non-stainless steel. The length of any branchline must be 10 per cent longer than the length of any floatline if the total length of any branchline plus floatline is less than 100 m. There are other restrictions that apply to other bycatch species in the NOAA guide including the prohibition on using live bait in the Gulf of Mexico (reduces billfish bycatch).

NOAA (2005b) has produced a guide for the US West coast highly migratory species. The restrictions in the guide on pelagic longline are very brief. The highly migratory species final management plan prohibits all pelagic longline fishing inside the West Coast US EEZ as well as shallow-set longline fishing in the adjacent high seas areas.

6.3 Other management scenarios or ideas

Largacha et al. (2005) report on a hook exchange programme that was carried out in Ecuador in 2004. Circle hooks of various sizes were exchanged for J hooks on 115 participating vessels on a voluntary basis. More than 15,000 circle hooks were freely exchanged for J hooks that the boats usually used. In addition, tools and instructions for releasing turtles were provided to the fishermen. An observer programme was conducted to monitor the effects of the hook exchange programme. This was all brought about by a broad coalition of local, national, and international stakeholders, including fishermen unions and cooperatives, industry groups, government and non-government bodies, and environmental groups. Technical support was provided by NOAA researchers from Pascagoula, Honolulu, and La Jolla (US), and by IATTC staff from La Jolla (US), Ecuador, and Panama. Financial support was provided by a host of organisations. Preliminary results of the programme, based on observer trips over one fishing season in the tuna fishery and a smaller sample in the mahi mahi fishery, were very encouraging. Circle hooks were found to reduce hooking rates of turtles by 44 to 88 per cent in the tuna fishery and by 16 to 37 per cent in the mahi mahi fishery. The total reduction in turtle mortality was estimated to have been 63 to 93 per cent in the tuna fishery and 41 to 93 per cent in the mahi mahi fishery. Catch rates for the tuna fishery were about the same with circle hooks and with J hooks, but the catch rate for mahi mahi dropped off by almost one third with circle hooks. The program had other benefits, however. There was a growing awareness of the turtle bycatch problem as a result of the several workshops that were conducted. A total of 56 workshops were organised that were attended by more than 2500 fishermen from 17 different locations, covering the entire coast of Ecuador. The results show that programmes such as this one can significantly reduce sea turtle mortality. However, data are needed from more than just one season and time is needed for fishermen to develop skills with circle hooks and with the release tools.

Gilman et al. (2005) report on design for a pilot fleet communication programme for the Hawaii tuna and swordfish fisheries aimed at reducing bycatch. There is anecdotal evidence that if a longline vessel catches a turtle, moving the vessel away from the grounds where the turtle capture occurred before making another set will reduce the chance of having another turtle interaction. This is based on observations from the Hawaii and Atlantic fisheries. In these fisheries, longline vessels could move to new grounds after observing a turtle interaction and then notify the rest of the fleet. Fleetwide communication protocols can report real-time observations of hotspots so that the entire fleet can avoid fishing in the area. This is a voluntary form of time/area closure to reduce bycatch that has the potential to allow commercial fisheries to operate as a coordinated "one fleet". Four parameters need to be considered when designing a fleet communication programme including:

- Technology for communication — fleet communication programmes can use e-mail via satellite connections, radio, phone, fax, or a combination of these.
- Observer programme — it may be possible to make use of onboard observers to transmit data on bycatch.
- Management — options for managing fleet communications include fishery associations, fishery management authorities, or private companies. Government organisations usually do not have the resources to process and transmit data in real-time.
- Programme policies — expert advice is needed to determine how long a hotspot should be avoided, and how large an area around a hotspot should be avoided.

The Food and Agricultural Organisation (FAO) of the United Nations has issued a set of guidelines to reduce sea turtle mortality in fishing operations (Oceanlaw 2004). The guidelines were an outcome of an expert consultation held in Rome in 2004. The guidelines are directed towards members and non-members of FAO, fishing entities, subregional and global organisations, whether governmental or non-governmental, concerned with fisheries management and sustainable use of aquatic ecosystems. Recommendations in the guidelines for longline fisheries focus on development and implementation of appropriate combinations of hook design, type of bait, depth, gear specifications and fishing practices in order to minimize bycatch or incidental catch and mortality of sea turtles including the following:

- Use of large circle hooks with no greater than a 10º offset, combined with whole fish bait;
- Arrangement of gear configuration and setting so that hooks remain active only at depths beyond the range of sea turtle interaction;
- Retrieval of gear earlier in the day and reducing soak times; and
- Retention and use of necessary equipment for appropriate release of incidentally caught sea turtles, including de-hookers, line cutters, and dip nets.

The Western and Central Pacific Fisheries Commission (WCPFC 2005) has issued a resolution to mitigate the impact of fishing for highly migratory fish species on sea turtles that includes implementing the FAO Guidelines to Reduce Sea Turtle Mortality in Fishing Operations (Oceanlaw 2004) in order to reduce the incidental catch of sea turtles and to ensure the safe handling of all turtles that are captured, in order to improve their survivability. The Commission urges all members to undertake trials of appropriate size circle hooks in commercial pelagic longline fisheries and to require longline fishing vessels flying their flags to carry on board and, when sea turtle interactions occur, employ the necessary equipment (de-hookers, line cutters, and dip nets) for the prompt release of incidentally caught sea turtles.

6.4 Summary of management options to address sea turtle and longline interactions

The above sections have suggested a range of management options being tried or considered in deferent regions of the work to address the sea turtle and longline interaction issue. Table 3 below summarises the management options currently being used or discussed, and they are presented in no specific order.

Table 3: Summary of main management options in regard to sea turtle and longline interactions

Management option	Comments
Time and area closures	Time and area closures can work if all fishing effort in the closed area is controlled, but is discriminatory if the fleet of one country is stopped from fishing in an area while others continue to fish in this area. Time and area closures can increase fishing effort in other areas when vessel displaced by the closure move to other locations to fish. There should be clear reasons and benefits identified before time and area closures are considered, as these affect the viability and livelihoods of the fishing sector and the sectors that support them. Seasonal area closures can work, however, for different species of sea turtles the

Management option	Comments
	time and area may differ, and change as a result of oceanographic conditions, so assessments may need to be undertaken before closures are implemented. Time and area closures can also work for areas with a high probability of sea turtle interactions, for example, seasonal migration paths to feeding or breeding grounds, as turtles are very migratory animals. Monitoring and enforcing time area closures can be costly and time consuming for managers.
Effort limit (number of sets)	Limiting the number of sets that can be made in a season or year can control fishing effort, however, a set needs to be defined (how many hooks) and the type of set (deep-set or shallow set) needs to be considered, as a restriction on the number of sets may be for one type of set, such as in the Hawaii shallow-set (swordfish) longline fishery. Independent monitoring (100% observer coverage) will also be needed.
Effort limits (amount of gear and/or soak time)	Research has shown that in some locations, sea turtle interactions increase with the length of soak time. Therefore, using less gear more often may be a way of reducing interactions. That is, setting and hauling a shorter longline twice in a 24 hour period may be more effective in reducing sea turtle interactions than setting and hauling a longer longline once per 24 hours. Managers may also want to restrict the number of hooks for a set. Independent monitoring (100% observer coverage) will also be needed.
Hook restrictions	The exclusive use of circle hooks could be implemented in a longline fishery as a management measure. Care will be needed in defining the hooks to be used, as different manufacturers have different ways to number their hooks. Hook material may also be regulated, with the banning of stainless steel circle hooks. Some doubt has been expressed by some conservation groups as to the success of using circle hooks, however, it is clear that circle hooks greatly reduce post-harvest mortality, as most turtles are hooked in the mouth with circle hooks.
Hook and bait types	Managers can stipulate that only circle hooks of a specified size with mackerel bait or circle hooks of a specified size with squid bait can be used in specific fisheries or at specified times of the year. Boats can be monitored in port for the hooks and bait, although observer coverage might also be necessary.
Imposing gear modifications	Gear modifications may be developed in the future that will assist reducing sea turtle interactions. Care must be taken though as the economics of the fishing operations need to be considered in the introduction of gear modifications. If a modification to gear is going to result in lower catches of target species, then fishermen are not going to want to make the changes.
Sea turtle interaction limits or allowable number of sea turtle interactions	Interaction limits can be calculated as has been done in the Hawaii swordfish fishery. Limits would need to be re-calculated at regular intervals to ensure their continued relevance. Observer coverage (100%) would be necessary to ensure independent monitoring and recording of all interactions. If the number of interactions is reaching the limits set, the fishery work need to be closed once the limit was reached.
Use of various satellite data	Fishermen use a range of satellite, altimetry and sea surface temperature data to identify the most likely or most productive fishing grounds. From the research, sea turtles are also looking for these same productive areas for feeding. Satellite data can be used to identify likely “turtle hotspots” to be avoided by fishermen, although these are likely to be the best fishing locations as well.
Fleet communications	On researcher has suggested that fishing fleets work together and communicate regularly on and sea turtle interactions. This may identify “turtle hotspots” that fishermen can avoid. How far vessels would need to travel away from potential “high interaction spots” would need to be assessed, as well as the role of managers in implementing such an approach.
Hook exchange	In countries where there are basically no management arrangements in place, simple approaches can be made towards change, such as a hook exchange programme, where circle hooks are exchanged for J hooks as a way to introduce circle hooks to the fishery.

Management option	Comments
Development of management and mitigation measures	The approach to fisheries management now taken in most countries it to fully include the fishing industry in all aspects of the process. This approach is necessary to ensure that appropriate management measures are developed, and that the fishing industry has accepted the measures and implements them and thus compliance is more likely. The same is true for the development of mitigation measures, with industry working alongside scientists, managers, NGOs and other stakeholders in the development and implementation of mitigation measures. Alternately, voluntary measures are often more effective than binding laws, and these should be encouraged wherever possible.
Imposing regulations	Government need to impose regulations from time to time, and these need to be realistic and flexible, so that they can be easily changes when events change or new technologies are developed. Again, it is best if regulations are developed with stakeholders, including the fishing industry, to ensure acceptance and implementation. It is also important that any regulations being implemented can be enforced by the regulating body. It is useless to impose regulations that can not be enforced, as they will only be ignored, and this makes it more difficult to implement other regulations and have them taken seriously.
Monitoring and enforcement (including observer coverage)	Monitoring and enforcement is an important part of any management measures being implemented. At sea observer coverage is the most effective approach, as this allows independent recording of activities. The amount of coverage though will depend on the measures in place. For instance, if interaction limits or certain types of effort restrictions are implemented in a fishery, then 100% observer coverage is necessary. In other fisheries, 20% coverage may be representative to know what is happening in that fishery. When covering a percentage of the fleet, it is important that observers are placed on as many different vessels as possible throughout the season. This shares the costs amongst the fleet, as well as giving a more representative sample of the fishing practices of the fleet. The actual cost of the observer programme and who pays for it, also needs to be considered in the setting up stage, as these programmes are expensive, and will depend on the fleet size and percentage of coverage to be undertaken.
Data collection	Data collection is important to identify what is being caught or interacted with in a fishery, and to measure change or progress in reducing interactions with sea turtles. Logbook systems are in place in some countries, while the less developed countries are starting to look at data collection systems. When implementing a logbook or data collection system, it is important to include the fishing sector in the design of the system, or those that will be providing the data. If such a scheme is imposed on fishermen without consultation, then the quality of the data being provided may be questionable. Possibly an approach that can be taken in some locations is to have trained people or “creel samplers” going to fishing ports and interviewing fishermen when they return from fishing, in preference to having fishermen themselves fill out log or data sheets. Identification sheets may also be necessary to allow those recording the data to better identify the catch to a species level. For fishermen, all sea turtles may look the same, even if several species are actually interacted with. The data collection though needs to be on a species basis, as turtle species interact differently and may require different mitigation techniques.
Turtle handling tools and their use on vessels	A range of de-hookers and other sea turtle handling tools have been developed, and in some countries it is mandatory for all longline vessels to carry and use these tools when necessary. In other locations, similar tools can be developed, and fishermen should be encourages to use them. There are also well described handling practices for sea turtles in the event that on is hooked by longline fishermen. These practices need to be followed at all times to maximise the chance of the sea turtle’s recovery and reduce post-capture mortality.
Required training and/or certification	In Hawaii, longline fishermen are required to attend annual workshops on handling sea turtles and other protected species (seabirds and cetaceans) to ensure they are aware of the latest equipment and handling methods. Similar workshops can be conducted in other countries to raise awareness and educate longline

Management option	Comments
	fishermen in the equipment that is available and the correct use of this equipment.
Production of awareness or educational materials	In countries where there are no management arrangements in place for their longline vessels, the first step will be to develop awareness raising materials on the sea turtle issue and distribute these to local fishermen. There is a suite of good materials around, and those currently involved in this work are happy to share these materials with others. In most cases, existing materials just need to be translated into local languages and distributed to fishermen. In addition to the materials, some training may be required to assist local fishermen to understand the problem, and to understand the equipment and handling methods being introduced.

As can be seen in Table 3, there is a wide range of options available to fisheries managers, and these cover well developed and lesser developed longline fisheries. In reality, no single approach is going to solve the issue, so a more integrated approach will need to be taken. Management of a specific longline fishery may require the implementation of many of the above options, while in a different fishery, other measures may be required. It should also be noted that the management options here are not exhaustive, and they only cover the fishing side of sea turtle interactions, and this is only part, possibly a minor part, of the overall problems that sea turtles are facing in regard to their declining numbers. The harvesting of adults and eggs for food, pollution, loss of nesting beaches and habitat are other issues that need to be tackled in parallel with the fishing interactions. Therefore a holistic, integrated management approach (ecosystem approach to fisheries) seems to have the most chance of success in solving the problem of declining sea turtle numbers, including interactions with longline fisheries.

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