PAPER

Pelagic Longline Fishing Gear: A Brief History and Review of Research Efforts to Improve Selectivity

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ABSTRACT

Pelagic longline gear had several independent evolutions, but the most widespread form appears to have been originally developed by the Japanese as early as the mid-19th century. Technological developments such as polyamide monofilament line and modern fishing vessel construction have resulted in the evolution and expansion of this gear type as the primary worldwide method of commercially harvesting large pelagic fishes such as broadbill swordfish and tunas.

Although the adaptability of the gear through changes in materials, lengths, and deployment strategies has resulted in generally high selectivity for many target species, the bycatch of protected species by pelagic longlines is considered a global problem in the conservation effort to sustain populations of sea turtles, sea birds, and some istiophorid billfishes (sailfishes; spearfishes; marlins). Recent research on the modification of pelagic longline fishing strategies uses this inherent adaptability of the gear to avoid or reduce the mortality of bycatch species. This is an alternative to the traditional management strategy of closed areas, which fishermen view as less effective and generally more restrictive (limiting) with respect to target catches. This work with academic partners and commercial fishermen has resulted in the development of bycatch reduction strategies which include safe handling and release gear and protocols, use of circle hooks in place of traditional J-style hooks, restrictions on gangion and mainline lengths, and corrodible hooks.

Brief History of Pelagic Longline Gear

The most widespread form of pelagic longline gear appears to have been originally developed by the Japanese. Nakamura (1951) reported that local tradition in the Izu region of Japan claims the gear was originated by an individual named Fujii in the Kaei Era (1848-1853) and that similar gear was in use by the inhabitants of the Bōsō area (Chiba Prefecture) around the same general time period. However, Shapiro (1950) reported that the gear was imported from the Wakayama Prefecture almost 100 years earlier and developed further by the fishermen of Mera, a fishing village near the entrance of Tokyo Bay.

The development of the Hawaii-based pelagic longline fishery began in 1917 when a Japanese fisherman named Imose began using this gear to fish the waters off the northwest Waianae coast of Oahu (June, 1950). Longline use was documented in the Mediterranean at the beginning of the twentieth century (Stiles, 2004). An early form of pelagic longline in the western North Atlantic Ocean was developed by New England fishermen to target bluefin tuna *Thunnus thynnus* on Stellwagen Bank in the mid-1940s after combining keg-line swordfish harpoon gear and halibut line-trawl (bottom longline) gear (Wilson, 1960). A form of pelagic longline gear which used heavy braided synthetic line floated just under the surface of the water was also developed in Norway in the late 1960s for a short-lived fishery that targeted porbeagle shark *Lamna nasus* (Gibson, 1998). It is also worth noting that small vessels using a very similar gear were also fishing at night for swordfish off the coast of Cuba during this period (Sainsbury, 1996). It is likely that there were other developments of this gear type in local fisheries throughout the Atlantic, Pacific, and Indian Oceans and Mediterranean Sea.

Improvements in fishing vessels, including the introduction of the internal combustion engine in the early 1900s, resulted in an expansion of the fishing grounds, enabling the Japanese to fish the Nojimasaki fishing grounds for albacore in the central Pacific by the early years of the Shōwa Era (circa 1926). The Japanese fleet had an operating radius of approximately 2000 miles eastward to the longitude of Midway Island (approximately 180° W) prior to World War II, although the vast majority of those vessels landed at their homeports in mainland Japan (Shapiro, 1950). Global expansion of longline fisheries began in the 1950s and 1960s, spreading throughout the Atlantic (North and South) and Mediterranean. This expansion was largely driven initially by the Japanese tuna market and supported by improved freezing technology and international transportation. Subsequently, liberalized trade regulations and emerging markets for swordfish and other species (e.g., shark fins for China) encouraged additional fleet expansion.

Multi-filament nylon mainlines still dominate the international fishery, but the development of single-strand monofilament line in the late 1970s and the combination of baited hooks with chemical light sticks resulted in the expansion of the pelagic longlines as the primary worldwide method of commercially harvesting large pelagic fishes. The majority of longline fishing effort occurs in the Pacific Ocean, while the remaining effort is in the Atlantic and the Indian Ocean (Lewison et al., 2004). Japan, Korea and the Republic of China (Taiwan) are the primary industrial fleets in the Pacific Ocean. In the Eastern Pacific, Peru, Ecuador, Costa Rica, Mexico, Guatemala, El Salvador, Nicaragua, Panamá, and Columbia have large artesanal longline fleets. European and North African nations (i.e., Spain, Italy, Greece, and Libya) dominate the Mediterranean Sea fishery. Spain is one of the dominant Atlantic longline nations, operating in both the North and South Atlantic, along with Japan, the United States, Portugal and Canada. The People's Republic of China, Brazil, Korea, Equatorial Guinea, Belize, Honduras, and Panama also fish the South Atlantic (Lewison et al., 2004).

Description of Pelagic Longline Gear

Longline gear consists of three basic components: the mainline, the branch line, and the baited hook. All of these parts are adaptable for targeting specific species through changes in materials, lengths, and deployment strategies. For example, setting the mainline along the seafloor, a demersal set targets flatfish, cod, groupers and coastal sharks. Using small buoys and float lines to suspend the gear below the surface results in a pelagic longline set that targets pelagic tunas, swordfish, billfish and other free-swimming predators. In between these two extremes are a variety of different configurations that are adapted by local fisheries to target specific species.

Pelagic longline gear is used worldwide to capture widely dispersed species. The gear is very effective at capturing large pelagic fishes, such as bluefin, bigeye *Thunnus obesus*, yellowfin *T. albacares*, and albacore *T. alalunga* tunas, broadbill swordfish *Xiphias gladius*, and the istiophorid billfishes. The widespread use of pelagic longline gear has resulted in several different names for the same components. Because much of the original literature describes the gear used by Japanese vessels for fisheries, Figure 1 describes the basic units of gear using both traditional Japanese and English terms.

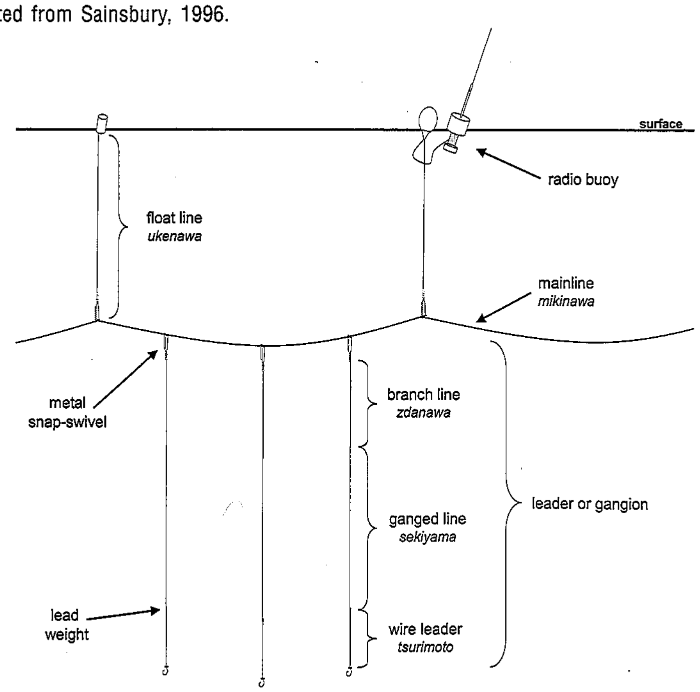
Mainline

The Japanese longline gear historically used lines made of hemp (Nakamura, 1951), with subsequent improvements in materials including cotton and braided nylon. Originally, the mainline (*mikinawa*) was not continuous, but rather a series of shorter sections of mainline with permanently attached branch lines. Sections were hand-tied together as the gear was deployed. As the gear was retrieved, sections were untied and coiled into separate baskets for storage. This method was labor intensive and some vessels switched to a system in which the mainline was simply coiled as a single unit in a dedicated storage container or compartment. However, the hand-coiled gear was still being used in Hawaii during the late 1940s (June, 1950), and the technical name for the length of gear between floats remains the "basket."

The most recent technological improvement in the mainline part of the gear was the development of heavy-gauge (3.0-3.5 mm), single-strand polyamide monofilament in the late 1970s. Although not as resilient to abrasion as the older braided nylon line, polyamide is lighter, less visible and has less drag.

FIGURE 1

Configuration of pelagic longline gear (not to scale), with Japanese terms italicized. The common modern gangion construction is shown on the left side of the basket and the more traditional form on the right. Adapted from Sainsbury, 1996.



Hauling Mechanisms

Technological advances in the Japanese fleet by the 1950s included a mechanical line hauler. Powered by electricity or from a belt connected directly to the vessel engine, the hauler pulled in mainline at the rate of approximately 400-800 feet per minute (Nakamura, 1951). After reaching the deck of the vessel, the line was either coiled into individual baskets or routed across the deck into the mainline storage compartment. Japanese style basket gear was utilized in the United States in the early 1950s but was replaced by continuous mainlines that were coiled on steel spools or reels, with float lines and branch lines as separate components. In the early days of the U.S. swordfish fishery, some vessels used a hand-cranked wooden mainline spool to store the mainline after being hauled by the line-hauler (Gibson, 1998). While Asian fleets still primarily rely on line haulers, most other fleets have adopted hydraulically-powered metal spools as the preferred mode of mainline storage.

Floats, Float Lines, and Buoys

Float lines (*ukinawa* or *abanawa*) are used to suspend the mainline at depth. These were originally attached to net-covered glass balls approximately 30 cm in diameter or paulownia wood floats, and often a bamboo pole and flag combination was attached to this float to increase visibility. In later years, a carbide lamp or battery-powered light was also attached to help monitor the movement of the gear during nighttime deployments and glass and wooden floats were replaced with aluminum floats. Float lines are stored in either plastic baskets or on spools.

Modern pelagic longline gear uses a combination of extruded foam, hard plastic, and polyethylene plastic inflatable floats to support the gear. At regular intervals along the mainline, vessels will attach either a "high-flyer"—a long aluminum pole with a diamond-shaped radar-reflecting top end—or a radio beacon buoy that transmits a radio signal which can be used as a direction-finder by the vessel captain. More sophisticated models of radio beacon buoys will only transmit when they receive a signal from the vessel, and the most recent versions will obtain a position from a global positioning satellite (GPS) system and transmit location coordinates to a computerized plotter. These various floats are distinguished colloquially in the U.S. longline fleet as "bullet floats" (bullet-shaped extruded foam floats), "ball floats" (large, inflatable polyethylene floats), and "buoys" (large marker floats, such as radio beacon buoys or high-flyers). Within a given longline "set", baskets are separated by bullet floats (see Figure 1). A number of baskets are separated by large marker buoys into "sections", with intermediate ball floats to help suspend the line at depth.

Branch Lines

The branch line (*zdanawa*), also called a "leader" or "gangion", was historically made of the same material as the mainline, to which a "ganged line" or *sekiyama* of cotton-wrapped steel wire was attached ("ganged" also means "wrapped"). At the end of the *sekiyama* was a small length of steel wire tipped with a hook. Modern pelagic longline vessels generally use a long section of monofilament sometimes interrupted by a small leaded swivel approximately 2 m above the hook. This final tippet section is sometimes called a "tail" and spare tippets can be made in quantity prior to haulback to facilitate replacement of damaged ends prior to storage of the branch lines between sets. Modern pelagic longline gear also employs metal snap-swivels to connect the float and branch lines to the mainline, rather than either splicing or hand-tying them into the large-gauge monofilament.

The number of branch lines per basket is highly variable by fishery and target species. In general, an increase in the number of branch lines also increases the sagging "catenary curve" of the mainline between floats, which allows both the basket as a whole to fish a broader depth range and the hooks in the middle of the basket to fish at greater depths than those near the float lines. Longline gear deployments targeting tunas generally employ more hooks per basket than those targeting swordfishes. Despite extensive field monitoring and theoretical work, accurate modeling of actual fishing depths of pelagic longline gear remains elusive (Bigelow et al., 2006), in part because of the varying effects of environmental influences on the gear.

Hooks

The shape and size of hooks has been affected by both catch and bycatch considerations (see Figure 2). Historically, vessels used standard J-style and Japanese style tuna hooks. Recent attention has been given to circle hooks (a hook with the point turned perpendicularly back to the shank) as a means to reduce bycatch mortality. In contrast to J-style and Japanese style tuna hooks, circle hooks tend to slide over soft tissue and rotate as the eye of the hook exits the mouth, frequently resulting in the hook catching in the corner of the jaw (Cooke and Suski, 2004; Trumble et al., 2002).

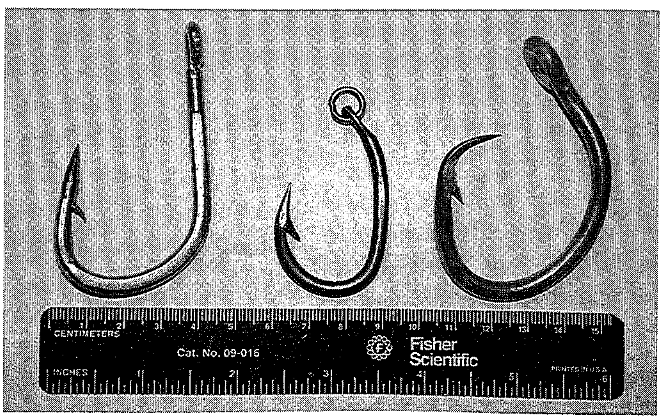
Circle hooks have been used since the early 1980s by commercial halibut fisheries in the U.S. Pacific Northwest (IPHC, 1998) and are being increasingly used in some U.S. marine recreational fisheries. Some vessels targeting tuna have switched voluntarily to circle hooks following preliminary studies that suggesting they may increase tuna catch rates (e.g., Falterman and Graves, 2002; Kerstetter and Graves, 2006a). The International Commission for the Conservation of Atlantic Tunas (ICCAT) has encouraged the use of circle hooks in the Atlantic pelagic longline fisheries and they are mandatory in the U.S.-based Atlantic longline fishery as well as in the Hawaii-based shallow-set swordfish pelagic longline fishery. Additional research is currently being conducted on the effect of the size of the circle hook on catch rates, as well as the hook construction (e.g., metal composition).

Other Technological Developments

Advances in technology have resulted in the introduction of many electronic devices to assist in navigation, communications, and finding target species. These tools can also be used to avoid interaction with bycatch species and improve selectivity of longline fishing. Other changes have increased fishing power by improving searching efficiency or increasing the time spent on fishing grounds. Technological advances include GPS-aided navigation, radar, echo sounders and sonar, weather facsimiles, bathythermographs, Doppler current meters, real time sea surface temperature data,

FIGURE 2

Three types of hooks commonly used in pelagic longline gear configurations. From left to right, a size 9/0 J-style hook, a size 7/0 ringed tuna hook, and a size 16/0 double-strength circle hook. Photo courtesy of K.M. Kerstetter.



ocean color imagery, and computer-aided data integration and position plotters, satellite communication and vessel monitoring systems. Improvements in fishing gear include the use of chemical light sticks, electronic lights (e.g., Electralumes®), electric line haulers and line shooters, and radio buoys.

Bycatch

Bycatch in pelagic longline fisheries is defined as non-target species that are discarded because they either have no commercial value or because they are protected or under management measures requiring they not be landed. These protected species include sea turtles, seabirds, marine mammals, some shark species, and some istiophorid billfishes. Discarded bycatch species with no commercial value include lancetfish *Alepisaurus* sp., snake mackerel *Gempylus serpens*, pelagic rays, and some sharks. This designation also applies to swordfish, tunas, and billfish caught in fisheries that have established minimum length regulations. The proportions of different species vary significantly by fishery target species and geographical region.

Due to the various possible gear configurations, the pelagic longline has been considered highly selective for large target species when compared with such gears as trawling or pelagic gillnetting (Yamaguchi, 1989). In many cases this reflects the fact that the catch is usually dominated by larger species, and several numerically dominant components of the bycatch have high survival rates on the line, particularly blue sharks and pelagic rays. However, the infrequent bycatch of protected species including sea birds, sea turtles, and marine mammals by pelagic longline gear is still considered a global problem in the conservation effort to sustain these species, largely because of the overall scale of longline effort. The cumulative effect of rare events is significant for several populations. Therefore, several of the species that are of particular international management concern are particularly challenging because they are rare components of the catch.

Longline fisheries are considered a critical threat to albatrosses and large petrels (Brothers et al., 1999). When fishing gear is being set, seabirds are hooked or entangled and drown as the gear sinks. The species of seabirds most frequently caught by longline vessels are albatrosses and petrels in the Southern Ocean, shearwaters in the North Atlantic fisheries; and albatrosses, gulls, and fulmars in the North Pacific fisheries.

Several sea turtle species are also occasionally captured in longline fisheries, including loggerhead *Caretta caretta*, leatherback *Dermochelys coriacea*, olive ridley *Lepidochelys olivacea*, Kemp's ridley *L. kempii*, and green *Chelonia mydas* sea turtles. Although the number of drownings recorded is very low, the injuries sustained in interactions with hooks and line are of concern as little data is available regarding post-release mortality.

Marine mammals that have been known to interact with longline gear and become entangled or hooked include pilot whales *Globicephala* sp., false killer whales *Pseudorca crassidens*, and Risso's dolphins *Grampus gresius*. Several other species also rarely interact with the gear. The nature of these marine mammal interactions is still poorly understood, and such events may result from depredation on the target catch of the gear rather than ingestion of the baited hooks.

Some istiophorid billfish species and sharks are variously considered bycatch, protected, or target species dependant on the specific fishery. The two main billfish species caught as bycatch in the multinational longline fishery are blue marlin *Makaira nigricans* and white marlin *Tetrapterus albidus*. Bycatch by pelagic longlines is a major source of adult mortality for both species, which are currently identified as overfished in the Atlantic Ocean (ICCAT, 2005).

Development of Gear Technologies to Reduce Bycatch

In recent years, pelagic longline fishers and scientists in many countries have been developing, testing, and implementing fishing techniques and gear modifications to improve the selectivity and sustainability of pelagic longline fisheries and increase post-release survival of by caught animals. This approach is preferable over other management strategies that reduce available fishing grounds, such as time/area closures, which have historically predominated U.S bycatch reduction measures, but which have been only rarely adopted by regional fisheries management organizations (RMFOs).

Over the past decade, national governments, RMFOs and longline industries have developed and tested numerous seabird mitigation methods in longline fisheries. Several methods nearly eliminate bird captures when correctly employed (Brothers et al., 1999). Methods which not only have the capacity to minimize bird capture, but are also practical and provide crew with incentives to employ them consistently and effectively, hold promise for minimizing seabird bycatch to negligible levels (Gilman, 2001). These methods include bird-scaring flag lines that stream behind the vessel ("tori lines"), line shooters, side setting, and weighted lines to rapidly sink the baits below the range of the birds, and dyed bait to reduce visibility during deployment.

Longline gear operating characteristics including geographic area, month and time of set, gear soak time, surface temperature, fishing depth, bait size, bait type, baiting technique, hook size, and hook type can have significant effects on the selectivity of pelagic longline gear (Hoey and Moore, 1999). Circle hooks with bending strengths capable of selectively releasing large bluefin tuna and marine mammals are being investigated as a bycatch mitigation technique. Adjustments to the gear and operating practices associated with live bait use in waters with surface temperatures greater than 25°C may also reduce sailfish *Istiophorus platypterus* and marlin bycatch rates. Initiatives to reduce effort in shallow depths while refocusing effort in cooler strata associated with frontal systems or by fishing at greater depths should all contribute to reductions in sailfish and marlin catch rates. One such technique has recently been developed to reduce shallow bycatch species and selectively target bigeye tuna by setting the gear to ensure all hooks are below 100 m depth (Beverly, 2004).

Many countries, including the United States, have conducted research to develop mitigation measures designed to reduce bycatch in pelagic longline gear with emphasis on sea turtle bycatch. This research has resulted in the development of bycatch reduction strategies which include: safe handling and release gear and protocols (Epperly et al., 2004), the use of circle hooks in place of traditional J-style hooks, the use of fish bait rather than squid, and gear restrictions such as branch line lengths 110% of the float line length, limits on the length of the mainline, and the use of non-stainless steel corrodible hooks. In addition, these mitigation measures include moving away from an immediate fishing area once an interaction has occurred and fostering vessel communications within the commercial fleet to avoid areas of high interaction ("hot spots"). Gilman et al. (2006) published a comprehensive review of longline bycatch research which includes data on reduction rates achieved with different mitigation techniques.

Circle hooks can reduce the mortality associated with fishing interactions for both fish and sea turtles. In a review of studies evaluating fish mortality associated with circle hooks compared to other types of hooks, Cooke and Suski (2004) found that circle hooks more frequently hooked fish in the jaw than in the gut and concluded that the overall mortality rates were consistently lower for circle hooks than for J-style hooks. This finding is consistent with the higher rate of post-release survival of white marlin caught by circle hooks on pelagic longline gear (Kerstetter and Graves, 2006b). In 2005 and 2006, 9 of 10 sailfish caught by circle hooks on longline gear survived for at least ten days following release (D.W. Kerstetter, unpub. data).

Watson et al. (2005) found that using large circle hooks (4.9 cm) in place of the traditional J-style hooks and switching to mackerel bait from squid bait reduced the incidental capture of loggerhead sea turtles 71%-90% and leatherback sea turtles 51%-66%. Circle hooks of smaller sizes have been shown to significantly reduce the rate of hook ingestion by the loggerhead turtles when compared to J-style hooks, potentially reducing post-release mortality (Bolten and Bjorndal, 2003). Evaluation of circle hooks in pelagic longline fisheries as a technique to reduce environmental impacts of pelagic longline gear have also been conducted in Australia, Japan, Peru, Uruguay, Ecuador, Costa Rica, Papua New Guinea, Vietnam, Mexico, Guatemala, El Salvador, Nicaragua, Brazil, Panama, and Columbia.

Conclusion

Pelagic longline gear is used worldwide for the commercial capture of large pelagic fishes such as tuna and swordfish. However, recent assessments of such co-occurring species as sea turtles and billfishes in catches with this gear have necessitated the development of a comprehensive strategy to reduce bycatch mortality for those species. The adaptability of pelagic longline gear naturally lends itself to experimental treatments designed to reduce bycatch and bycatch mortality. Recent research has demonstrated that selective changes in deployment strategies and gear technology can both preserve target catches and significantly reduce bycatch rates and bycatch mortality.

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