Catch to Bycatch Ratios: Comparing Hawaii's Longline Fisheries with Others

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ABSTRACT

The ecological impacts of pelagic longline fisheries vary with when, where, and how the mainline and hooks are set. The quantity and species composition of longline targeted and incidental catch are strongly influenced by gear configurations, especially the depth of hooks. Hawaii pelagic longline fisheries are sometimes characterized as having "high bycatch." To assess this statement quantitatively, the present study examined diverse longline fisheries, including those in Hawaii, that supply or have the potential to supply the same pelagic fishery products to U.S. markets. Incidental catch rates of sea turtles and finfish bycatch were estimated for the fisheries where data were available. The term "bycatch" is defined as fish released at sea dead or with a poor chance of survival. Indices of bycatch per unit effort (BPUE) and catch per unit effort (CPUE) were calculated from reported target catch, effort and incidental catch data for these fisheries. Catch to bycatch ratios (C/B ratio) were calculated by dividing CPUE by BPUE. C/B ratios provide a standardized index that allows 1) scaling of pelagic longline bycatch rates from low to high; and 2) comparison of Hawaii's pelagic longline fisheries with others on this quantitative scale.

The major finding of this research is that Hawaii's tuna longline fishery has a lower C/B ratio of sea turtles and finfish waste (except for longnose lancetfish) compared to most competing pelagic longline fisheries studied. Claims of high rates of incidental catch of sea turtles and finfish bycatch (waste) associated with Hawaii tuna longline fishing are therefore, incorrect. The extraordinary amount of regulation and monitoring of Hawaii longline fisheries and the rich source of data they provide for resource assessment and technological solutions to bycatch issues, qualify them as a model for fisheries management. The positive attributes of the Hawaii fishery can be considered a "value-added" component of Hawaii longline products to "brand" and differentiate them from non-Hawaii longline products that have significantly higher associated bycatch.

1. PROBLEM STATEMENT

All food production systems, including fishing, have associated ecological costs, although these may not be fully recognized or acknowledged. Rising awareness of such costs is shifting attention from the traditional management of single species or species groups to a new perspective known as ecosystem-based fishery management (FAO, 2001) or ecosystem approach to fisheries (FAO, 2003). This approach refers to a holistic view of the interrelationships between physical and living components (including people) on various geographic and temporal scales. It recognizes the importance of interactions among different fish species that are targeted or taken incidentally and the possible effects of fishing (direct and indirect) on habitat or on other species (fish and non-fish) that occupy the habitat.

The ecosystem perspective has heightened concern about the possible impacts of fisheries bycatch. As a consequence, incidental catches of non-target fish species and protected marine mammals, seabirds, and sea turtles have become a very important factor in the management of some fisheries (Hall, 1996). Bycatch is neither a new issue nor a new problem. Pelagic fisheries bycatch became highly visible because of cases involving charismatic species such as dolphins and sea turtles (Hall et al., 2000). The eastern Pacific tuna purse seine fishery-dolphin interactions in the 1960s marked the beginning of such concerns (Hall, 1996). This was followed by the well-publicized debate over the use of high seas drift nets that entangled huge numbers of non-target fish, marine mammals, sea turtles, and sea birds in the late 1980s (Hinman, 1998).

Some environmental advocacy groups specifically campaign against fish bycatch in U.S. fisheries (e.g., Dobrzynski et al., 2002). Bycatch associated with target fish is one of the criteria used in the Monterey Bay Aquarium's Seafood Watch program for advising consumers to make environmentally friendly seafood purchasing decisions (www.montereybayaquarium.org).

A 1995 United Nations agreement on conserving highly migratory fish stocks includes a directive to reduce bycatch (Doulman, 1995). In 1996, the U.S. Congress passed legislation amending the 20-year old Fishery Conservation and Management Act to include, for the first time, an explicit mandate to "minimize bycatch and, to the extent bycatch cannot be avoided, minimize the mortality of such bycatch" (Hinman, 1998). However, limited information on the stock condition of incidentally-captured species often prevents bycatch data from being compared across fisheries and considered in a reasonable biological or stock context (Hoey and Moore, 1999).

The ecological implications of discarding incidentally captured but unwanted animals are not well understood; however, the practice is perceived by resource managers and the general public as wasteful. Dead biological matter discarded in the ocean is a food subsidy and, thus, it is presumably quickly recycled. The effects may be considered positively or negatively depending on the values placed on different animals that may benefit from this food supplement and its redistribution (Harris and Ward, 1999).

It is clear that the impact of pelagic longline fisheries on populations of incidentally-captured sea turtle or finfish species, and thus the magnitude of bycatch as a management issue, depends on the following.

- The rate of capture; and
- The proportions that are released after capture alive with a good chance of survival versus dead or mortally injured.

2. PURPOSE AND ORGANIZATION OF STUDY

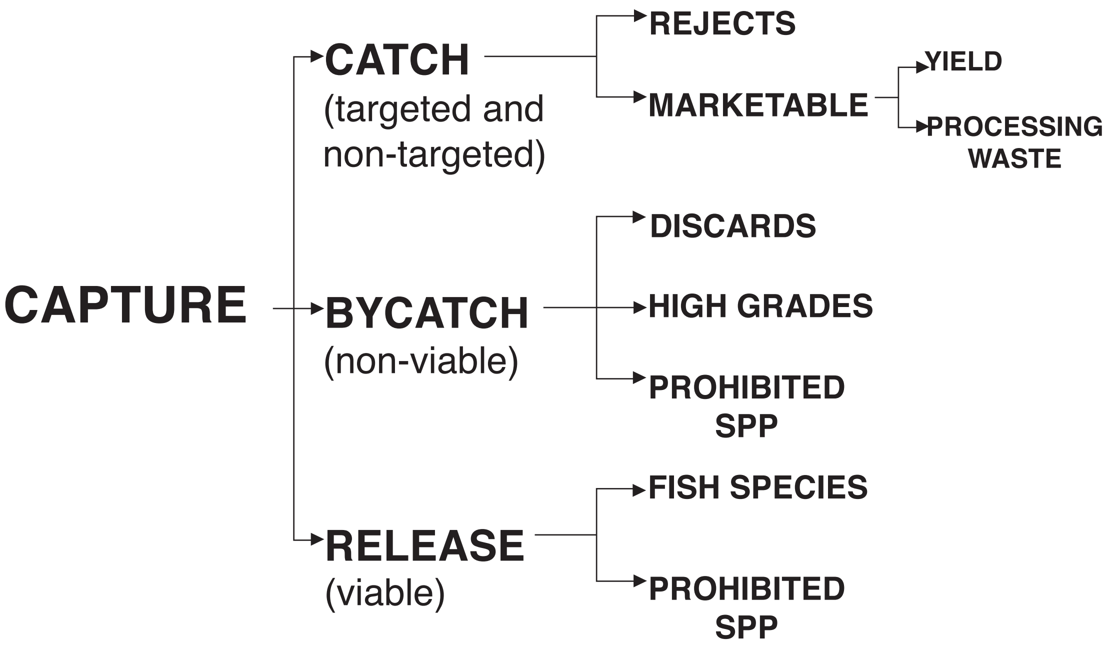
Hawaii pelagic longline fisheries are sometimes characterized as having high bycatch. There are two problems with this generalization: 1) "high" is not measured according to any quantitative scale; and 2) some definitions of finfish bycatch include non-target fish species that are released alive after capture, a conservation practice known as "catch and release" in recreational fisheries. The specific tasks of the present research are as follow.

- Clarify the term bycatch in relation to Hawaii longline fisheries (Section 3).
- Profile the heterogeneous fishing gear configurations and practices of selected pelagic longline fleets worldwide (Section 4).
- Assess the general factors that affect the incidental take of sea turtles (Section 5.1) and of unwanted fish (Section 5.2).
- Estimate target fish CPUE and incidental catch of sea turtles (BPUE, number of animals taken per unit of effort) (Section 6.1) in selected pelagic longline fisheries.
- Estimate target CPUE and BPUE of wasted fish (weight of animals discarded dead or dying per unit of effort) (Section 6.2) in selected pelagic longline fisheries.
- Compare the Hawaii longline fisheries with others in terms of C/B ratios of sea turtles (Section 7.1) and of wasted fish (Section 7.2).
- Discuss the study results and make recommendations for fishery managers to consider (Section 8).

3. DEFINITION OF BYCATCH

Finfish bycatch in U.S. fisheries has negative connotations because the word is perceived by the general public to be equivalent to "mortality" and "waste." Some usages of the term fail to distinguish animals released alive and vigorous after incidental capture from those that are dead or dying.

A clear definition of terms is a prerequisite for objective study of bycatch. The conceptual framework of Hall (1996) is useful for considering the possible fates of animals captured in fisheries (Figure 1). According to this definition, bycatch is limited to non-viable (i.e., dead or mortally injured) releases of target or non-target fish and prohibited species such as sea turtles, seabirds, or marine mammals. Fish that are caught and retained are not bycatch because they are used. Nor does bycatch include fish that are alive and viable (i.e., likely to survive) when released after incidental capture. Under the Hall definition, bycatch is clearly synonymous with waste.



Based on definitions of Martin Hall (1996)

Figure 1. Possible fate of animals, including bycatch, captured by pelagic longline fisheries.

However, there are a variety of other interpretations of the term bycatch. The Magnuson-Stevens Fishery Management and Conservation Act (MSA), under which fisheries are managed in U.S. waters, defines bycatch as animals that are caught but not sold or kept for personal use. Included are fish and non-fish species that are released alive or dead, as well as any that are injured or killed as a result of direct contact with fishing gear. The latter group includes fish that are stripped from fishing gear by predators before they can be brought aboard fishing vessels as well as any species injured or killed by lost or discarded fishing gear ("ghost fishing") (WPRFMC, 2003).

Sea turtle "takes" in Hawaii longline fisheries include unintentional interactions with fishing line and/or hooks, both lethal and non-lethal. A sea turtle take is not equivalent to a kill. Pelagic longline fisheries impact sea turtle populations if incidentally-captured animals die, not if they are released after incidental capture and survive. The mortality of sea turtles incidentally-caught in pelagic longline fishing combines immediate mortality and post-release mortality of injured animals. Post-release mortality of incidentally-caught sea turtles has not been estimated for most pelagic longline fisheries. There is little agreement among scientists and managers about the percentages of deeply-hooked and lightly-hooked sea turtles released alive that are likely to suffer delayed mortality as a result of interactions with longline gear. Until there are better estimates of post-release mortality, the analysis of mortality impacts has to be based on non-lethal and lethal sea turtle takes rather than mortalities alone.

In the Hawaii longline fishery relatively large quantities of finfish are released alive after incidental take but there is little to no information on post-release mortality (WPRFMC, 2003). By including fish released alive as bycatch, the MSA places a negative connotation on this beneficial practice. The Act provides an exception from this provision for some recreational catch-and-release fisheries but such exceptions have not yet been established for any fisheries in the western Pacific region (WPRFMC, 2003). The MSA is contradictory in that release of live fish may not be bycatch in some U.S. recreational fisheries but is always bycatch in U.S. commercial fisheries.

Other fisheries managers define finfish bycatch as all incidentally caught non-target species (Harris and Ward, 1999), whether the incidental catch is retained or not, without considering the potential value as byproducts of fishing. The same definition of bycatch is used by the Oceanic Fisheries Programme of the Secretariat of the Pacific Community (SPC) to describe non-target species caught in western and central Pacific tuna fisheries (Williams, 1996) "Any catch of species (fish, sharks, marine mammals, turtles, seabirds, etc.) other than the target species. 'Incidental catch' can be regarded as synonymous…." (Bailey et al., 1996: 2.1).

Two components of catch are combined in this definition: the non-target species catch that are retained and the non-target species that are discarded (Williams, 1996). The latter definition is confusing because "…it mixes what is waste with what is an additional source of income to the fishery" (Hall, 1995: 41).

4. TYPOLOGY OF PELAGIC LONGLINE PRACTICES

Pelagic longline fisheries operate in an area of more than two-thirds of world's oceans (about 50 million square nautical miles) (FAO, 2001). Some people regard pelagic longlining as a "relatively environmentally friendly" fishing method (Anon., undated), whereas others suggest that "the best way to describe fishing with a longline is laying an underwater minefield" (Hinman, 1998) or they view pelagic longlining as "…one of the most lucrative and perhaps destructive fisheries in the world" (Crowder and Myers, unpublished research proposal to the Pew Charitable Trusts). The problem with these generalizations is that pelagic longlining is not a homogenous method of fishing and its environmental impacts can vary significantly with specific gear configurations and fishing practices.

The general design of pelagic longline gear is relatively simple (Figure 2). Operating characteristics such as area and season fished, time of set, ocean temperature, fishing depth, bait, and other factors significantly affect the catch rates and mix of species caught (Hoey and Moore, 1999).

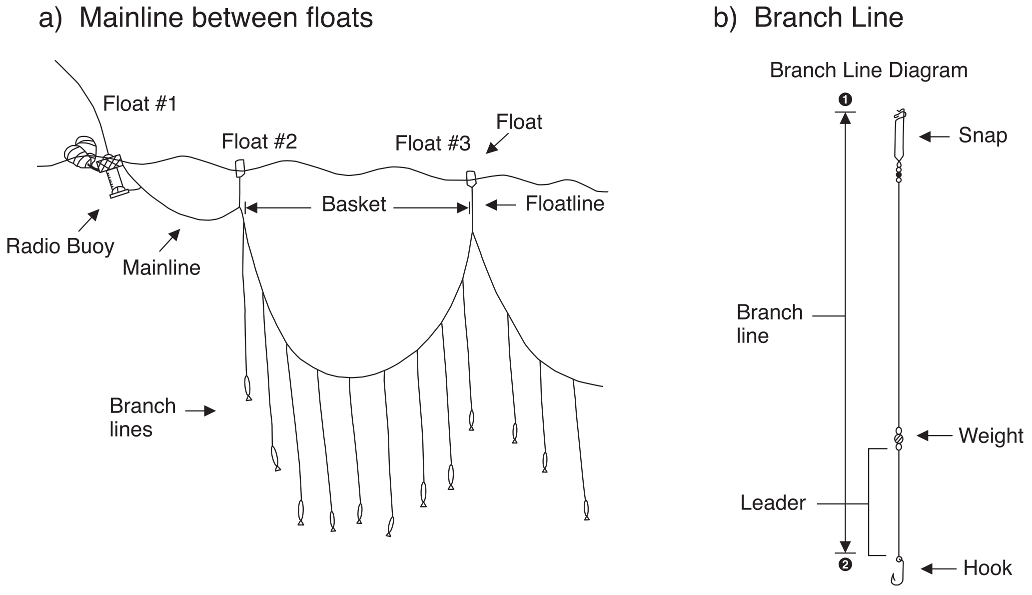


Figure 2. General design of pelagic longline gear.

Table 1 describes the diversity in longline gear, deployment, and fishing tactics recorded in the present research and discusses the possible implications for the incidental catch of sea turtles and finfish bycatch. Tables 2-6 profile and compare the distinguishing characteristics of the following pelagic longline fisheries.

Central and Western Pacific Ocean
Australia
China
Hawaii
Japan
Samoa
Taiwan

Indian Ocean
Sri Lanka

Eastern Pacific Ocean
California
Chile
Costa Rica
Mexico

Atlantic Ocean
Brazil
Namibia
South Africa

Detailed profiles are limited to longline fisheries that, like Hawaii, produce fresh pelagic fish or have that potential. The operating characteristics of Asian distant-water deep-freezing longline fleets are discussed in relation to potential incidental catch of sea turtles but no detailed profiles are provided in the present study.

Table 1. Possible implications of pelagic longline operational characteristics for the incidental catch of sea turtles and finfish bycatch.

Characteristic	Diversity Recorded in Present Study	Possible Implications for Sea Turtle Bycatch	Possible Implications for Finfish Waste
Target species	Yellowfin, bigeye, albacore, bluefin tuna, swordfish, marlin, mahimahi, shark	When shallow-water fish are targeted, especially mahimahi and shark, more hooks are set in the shallow "turtle layer."	When deep-water fish, especially bigeye and albacore tuna, are targeted, a high percentage of unwanted fish hooked in the thermocline layer may not survive due to changes in pressure, light and ocean temperature when hauled to the surface
Hook soak period	Day or night	Unknown	Different mixes of incidental finfish species are caught in day and night soak periods.
Mainline material	Nylon rope or monofilament	Unknown, although sea turtles may be attracted to and follow mainline.	Unknown
Mainline shooter	With shooter, the line settles deep because line is slack; without shooter, line settles shallow because it is taut.	Deep sets catch 10 times fewer sea turtles than shallow sets.	Deep sets incidentally catch finfish species from thermocline stratum; shallow sets incidentally catch finfish species from mixed layer.
Hooks/set	400 to 3000	No effect on incidental capture rate.	No effect on incidental capture rate.
Leader material	Monofilament; 1.5 mm wire; or 2.5 mm wire (to target shark); attached to branch line with or without leaded swivels	Unknown	Higher percentage of incidental finfish catch retained on wire leader
Bait	Saury, sardine, mackerel, pilchard (to target tuna); squid to target mahimahi, swordfish; skipjack tuna and mackerel to target shark	Squid bait more likely to result in incidental capture of loggerhead turtles than other bait types. Blue-dyed squid may reduce incidental capture of green and loggerhead turtles.	Different bait types presumably catch different mixes of incidental finfish species.
Lightsticks	None; every hook or every few hooks	Used in shallow sets. Some sea turtle species foraging at night may be attracted to lightsticks or certain colors of lightsticks, confusing them for prey.	Used in shallow sets. May affect species mix of incidental finfish catch in mixed layer.

Characteristic	Diversity Recorded in Present Study	Possible Implications for Sea Turtle Bycatch	Possible Implications for Finfish Waste
Hook type	Ring hook; J hook; circle hook	Large circle hooks less likely to hook loggerhead and leatherback turtles than J-hooks.	Hook type presumably affects species mix of incidental finfish catch.
Float line length	0 to 40m	Longer float lines are associated with deeper hook depths. Deep sets incidentally capture 10 times fewer sea turtles than shallow sets.	Longer float lines are associated with deeper hook depths. Deep sets incidentally capture finfish species from the thermocline stratum, whereas shallow sets incidentally capture finfish species from the mixed layer.
Branch line length	5 to 30m	Large branch lines may allow hooked or entangled turtles to reach the ocean surface to breathe.	Longer branch lines may increase the percentage of finfish (target and non-target) that are alive when retrieved.
Minimum depth fished	5 to 45m	Shallow minimum depth places larger no. of hooks set in the shallow “turtle layer,” resulting in higher sea turtle capture rates than deeper minimum depth.	Shallow minimum depth produces incidental finfish catch from the mixed layer.
Range of depth fished	5 to 400m	Deep range of fishing significantly reduces sea turtle capture rates compared to shallow range of fishing.	Deep range of fishing produces incidental finfish catch from the thermocline layer in a weak condition for survival if released after capture.
Hook soak time	6 to 20 hrs.	Longer period, combined with shallow depth of fishing, increases possibility of incidental sea turtle capture.	During longer period, some incidentally-caught finfish will fall off line or be lost to predators and, thus, not be accounted for in observer data.
Treatment of catch	Iced; refrigerated seawater; frozen	No effect	Bycatch rate may be affected by storage and marketing options for the catch.

Table 2. Typical operating characteristics, Western Pacific deep-set fresh tuna longline fisheries.

Vessel Flag	U.S. (Hawaii)[1]	Samoa[2]	Japan[3]
Target species	Bigeye, yellowfin tuna	Albacore tuna	Bigeye, yellowfin tuna
Hook soak period	Day	Day	Day
Mainline material	Monofilament	Monofilament	Multi-strand hard nylon
Mainline shooter	Yes	Yes	Yes
Hooks/set	2500	2700	2400
Leader	Wire, monofilament	Monofilament	Monofilament
Bait	Saury, sardine	Sardine, pilchard	Saury, mackerel
Lightsticks	No	No	No
Hook type	3.6 mm Asian ring hook; 65 gm weight < 1m from hooks	Circle hook 15/0	Asian ring
Hooks between floats	18-30	30-35	15-20
Float line length	30 m	27 m	20-40 m
Branch line length	13 m	13 m	25-30 m
Minimum depth fished[4]	43 m	40 m	45 m
Range of depth fished	43-400 m	40-180 m	45-400 m
Hook soak time	10-12+ hrs	8 hrs	10-12 hrs
Treatment of catch	Iced (freshwater)	Frozen brine for albacore; freshwater ice for yellowfin, bigeye tuna.	Refrigerated seawater

[1] Pacific Ocean Producers, Catalog 2004 and personal communications; Baird (2001); National Marine Fisheries Service Honolulu Laboratory, Fishery Monitoring and Economics Program, unpubl. information; Gilman et al. (2002).

[2] Pacific Ocean Producers, Tony Costa, pers. comm. with P. Bartram, Jan. 17, 2003.

[3] Itano (2001); Park (2001; 2002); P. Bartram, interviews with Japanese longline captains and transshipment agents in Guam, various dates 1998-present. Information is specific to fresh tuna transshipment fleets operating from Pacific island bases.

[4] After Park (2002) = float line length + branch line length

Table 3. Typical operating characteristics, Western Pacific shallow-set, mixed-species longline fisheries.

Vessel Flag	U.S. (Hawaii)[1]	Taiwan[2]	China[3]	Australia[4]
Target species	Swordfish, bigeye tuna	Bigeye, yellowfin tuna, billfish	Bigeye, yellowfin tuna	Bigeye, yellowfin tuna, swordfish, striped marlin
Hook soak period	Night	Mostly night; day when live milkfish bait used to target YF	Night	80% night; 20% day
Mainline material	Monofilament	Nylon rope	Nylon rope	Monofilament
Mainline shooter	No	No	No	50% yes; 50% no
Hooks/set	800-1000	1000-1500	800-1200	900-1100
Wire leader	No	No	1.5 mm (when targeting mixed species)	10% wire; 90% monofilament
Bait	Squid	Squid to target BE; Mackerel, live milkfish to target YF	Squid, mackerel	Squid
Lightsticks	Yes	No	No	Yes
Hook type	Mustad #9/0 J hook	Asian ring	Asian ring 3.4	Asian ring 3.4, 3.6; 17/0 Japanese circle
Hooks between floats	2-5	4-5	4-5	8
Float line length	8-10 m	10-25 m	10-32 m	15 m
Branch line length	13-17 m	25 m	25 m	20 m
Minimum depth fished[5]	21 m	35 m	35 m	35 m
Range of depth fished	21-70 m	35-250 m	35-120 m	35-50 m
Hook soak time	Night (10-11+ hrs)	12 hrs.	10-11 hrs.	8-12 hrs.
Treatment of catch	Ice (saltwater for swordfish; freshwater for other catch)	Refrigerated seawater	Ice (freshwater); Refrigerated seawater	Ice slurry

[1] Historic Hawaii swordfish fishery (terminated mid-2001 under Federal regulations). Pacific Ocean Producers, Catalog 2004 and personal communications; Baird (2001); National Marine Fisheries Service Honolulu Laboratory, Fishery Monitoring and Economics Program, unpubl. Information; Gilman et al. (2002). J hooks and squid bait are prohibited and only large circle hooks and mackerel-type bait are permitted under present NMFS regulations for the reopened Hawaii swordfish fishery.

[2] Park (2001; 2002); P. Bartram, interviews with Taiwanese longline captains and transshipment agents in Guam, various dates 1998-2002; P. Bartram interview with Marshall Islands' Taiwan longline fleet manager January 2003 and personal observations at Marshall Islands Marine Resources Authority's tuna transshipment base, Majuro, Republic of the Marshall Islands, various dates 2003; P. Bartram interviews with Taiwan fleet managers and personal observations at Palau International Traders International and Palau Marine Industries Corp. tuna transshipment bases, October 2003. Information is specific to fresh tuna transshipment fleets operating from Pacific island bases.

3 Park (2001; 2002); P. Bartram, interviews with Chinese longline captains, fleet managers and transshipment agents at Palau International Traders Inc. tuna transshipment base and Marshall Islands Marine Resources Authority's tuna transshipment base, Majuro, RMI, various dates 2003; and personal observations aboard F/V Clearwater I, August 2003. Information is specific to fresh tuna transshipment fleets operating from Pacific island bases.

[4] Pacific Ocean Producers, Tony Costa, pers. comm. with P. Bartram, Sept. 24, 2003.

[5] After Park (2002) = float line length + branch line length

Table 4. Typical operating characteristics, Indian Ocean shallow-set mixed-species longline fisheries.

Vessel Flag	**Taiwan and China (landing in Sri Lanka)**[1]
Target species	Swordfish, tuna
Hook soak period	Night
Mainline material	Monofilament
Mainline shooter	No
Hooks/set	800-1500
Wire leader	No
Bait	Mackerel, squid
Lightsticks	No
Hook type	#6/0 J
Hooks between floats	5-10
Float line length	30-40 m
Branch line length	22 m
Minimum depth fished[2]	52 m
Range of depth fished	52-300 m
Hook soak time	8-12 hrs.
Treatment of catch	Refrigerated seawater (-1 to -2° C)

[1] R. Fernando, Tropic Frozen Foods Ltd, Sri Lanka, pers. comm. with P. Bartram, April 14, 2004.

[2] After Park (2001) = float line length + branch line length

Table 5. Typical operating characteristics, Eastern Pacific shallow-set swordfish and mixed-species longline fisheries.

Vessel Flag	**U.S. (California)**[1]	**Chile**[2]	**Mexico**[3]	**Taiwan**[4] **(landing in Costa Rica, Panama)**	**Costa Rica (artisanal)**[5]
Target species	Swordfish	Swordfish	Swordfish	Billfish, bigeye, yellowfin tuna, shark	Mahimahi, tuna
Hook soak period	Night	Night	Night	Night	Mahimahi—day; Tuna—night
Mainline material	Monofilament	Monofilament	Monofilament	Nylon rope	Monofilament
Mainline shooter	No	No	No	No	No
Hooks/set	800	1100	800-1000	1000-1200	400-800
Wire leader	No	No	No	>2.5 mm when targeting shark	No
Bait	Squid	Squid	Squid	Squid (mackerel, skipjack tuna when targeting shark)	Squid
Lightsticks	Yes	Yes	Yes	No	No
Hook type	Mustad #9/0 J hook	Mustad #9/0 J offset; 30 gm weight above hook	Eagle Claw L9014	Asian ring	Circle hook
Hooks between floats	2-5	5	5	4-5	4-5
Float line length	8-10 m	10 m	16 m	10 m when targeting shark	0-6 m
Branch line length	13-17 m	10 m	14 m	10 m when targeting shark	5-7 m
Minimum depth fished[6]	23 m	20 m	30 m	20 m when targeting shark	5 m
Range of depth fished	21-70 m	20-45 m	30-200 m	20-30 m when targeting shark	5-20 m mahimahi 25-50 m billfish
Hook soak time	10-11+ hrs	6-8+ hrs	10-12 hrs	10-12 hrs	12+ hrs
Treatment of catch	Iced (saltwater for swordfish; freshwater for other catch)	Iced (freshwater)	Iced (freshwater)	Refrigerated seawater	Iced (freshwater)

[1] Pacific Ocean Producers, Catalog 2004 and personal communications; Baird (2001); National Marine Fisheries Service Honolulu Laboratory, Fishery Monitoring and Economics Program, unpubl. information. NMFS regulations to prohibit shallow set longline fishing east of 150° W longitude went into effect April 12, 2004, effectively closing the California-based shallow set longline fishery.

[2] Describes high-seas domestic longline fleet of approximately 15 vessels. Sources: Luis Vares, Patron De Pesca Longline, pers. comm. with J. Kaneko and P. Bartram, Nov. 21, 2002; Weidner and Serrano (1997).

[3] Jorge Romano, Pesquera Integral Isla Bonita, pers. comm. P. Bartram, Nov. 22, 2002.

[4] Assumes eastern Pacific operational characteristics similar to those in western Pacific from P. Bartram interviews with Taiwan longline vessel agents, Majuro and Palau, 2003. The Taiwan-flag longline fleet landing in Costa Rica targets mixed species but harvesting of sharks for fins is a crucial part of its economic strategy (PRETOMA, 2003).

[5] Arauz et al. (1999); Arauz (2000, 2001).

[6] After Park (2001) = float line length + branch line length

Table 6. Typical operating characteristics, Atlantic shallow-set swordfish and mixed-species longline fisheries.

Vessel Flag	Brazil[1]	South Africa[2]	Namibia[3]
Target species	Swordfish, sharks	Swordfish, tuna	Swordfish, tuna, other large pelagics, including shark
Hook soak period	Night	Night	Night
Mainline material	Monofilament	Monofilament	Monofilament
Mainline shooter	No	No	Some vessels yes; some no
Hooks/set	1000	1500	1400
Wire leader	No	No	Yes
Bait	Squid, chub, mackerel, sardines	Squid	Squid, mackerel
Lightsticks	Yes	Yes	Mackerel bait yes; squid bait no
Hook type	Mustad #9/0 J; 75 gm weight above hook	Mustad #9/0 J; 30 gm weight above hook	Mustad #9/0 J
Hooks between floats	5-6	4	5
Float line length	18 m	15-30 m	9 m
Branch line length	16 m	12-18 m	15 m
Minimum depth fished[4]	34 m	27 m	24 m
Range of depth fished	34-80 m	27-50 m	24-100 m
Hook soak time	10-11+ hrs.	10-11 hrs.	20 hrs.
Treatment of catch	Iced (freshwater)	Iced (freshwater)	Blast frozen

[1] T. Neves, Albatross Project, Environmental Secretariat of Sao Paulo State, Brazil, pers. comm. with J. Kaneko, Feb. 17, 2003; data obtained from longline skippers and Weidner and Arocha (1999).
[2] P. Nichols, Ministry of Fisheries and Marine Resources, Namibia, pers. comm. with J. Kaneko, June 14, 2003.
[3] P. Nichols, Ministry of Fisheries and Marine Resources, Namibia, pers. comm. with J. Kaneko, June 14, 2003.
[4] After Park (2001) = float line length + branch line length

5. FACTORS AFFECTING INCIDENTAL CATCH RATES OF PROTECTED SPECIES AND FINFISH BYCATCH IN PELAGIC LONGLINE FISHING

Operating characteristics ultimately determine the incidental catch rate of protected species, finfish bycatch and species composition in pelagic longline fisheries. Bycatch rates depend on how gear is configured, where and when it is set in relation to the habitat, and distribution and behavior of these species.

5.1 Sea Turtles

Incidental catch of sea turtles occurs when feeding animals opportunistically encounter baited longline hooks or when they are accidentally entangled with longline gear. These interactions occur during the pelagic periods of sea turtles' lives when they are migrating through the open ocean to and from inshore feeding or breeding/nesting habitats. Some species of sea turtles have more pelagic habits than others. Sea turtles rely on their visual senses in their search for food and need to surface at regular intervals to breathe. Some species also exhibit a preference for distinct thermal regimes. These basic attributes have implications for the likelihood of potential interactions with pelagic longline fishing gear and the outcomes of those interactions (Oceanic Fisheries Programme, 2001).

Seasonal aggregations of sea turtles occur in the proximity of nesting beaches, whereas densities are expected to be significantly lower during the solitary pelagic phase. Fishing in proximity to nesting aggregations should be expected to have greater potential for sea turtle interactions than in the open ocean, where turtle density is lower (Segura and Arauz, 1995).

Observer-reported encounters in the Secretariat of the Pacific Community (SPC) statistical area clearly show that longline fisheries in the western tropical Pacific (10° N–10° S latitude) have far more sea turtle interactions than in the western sub-tropical Pacific (10° S–35° S) or western temperate Pacific (35°–45° S) (OFP, 2001). Unfortunately, a large proportion of observed sea turtle encounters in the SPC statistical area could not be identified to the species level. Green turtles and olive ridley turtles constituted the majority of sea turtles identified to the species level but this should not be taken as indicative of the relative sea turtle composition within the incidental catch of longline fisheries. The higher latitude distribution of loggerhead turtles, however, makes it highly unlikely that there are any takes of this species in SPC observer records for the tropical western Pacific.

Several characteristics of pelagic longline gear and deployment practices could affect the levels of fishery interaction with sea turtles (i.e., incidental catch or take rate)—bait type and color, hook size and shape, and day or night setting. The depth of set appears to be a far more important factor. Analysis of the SPC observer data suggests that in the tropical western Pacific setting longline gear shallow increases the rate of sea turtle takes by about 10 times compared to deep setting (OFP, 2001). Shallow sets are defined as longline gear configurations where <10 hooks are set between floats. Based on the long-term observer program of the Micronesian Maritime Authority, shallow night longline sets in the Exclusive Economic Zone of the Federated States of Micronesia (FSM) are four times more likely to catch turtles than deep longline sets, and hawksbill turtles are all caught on shallow night sets (Park, 2002). The OFP analysis also shows that when sea turtle takes occur on deep-set gear, they are almost always on the shallowest hooks (OFP, 2001).

This information suggests a “turtle layer” in the water column or critical depth range of hooks where most sea turtle encounters would be expected to occur in western tropical Pacific longline fisheries (OFP, 2001). Observer data from the Hawaii longline fishery also suggest the concept of a turtle layer in the sub-tropical North Pacific, where interactions on shallow-set longline gear are an order of magnitude higher than interactions on deep-set gear (NMFS, 2001a). Figure 3 depicts the hypothesized turtle layer in relation to shallow-set and deep-set longline gear configurations.

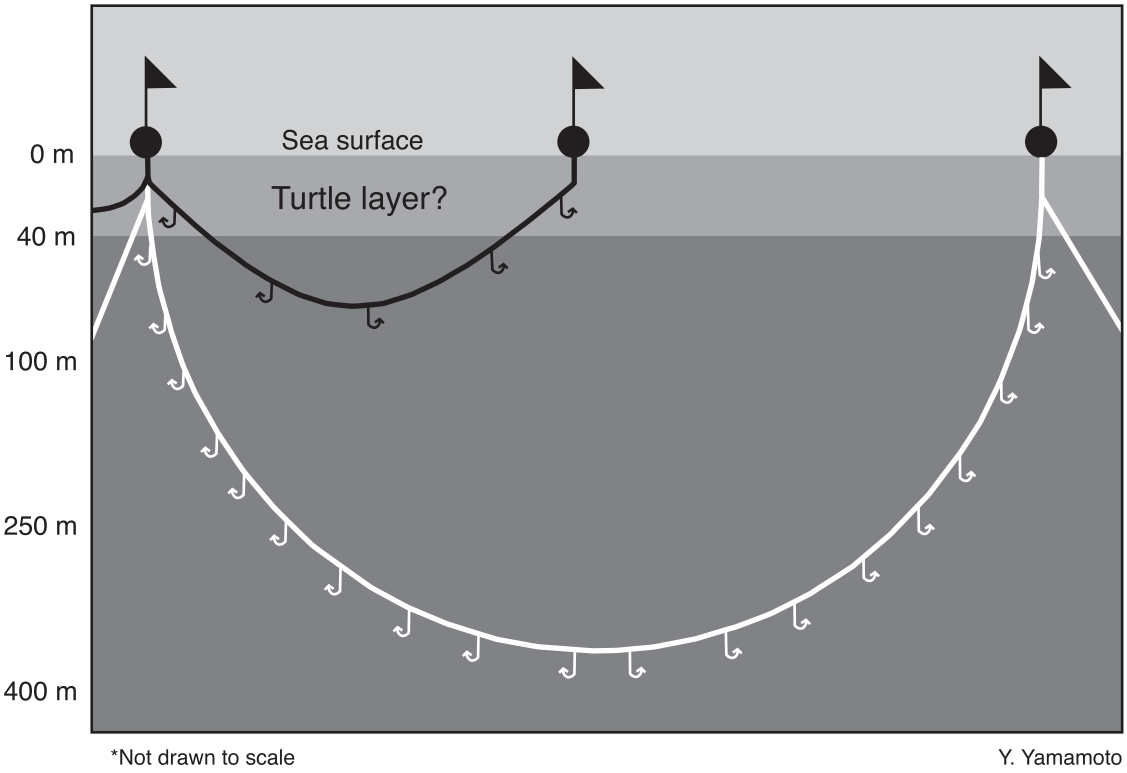


Figure 3. Comparison of deep-set and shallow-set pelagic longline gear in relationship to the proposed "sea turtle layer."

Longline fishing depth varies significantly among the fleets profiled in the present study. The depth at which longline gear fishes is known to be influenced by the set configuration, primarily the length of mainline between floats (a "basket") and the sagging rate (Boggs, 1992). Fishing depth will also be influenced by a variety of environmental factors, particularly wind and currents (Boggs, 1992). The number of hooks between floats has been found to be a useful proxy for the targeted fishing depth of longline gear (Hampton et al., 1998).

Of the longline fisheries considered in the present study, Japan and Hawaii tuna fleets set gear the deepest (40-400 m depth range fished), whereas the mixed-species fisheries of most other nations set gear at shallower depths (35-250 m). Longline fisheries targeting swordfish, shark and mahimahi in the Pacific and Atlantic make even shallower sets (5-70 m depth range fished).

It has often been assumed that the distant-water Taiwan frozen tuna longline fleet deploys gear in the same way as Japan's distant-water frozen tuna longline fishery. Several sources of information indicate that the Taiwan distant-water longline fishery sets gear in a manner similar to what was defined as a "mixed set" in the Hawaii longline fishery from 1994-1999. According to a report at the First International Fishermen's Forum (Huang, p. 23 in Baird 2001), Taiwan's distant-water tuna longline fleet typically sets 8-11 branch lines or hooks between floats and soaks the gear during daylight hours (as opposed to Taiwan's offshore longline fleet that sets 4-5 hooks between floats and soaks gear at night). Williams (2003: Figure 3, p. 5) reports that the distant-water Taiwanese longline fleet targeting albacore in the sub-tropical South Pacific (10-30° S) generally uses 9-12 hooks between floats and soaks gear during daylight hours.

From 1994-1999, all Hawaii longline sets with 10 or more branch lines between floats were characterized as "deep sets." A drawing of an atypical ("mixed") Hawaii tuna set configuration with 11 hooks between floats in WPFRMC (2004a: 13) shows that 8 of the hooks hypothetically would remain shallower than 100 m. This configuration does not necessarily result in a deep hook placement, especially if no slack is maintained while setting the mainline and it is characterized as a mixed set in the Hawaii longline fishery. Observed sea turtle takes for mixed sets were combined with observed sea turtle takes for swordfish sets for the purpose of distinguishing shallow sets from deep sets in NMFS' definitions (NMFS, 2001a) that have been used in biological opinions and regulations applied to the Hawaii longline fishery. The mixed set gear configuration in the Hawaii longline fishery is similar to that of the distant-water Taiwanese frozen tuna longline fishery. Using NMFS's criteria for combining mixed and swordfish gear configurations into a "shallow set" category for purposes of estimating incidental catch rates of sea turtles, the Taiwan distant-water freezer longline fishery should also be considered shallow set.

With a minimum of 53 million hooks being set annually by the distant-water Taiwan freezer longline fleet in the central and western Pacific (Lawson, 2003: 53) and another 24 million hooks being set in different shallow configurations by other (principally Taiwan and China) longline fleets, (OFP, 2001: 19), a conservative estimate of the total shallow-set longline fishing effort by non-U.S. fleets in the central and western Pacific would be 77 million hooks per year. Under new regulations that allow up to 2,120 sets per year (WPRFMC, 2004a), a maximum of two million shallow-set hooks might be set per year in the model Hawaii swordfish fishery. Thus, the model fishery could account for about 2.5 percent of the total annual shallow-set longline fishing effort in the central and western Pacific.

5.2 Finfish Waste

Apex fish species make up the majority of the targeted fish and bycatch of pelagic longline fisheries. Data on the responses of oceanic gyre food webs to fishing are generally limited, so the food web impacts at lower trophic levels are not documented. Seki and Polovina (2001) used a dynamic ecosystem model to investigate possible impacts. They found no evidence that the removal of any single high trophic level species significantly altered the food web. The lack of a keystone species appears to be due to a high degree of diet overlap among the high trophic level species. Fisheries in oceanic gyres alter the food web by reducing the biomass at the top of the food web. When this reduction becomes substantial, it may result in some increase in biomass at mid-trophic levels (Seki and Polovina, 2001: 964).

Most longline fisheries are multi-species; i.e., they rely on the harvest of several ecologically related pelagic fish species for fishing income (Hoey and Moore, 1999). Discard of unwanted dead or live fish varies among longline fisheries due to several factors including the spatial and temporal variations in species distributions, fishing methods, skipper experience and preference, shipboard refrigerated storage capacity, marketing practices at unloading ports, differences in operating and marketing costs, and regulations (Anon. 20030a).

The present study focuses on wasted finfish, or "true bycatch;" i.e., fish discarded dead or mortally injured after incidental capture by pelagic longline fisheries. The delayed mortality of fish that are alive when discarded represents a large source of uncertainty in estimating true bycatch. Delayed mortality is related not only to the stress of capture and handling on deck but also to a suite of environmental stressors (e.g., exposure of deep-dwelling species to pressure changes, increased temperature and light) and biological stressors (size- and species-related sensitivities to stress) (Davis, 2002).

Pelagic longlining is selective in which ocean strata are targeted (i.e., the depth range in which the most hooks are set) but it is unselective in which pelagic fish are hooked within those strata, although they are predominantly high-level predator species. Thus, the species composition of what is captured changes with depth of set and possibly other factors, such as whether gear soaks during the day or night. Figure 4 shows typical time periods of setting, soaking and hauling for deep-set and shallow-set longline gear configurations.

The frequency of target species discards (as a percentage of each species' observed catch) in western and central Pacific longline fisheries has been summarized by Sharples et al. (2000) from observer reports in SPC data holdings. For tuna and billfish species, the proportion discarded by different fleets (vessel nation) and reasons for discards are summarized in the same report. The main reason for discard of tuna and marlin is shark or whale damage. Over half of all marlin were alive when retrieved to the vessel compared to only about one-third of swordfish, sailfish, and shortbill spearfish.

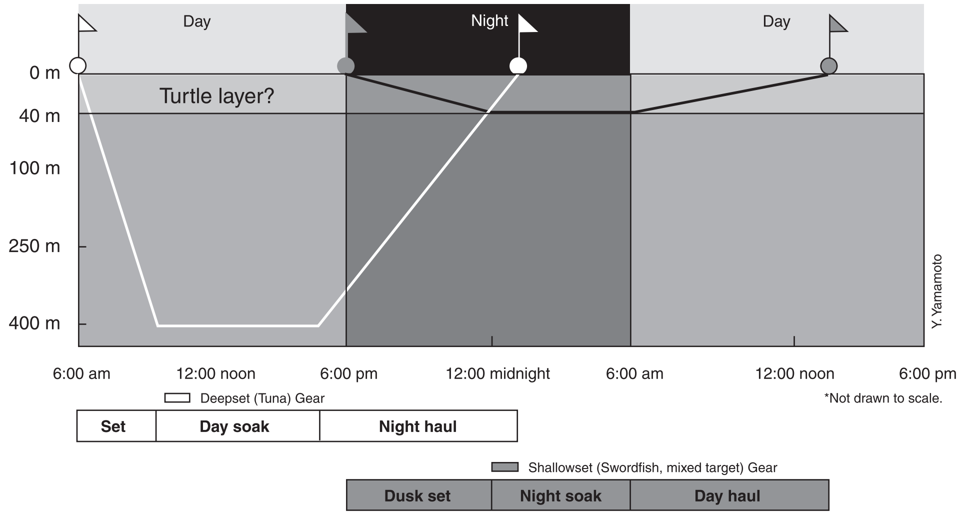


Figure 4. Conceptual diagram contrasting deep-set and shallow-set pelagic longline fishing methods: time of setting, soaking and hauling.

Unwanted finfish may be discarded dead or alive after retrieval onto the vessel or the fish may be cut or jerked free from the line by the crew before the fish are landed on the vessel. Discarding can occur for several reasons: 1) undesirable, poor food quality or low value species (e.g., oilfish, snake mackerel, lancetfish); 2) limited cold storage space on vessel (e.g., distant-water longline vessels making long trips far from offloading ports); 3) damaged fish (e.g., mauled by sharks or marine mammals); 4) difficult to land or process (e.g., large sharks, marlin) (Bailey et al., 1996); or 5) too small (e.g., swordfish) (Sharples et al., 2000).

6. BYCATCH PER UNIT OF EFFORT (BPUE) IN SELECTED LONGLINE FISHERIES

Fisheries bycatch can be expressed quantitatively as a function of the catch of primary target species. The specific index proposed by Hall (1996) is a ratio of numbers or weights of incidentally caught animals per unit of fishing effort (BPUE) or per unit of target fish catch (B/C). These indices standardize bycatch rates and allow comparison of different fisheries that harvest and market the same products.

The problem in calculating BPUE for the world's pelagic longline fisheries is the paucity of data, especially concerning the proportions of sea turtles and finfish captured and released alive and the post-release survival of injured finfish and sea turtles. The unreliability of logbook data to provide indications of incidental catch levels (except for the more valuable billfish species) has led to recommendations for improvement of longline observer programs to expand coverage; to document species, quantities, sizes and life status of animals when discarded, spatial and temporal variations in discards; and to indicate reasons for discarding (Bailey et al., 1996; Lawson, 1997; WPRFMC, 2003).

Most researchers and managers have identified shipboard observer data as the most reliable means for obtaining indications of bycatch in pelagic longline fisheries (Bailey, et al., 1996; Cheng, 2003; WPRFMC, 2003). NMFS (2003) has also concluded that at-sea observation typically provides the best way to obtain reliable and accurate bycatch estimates.

Interactions with sea turtles in central and western Pacific longline fisheries are relatively rare (Williams, 1996), so there is great uncertainty in estimating fisheries-wide sea turtle take and mortality from a low level of observer coverage (OFP, 2001). During the first 6 years of the Hawaii longline observer program (1994-1999), observers were placed on 3-5 percent of fishing trips by the Hawaii fleet. As a result of court orders and subsequent regulations, the level of coverage was increased to a minimum of 20 percent in later years. However, interactions with turtles are now so infrequent that take estimates are actually less precise than before—despite higher observer coverage (Wetherall, 2003). This occurred as a result of regulations in effect from mid-2001 to April 1, 2004 that prohibited Hawaii longline vessels from making shallow sets, the primary source of turtle interactions.

Finfish bycatch in this study is limited to waste; i.e., animals released dead or dying after incidental capture (Hall, 1996). To distinguish this negative effect (i.e., waste) from the positive effect of releasing finfish alive after incidental capture, observer programs need to record the life status of finfish releases. NMFS now instructs Hawaii longline observers to distinguish bycatch based on live or dead condition.

"…'Alive' indicates that the animal swam away when released from the gear or were thrown back overboard. Fish returned alive must be recorded as live in the caught condition column…'Dead' indicates the animal did not swim away after being returned. There may be no visible muscular activity and the animal may be stiff or limp. Inactive fish should be marked as returned dead." (Pacific Islands Regional Office, 2003: 45)

The SPC requires observers to record the life status of the individual catch from longline vessels at the time of retrieval in one of the following categories (Williams, 1997).

- Alive
- Alive healthy
- Alive—injured or distressed (with a good chance of surviving)
- Alive but dying
- Dead
- Condition unknown

Observers report that it can be difficult to decide if injured animals are dying (Sharples et al., 2000).

In the following sections (6.1, 6.2), BPUE is estimated for sea turtles (i.e., lethal and non-lethal incidental takes) and for wasted fish (i.e., true bycatch) in selected longline fisheries for which some observer data are available. Calculation of BPUE is based on a wide variation of observer coverage of these fisheries. For some fleets, BPUE is calculated from a very small number of observations.

For sea turtles, BPUE is expressed as numbers of animals (both dead and alive) incidentally captured by 10,000 hooks of longline fishing effort. Numbers of fish, instead of weight, are generally preferred to compare catch levels since the average weights of some pelagic species can vary markedly (Bailey, et al., 1996). In the present study, however, it is more useful to express BPUE of finfish waste in terms of weight so that comparisons can be made in the context of global fish trade.

6.1 C/B and B/C Ratios for Sea Turtles in Selected Longline Fisheries

This section contains a series of tables (Tables 7-11) that make preliminary estimates of sea turtle BPUE based on observer data (some of it very limited) for selected longline fisheries in the central and western Pacific, eastern Pacific, Indian Ocean and South Atlantic. Sea turtle BPUE—number of animals taken per 10,000 hooks—is compared to target fish CPUE (weight of target species per 10,000 hooks) for the same fisheries. C/B ratios are calculated by dividing CPUE by BPUE (canceling out the PUE term) to express the weight (mt) of target catch associated with the take of one sea turtle. B/C ratios are the inverse, calculated as the number of sea turtle takes per weight (mt) of target catch. These indices are derived by performing the calculations shown in Table 7.

For the purposes of this analysis, all takes of all sea turtle species are treated equally. Lumping is necessary because of the paucity of data and inadequate species identification in most observed longline fisheries. The impact of a turtle take actually varies considerably depending on the species taken, its condition after capture, its life stage and the status of its population. For example, a take of an adult from a severely depleted population, such as eastern Pacific leatherbacks, would be more significant than the take of a juvenile from a healthier population, such as Atlantic leatherbacks. However, no distinction or weighting based on turtle species, life stage or population status is made in the present study.

Table 7. Derivation of BPUE, CPUE, B/C and C/B ratios in Tables 8-11.

Column (1) Area and Longline fishery	**Column (2) CPUE Target fish (mt/10,000 hooks)**	**Column (3) BPUE Sea turtle (takes/10,000 hooks)**	**Column (4) B/C Ratio Sea turtle (takes/ mt target fish)**	**Column (5) C/B Ratio Target fish (mt/ sea turtle take)**
Longline fishing grounds and flag of Fishery A	Average catch of targeted fish species per 10,000 hooks. Footnotes give sources of data for this calculation.[1]	Number of sea turtles (combined species) incidentally-captured per 10,000 hooks. Footnotes give sources of data for this calculation.[2]	Column 3 calculation divided by column 2 calculation. Results may differ for fisheries with similar column 3 incidental catch rates because of the sensitivity to column 2 target species catch rates.	Column 2 calculation divided by column 3 calculation. Results may differ for fisheries with similar column 3 incidental catch rates because of the sensitivity to column 2 target species catch rates.
Longline fishing grounds and flag of Fishery B	As above	As above	As above	As above
Longline fishing grounds and flag of Fishery C	As above	As above	As above	As above

[1, 2] Footnotes give sources of data for this calculation

Table 8. Sea turtle BPUE, target fish CPUE, B/C and C/B in selected central and western Pacific deep-set pelagic longline fisheries.

Area and Longline fishery	CPUE Target fish (mt/10,000 hooks)	BPUE Sea turtle (takes/10,000 hooks)	B/C Ratio Sea turtle (takes/mt target catch)	C/B Ratio Target fish (mt/sea turtle take)
Sub-tropical South Pacific—American Samoa and Samoa alia albacore longline fisheries	Tuna 5.4[1]	None caught in 54,000 hooks[2]	0	100+
Western Tropical Pacific—Japan BE, YF tuna longline fishery	Tuna 4.1[3]	0.0692[4]	0.02	59
Sub-tropical central North Pacific—Hawaii BE, YF tuna longline fishery	Tuna 3.0[5]	0.051[6]	0.017	59

[1] Calculated from WPRFMC (2004b: average CPUE and fish weight estimates for albacore, bigeye and yellowfin tuna for 2000-2002, Tables 7a, 7b, 8).

[2] Calculated from OFP unpublished observer data for Samoa plus PacMar Inc., unpubl. research for American Samoa, Oct. 2003-April 2004).

[3] Calculated from Miyabe et al. (2003: p. 8, Table 2, average of 1998-2001).

[4] Calculated from OFP (2001).

[5] Calculated from WPRFMC (2004b: average CPUE and fish weight estimates for albacore, bigeye and yellowfin tuna, 1994-2002, p. 3-48, 3-49).

[6] Sea turtle take/tuna set from NMFS (2001a: Table IV-13) standardized to 10,000 hooks based on 1,900 hooks/tuna set during 1994-1999 period (Ito and Machado, 2001: Tables 3, 4).

Table 9. Sea turtle BPUE, target fish CPUE, B/C and C/B in selected central and western Pacific shallow-set pelagic longline fisheries.

Area and Longline fishery	CPUE Target fish (mt/10,000 hooks)	BPUE Sea turtle (takes/ 10,000 hooks)	B/C Ratio Sea turtle (takes/mt target catch)	C/B Ratio Target fish (mt/sea turtle take)
Western Tropical Pacific—Taiwan BE, YF tuna longline fishery	Tuna 3.3[1]	0.6129[2]	0.19	5.4
WTP—People's Republic of China BE, YF tuna longline fishery	Tuna 2.4[3]	0.6129[2]	0.26	3.9
Eastern Australia swordfish fishery	Swordfish 4.8[4]	0.24[5]	0.05	20
Sub-tropical and temperate central North Pacific—Hawaii swordfish longline fishery (March 3, 1994 to June 30, 2001)	Swordfish 10.5[6]	1.7[7]	0.16	6.2

[1] Calculated from catch/effort statistics of Taiwan offshore longline fleet summarized by SPC unpubl. data.

[2] Calculated from OFP (2001).

[3] Calculated from Liuxiong (2002: Table 1, 3, average of 2000-2001).

[4] Calculated from Bromhead and Findlay (2003: Table 1, average of 1999-2002) by adjusting processed weight to whole weight (PW/0.89 = WW).

[5] Robins et al., (2002).

[6] Calculated from WPRFMC (2004b: average swordfish CPUE and average fish weight estimates 1994-1999, p. 3-50 and Table 6).

[7] Calculated as follows: average take of leatherback, loggerhead, olive ridley and green turtles per shallow swordfish-style set west of 150° W. (1994 through mid-2002) = 0.14/set (Caretta, 2003) divided by 820 hooks/set average (Ito and Machado, 2001) x 10,000 hooks.

Table 10. Sea turtle BPUE, target fish CPUE, B/C and C/B in selected eastern Pacific shallow-set pelagic longline fisheries.

Area and Longline fishery	CPUE Target fish (mt/ 10,000 hooks)	BPUE Sea turtle (takes/10,000 hooks)	B/C Ratio Sea turtle (takes/mt target catch)	C/B Ratio Target fish (mt/sea turtle take)
Tropical eastern Pacific Costa Rica offshore	Mahimahi 4.5[1]	66.7[2]	14.8	0.07
Tropical eastern Pacific Costa Rica near nesting beaches	Mahimahi 4.5[1]	194[3]	43.1	0.02
Temperate eastern Pacific California	Swordfish 12.9[4]	1.8[5]	0.14	7.2

[1] Calculated from the number of mahimahi caught per 1000 hooks (Arauz, 2001), assuming an average fish size based on Hawaii fresh mahimahi imports from Costa Rica (7.25 kg).

[2] Average incidental take of olive ridley and green turtles by Costa Rica artisanal longline fishery calculated from Arauz et al., (1999).

[3] Average incidental take of olive ridley and green turtles by Costa Rica industrial longline fishery calculated from Arauz (2001).

[4] Swordfish catch rates calculated from western Pacific longline logbook summary (all vessels California and high seas) for calendar years 2000-2002 (www.nmfs.hawaii.edu/fmpi/hilong/summary). Assumes average size (158 lb/fish) similar to swordfish landed by Hawaii longline fishery 2000-2001 (WPRFMC, 2004b: Table 6).

[5] Calculated as follows: average take of leatherback, loggerhead and olive ridley turtles per shallow swordfish-style set east of 150° W. (1994 through mid-2002) = 0.15/set (Caretta, 2003) divided by 820 hooks/set average (Ito and Machado, 2001) x 10,000 hooks.

Table 11. Sea turtle BPUE, target fish CPUE, B/C and C/B in selected south Atlantic shallow-set pelagic longline fisheries.

Area and Longline fishery	CPUE Target fish (mt/10,000 hooks)	BPUE Sea turtle (takes/10,000 hooks)	B/C Ratio Sea turtle (takes/mt target catch)	C/B Ratio Target fish (mt/loggerhead take)
South Atlantic Brazil—offshore	Swordfish 3.76[1]	18[2]	4.8	0.21
South Atlantic Brazil—near nesting beaches	Swordfish 3.76[1]	116[3]	30.9	0.03
South Atlantic South Africa	Swordfish 3.76[4]	5.95[5]	1.58	0.6

[1] Calculated from Anon. (2000).

[2] Average incidental take of mostly loggerhead turtles in the high seas off Brazil and Uruguay (Achaval et al., (2000).

[3] Average incidental take of loggerhead turtles in portions of Brazil's EEZ thought to be migratory corridors to or from nesting beaches (Barata et al., 1998).

[4] Assumes that average swordfish catch rates off South Africa are similar to those off Brazil.

[5] Hawksbill and loggerhead average incidental take by Taiwan distant-water longline fishery in temperate South Atlantic high seas (Cheng, 2003).

6.2 C/B and B/C Ratios for Finfish in Selected Longline Fisheries

A species-by-species accounting of finfish waste in pelagic longline fisheries is beyond the scope of the present study. Instead, four species of longline incidental finfish catch were selected to represent a spectrum of fates: discarded (longnose lancetfish), discarded after finning (blue shark), retained after finning (silky shark) and retained (shortbill spearfish).

- Blue shark (*Prionace glauca*) is a major component of the incidental finfish catch by both deep-set and shallow-set longline fleets. In non-U.S. fisheries, only the fins of this species are retained because the meat is inedible. Under the Shark Finning Prohibition Act, retention of fins without a corresponding amount of carcasses is illegal for U.S. fisheries.

- Silky shark (*Carcharinus falciformis*) is a major component of shallow-set longline fisheries in some areas. Taiwanese and Chinese fishing crews remove the fins but frequently retain the trunks of this species for processing.
- Longnose lancetfish (*Alepisaurus ferox*) is a major component of longline incidental finfish catch. Except for small quantities occasionally retained for crew use, most fish are discarded.
- Shortbill spearfish (*Tetrapturus angustirostris*) is a minor component of longline incidental finfish catch but the level of discard is strongly influenced by fishing trip length in relation to species' shelf life, marketing opportunities and practices at ports of landing. In the Hawaii tuna longline fishery, for example, spearfish caught during the first few days of a trip may be discarded because of the short shelf life of this species. But spearfish are retained when caught later in a trip (Gilman et al., 2003: 19).

Fish that are discarded alive and likely to survive are not wasted and, therefore, are not considered a part of true bycatch. This section contains a series of tables (Tables 12-20) that make preliminary estimates of finfish waste BPUE based on observer data (some of it very limited) for selected longline fisheries in the central and western Pacific and eastern Pacific. Finfish waste BPUE—weight of animals taken per 10,000 hooks—is compared to target fish CPUE (weight of target species per 10,000 hooks) for the same fisheries. B/C ratios are calculated by dividing BPUE by CPUE and expressed as weight (mt) of finfish waste per mt of target catch. The C/B ratio is the weight (mt) of target catch to generate one mt of finfish waste. These indices are derived by performing the calculations shown in Table 12.

Table 12. Derivation of BPUE, CPUE, B/C and C/B ratios in Tables 13-20.

Column (1) Area and Longline fishery	**Column (2) CPUE Target fish (mt)/10,000 hooks**	**Column (3) BPUE Finfish waste (mt)/10,000 hooks**	**Column (4) B/C Ratio Finfish waste (mt)/target fish (mt)**	**Column (5) C/B Ratio Target fish (mt)/finfish waste (mt)**
Longline fishing grounds and flag of Fishery A	Average catch of targeted fish species per 10,000 hooks. Footnotes give sources of data for this calculation.[1]	Number of fish discarded dead or dying x average species wt. (mt) per 10,000 hooks. Footnotes give sources of data for this calculation.[2]	Column 3 calculation divided by column 2 calculation. Results may differ for fisheries with similar column 3 incidental catch rates because of the sensitivity to column 2 target species catch rates.	Column 2 calculation divided by column 3 calculation. Results may differ for fisheries with similar column 3 incidental catch rates because of the sensitivity to column 2 target species catch rates.
Longline fishing grounds and flag of Fishery B	As above	As above	As above	As above
Longline fishing grounds and flag of Fishery C	As above	As above	As above	As above

[1, 2] Footnotes give sources of data for these calculations.

Table 13. Blue shark BPUE, target fish CPUE, B/C and C/B in selected central and western Pacific deep-set pelagic longline fisheries.

Area and Longline fishery	CPUE Target fish (mt)/10,000 hooks	BPUE Blue shark bycatch (mt)/ 10,000 hooks)	B/C Ratio Blue shark bycatch (mt)/ target fish (mt)	C/B Ratio Target fish (mt)/ blue shark bycatch (mt)
Western Tropical Pacific—Japan BE, YF tuna longline fishery	4.1[1]	0.04[2]	0.01	103
Sub-tropical central North Pacific—Hawaii BE, YF tuna longline fishery	3.0[3]	0.028[4]	0.01	107

[1] Calculated from Miyabe et al., (2003: p. 8, Table 2, average of 1998-2001).

[2] Calculated as follows: average CPUE of blue shark observed discarded dead, injured, or unknown condition in western tropical Pacific (10°N–10°S) deep-set longline fisheries = 0.217/1000 hooks (summary of unpubl. SPC observer data, P. Williams, pers. comm. to P. Bartram, April 26, 2004) = 2.17/10,000 hooks x 40 kg average size of blue shark between 20° N and 20° S latitudes in Pacific Ocean (Stevens, 1996).

[3] Calculated from WPRFMC (2004b: average CPUE and fish weight estimates for albacore, bigeye and yellowfin tuna, 1994-2002, p. 3-48, 3-49).

[4] Calculated as follows: Hawaii deep-set longline catch disposition for blue shark summarized for WPRFMC by NMFS PIFSC, May 12, 2004. Primary source is observer data gathered by NMFS PIRO observers assigned to Hawaii longline fleet, July 1, 2001-August 29, 2003 (after U.S. Shark Finning Prohibition Act went into force). Animals released dead, finned/dead or unknown are considered to be finfish waste = 1.77/10,000 hooks x 40 kg average size of blue shark between 20 N and 20 S latitudes in Pacific Ocean (Stevens, 1996).

Table 14. Blue shark BPUE, target fish CPUE, B/C and C/B in selected western and eastern Pacific shallow-set pelagic longline fisheries.

Area and Longline fishery	CPUE Target fish (mt)/10,000 hooks	BPUE Blue shark bycatch (mt)/ 10,000 hooks)	B/C Ratio Blue shark bycatch (mt)/ target fish (mt)	C/B Ratio Target fish (mt)/blue shark bycatch (mt)
Western Tropical Pacific—Taiwan BE, YF tuna longline fishery	Tuna 3.3[1]	0.24[2]	0.07	13.8
WTP—People's Republic of China BE, YF tuna longline fishery	Tuna 2.4[3]	0.24[2]	0.1	10
Sub-tropical and temperate central North Pacific—Hawaii swordfish longline fishery (March 3, 1994 to June 30, 2001)	Swordfish 10.5[4]	1.6[5]	0.15	6.6
Tropical eastern Pacific Costa Rica	Mahimahi 4.5[6]	0.12[7]	0.03	37.5

[1] Calculated from catch/effort statistics of Taiwan offshore longline fleet summarized by SPC.

[2] Calculated as follows. Average CPUE of blue shark observed discarded dead, injured, or unknown condition in western tropical Pacific (10°N–10°S) shallow-set longline fisheries, including a shark-targeted fishery = 1.34/1000 hooks (summary of unpubl. SPC observer data, P. Williams, pers. comm. to P. Bartram, April 26, 2004) = 13.4/10,000 hooks x 40 kg average size of blue shark between 20° N and 20° S latitudes in Pacific Ocean (Stevens, 1996).

[3] Calculated from Liuxiong (2002: Table 1, 3, average of 2000-2001).

[4] Calculated from WPRFMC (2004b: average swordfish CPUE and average fish weight estimates 1994-1999, p. 3-50 and Table 6).

[5] Calculated as follows. Hawaii shallow-set longline catch disposition for blue shark summarized for WPRFMC by NMFS PIFSC, May 12, 2004. Primary source is observer data gathered by NMFS PIRO observers assigned to Hawaii longline fleet, March 3. 1994 – June 30, 2001 (before U.S. Shark Finning Prohibition Act went into force). Animals released dead, finned/dead and unknown are considered to be finfish waste = 88.4 /10,000 hooks x 40 kg average size of blue shark between 20° N and 20° S latitudes in Pacific Ocean (Stevens, 1996).

[6] Calculated from the number of mahimahi caught per 1000 hooks (Arauz 2000, Table 2), assuming an average fish size based on Hawaii fresh mahimahi imports from Costa Rica (7.25 kg).

[7] Calculated as follows. Average CPUE of blue shark in Costa Rica domestic artisanal longline fishery = 7.38/10,000 hooks (Arauz, 2000, Table 7) x 93% of blue shark discarded after finning (Arauz, 2000, Table 4) x 40 kg average size of blue shark between 20° N and 20° S latitudes in Pacific Ocean (Stevens, 1996).

Table 15. Silky shark BPUE, target fish CPUE, B/C and C/B in selected central and western Pacific deep-set pelagic longline fisheries.

Area and Longline fishery	CPUE Target fish (mt)/10,000 hooks	BPUE Silky shark bycatch (mt)/10,000 hooks	B/C Ratio Silky shark bycatch (mt)/Target fish (mt)	C/B Ratio Target fish (mt)/ silky shark bycatch (mt)
Western Tropical Pacific—Japan BE, YF tuna longline fishery	Tuna 4.1[1]	0.015[2]	0.004	273
Sub-tropical central North Pacific—Hawaii BE, YF tuna longline fishery	Tuna 3.0[3]	0.005[4]	0.002	600

[1] Calculated from Miyabe et al. (2003: p. 8, Table 2, average of 1998-2001).

[2] Calculated as follows. Average CPUE of silky shark observed discarded dead, injured, or unknown condition in western tropical Pacific (10°N–10°S) deep set longline fisheries = 0.11/1000 hooks (summary of unpubl. SPC observer data, P. Williams, pers. comm. with P. Bartram, April 26, 2004) = 1.1/10,000 hooks x 30 kg median size of silky shark in Pacific (Oshitani et al., 2003: Fig. 3).

[3] Calculated from WPRFMC (2004b: average CPUE and fish weight estimates for albacore, bigeye and yellowfin tuna, 1994-2002, p. 3-48, 3-49).

[4] Calculated as follows. Hawaii deep-set longline catch disposition for silky shark summarized for WPRFMC by NMFS PIFSC, May 12, 2004. Primary source is observer data gathered by NMFS PIRO observers assigned to Hawaii longline fleet, July 1, 2001 – August 29, 2003 (after U.S. Shark Finning Prohibition Act went into force). Animals released dead, finned/dead and unknown are considered to be finfish waste = 0.345/10,000 hooks x 30 kg median size of silky shark in Pacific (Oshitani et al., 2003: Fig. 3).

Table 16. Silky shark BPUE, target fish CPUE, B/C and C/B in selected western and eastern Pacific shallow-set pelagic longline fisheries.

Area and Longline fishery	CPUE Target fish (mt)/10,000 hooks	BPUE Silky shark bycatch (mt)/ 10,000 hooks	B/C Ratio Silky shark bycatch (mt)/ Target fish (mt)	C/B Ratio Target fish (mt)/silky shark bycatch (mt)
Western Tropical Pacific—Taiwan BE, YF tuna longline fishery	Tuna 3.3[1]	0.063[2]	0.02	52
WTP—People's Republic of China BE, YF tuna longline fishery	Tuna 2.4[3]	0.063[2]	0.03	38
Sub-tropical and temperate central North Pacific—Hawaii swordfish longline fishery (March 3, 1994 to June 30, 2001)	Swordfish 10.5[4]	0.001[5]	0.0001	10500
Tropical eastern Pacific—Costa Rica	Mahimahi 4.5[6]	0.038[7]	0.01	118

[1] Calculated from catch/effort statistics of Taiwan offshore longline fleet summarized by SPC.

[2] Calculated as follows. Average CPUE of silky shark observed discarded dead, injured, or unknown condition in western tropical Pacific (10°N–10°S) shallow set longline fisheries, including a shark-targeted fishery = 0.465/1000 hooks (summary of unpubl. SPC observer data, P. Williams, pers. comm. with P. Bartram, April 26, 2004) = 4.65/10,000 hooks x 30 kg median size of silky shark in Pacific (Oshitani et al., 2003: Fig. 3).

[3] Calculated from Liuxiong (2002: Table 1, 3, average of 2000-2001).

[4] Calculated from WPRFMC (2004b: average swordfish CPUE and average fish weight estimates 1994-1999, p. 3-50 and Table 6).

[5] Calculated as follows. Hawaii shallow-set longline catch disposition for silky shark summarized for WPRFMC by NMFS PIFSC, May 12, 2004. Primary source is observer data gathered by NMFS PIRO observers assigned to Hawaii longline fleet, March 3, 1994–June 30, 2001 (before U.S. Shark Finning Prohibition Act went into force). Animals released dead, finned/dead and unknown are considered to be finfish waste = 0.065/10,000 hooks x 30 kg median size of silky shark in Pacific (Oshitani et al., 2003: Fig. 3).

[6] Calculated from the number of mahimahi caught per 1000 hooks (Arauz, 2000, Table 2), assuming an average fish size based on Hawaii fresh mahimahi imports from Costa Rica (7.25 kg).

[7] Calculated as follows. 46.84 silky shark/10,000 (Arauz, 2000: Table 7) x 6% discarded after finning (Arauz, 2000: Table 4) x 30 kg median size of silky shark in Pacific (Oshitani et al., 2003: Fig. 3).

Table 17. Longnose lancetfish BPUE, target fish CPUE, B/C and C/B in selected central and western Pacific deep-set pelagic longline fisheries.

Area and Longline fishery	CPUE Target fish (mt/10,000 hooks)	BPUE Longnose lancetfish bycatch (mt)/ 10,000 hooks)	C/B Ratio Longnose lancetfish bycatch (mt)/ target fish (mt)	B/C Ratio Target fish (mt)/longnose lancetfish bycatch (mt)
Western Tropical Pacific—Japan BE, YF tuna longline fishery	Tuna 4.1[1]	0.001[2]	0.0002	4100
Sub-tropical central North Pacific—Hawaii BE, YF tuna longline fishery	Tuna 3.0[3]	0.013[4]	0.004	231

[1] Calculated from Miyabe et al. (2003: p. 8, Table 2, average of 1998-2001).

[2] Calculated as follows. Average CPUE of longnose lancetfish observed discarded dead, injured, or unknown condition in western tropical Pacific (10°N–10°S) deep set longline fisheries = 0.142/1000 hooks (summary of unpubl. SPC observer data, P. Williams, pers. comm. to P. Bartram, April 26, 2004) = 1.4/10,000 hooks x 2 kg median weight from weight-on-length relationship in Uchiyama and Kazama (2003: Figure 20, p. 34).

[3] Calculated from WPRFMC (2004b: average CPUE and fish weight estimates for albacore, bigeye and yellowfin tuna, 1994-2002, p. 3-48, 3-49).

[4] Calculated as follows. Hawaii deep-set longline catch disposition for longnose lancetfish summarized for WPRFMC by NMFS PIFSC, May 12, 2004. Primary source is observer data gathered by NMFS PIRO observers assigned to Hawaii longline fleet, March 3, 1994–August 29, 2003. Animals released dead and unknown are considered to be finfish waste = 14.8 /10,000 hooks x 2 kg median weight from weight-on-length relationship in Uchiyama and Kazama (2003: Figure 20, p. 34).

Table 18. Longnose lancetfish BPUE, target fish CPUE, B/C and C/B in selected central and western Pacific shallow-set pelagic longline fisheries.

Area and Longline fishery	CPUE Target fish (mt/10,000 hooks)	BPUE Longnose lancetfish bycatch (mt)/ 10,000 hooks)	C/B Ratio Longnose lancetfish bycatch (mt)/ target fish (mt)	B/C Ratio Target fish (mt)/longnose lancetfish bycatch (mt)
Western Tropical Pacific—Taiwan BE, YF tuna longline fishery	Tuna 3.3[1]	0.001[2]	0.0003	3300
WTP—People's Republic of China BE, YF tuna longline fishery	Tuna 2.4[3]	0.001[2]	0.0004	2400
Sub-tropical and temperate central North Pacific—Hawaii swordfish longline fishery (March 3, 1994 to June 30, 2001)	Swordfish 10.5[4]	0.01[5]	0.001	1050

[1] Calculated from catch/effort statistics of Taiwan offshore longline fleet summarized by SPC unpubl. data.

[2] Calculated as follows. Average CPUE of longnose lancetfish observed discarded dead, injured, or unknown condition in western tropical Pacific (10°N–10°S) shallow-set longline fisheries, including a shark-targeted fishery = 0.082/1000 hooks (summary of unpubl. SPC observer data, P. Williams, pers. comm. to P. Bartram, April 26, 2004) = 0.8/10,000 hooks x 2 kg median size in length-weight relationship of 200 (Uchiyama and Kazawa, 2003: Figure 20, p. 34).

[3] Calculated from Liuxiong (2002: Table 1, 3, average of 2000-2001).

[4] Calculated from WPRFMC (2004b: average swordfish CPUE and average fish weight estimates 1994-1999, p. 3-50 and Table 6).

[5] Calculated as follows. Hawaii shallow-set longline catch disposition for longnose lancetfish summarized for WPRFMC by NMFS PIFSC, May 12, 2004. Primary source is observer data gathered by NMFS PIRO observers assigned to Hawaii longline fleet, March 3. 1994–June 30, 2001. Animals released dead and unknown are considered to be finfish waste = 11.0/10,000 hooks x 2 kg median size in length-weight relationship of 200 (Uchiyama and Kazawa, 2003: Figure 20, p. 34).

Table 19. Shortbill spearfish BPUE, target fish CPUE, B/C and C/B in selected central and western Pacific deep-set pelagic longline fisheries.

Area and Longline fishery	CPUE Target fish (mt)/10,000 hooks	BPUE Shortbill spearfish bycatch (mt)/ 10,000 hooks	B/C Ratio Shortbill spearfish bycatch (mt)/ target fish (mt)	C/B Ratio Target fish (mt)/shortbill spearfish bycatch (mt)
Western Tropical Pacific—Japan BE, YF tuna longline fishery	Tuna 4.1[1]	0.002[2]	0.001	2050
Sub-tropical central North Pacific—Hawaii BE, YF tuna longline fishery	Tuna 3.0[3]	0.002[4]	0.001	1500

[1] Calculated from Miyabe et al. (2003: p. 8, Table 2, average of 1998-2001).

[2] Calculated as follows. Average CPUE of shortbill spearfish observed discarded dead, injured, or unknown condition in western tropical Pacific (10°N–10°S) deep-set longline fisheries = 0.028/1000 hooks (summary of unpubl. SPC observer data, P. Williams, pers. comm. with P. Bartram, April 26, 2004) = 0.28/10,000 hooks x 14.5 kg average weight of shortbill spearfish caught 1994-2002 in Hawaii longline fishery (WPRFMC, 2004b: Table 6).

[3] Calculated from WPRFMC (2004b: average CPUE and fish weight estimates for albacore, bigeye and yellowfin tuna, 1994-2002, p. 3-48, 3-49).

[4] Calculated as follows. Hawaii deep-set longline catch disposition for shortbill spearfish summarized for WPRFMC by NMFS PIFSC, May 12, 2004. Primary source is observer data gathered by NMFS PIRO observers assigned to Hawaii longline fleet, March 3, 1994–August 29, 2003. Animals released dead and unknown are considered to be finfish waste = 0.34/10,000 hooks x 14.5 kg average weight of spearfish caught 1994-2002 in Hawaii longline fishery (WPRFMC, 2004b: Table 6).

Table 20. Shortbill spearfish BPUE, target fish CPUE, B/C and C/B in selected central and western Pacific shallow-set pelagic longline fisheries.

Area and Longline fishery	CPUE Target fish (mt)/10,000 hooks	BPUE Shortbill spearfish bycatch (mt)/ 10,000 hooks	B/C Ratio Shortbill spearfish bycatch (mt)/ target fish (mt)	C/B Ratio Target fish (mt)/shortbill spearfish bycatch (mt)
Western Tropical Pacific—Taiwan BE, YF tuna longline fishery	Tuna 3.3[1]	0.001[2]	0.0003	3300
WTP—People's Republic of China BE, YF tuna longline fishery	Tuna 2.4[3]	0.001[2]	0.0004	2400
Sub-tropical and temperate central North Pacific—Hawaii swordfish longline fishery (March 3, 1994 to June 30, 2001)	Swordfish 10.5[4]	0.004[5]	0.0004	2625

[1] Calculated from catch/effort statistics of Taiwan offshore longline fleet summarized by SPC unpubl. data.

[2] Calculated as follows. Average CPUE of shortbill spearfish observed discarded dead, injured, or unknown condition in western tropical Pacific (10°N–10°S) shallow-set longline fisheries, including a shark-targeted fishery = 0.019/1000 hooks (summary of unpubl. SPC observer data, P. Williams, pers. comm. to P. Bartram, April 26, 2004) = 0.19/10,000 hooks x 14.3 kg average weight of shortbill spearfish caught 1994-1999 in Hawaii longline fishery (WPRFMC, 2004b: Table 6).

[3] Calculated from Liuxiong (2002: Table 1, 3, average of 2000-2001).

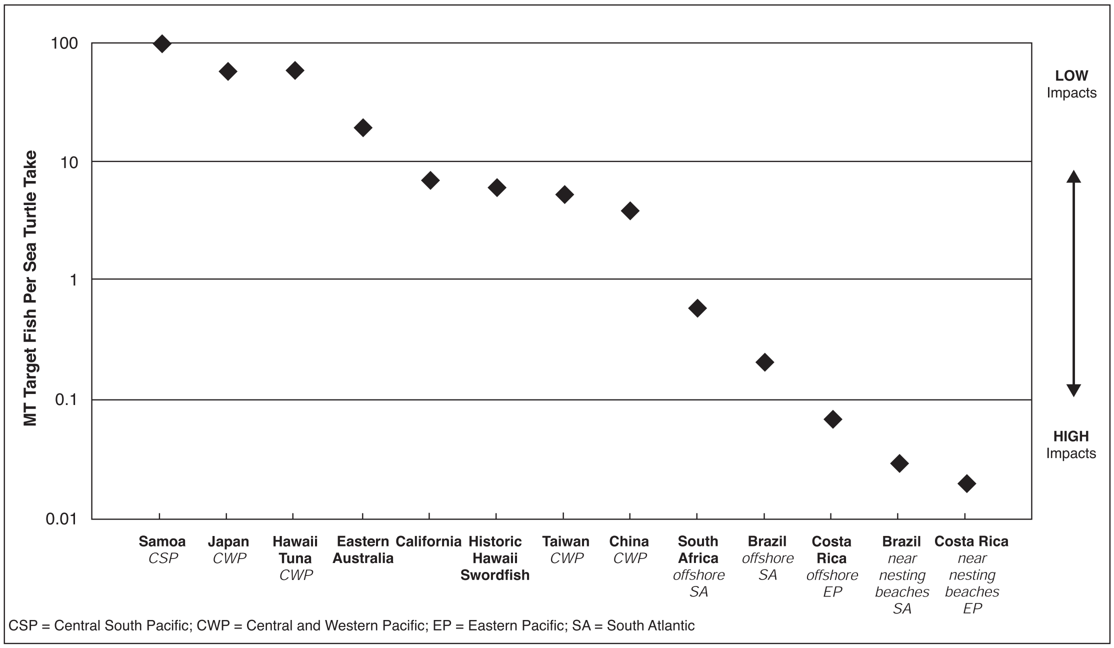
[4] Calculated from WPRFMC (2004b: average swordfish CPUE and average fish weight estimates 1994-1999, p. 3-50 and Table 6).

[5] Calculated as follows. Hawaii shallow-set longline catch disposition for shortbill spearfish summarized for WPRFMC by NMFS PIFSC, May 12, 2004. Primary source is observer data gathered by NMFS PIRO observers assigned to Hawaii longline fleet, March 3. 1994–June 30, 2001. Animals released dead and unknown are considered to be finfish waste = 0.54/10,000 hooks x 14.3 kg average weight of shortbill spearfish caught 1994-1999 in Hawaii longline fishery (WPRFMC, 2004b: Table 6).

6.3 Comparing Hawaii and Other Longline Fisheries Based on C/B Ratios.

In this section, the C/B ratio (catch/bycatch) estimates calculated in Sections 6.1 (sea turtles) and 6.2 (four species of finfish waste) are plotted on semi-log graphs (Figures 5-7) for easy comparison of selected longline fisheries. Fisheries with the larger C/B ratios have less bycatch associated with target fish production than fisheries with low C/B ratios. The relative bycatch impacts associated with fishery products from the various fisheries can be compared in this way. When bycatch is interpreted as a function of target catch (after Hall, 1996), marketers and consumers, as well as resource managers, can better understand the environmental impacts that are endorsed when longline fish products are purchased from different fisheries.

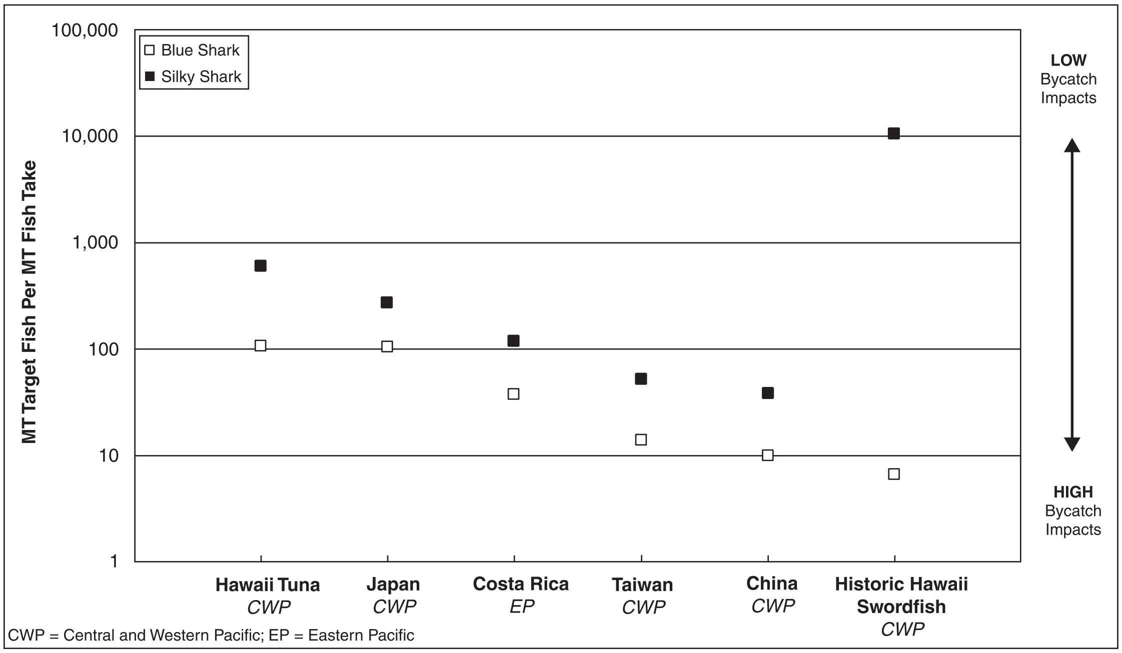
Figure 5 expresses fishery sea turtle impacts as the C/B ratio of the average weight of target catch (mt) that is harvested associated with one incidental sea turtle take. Moving from left to right in Figure 5, fishery products from the Samoa, Japan and Hawaii tuna longline fisheries have much fewer associated sea turtle interactions than products from the longline fisheries of Brazil and Costa Rica.



Data source: Tables 8, 9, 10, 11.

Figure 5. Catch to bycatch ratios (C/B): Mean harvest of target fish (mt) associated with one sea turtle take in selected pelagic longline fisheries.[1]

Figure 6 presents fishery bycatch impacts on two selected shark species (blue and silky sharks) as the C/B ratio of the average weight of target catch (mt) that is harvested in association with one mt of bycatch of each of the shark species. Moving from left to right in Figure 6, the bycatch impacts on blue sharks associated with tuna from the Hawaii and Japan deep set longline fisheries are less severe than the blue shark bycatch that was associated with the historic Hawaii swordfish fishery that used shallow longline setting methods. In general, the relative silky shark bycatch impacts associated with fishery products increase from left to right in Figure 6. The historic Hawaii swordfish fishery is the exception with the bycatch impact on silky sharks being much lower than the other fisheries, whereas blue shark impacts were the highest of the fisheries compared.



^{1}Data source: Tables 13, 14, 15, 16.

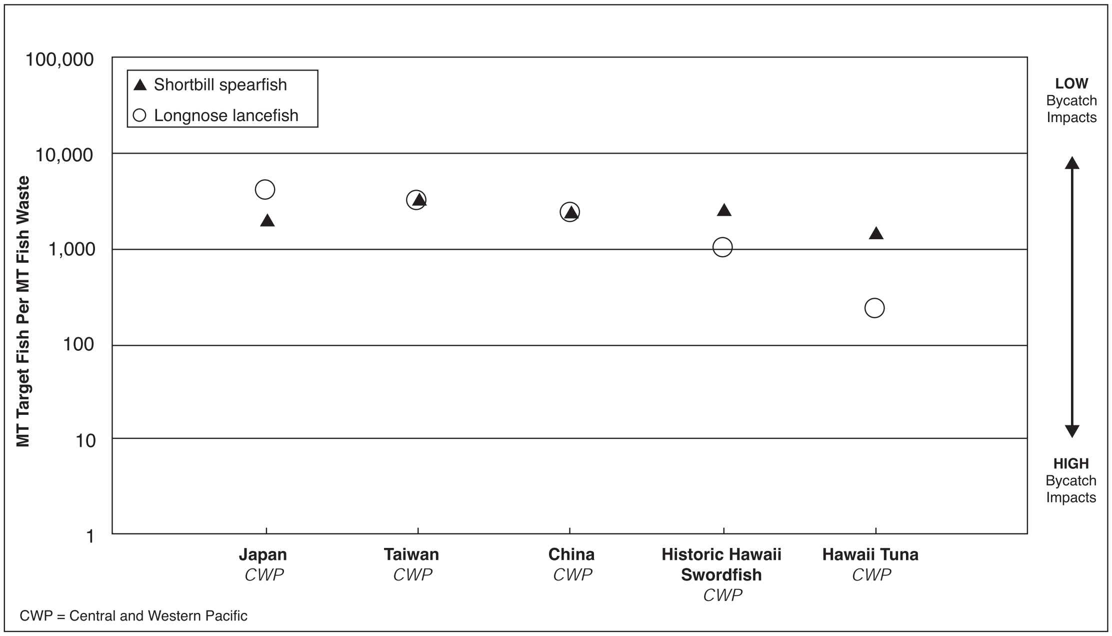
Figure 6. Catch to bycatch ratios (C/B): Average harvest of target fish (mt) to produce one mt of selected shark species bycatch (waste) in selected pelagic longline fisheries.^{1}

Figure 7 compares fishery bycatch impacts on two selected fish species (longnose lancetfish and shortbill spearfish) in terms of C/B ratios expressed as the average weight of target catch (mt) that is harvested in association with one mt of these two fish species that are wasted as bycatch. The C/B ratios for spearfish were similar among the fisheries compared in Figure 7. Bycatch of lancetfish associated with target fish production increased from left to right in Figure 7, with the Hawaii tuna longline fishery having the greatest adverse impact on lancetfish of the fisheries compared.

7. UTILITY OF BPUE, B/C AND C/B RATIOS

7.1 Evaluate Indirect Effects of Hawaii Longline Fisheries Management Actions on Sea Turtle Bycatch

BPUE, B/C and C/B ratios have been used to evaluate the indirect effects (also known as transferred market effects or market leakage) resulting from the NMFS-ordered regulation of Hawaii longline fisheries in mid-2001 (WPRFMC, 2004a). These regulations curtailed the swordfish sector completely and restricted the tuna sector during the months of April and May. New regulations for these fisheries went into force in April 1, 2004, but for three years, the supply of Hawaii fresh swordfish was halted and the supply of Hawaii fresh tuna was seasonally disrupted. Much of the supply lost from Hawaii was replaced by fresh imports from foreign longline fisheries, according to U.S. market sources that deal in these products. The indirect effects on sea turtle takes of such product substitution are analyzed in the following sections using the B/C ratios derived in Section 6.1.



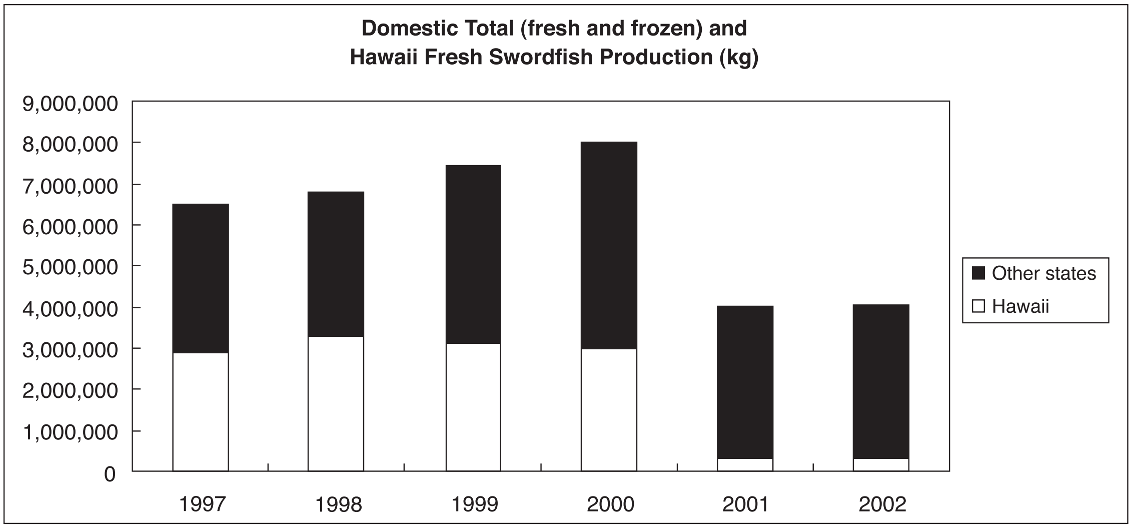
[1]Data source: Tables 17, 18, 19, 20.

Figure 7. C/B ratios: Average harvest of target fish (mt) to produce one mt of selected fish bycatch (waste) in selected pelagic longline fisheries.[1]

Before the NMFS halted Hawaii longline swordfish production in mid-2001, most of the catch from this fishery was shipped fresh by airfreight to the U.S. mainland (NMFS, 2001b), where it claimed a large share of the fresh swordfish market (Figure 8). The U.S. market niche for higher-priced fresh swordfish is distinct from the lower-priced niche for lower-priced frozen swordfish (Figure 9).

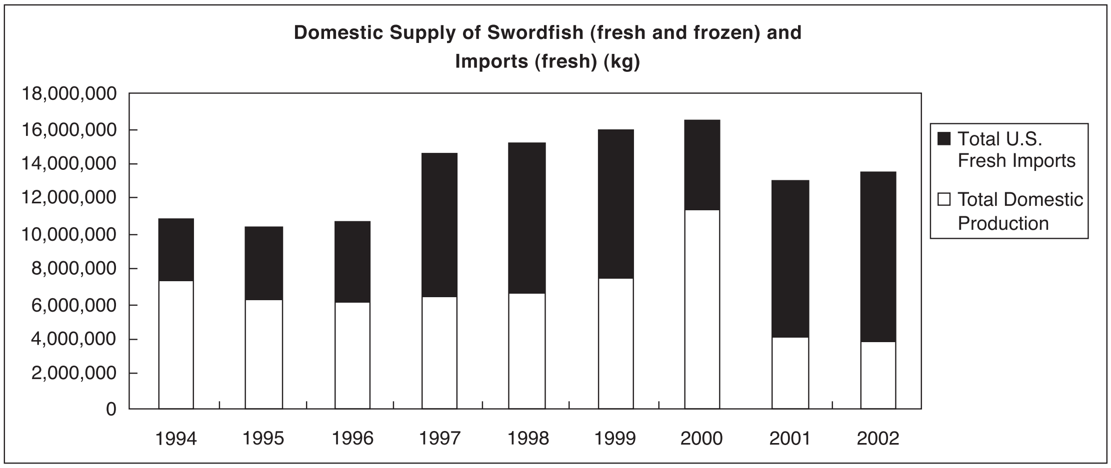
The U.S. is the world's largest swordfish market (Ward and Elscot, 2000) and any shortfall in domestic production is likely to be filled by imports. The U.S. fresh swordfish supply is becoming increasingly dependent on imported products (Redmayne, 2001).

Several U.S. fresh fish marketers who were formerly major dealers in Hawaii longline swordfish products were interviewed for this study, including Tom Kraft (Norpac Fisheries Export., Honolulu, HI), Saul Phillips (Export Inc., New Jersey), and Tim Malley (Stavis Seafoods, Inc., Boston). Interviews were conducted during the period March 11-13, 2003, at the Boston International Seafood Show. During wide-ranging discussions about the Hawaii swordfish fishery—past, present and future—the marketers were asked which suppliers of the many fresh swordfish exporting countries had taken over the specific Hawaii share of the market following the Hawaii swordfish fishery closure. They identified the primary sources of fresh swordfish replacing Hawaii longline products as eastern Pacific suppliers—California (relocated Hawaii swordfish longline boats), Mexico, Panama, Costa Rica—plus South Africa. Between 2001 and 2002, exports of fresh swordfish from some of these fisheries increased substantially. Most notably, fresh swordfish imports from Panama increased from 225 mt in 2001 to nearly 1,130 mt in 2002 (www.st.nmfs.gov).



[1]Data source: NMFS, www.st.nmfs.gov

Figure 8. Domestic total (fresh and frozen) and Hawaii fresh swordfish production between 1997 and 2002.[1]



[1]Data source: NMFS, www.st.nmfs.gov

Figure 9. Domestic (fresh and frozen) and imported fresh swordfish supply to the US market between 1994 and 2002.[1]

Leatherback turtles from the eastern Pacific population are particularly at risk of incidental capture of longline fisheries operating in the vicinity of the Galapagos Islands. Morreale et al. (1996) and Eckert and Sarti (1997) have demonstrated the existence of a corridor for leatherbacks of the central American region and southern Mexico on their southward post-nesting migration toward South America. Turtles that have been satellite-tracked head toward the Galapagos Islands where they taper into higher concentrations, perhaps in a feeding migration, before dispersing again towards South American waters (Morreale et al., 1996). The clustering of many individuals along this migratory corridor greatly increases the vulnerability of eastern Pacific leatherback turtles to incidental capture in longline fisheries, especially because of the prevalence of shallow-set fishing practices off Mexico and Central America.

Neither the industry sources interviewed nor published sources of information can provide a precise accounting of Hawaii swordfish replacement by country of product origin. After swordfish-style longlining was prohibited in Hawaii, about 20 vessels relocated to the eastern Pacific (NMFS, undated), where they continued to target swordfish and make incidental catches of sea turtles at approximately the same rate as in the Hawaii swordfish-style longline fishery (i.e., 1.7 sea turtle takes per 10,000 hooks from Caretta, 2003).

Sea turtle take rates in U.S. swordfish longline fishing west and east of 150^{o} E latitude are compared by Caretta (2003). The area east of 150 W is the region most utilized by vessels landing in California, although there is overlap with the historic Hawaii-based swordfish vessels. At both per-set and per-1000-hooks levels sea turtle take rates are higher east of 150^{o} W (1.8 takes/10,000 hooks) than in the historic Hawaii swordfish fishery (1.7 takes/10,000 hooks), although the differences are not statistically significant (Caretta, 2003).

Except for California, the other most likely replacement sources of swordfish all have higher associated sea turtle BPUE (Table 21). Thus, it is highly likely that the NMFS-ordered regulations that were in effect from mid-2001 through March 2004 had the indirect effect of increasing sea turtle takes associated with Hawaii swordfish replacement fisheries, rather than achieving the stated objective of reducing sea turtle takes overall.

Table 21. Comparison of the number of sea turtle takes per 100 mt of fresh swordfish from Hawaii and imported swordfish that replaced Hawaii swordfish after the 2001 fishery closure.

Area and Longline fishery	Sea turtle takes/100 mt fresh swordfish catch[1]
Eastern tropical Pacific offshore of nesting beaches (e.g., Costa Rica, Mexico)	4310
Eastern tropical Pacific offshore (e.g., Costa Rica, Panama)	1480
South Africa	158
Historic Hawaii Shallow-set swordfish-style	16

[1] Calculated from Tables 9, 10 and 11.

7.2 Compare Bycatch Impacts Associated with Pelagic Fish Sources

C/B and B/C ratios have the potential to enable marketers and consumers to compare some of the environmental consequences that they are endorsing when they purchase seafood from different sources. The environmental impacts of fishing with different gears in different locations are transferred along with the target fish exports through the mechanism of international trade. "Products are now increasingly sourced globally, and a shortfall in supplies of one species or one specific origin, will soon be filled with substitutes from other sources." (Lem, 2000:125)

Sea turtle BPUE estimates (Figure 5) suggest that the best choices of fresh pelagic fish (i.e., highest C/B ratios) for consumers concerned about impacts on sea turtles would be the Samoa, Hawaii and Japan tuna longline fisheries. The Australia longline fishery would be a better choice than the historic Hawaii swordfish or China and Taiwan longline fisheries. The Costa Rica (and eastern tropical Pacific neighbors) and South Africa longline fisheries would probably be the worst choices for fresh pelagic fish. The Hawaii swordfish fishery has reopened under new regulations (April 1, 2004) expected to reduce sea turtle takes so significantly that this fishery will become the best choice for fresh swordfish with low associated sea turtle BPUE and high C/B ratio.

Finfish waste estimates expressed as C/B ratios (Figure 6) suggest that the Hawaii tuna longline fishery is the best choice of fresh pelagic fish for consumers concerned about shark waste and Taiwan, China and Costa Rica longline fisheries would be worse choices. The historic Hawaii swordfish fishery would be a poor choice for those concerned about blue shark but a good choice for those concerned about silky shark. None of the longline fisheries examined have major impacts on shortbill spearfish waste. Japan, Taiwan and China longline fisheries are better choices of pelagic fish than Hawaii longline fisheries for consumers who are concerned about longnose lancetfish waste.

8. MAJOR FINDINGS

- Pelagic longline fishing is not a single or static method of fishing and it is constantly evolving. "Splitting" rather than "lumping" is crucial for evaluating and comparing the impacts of diverse longline gear configurations and fishing tactics on bycatch.

- BPUE and its derivatives B/C and C/B ratios (after Hall, 1996) are useful indices to scale and to make meaningful comparisons of the bycatch impacts of different pelagic longline fisheries. When placed on quantitative BPUE scales for sea turtles and three species of incidentally caught finfish, the Hawaii tuna longline fishery is actually low in associated bycatch. Compared to other fisheries examined, Hawaii is high in bycatch of a fourth finfish species—longnose lancetfish.

- Unilateral management of the Hawaii longline fishery to protect sea turtle populations failed. NMFS-ordered regulations in effect from mid-2001 to April 1, 2004 indirectly increased sea turtle takes because Hawaii longline products were replaced in the market with pelagic fish from sources with higher associated sea turtle B/C ratios. "Sea turtles migrate for long distances, weaving in and out of Exclusive Economic Zones of coastal countries and the high seas. Efforts at protection in one or more nations can shift harvests of swordfish…, and hence incidental takes of sea turtles, to harvesters of other nationalities, a production leakage. Attempted protection of turtles and the subsequent production leakage might well not change sea turtle mortality rates, since swordfish… harvests from non-protecting nations can replace the diminished harvests of protecting nations through the active import markets, a trade leakage." (Ahmed and Squires, 2003: 16-17)

- Due to the global scale and interconnections of fish production and marketing systems, bycatch does not disappear as a result of regulating one area or one nation's fishery. The impacts are simply transferred to other places (Crespo and Hall, 2002), where there may be a lack of fishery regulations, monitoring and enforcement. Regulators need to be careful, therefore, not to penalize low-bycatch fisheries and indirectly stimulate the expansion of high-bycatch fisheries through production leakage and market leakage effects.

- When the Hawaii longline fishery is characterized as having high finfish bycatch, the general public is misled to believe that there is large associated waste. This false impression is created because of the confusing Magnuson-Stevens Act definition of bycatch. This definition combines finfish waste (i.e., non-target finfish released dead or dying) with non-target finfish released alive after incidental capture. Thus, the Hawaii longline fishery is being penalized for a practice (catch and live release) that is considered to have conservation benefits in most fisheries.

- The present research examined only four species of finfish that are incidentally captured in pelagic longline fisheries. More thorough analysis should be performed of life status (live versus dead) of finfish discards by Hawaii longline fisheries. This information exists in the Hawaii longline observer database maintained by NOAA Pacific Islands Regional Office. Such analysis would help to differentiate the amount of finfish that is actually wasted (true bycatch) from the fish that are released with a good chance of survival. This distinction would better inform the general public about the actual bycatch impacts of Hawaii pelagic longline fisheries.

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