Assessing Impacts of North Pacific High-Seas Driftnet Fisheries on Marine Turtles: Progress and Problems[1]

George H. Balazs and Jerry A. Wetherall

Honolulu Laboratory
Southwest Fisheries Science Center
National Marine Fisheries Service
2570 Dole St., Honolulu, HI, 96822 U.S.A.

I. Introduction

Marine turtles are caught incidentally and killed in North Pacific high-seas driftnet fisheries. Because all marine turtle populations in the Pacific are considered to be endangered or vulnerable any mortality due to incidental entanglement is cause for concern. It is essential that the level of mortality caused by driftnets and other fishing gear be assessed.

Three species of marine turtles have been identified with assurance in the driftnet fishing area and driftnet bycatch: leatherback, loggerhead, and green turtles. There have been no confirmed records of olive ridley or hawksbill turtles to date. This review focuses on the three species known to be affected by the driftnet fisheries. It provides a synopsis of information on life history and distribution, mortality factors, and driftnet bycatch. Unresolved impact assessment issues and data needs are also identified.

II. Description, Life History, and Distribution

A. Leatherback Turtle

The leatherback, Dermochelys coriacea, is the most distinctive and easily recognizable of the seven extant species of marine turtles. This is due to its large adult size, presence of seven longitudinal dorsal ridges, and absence of any cornified epidermal scutes, scales, or claws found in the hardshelled species of marine turtles. The leatherback is black with white speckling on the dorsal surfaces, and whitish on the ventral surfaces where five longitudinal ridges occur. The overall body has been described as deep and somewhat barrel-shaped, having a continuous covering of tough rubbery skin (Pritchard 1971, 1979; Groombridge 1982). With a verified maximum weight of over 910 kg, the leatherback is the largest living turtle. It is the sole species included in the family Dermochelyidae; all other species of marine turtles being in the family Cheloniidae. The front

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flippers are disproportionately long compared to other marine turtles, making the leatherback a powerful swimmer in the open seas that it inhabits.

Leatherbacks, along with the olive ridley turtle, Lepidochelys olivacea, are ecologically unique among marine turtles by leading a completely pelagic existence throughout life, except during nesting. Like all marine turtles, the adult females must periodically return to land to lay eggs. The early life stages of other marine turtles (hatchlings and juveniles up to 25-50 cm or more in carapace length (CL), depending on the species) all pass through a pelagic phase of development (Carr 1986a). Then, after several years or more, they recruit to coastal or reef areas and establish a benthic existence.

The leatherback's diet is also unique among marine turtles in that it consists almost entirely of jellyfish (Scyphomedusidae) and planktonic tunicates such as Salps and Pyrosoma (Thaliacea). Leatherbacks are known to be among the deepest diving of air-breathing vertebrates with depths of 1200 m having been documented (Eckert et al. 1986, Mrosovsky 1987). The reason for diving so deep has not been determined, but may be related to feeding, or possibly thermoregulation; a leatherback may need to cool itself while in tropical waters or following strenuous nesting on land.

The leatherback is a circumglobal species with historically repetitive nesting occurring on certain selected beaches located between 30°N and 20°S. Away from these beaches leatherbacks are highly migratory, covering great distances that involve intentional movements into temperate and cooler waters to forage. Measurements on a leatherback captured off Nova Scotia show that the species is capable of maintaining a body temperature of at least 18°C above ambient seawater of 7.5°C. As with all marine turtles, very little is known of leatherback ecology and life history when they inhabit the open seas. For example, post-hatchling and subadult leatherbacks are almost never encountered anywhere.

Leatherback populations found in pelagic regions of the North Pacific originate from, and return to reproduce, at distant nesting beaches of uncertain identity. A plausible nesting beach of origin for leatherbacks encountered by driftnet vessels fishing in the North Pacific Transition Zone would be Rantau Abang in Trengganu State on the east coast of peninsular Malaysia. During the past 30 years, the leatherback population at this world-famous nesting beach has declined from an estimated 1000-2000 females nesting annually, to about 30-50 nesting females during the 1989 season (Mortimer 1990; see also Siow and Moll 1982). Leatherback nesting sites south of the equator in Irian Jaya (Indonesia) may also contribute to pelagic populations in the North Pacific, although much less is known about them.

Leatherbacks occurring off Japan (Nishimura 1964) almost certainly originate from one or both of these nesting areas in southeast Asia. The leatherback's penetration eastward into the North Pacific could be easily facilitated by (but not necessarily require) the Kuroshio Extension current. Leatherback nesting of any magnitude elsewhere in the Pacific occurs only along the Americas. Major nesting beaches occur from Michoacan south to Oaxaca, in Mexico, and in northern Costa Rica (Pritchard 1982). Leatherbacks from this eastern Pacific region may also contribute to pelagic populations encountered during driftnet fishing, since the species is commonly seen in the Pacific northwest. The leatherback nesting population on the Pacific coast of Mexico is probably the largest in the world, numbering thousands of females annually, but its current conservation status is unclear.

B. Loggerhead Turtle

The loggerhead, Caretta caretta, is a hardshelled marine turtle with an elongated reddish-brown carapace having five vertebral scutes and five (but sometimes only four) pairs of costal scutes. The plastron and other ventral surfaces are yellowish-white to yellowish-brown. The head, which has two pairs of prefrontal scales, is large, broad, and triangular with powerful jaws. Adults have a smooth carapace measuring 70-90 cm in length at the onset of sexual maturity. The maximum adult size of the loggerhead rarely exceeds 110 cm CL. In juveniles up to 35-50 cm CL the carapace has projections or elevated knobs toward the posterior of each vertebral scute and, to a lesser degree, each costal scute (Dodd 1988, Groombridge 1982, Pritchard 1979).

The loggerhead is a circumglobal species found in temperate and subtropical waters. Nearly all nesting (except for the Western Caribbean) takes place north of 25°N, and south of 25°S. Adult loggerheads undertake lengthy reproductive migrations to and from their historical nesting sites, but dispersal patterns in foraging areas are not well known for any population.

As with other marine turtles, hatchling loggerheads rapidy depart from their natal beaches and enter into a pelagic and planktonic stage of development where they are only rarely located and studied. The time spent in the open ocean is believed to last for at least three, and very likely five or more years. Research conducted by Carr (1986a, 1986b), and more recently by Bolten and Bjorndal (1991), has shown that some young Atlantic loggerheads feed at the surface over deep water near the Azores, where convergences and downwelling concentrate available food such as coelenterates and other planktonic invertebrates. The loggerheads in this pelagic region almost certainly originate from major nesting beaches in the Southeastern United States. Passive drift in the Gulf Stream and North Atlantic Gyre, in combination perhaps with periods of residency in smaller local ocean gyres, has been proposed to account for the turtles' hypothesized eventual return to the Americas. Upon returning, at a size exceeding 50-60 cm CL, recruitment to benthic habitats takes place. As benethic dwellers at this larger size loggerheads continue to be carnivorous, but now feeding primarily on molluscs and crustaceans.

In the North Pacific, where even less is known about the ecological geography of immature loggerheads, the only major nesting beaches are in the southern part of Japan along the east and west coasts of Kyushu, the southeast coast of Shikoku, and the southeast and northeast coasts of Honshu (Nishimura 1967, Uchida and Nishiwaki 1982, Dodd 1988). Although reliable counts are not available, as many as 2000-3000 loggerheads may nest annually on beaches throughout Japan.

In the temperate zone of the South Pacific, loggerhead nesting is widespread and abundant in Queensland and Western Australia, where in excess of 3000 females are estimated to nest annually (Limpus 1982). In the Eastern Pacific, along the Americas, as well as in the central Pacific, nesting loggerheads are virtually nonexistent. However, large numbers of subadult loggerheads have been reported over deep water 42 km off the Baja California coast of Mexico (Dodd 1988, Balazs 1989). In southern Mexico and Pacific Central America, loggerheads are exceedingly rare, if in fact they occur there at all. The origin of young loggerheads off Baja California is therefore an enigma in need of investigation. The possibility exists that these turtles may be part of the Japanese population. Some support for this hypothesis has been provided by Uchida and Teruya (1991) in reporting the recovery of a tagged loggerhead found 75 km off San Diego (Southern California) that had been released 2.3 years earlier off Okinawa at a size of 17.5 cm carapace length.

Immature loggerheads encountered during driftnet fishing in the North Pacific most probably originate from nesting beaches in Japan, being transported to the north and east by the Kuroshio and its extension. The apparent similarities of young loggerheads reported off Baja California to the circumstances off the Azores, raises the possibility of pelagic Pacific-wide migrations by the Japanese loggerheads. Additional research will be needed to confirm or reject this hypothesis.

C. Green Turtle

The green turtle, Chelonia mydas, is a hardshelled marine turtle with a smooth heart-shaped carapace having five vertebral scutes and four pairs of costal scutes. The head is relatively small and anteriorly rounded with a single pair of elongated prefrontal scales. The coloration of the carapace in adult green turtles, as well as immature size classes, varies considerably, ranging from black to brown, olive, yellow and combinations thereof. The plastron and other ventral surfaces range from pure white in the juvenile to yellowish and orange in the adult. However, green turtles that nest on the Pacific coast of Mexico (often referred to as the "black turtle") are distinguished by their heavy black dorsal pigmentation, a highly arched carapace, small size at the onset of sexual maturity (70 cm compared to >82 cm elsewhere), and considerable gray or black pigment in the plastron (Hirth 1971, Pritchard 1979, Groombridge 1982).

The green turtle's lower jaw-edge is coarsely serrated corresponding to strong grooves and ridges on the inner surface of the upper jaw. This generic feature relates to the fact that green turtles are the only marine turtle with a nearly exclusive herbivorous diet (e.g. sea grass and algae) following their recruitment into shallow benthic habitats from the pelagic phase of development. Nutritional limitations of herbivory (Bjorndal 1982) result in green turtles exhibiting generally slow rates of growth and a delayed sexual maturity estimated to be 15-50 years in the wild. The average adult size of the green turtle varies between nesting sites (e.g. 92 cm in Hawaii, 105 cm in Surinam) where migrations are periodically undertaken and nesting females show a strong fidelity throughout their reproductive life.

The green turtle is a circumglobal and highly migratory species nesting mainly in tropical and subtropical regions. It inhabits waters that usually remain above 20°C in the coldest month. Like other marine turtles, the species should not be regarded as a single interbreeding assemblage, but rather as a complex of populations, or stock units, having geographically discrete nesting sites. These breeding populations have little, if any, ability to demographically reinforce one another. Once a population has been depleted, there is no evidence that it can be restored over forseeable time by turtles originating from other populations.

Approximately 150 separate nesting colonies for the green turtle are known worldwide, however only about 10-15 of these are considered large enough to involve 2000 or more nesting females per year (Groombridge 1982). In the Pacific, major populations are restricted to Australia, Mexico, and Malaysia. Small, and in many cases reduced, nesting colonies of green turtles are scattered throughout the insular Pacific islands of Polynesia, Micronesia, and Melanesia (Forsyth and Balazs 1989).

Green turtles encountered during driftnet fishing in the North Pacific may originate from a number of known proximal, or even distant, breeding colonies in the region. However, the most likely candidates would include French Frigate Shoals in the Hawaiian Islands (Balazs 1980), and the Ryukyu and Ogasawara Islands of Japan (Suganuma 1991, Uchida and Nishiwaki 1982).

III. Sources of Marine Turtle Mortality

Marine turtles have been adversely affected by an array of human-induced factors that have resulted in the species being designated as threatened and endangered. Declines in marine turtles have brought them under restrictive, but by no means fully effective, international trade agreements by consenting nations (CSTC 1990, Groombridge and Luxmoor 1989).

All marine turtle life stages are susceptible to human-induced mortality. On nesting beaches direct exploitation of turtles for meat, eggs, hides, and other products takes place for both commercial markets and local utilization. For example, in Japan, in Kagoshima Prefecture, loggerhead eggs are taken for local consumption, and fishermen often take the adults to eat whenever encountered in the nearshore waters (Deguchi 1991). In the Ogasawara Islands, green turtles are hunted for food by the local inhabitants, and subadults are commonly caught and drowned in monofilament fishing nets (Suganuama 1991). Likewise, in the Hawaiian Islands green turtles were historically harvested by the indigenous population, and later by European settlers. Although protected now by Hawaii state and U.S. Federal laws, they are frequently killed in inshore gillnets targeting fish.

On nesting beaches and in nearshore waters, habitat degradation and destruction has occurred from such diverse factors as coastal development, dredging, vessel traffic, erosion control, sand mining, vehicular traffic on beaches, and artificial lighting that repels the adults and disorients the hatchlings. Human alteration of terrestrial habitats can also change the feeding patterns of natural predators, thereby increasing predation on marine turtle nests and eggs.

Petroleum and other forms of chemical pollution affect turtles throughout their marine and terrestrial habitats. Direct poisoning, as well as blockage of the gastrointestinal tract by ingested tar balls, as been reported. Low level chemical pollution possibly causing immunosuppression has been suggested as a factor in the epidemic outbreak of a tumor disease in green turtles (Balazs and Pooley 1991). Plastics and other persistent buoyant debris discharged into the ocean are now also recognized as harmful pollutants, especially to juvenile and subadult turtles in the pelagic environment. Both the entanglement in, and ingestion of, this synthetic debris have been documented (Balazs 1989, Carr 1987).

The incidental capture and mortality of turtles has been documented in various fisheries, include those using longlines, trawls, purse seines, and gillnets (Crouse 1984). In the Eastern Tropical Pacific marine turtles are sometimes taken in tuna purse seines and throughout the Pacific they are occasionally hooked or entangled by tuna longline gear. Little quantitative information on such indidental capture has been available. Recently, however, Nishemura and Nakahigashi (1990) estimated that in the North Pacific and South China Sea approximately 21,200 turtles, including loggerheads and greens, were captured each year in tuna longlines and bottom trawls, with a mortality of roughly 12,300 turtles per year. The estimates were based on turtle capture rates reported in a survey of fisheries research and training vessels and extrapolated to total longline fleet effort. We were not able to evaluate the reliability of these estimates.

IV. Driftnet Entanglement and Bycatch

A. Squid Driftnet Vessels

Limited information is available on marine turtle entanglement in high-seas driftnets. The first systematic data collection was in the 1989 pilot observer program on Japanese squid driftnet vessels. In this program 22 marine turtles were seen entangled in 1.4 million monitored 50-m tans, a bycatch rate of 15.4 turtles per million tans. This includes all turtles caught in monitored net sections, whether or not they were decked.

The total effort by the Japanese squid fleet in 1989 was 34.38 million tans. Thus a simple estimate of the total marine turtle bycatch for the fleet in 1989 is 529 turtles. A more complex estimate based on time-area stratification of the squid fishing area is 544 turtles (approximate 95% confidence interval 360 to 742). Because the number of turtles seen was small only an aggregate estimate was computed. The 22 observed turtles included 9 leatherbacks, 1 green turtle, and 12 unidentified turtles.

In the 1990 monitoring programs data were collected by Japanese, Canadian, and United States observers from nearly 2.3 million monitored 50-m tans on Japanese squid vessels. In addition, data were collected for the first time from Korean and Taiwanese squid driftnet vessels by observers from the host countries and the United States. On the Korean and Taiwanese vessels U.S. observers monitored the retrieval of about 300 thousand poks (equilavent to tans; the term *tans* will be used hereafter) and 91 thousand tans, respectively. Data collected by Korean and Taiwanese observers are still being processed and are not included here.

Preliminary estimates of marine turtle bycatch rates in 1990 based on the available data from squid driftnet vessels are as follows:

	Japan		Korea		Taiwan	
Species	No.	No. per 10^6tans	No.	No. per 10^6tans	No.	No.per 10^6tans
Unidentified	7	3.1	1	3.3	0	
Leatherback	27	11.9	2	6.7	0	
Loggerhead	1	0.4	0		0	
Green	0		0		1	11.0
Total	35	15.4	3	10.0	1	11.0
Tans Monitored (1000's)	2,278		300		91	

The average turtle bycatch rate in the 1990 Japanese squid driftnet fishery was 15.4 per 10^6 tans, identical to the bycatch rate in the 1989 pilot observer program. Estimates of the total bycatch of turtles in the 1990 Japanese squid fishery will require further analysis. Similar estimates will be computed for the 1990 Korean and Taiwanese squid fleets when sufficient data are available.

B. Tuna/Billfish Driftnet Vessels

In 1990 data on marine turtle bycatch were collected by United States and host country observers on Japanese and Taiwanese large-mesh driftnet vessels targeting tuna or billfish. Data collected by the Taiwanese observers have not been fully examined, so results here do not include them. Further, U.S. observer effort on Taiwanese large-mesh vessels was distributed during the fishing season on an opportunistic basis. We do not know yet whether this sampling was representative of the Taiwanese large-mesh fleet effort distribution in 1990.

Observations on Japanese large-mesh vessels were made only in the last few months of 1990. Observer data were collected during the early part of 1991 on Japanese large-mesh vessels but are not yet available for analysis.

Bearing in mind these limitations the following preliminary estimates of bycatch rates on the large-mesh driftnet vessels were computed:

Species	Japan No.	Japan No. per 10^6tans	Taiwan No.	Taiwan No. per 10^6tans
Unidentified	20	302.1	18	268.0
Leatherback	4	60.4	8	119.0
Loggerhead	27	407.9	8	119.0
Green	6	90.6	0	
Total	57	861.0	34	506.0
Tans Monitored (1000's)	66		67	

The overall marine turtle bycatch rates were about 50 times higher on large-mesh driftnet vessels than squid driftnet vessels. Further, the species composition of the turtle bycatch in the two types of gear was significantly different. The bycatch of squid driftnet vessels appears to be primarily leatherbacks tolerant of colder waters along the Subarctic Boundary. Small loggerheads and green turtles have also been identified in the squid driftnet bycatches.

The bycatch of the large-mesh vessels, fishing generally in lower latitudes, consists mostly of loggerheads and "unidentified" marine turtles. In most instances United States observers noted that the latter turtles were not leatherbacks. Greens turtles and leatherbacks have also been identified in the large-mesh driftnet bycatches.

Differences in bycatch rate among species of marine turtles are probably due primarily to differences in their pelagic distributions, which appear to vary by species, size/age of the turtles, season, and other factors. Mesh size of the gear may also affect entanglement rates but we note that large-mesh gear has caught turtles ranging from 12 cm CL loggerheads to 200 cm leatherbacks.

Most leatherbacks encountered were longer than 100 cm, with several over 200 cm. Carapace lengths of loggerheads ranged from 12-84 cm, most were 40-70 cm, and several were 20 cm or smaller. Green turtles were 35-49 cm and unidentified turtles ranged from 23-100 cm.

Reliable estimates of the total marine turtle bycatch in large-mesh driftnet fisheries are not yet available. They will require more observer data and data on the magnitude and time-space distribution of total fleet effort.

C. Driftnet-Inflicted Mortality

In addition to counting turtles in the bycatch, observers recorded the condition of each turtle as "dead", "alive", or "unknown". The proportion of "dead" turtles in the bycatch may be used to estimate a "best case" (minimum) mortality rate. The total proportion of those turtles "dead" or "unknown" may be used to compute a "worst case" (maximum) mortality rate. Proportional allocation of the "unknown" turtles among the other categories produces what might be called a "most likely" estimate of mortality rate. This characterization of "worst case" neglects any delayed mortality of turtles released alive, e.g., those which are cut free of the net but swim away trailing fragments of line and webbing, or die later because of injuries, debilitation, or forced submergence in the nets.

In the 1989 pilot program on Japanese squid vessels 12 of the 22 turtles observed were recorded as dead or unknown. Therefore, a very rough estimate of the "worst case" marine turtle mortality in the 1989 Japanese squid fishery is 544 x (12/22) or about 300 turtles.

More data on mortality rates of entangled turtles were collected in the 1990 observer programs, including some data from turtles caught in May operations (These data were not included in bycatch rate estimates above). Excluding data collected by Taiwanese observers, which have not been fully evaluated, the following tentative results were obtained in 1990:

	Alive		Dead		Unknown		Total
Fishery	No.	%	No.	%	No.	%	No.
Squid	38	84.4	4	8.9	3	6.7	45
Tuna/ billfish	73	79.4	12	13.0	7	7.6	92
Overall	111	81.0	16	11.7	10	7.3	137

According to these provisional data at least 81% of the turtles observed in the bycatch were returned to the sea alive. At least 12% were dead and 7% were in unknown condition. If the 8% unknowns are allocated proportionally to the other categories the percentages are 87% alive, 13% dead. If it is assumed that all unknown turtles were dead the percentages become 81% alive, 19% dead.

The percentage of turtles recorded as dead was somewhat higher on large-mesh vessels than on squid vessels. Differences between species and the effects of other factors such as turtle size will be analyzed when all 1990 data are available. Likewise, estimates of total marine turtle mortality in the squid and large-mesh fisheries will be made when all 1990 data are in hand.

V. Status of Populations

The leatherback is listed as endangered worldwide by the International Union for Conservation of Nature and Natural Resources (IUCN), and it appears on Appendix I (most restrictive category) of the Convention on International Trade in Endangered Species of Fauna and Flora (CITES). The species is also listed as endangered under the U.S. Endangered Species Act.

The loggerhead is listed as vulnerable worldwide by the IUCN, and it appears on Appendix I of CITES. The species is listed as threatened under the U.S. Endangered Species Act.

The green turtle is listed as endangered worldwide by the IUCN, and it appears on Appendix I of CITES. The species is listed as threatened under the U.S. Endangered Species Act, except for nesting populations in Florida and on the Pacific Coast of Mexico where they are listed as endangered.

In the case of Pacific leatherbacks and the Hawaiian green turtle, available data indicate that current populations are at much lower levels than those observed historically. Less appears to be known about Japanese loggerheads and green turtles.

Most available information on marine turtle stock size pertains to nesting females and is often piecemeal, qualititive and anecdotal. Because nesting females are often accessible, however, it is relatively easy to survey nesting populations and estimate hatchling production. Assessment of juvenile and subadult abundance is much more difficult. In Hawaii the green turtle nesting colony at French Frigate Shoals has been assessed annually since 1973. The number of nesting females appears to be increasing gradually, possibly a result of laws protecting turtles from harvesting. Tag-recapture methods are now being used to estimate inshore populations of Hawaiian green turtles; no results are yet available. Models to determine likely population recovery rates are also under development.

Little is known about the capacity of marine turtles to compensate for increased mortality through density-dependent increases in growth, maturation rate, clutch size, or nesting success. Considerable variation in growth rates has been documented among tagged turtles in the wild, suggesting some compensatory response is possible. Nevertheless, given the longevity and late maturation of marine turtles population recovery is likely to be very protracted, and decades may be required to detect significant changes in nesting populations unless mortality rates are reduced sharply in all age groups.

VI. Unresolved Problems in Impact Assessment

- Unknown population sizes of Pacific marine turtles
- Unknown rates of growth, and age-size relationships, and age-specific mortality rates
- Unknown rates of delayed mortality after release from driftnet vessels
- Unknown stock origins and migration routes
- Unknown time spent by turtles in pelagic environment where they are exposed to driftnets, other high-seas fishing gear, and synthetic debris.
- Unknown capacity of turtle populations to adapt and compensate for incidental mortality due to fishing gear entanglement

VII. Information Needs

- Estimates of annual hatchling production in affected turtle populations
- Retention rate and utilization of marine turtles by high-seas driftnet vessel crews
- Migratory patterns and pelagic ecology of marine turtles
- Size of populations by age-class and sex
- Reproductive rate parameters, e.g., age at maturity, remigration intervals, nesting frequency, clutch size, and hatching success
- Growth rates and natural mortality rates

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