# Bycatch of Marine Turtles in North Pacific High-Seas Driftnet Fisheries and Impacts on the Stocks

by

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## I. ABSTRACT

Four species of marine turtles, all listed as threatened or endangered by the IUCN, have been documented in the bycatch of North Pacific high-seas driftnet fisheries. Bycatch rate data collected by observers, combined with driftnet fleet effort data, indicate a total marine turtle bycatch of about 6,100 turtles in 1990. The overall minimum marine turtle mortality due to driftnet entanglement in 1990 was about 1,700 turtles. Most of the mortalities were of loggerheads taken in the large-mesh driftnet fisheries of Japan and Taiwan. A reliable assessment of driftnet fishery impacts is hampered by lack of essential data on marine turtle population status and dynamics.

## II. INTRODUCTION

At least four species of marine turtles are caught incidentally and killed in North Pacific high-seas driftnet fisheries conducted by Japan, the Republic of Korea, and Taiwan. Because all marine turtle populations in the Pacific, and worldwide, are considered to be endangered or vulnerable, any mortality due to incidental entanglement in driftnets is cause for concern. Large-scale driftnet fishing may impact marine turtle populations by increasing mortality on juvenile, subadult, and adult turtles. The risk of mortality in driftnets is greatest for species which spend much of their lives in the open sea, such as leatherbacks and loggerheads. Assessing the impacts quantitatively and reliably, however, is difficult because essential data on population size and age structure are lacking.

The purpose of this paper is to summarize available information on the affected turtle populations and to discuss data bearing on the assessment of driftnet fishery impacts. We begin by reviewing information on the biology, life history, and distribution of the North Pacific marine turtle species encountered to date in the driftnet fisheries. We summarize data collected by scientific observers from the United States, Japan, Taiwan, Canada, and Korea as part of recent cooperative monitoring programs on the high-seas driftnet vessels. These data provide insights on many aspects of the pelagic distribution and ecology of marine turtles in the area of the driftnet fisheries that were totally unknown previously. We then review preliminary estimates of the magnitude of the mortality inflicted on marine turtle populations by driftnet fishing, again using data collected recently in the cooperative observer programs and additional information provided by the governments of Japan, Taiwan, and Korea. Finally, we discuss the difficulties of assessing population impacts given the high degree of uncertainty about the actual state of the populations and their dynamics.

## III. SPECIES AND POPULATIONS AFFECTED

Four species of marine turtles have been positively identified in the bycatch of the high-seas driftnet fisheries. These are the leatherback (*Dermochelys coriacea*), the loggerhead (*Caretta caretta*), the green turtle (*Chelonia mydas*), and the hawksbill (*Eretmochelys imbricata*). Although some observers have recorded the bycatch of the olive ridley (*Lepidochelys olivacea*) in monitored net sections, their identifications have been shown to be either incorrect or inconclusive.

### 1. Leatherback Turtle

The leatherback 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; Pritchard and Trebbau 1984; 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 are in the family Cheloniidae, the so-called "hard-shelled" turtles. The front 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, 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 which nests 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.

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 1,000-2,000 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) very likely 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; Pritchard and Trebbau 1984). Leatherbacks from these eastern Pacific nesting beaches may also contribute to pelagic populations encountered by driftnets in the North Pacific, since the species is commonly seen in higher latitudes of the eastern North Pacific off Canada and the U.S. 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.

## 2. Loggerhead Turtle

The loggerhead 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 100 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; Pritchard and Trebbau 1984).

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 or 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 rapidly 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 benthic dwellers at this larger size loggerheads continue to be carnivorous, but now feeding primarily on molluscs and crustaceans.

In the North Pacific, where until recently even less was 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 2,000-3,000 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 3,000 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; Bartlett 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.

## 3. Green Turtle

The green turtle is a hard-shelled 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 CL compared to $>82$ cm CL elsewhere), and considerable grey or black pigment in the plastron (Hirth 1971; Pritchard 1979; Pritchard and Trebbau 1984; 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 foreseeable 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 2,000 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; Balazs *et al.* 1990) and the Ryukyu and Ogasawara Islands of Japan (Suganuma 1985; Uchida and Nishiwaki 1982).

### 4. Hawksbill Turtle

The hawksbill turtle is a hardshelled marine turtle distinguished by its narrow head, tapering beak, thick overlapping scutes (known in commerce as "tortoiseshell" or "bekko"), and a strongly serrated margin to the carapace. The head has two pairs of prefrontal scales, while the carapace has five vertebral scutes and four pairs of costal scutes. There are highly variable colour patterns to the carapace ranging from clear amber to brown to black. The plastron in the adult is usually pure yellow or orange-yellow, while juveniles frequently have large black spots on the plastron. Mean carapace lengths of adult female hawksbills range from 66 cm to 86 cm worldwide (Witzell 1983; Pritchard and Trebbau 1984; Groombridge 1982).

The hawksbill occurs circumglobally and is the most tropical of all marine turtles. Nesting is widespread, but sparse, in tropical regions worldwide; large nesting colonies are atypical. In benthic habitats, following an unknown developmental period spent on the high-seas, hawksbills forage principally on sponges. In the Pacific, with the exception of Australia, nesting does not occur in abundance (Groombridge and Luxmoore 1989). The hawksbill is commonly considered one of the most endangered species of marine turtles due to the long history of international commercial trade in tortoiseshell.

Hawksbills encountered in the North Pacific high-seas driftnet fisheries may originate from the proximal, albeit low level, nesting sites to the southwest in the Hawaiian Islands (see Balazs *et al.* 1990). An alternate, or additional, origin may be beaches in the south of Japan, including the Ryuku Islands and Okinawa, where hawksbill nesting occurs as a rare event (Uchida and Nishiwaki 1982; Kamezaki 1987; Teruya and Uchida 1988).

## IV. 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 Luxmoore 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 Kagoshima Prefecture, Japan, 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 (Suganuma 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 have 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, has been reported. Low level chemical pollution possibly causing immunosuppression has been suggested as one factor in the epidemic outbreak of a tumour 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 1985; Carr 1987).

The incidental capture and mortality of turtles has been documented in various fisheries, including those using longlines, trawls, purse seines, and gillnets (Crouse 1984). In the North Pacific, the incidental take of leatherbacks in the high-seas driftnet fisheries was first reported by Balazs (1982a), who earlier (Balazs 1982c) had described the occurrence of leatherbacks in the region as reported to him by commercial fishermen. 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 incidental capture has been available. Recently, however, Nishimura 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 reported mortality of 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.

## V. STATUS OF MARINE TURTLE 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 Wild 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.

The hawksbill is listed as endangered worldwide by the IUCN, and it appeared on Appendix I of CITES. It is also listed as endangered under the U.S. Endangered Species Act.

In the case of Pacific leatherbacks, hawksbills, 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, qualitative and anecdotal. Because nesting females are 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. Although there is considerable interannual variation in the estimates of nesting females, the trend appears to be upward, possibly a result of state and federal laws protecting turtles from exploitation. Tag-recapture methods are now being explored to estimate inshore populations of Hawaiian green turtles; no results are yet available. Models to determine likely population recovery rates are also under development.

Virtually nothing is known about the capacity of marine turtle populations to compensate for increased mortality through density-dependent changes in growth, maturation rate, remigration interval, clutch size, or other factors. Considerable variation in growth rates has been documented among tagged turtles in the wild, even within single populations (Balazs 1982b; Bjorndal and Bolten 1988a, 1988b). Observed growth rate variation may have genetic origins or be due to differences in ambient temperature or quality of forage. Conceivably, growth rates could also depend on the quantity of food available. While the latter possibility may suggest that density-dependent growth compensation is possible, such responses have not been demonstrated. Except on turtle nesting beaches, where nest superimposition has been observed and suggested as a mechanism of density dependence in hatchling production (e.g., Bustard and Tognetti 1969), comments about density-dependent compensation are speculative. Further, given the longevity and late maturation of marine turtles, population recovery is likely to be very protracted and decades may be required to rebuild depleted nesting populations unless mortality rates are reduced sharply in all age groups.

## VI. BYCATCH IN THE DRIFTNET FISHERIES

### 1. Species Composition and Bycatch Rates

In the first multinational observer program, the 1989 pilot program on Japanese squid driftnet vessels, 9 of the 22 marine turtles recorded in the bycatch were leatherbacks; the remainder were unidentified. More extensive data collected in the 1990 observer programs in the Japanese, Korean, and Taiwanese squid driftnet fleets, and the large-mesh driftnet fleets of Japan and Taiwan, have shown that the turtle bycatch species composition varies considerably between the fisheries (Table 1). In the June-December 1990 Japanese squid fishery, observers identified 77.1% of the 35 marine turtles seen in the monitored bycatch as leatherbacks and 2.9% as loggerheads; the other 20.0% were unidentified. In the 1990 observer programs on Korean and Taiwanese squid driftnet vessels the monitored bycatch (a combined total of 8 turtles) included leatherback, green, loggerhead, and unidentified turtles (not differentiated between leatherback and hard-shelled species.)

In the large-mesh fisheries of Japan and Taiwan the turtle species composition of the monitored bycatch appears to be quite different. In the observer program on Japanese large-mesh vessels, conducted between September 1990 and May 1991, the monitored bycatch of 289 turtles consisted of 50.2% loggerheads; 31.1% unspecified hard-shelled turtles, 10.4% greens; 5.2% unidentified turtles; 2.8% leatherbacks; and a single (0.3%) hawksbill (Table 1). The monitored bycatch on

Table 1. Species composition and average bycatch rates (number per million standardized tans or poks) of marine turtles in the 1990 squid driftnet fisheries of Japan, Korea, and Taiwan, the 1990 large-mesh driftnet fishery of Taiwan, and the 1990-1991 large-mesh driftnet fishery of Japan.

SQUID FISHERIES

| | Japan | | | Taiwan | | | Korea | | |
|---|---|---|---|---|---|---|---|---|---|
| Monitored effort (millions of tans or poks) | | 2.28 | | | 0.17 | | | 0.67 | |
| Species | Bycatch | CPUE | Percent | Bycatch | CPUE | Percent | Bycatch | CPUE | Percent |
| Leatherback | 27 | 11.8323 | 77.14 | 0 | 0.0000 | 0.00 | 2 | 2.9866 | 33.33 |
| Loggerhead | 1 | 0.4382 | 2.86 | 0 | 0.0000 | 0.00 | 0 | 0.0000 | 0.00 |
| Green | 0 | 0.0000 | 0.00 | 1 | 5.8680 | 50.00 | 1 | 1.4933 | 16.67 |
| Hawksbill | 0 | 0.0000 | 0.00 | 0 | 0.0000 | 0.00 | 0 | 0.0000 | 0.00 |
| Unspecified hard-shelled | 0 | 0.0000 | 0.00 | 1 | 5.8680 | 50.00 | 0 | 0.0000 | 0.00 |
| Unidentified | 7 | 3.0676 | 20.00 | 0 | 0.0000 | 0.00 | 3 | 4.4799 | 50.00 |
| TOTAL | 35 | 15.3381 | 100.00 | 2 | 11.7361 | 100.00 | 6 | 8.9597 | 100.00 |

LARGE-MESH FISHERIES

| | Japan | | | Taiwan | | |
|---|---|---|---|---|---|---|
| Monitored effort (millions of tans) | | 0.51 | | | 0.19 | |
| Species | Bycatch | CPUE | Percent | Bycatch | CPUE | Percent |
| Leatherback | 8 | 15.6375 | 2.77 | 8 | 41.0362 | 10.53 |
| Loggerhead | 145 | 283.4301 | 50.17 | 8 | 41.0362 | 10.53 |
| Green | 30 | 58.6407 | 10.38 | 0 | 0.0000 | 0.00 |
| Hawksbill | 1 | 1.9547 | 0.35 | 0 | 0.0000 | 0.00 |
| Unspecified hard-shelled | 90 | 175.9221 | 31.14 | 5 | 25.6476 | 6.58 |
| Unidentified | 15 | 29.3204 | 5.19 | 55 | 282.1236 | 72.37 |
| TOTAL | 289 | 564.9055 | 100.00 | 76 | 389.8435 | 100.00 |

Taiwanese large-mesh vessels included 76 marine turtles, of which 10.5% were leatherbacks, 10.5% were loggerheads, 6.6% were unspecified hard-shelled turtles, and 72.4% were completely unidentified.

In addition to the differences in species composition of the turtle bycatch, observer data indicate substantial differences in marine turtle bycatch rates between squid and large-mesh driftnet fisheries. In the Japanese squid driftnet fishery, 1990 observer data showed an aggregate bycatch rate of 15.3 turtles per million standardized tans (a standardized tan is defined as a 50 m length of driftnet.) In the 1990 Korean squid fishery, the turtle bycatch rate was 9.0 turtles per million standardized poks (equivalent to tans). The turtle bycatch rate was 11.7 turtles per million tans in the 1990 Taiwanese squid fishery.

In the large-mesh driftnet fishery the overall turtle bycatch rate was 564.9 turtles per million tans for Japan (1990-1991 season) and 389.8 turtles per million tans for Taiwan (1990 season). The ratio of turtle bycatch in the large-mesh driftnet fleet to the bycatch rate in the squid fleet was 33:1 for Taiwan, and 37:1 for Japan.

## 2. Turtle Size Composition

Information about the size distribution of marine turtles in waters fished by the high-seas driftnet fleets did not exist prior to the cooperative observer programs. Observer guidelines for all U.S. observers, and most other observers, called for them to measure the curved carapace length of each turtle encountered or, if accurate measurements were impossible, to estimate the carapace length. We do not yet have access to all turtle length data collected, but those available to us provide a preliminary assessment of length composition.

Estimates or measurements of leatherback carapace lengths ranged from 70 cm to about 300 cm, with most falling between 100 cm and 200 cm. Almost all leatherbacks dropped out of the nets during retrieval or were cut out before being decked, so lengths were simply estimated, often roughly. It is likely that many of the leatherbacks encountered were mature.

Loggerheads ranged from 12 cm to about 90 cm CL. There was a bimodal distribution, with most turtles falling between 40 cm and 80 cm, and a somewhat smaller cluster between 10 cm and 30 cm (Figure 1). Many loggerheads were decked and accurate measurements were made. Available data on growth rates and size at maturity suggest that the majority of loggerheads encountered were immature.

Green turtles ranged from 24 cm to 49 cm CL, and also showed a bimodal distribution, with one group shorter than 35 cm and a second group longer than 40 cm (Figure 1). All green turtles measured by observers were immature.

The single hawksbill recorded by an observer was 46 cm CL, and was immature.

## 3. Spatial Distribution of the Turtle Bycatch

The temporal and spatial variation in turtle bycatch rates and factors affecting them are still being studied and will be the subject of a later report (Balazs and Wetherall *in prep*). A preliminary analysis, however, shows that leatherbacks were taken over a wide range of longitudes, from 156°W to 150°E, and at latitudes from 31°N to 43°N. Loggerheads were also encountered over a wide area, from 154°W to 150°E, and from 28°N to 39°N. Green turtles were identified in the bycatch from 154°W to 154°E, and from 28°N to 37°N. The single hawksbill was encountered at 173°E and 29°N. These descriptions of distribution are based on the combined data from the 1989 and 1990 observer programs but mask any monthly variations, which we have not yet analyzed. Further, they indicate only the spatial distribution of turtle bycatch within the range of the monitored fishing effort, not the potential spatial distribution within the broader range of total fleet effort (Figures 2-5), or the potential spatial distribution of the turtles themselves.

## 4. Total Bycatch in the Squid Driftnet Fisheries

Estimates of total bycatch may be made by expanding the bycatch rate statistics by the total fishing effort exerted by the squid driftnet fleet. Some of the fleet effort data essential to the reliable estimation of bycatch levels are not yet available. Further, all estimates involve assumptions which may not be verifiable. In several instances the bycatch estimates discussed here are preliminary but should at least indicate the general magnitude of the bycatch.

In the 1989 Japanese squid driftnet fishery 22 turtles were counted by observers in 1.4 million monitored tans of fishing effort. Since the total fleet effort was 34.4 million tans, a simple expansion of the sample data provides a total bycatch estimate of 529 turtles. By dividing the data into time-area strata, Balazs and Wetherall (1991) estimated a total bycatch of 544 turtles, all species combined (95% confidence interval 360-742 turtles). If the 544 turtles are apportioned by the species composition of the monitored bycatch the results suggest a total bycatch of 222 leatherbacks and 322 unidentified turtles. Using the same data but different assumptions, Yatsu and Hayase (1991) estimated a total bycatch of 472 marine turtles including 221 leatherbacks and 251 other turtles.

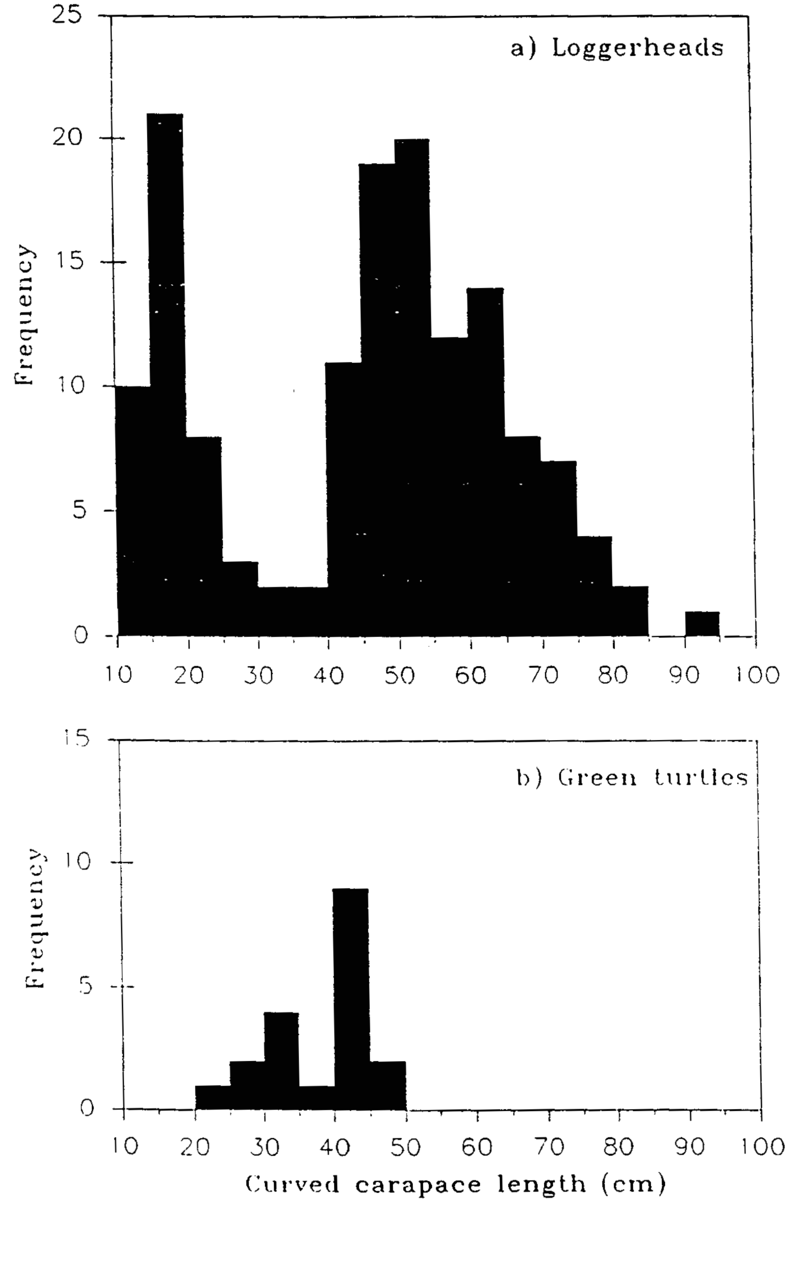


Fig. 1. Carapace length frequency distributions for (a) loggerheads and (b) green turtles encountered in North Pacific high-seas driftnet fisheries, based on U.S. observer data.

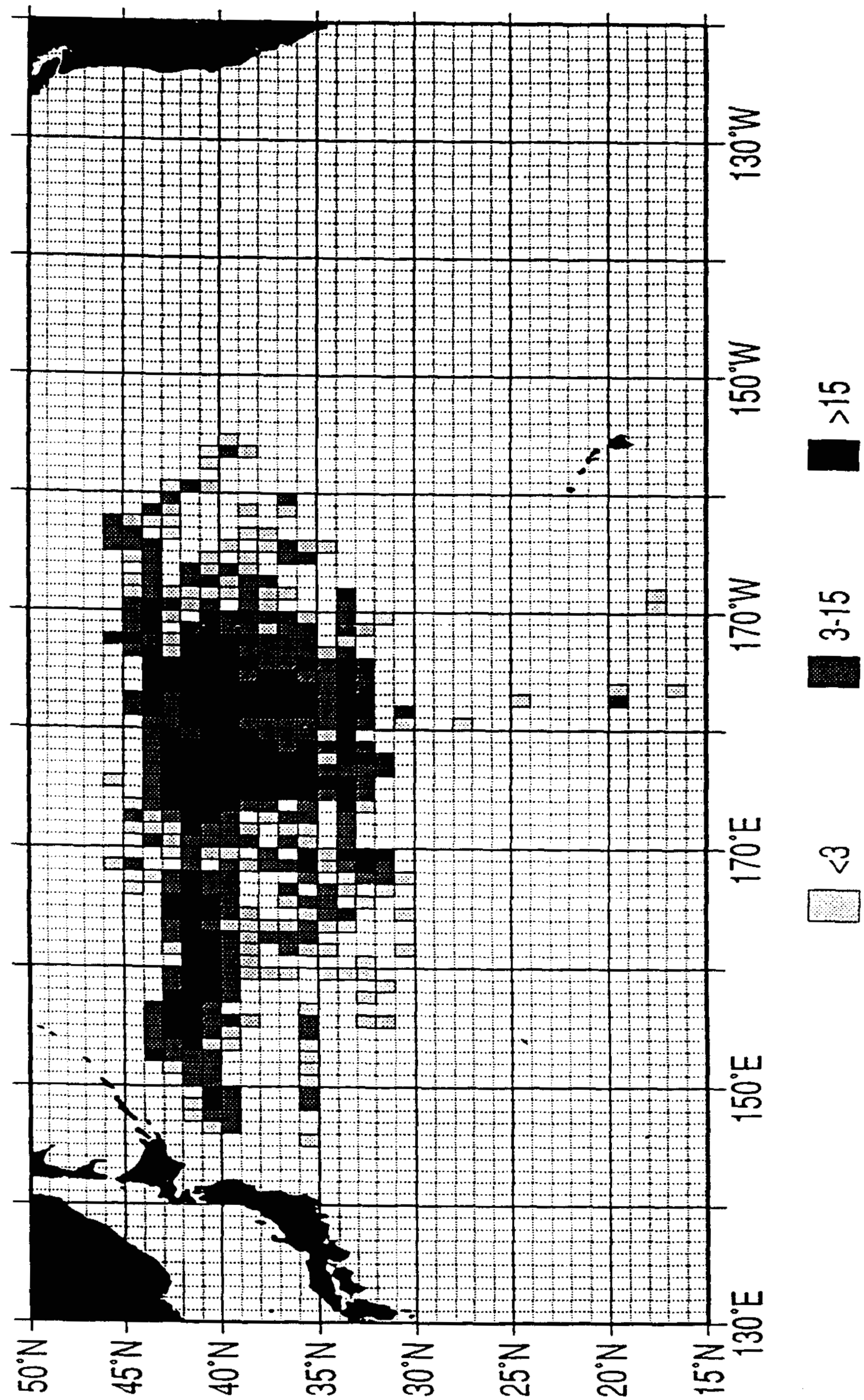


Fig. 2. Distribution of fishing effort in the 1990 Taiwanese North Pacific high-seas driftnet fishery (squid and large-mesh gear combined). Units are vessel-days of fishing.

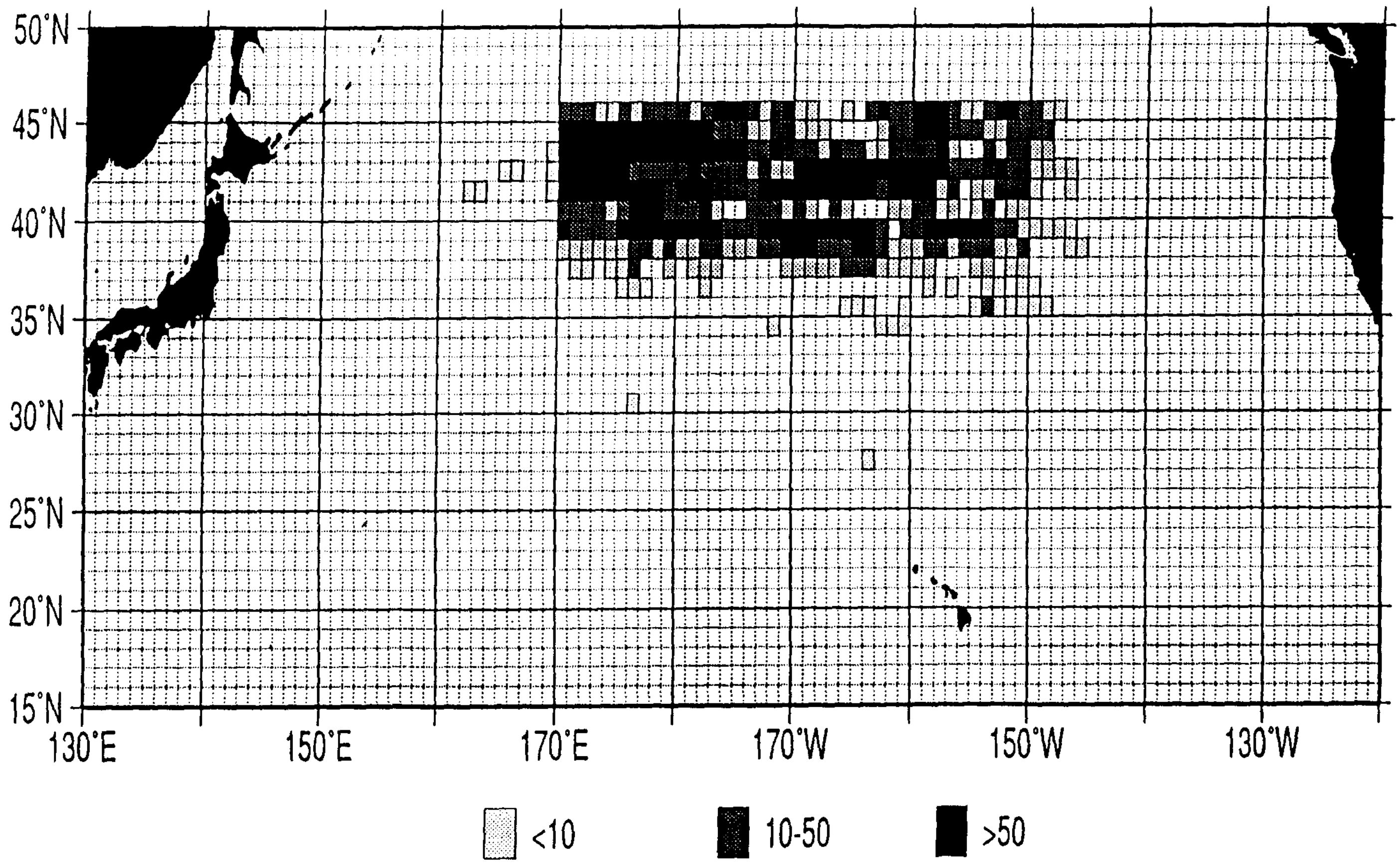


Fig. 3. Distribution of fishing effort in the 1990 Japanese North Pacific high-seas squid driftnet fishery. Units are thousands of standardized (50-m) tans deployed.

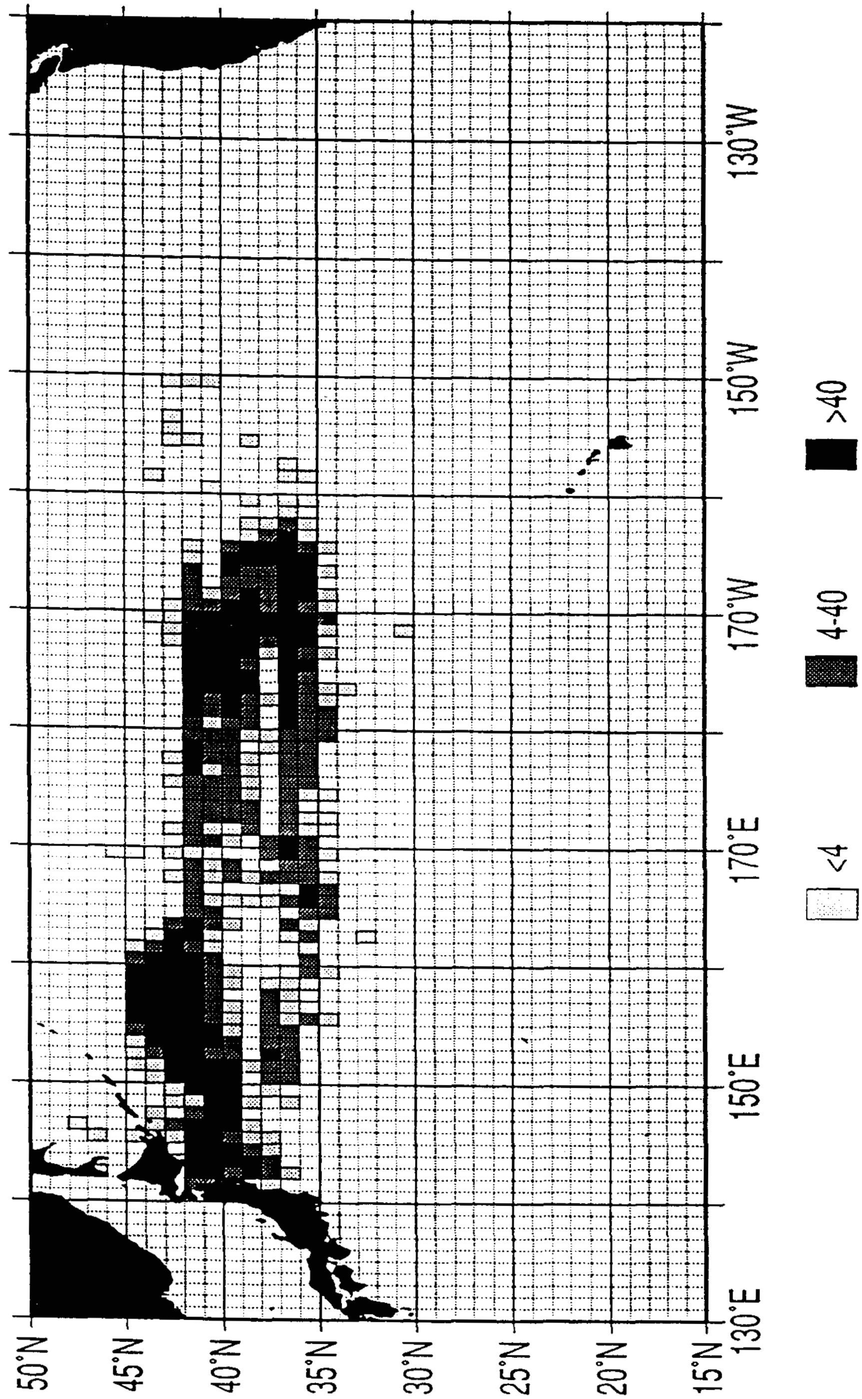


Fig. 4. Distribution of fishing effort in the 1990 Korean North Pacific high-seas squid driftnet fishery. Units are thousands of standardized (50-m) poks deployed.

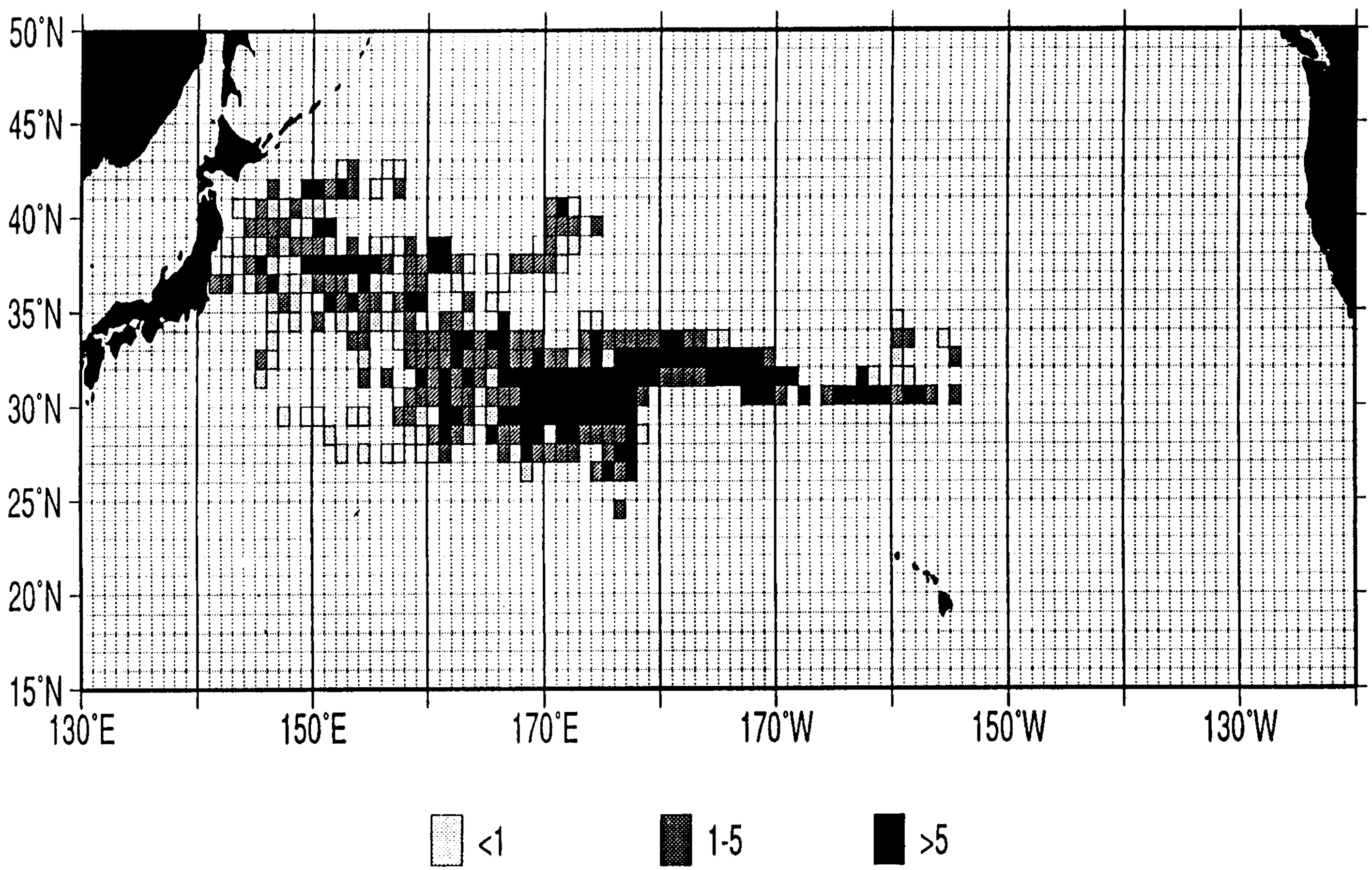


Fig. 5. Distribution of fishing effort in the 1990-1991 Japanese North Pacific high-seas large-mesh driftnet fishery. Units are thousands of standardized (50-m) tans deployed.

Table 2. Estimated bycatch of marine turtles (number of turtles) in the 1990 squid driftnet fisheries of Japan, Korea, and Taiwan, the 1990 large-mesh driftnet fishery of Taiwan, and the 1990-1991 large-mesh driftnet fishery of Japan.

| | Squid Fisheries | | | | Large-Mesh Fisheries | | |
|---|---|---|---|---|---|---|---|
| Species | Japan | Korea | Taiwan | Total | Japan | Taiwan | Total |
| Leatherback | 300 | - | - | - | 45 | 411 | 456 |
| Loggerhead | 5 | - | - | - | 1,200 | 3,489 | 4,689 |
| Green | - | - | - | - | 248 | - | 248 |
| Hawksbill | - | - | - | - | 8 | - | 8 |
| Unspecified hard-shelled | - | - | - | - | - | - | - |
| Unidentified | 101 | - | - | - | - | - | - |
| Total | 406 | 221 | 28 | 655 | 1,501 | 3,900 | 5,401 |

In the 1990 Japanese squid driftnet fishery, observers documented the bycatch of 35 turtles in 2.3 million monitored tans. A simple estimate of total bycatch, given the total fleet effort of 22.8 million tans, is 347 marine turtles. Empirical bootstrap distributions of total bycatch, based on a time-area stratification of the squid driftnet fishery data (Wetherall and Yong 1993), are 375 turtles of all species (approximate 95% confidence limits, 255 and 499), and 264 leatherbacks (approximate 95% confidence limits, 176 and 357). Yatsu and Hayase (1991), using a similar procedure, estimated a total fleet bycatch of 300 leatherbacks, 5 loggerheads, and 101 other (including unidentified) marine turtles.

In the 1990 Korean squid driftnet fishery, the total fleet effort during the April-December fishing season was 24.6 million poks. U.S. and Korean observers monitored 2.7% of the effort, documenting a bycatch of 6 turtles, a bycatch rate of 9.0 turtles per million poks. A simple, direct estimate of the total turtle bycatch by the 1990 Korean squid fleet is therefore 221 turtles. The sample size is too small to allow a reliable division of the bycatch by species.

Estimation of the total turtle bycatch in the 1990 Taiwanese squid driftnet fishery is complicated by the lack of reliable information on total effort by the Taiwanese squid fleet. The official Taiwan government statistics indicate a total effort of 11,266 vessel days of fishing by the combined squid and largemesh driftnet fleets. We assumed that about 1/3 of this effort was directed at squid, or 3,755 vessel days, equivalent to 3,755 fishing operations. U.S. and Taiwanese observers counted 2 turtles in the monitored net sections of 353 fishing operations. The total number of turtles entangled per fishing operation is therefore estimated to be 0.0076, assuming that the observers monitored 75% of the total tans retrieved during the monitored operations. Thus the total marine turtle bycatch for the Taiwanese squid driftnet fleet in 1990 is estimated as 28 turtles. This cannot be reliably partitioned by species.

The combined estimate of 1990 marine turtle bycatch by the three squid driftnet fleets is 655 turtles (Table 2). Because of the very small samples seen in the Korean and Taiwanese fisheries we are reluctant to estimate total bycatches by species.

## 5. Total Bycatch in the Large-mesh Driftnet Fisheries

Fleet effort data for the 1990-1991 Japanese large-mesh driftnet fishery (the season extended from August 1990 through May 1991) were made available just prior to the revision of this paper and we have not yet carefully analyzed them. They indicate, however, a total effort of 2,665,474 standardized tans in 3,488 fishing operations. In 513,367 tans monitored by observers (involving 829 fishing operations), the aggregate bycatch of marine turtles was 289 turtles, or 563.0 turtles per million standardized tans. Expanding this bycatch rate by the total fleet effort provides a provisional total bycatch estimate of 1,501 turtles for the 1990-1991 fishing season. Apportioning the total bycatch according to the observed species composition provides the following bycatch breakdown: 42 leatherbacks; 753 loggerheads; 156 green turtles; 5 hawksbills; and 545 unidentified turtles, of which at least 467 were unspecified hardshelled turtles. A further allocation of the unidentified bycatch according to the species composition of the identified turtles yields the following overall results: 45 leatherbacks; 1,200 loggerheads; 248 green turtles; and 8 hawksbills. These estimates are only rough approximations, and are subject to revision after a more thorough analysis of time-area variations. With respect to precision of the estimates, however, we note that observers monitored 19.2% of the total standardized tans deployed by the fleet, and 23.8% of the fleet's fishing operations.

Estimation of bycatch in the 1990 Taiwanese large-mesh driftnet fishery is complicated by the lack of reliable fishing effort data. There apparently is no way to separate driftnet fleet effort statistics into squid and large-mesh components. The official Taiwan fishing statistics indicate a total driftnet fleet effort of 11,266 fishing operations in 1990. The proportion of these involving large-mesh gear was probably about 2/3, based on the distribution of catch rates of the target species in each fishery, flying squid (*Ommastrephes bartrami*) and albacore (*Thunnus alalunga*). This division suggests a total large-mesh effort of about 7,500 operations. Assuming that observers counted the bycatch in an average of 75% of the total driftnet deployed in each monitored operation, the bycatch rate of marine turtles was about 0.39/0.75 or 0.52 turtles per large-mesh fishing operation. Expanded to the entire fleet, these figures give a rough estimate of 3,900 turtles taken overall by the Taiwanese fleet in 1990. The breakdown by species would be approximately as follows: 411 leatherback turtles; 411 loggerhead turtles; and 3,078 unidentified turtles. Allocating the unidentified turtles is more difficult, but it is likely that most of these turtles were loggerheads. Under this assumption, the composition of the 1990 Taiwanese large-mesh fleet turtle bycatch is estimated to be 411 leatherbacks and 3,489 loggerheads.

Combining these estimates, we judge that the total take of marine turtles in the 1990-1991 season Japanese large-mesh fishery and the 1990 Taiwanese large-mesh fishery was about 5,401 turtles (Table 2). The aggregate species composition was approximately as follows: 456 leatherbacks, 4,689 loggerheads, 248 green turtles, and 8 hawksbills.

The total marine turtle bycatch in the 1990 squid driftnet fisheries of Japan, Korea, and Taiwan, the 1990 large-mesh fishery of Taiwan, and the 1990-1991 large-mesh fishery of Japan was estimated to be 6,056 (Table 2).

## VII. TOTAL MORTALITY IN THE DRIFTNET FISHERIES

### 1. Status, Condition, and Disposition of Turtles in the Bycatch

Driftnet observer data include assessments of the status, condition, and disposition of entangled turtles. All observers noted the condition of turtles encountered, according to the following criteria:

*dead* - turtle showed no signs of life when it was decked or seen dropping out of the net.

*alive* - turtle was released alive after being decked, or dropped out of the net alive before being decked, and was thought to have a high probability of survival.

*unknown* - condition of turtle could not be determined, or turtle was alive but in such poor condition that its survival was considered unlikely.

In addition to collecting basic data on condition, U.S. observers were required to complete a special data form for each turtle encountered which provided further information on whether the turtle was decked, cut out of the net, or dropped out of the net before being decked.

In the Taiwanese and Korean squid driftnet fisheries, the number of turtles recorded in monitored net sections were too few to assess reliably the proportion of turtles in each condition category. But data from the 1989 and 1990 Japanese squid driftnet fisheries indicate that about 80% of the turtles in the monitored bycatch were released or dropped out "alive".

In the case of large-mesh driftnet fisheries, where more turtles were entangled, better estimates of turtle condition are available. In the 1990-1991 Japanese large-mesh fishery the percentages of turtles in the three categories were:

| SPECIES | TOTAL TURTLES | PERCENT DEAD | PERCENT ALIVE | PERCENT UNKNOWN |
|---|---|---|---|---|
| Leatherback | 8 | 0 | 75 | 25 |
| Loggerhead | 145 | 22 | 73 | 5 |
| Green | 30 | 30 | 63 | 7 |
| Hawksbill | 1 | 100 | 0 | 0 |
| Unspecified Hard-shelled | 90 | 23 | 66 | 11 |
| Unidentified | 15 | 7 | 66 | 27 |
| Total | 289 | 22 | 69 | 9 |

Overall, in the 1990-1991 Japanese large-mesh fishery 22% of the turtles seen entangled in monitored net sections were "dead". In the 1990 Taiwanese large-mesh fishery 32% of the turtles were classified as "dead". Most turtles observed on Taiwanese large-mesh vessels were not identified to species.

Leatherback turtles, which predominated in the monitored squid driftnet bycatch, were typically so large that they dropped out or tore out of the net during retrieval or were cut out of the net without being hauled aboard. Some turtles, particularly leatherbacks, classified as in an "unknown" condition were released alive but swam away from the vessel still entangled in pieces of corkline and webbing. Although the fate of such turtles is unknown, it is highly likely that they eventually died or were debilitated due to continuing entanglement. In the large-mesh fisheries, where a greater number of turtles were encountered, data collected by U.S. observers indicate that 40% of entangled leatherback turtles were decked, compared with 83% of the loggerheads and 100% of the green turtles. U.S. observers noted that decked turtles were often treated harshly by the crews before being returned to the sea.

## 2. Estimates of Total Mortality

Estimates of the *minimum* mortality due to driftnets may be computed by multiplying the total bycatch estimates by the proportions of entangled turtles classified as "dead" at the time of retrieval. This procedure gives only lower bounds to mortality for at least two reasons: (1) the numbers of "dead" turtles probably underestimate the true mortality of turtles entangled in monitored fishing operations, and (2) the mortality rates in monitored operations may underestimate mortality rates in the fleet at large. In regard to the first reason, in each of the other condition categories, "alive" and "unknown", there were undoubtedly some turtles that died later as a result of handling or their entanglement in the driftnet. It is impossible to know how many of such turtles died. However, many turtles in the "unknown" category probably had little chance of survival, since they were still entangled in fragments of driftnet webbing and line or were severely injured. Other turtles in the "alive" or "unknown" categories likely suffered physiological stress or debilitation (Kemmerer 1989, and other studies cited in Eckert 1991) as a result of entanglement or handling. With respect to the second reason, it is at best debatable whether entangled turtles were treated as carefully on driftnet vessels not carrying scientific observers (the vast majority of the fleet) as on vessels with observers, and whether all decked turtles were returned to the sea.

Observer data indicate that in 1990 the Japanese squid driftnet fishery inflicted a minimum total mortality of 81 turtles. Most of the mortality involved leatherbacks. Applying the same criteria and mortality rates to the Korean and Taiwanese squid fisheries, we roughly estimate an aggregate mortality of 131 turtles in the three squid driftnet fisheries in 1990, all species combined.

In the large-mesh fisheries, where more data are available, the following mortality estimates were derived for Taiwan (1990) and Japan (1990-1991 season).

| SPECIES | JAPAN | TAIWAN | COMBINED |
|---|---|---|---|
| Leatherback | 0 | 103 | 103 |
| Loggerhead | 264 | 1,116 | 1,380 |
| Green | 74 | 0 | 74 |
| Hawksbill | 8 | 0 | 8 |
| Total | 346 | 1,219 | 1,565 |

These rough mortality estimates for single fishing seasons provide only a narrow glimpse of the driftnet fishery impacts on marine turtles. A full assessment of impacts would consider the turtle mortality generated by the driftnet fleets over their entire history and geographical range. Unfortunately, sufficient data are lacking. No bycatch data are available prior to the 1989 pilot observer program on Japanese squid vessels, yet the squid driftnet fisheries have been operating since 1979 or 1980. Similarly, the large-mesh driftnet fishery of Japan has been in existence since the early part of this century, with significant offshore expansion occurring in the 1980s. The Taiwanese entry into large-mesh fishing, directed at albacore, has been more recent.

Knowledge of effort history in the large-mesh fisheries is particularly important because of the higher rates of marine turtle bycatch in these fisheries. Only limited data are available, however, on the large-mesh effort prior to 1990. In the case of Taiwan, the combined squid and large-mesh fishing effort in 1989 was 17,598 fishing days, 56% higher than the effort in 1990; the breakdown by fishery is unknown. Likewise, the fishing effort by the Japanese large-mesh fishery was probably greater prior to the 1990-1991 season, when the first observers were deployed, but reliable effort estimates are not available. Fleet data reported by Watanabe (1991) suggest that Japanese large-mesh vessels engaged in roughly 8,300 fishing operations in 1988, considering only those driftnet vessels over 100 gross tons, or 10,300 operations if all vessels over 50 gross tons are included. This is 2.5-3.0 times greater than the total effort reported for the 1990-1991 large-mesh driftnet fishing season. The only data available that might indicate the history of Japanese large-mesh effort is the number of vessels registered to operate in the fishery. In 1988 the number of registered vessels was 459, well below the peak fleet size of 717 vessels in 1982, and below the 1980-1988 mean of 529 registered vessels. These data imply that the average annual effort during 1980-1988 may have been about 9,500-11,900 operations. If turtle bycatch rates in the Japanese large-mesh driftnet fishery throughout the 1980s were similar to the 1990-1991 bycatch rates, that fleet may have killed each year roughly between 1,000 turtles (minimum mortality, as defined above), and 5,000 turtles (if all turtles entangled were killed). Clearly such estimates are highly speculative, but they indicate the possible magnitude of turtle mortality given the best information available.

The minimum total turtle mortality in the North Pacific high-seas driftnet fisheries may have been on the order of 2,500 turtles per year during the late 1980s. The actual mortality was probably greater than this, but less than the estimated total driftnet bycatch of perhaps 9,000 turtles per year. Based on 1990 observer data, most of the mortalities would have been loggerheads taken in the Japanese and Taiwanese large-mesh fisheries.

## VIII. POPULATION IMPACTS

Assessment of the impacts of driftnet fishing on marine turtle populations requires a comprehensive understanding of their biology, population size, population structure, and factors affecting population dynamics. As indicated, to make reliable assessments it is also essential to know the history of mortality in the population, including mortality inflicted by driftnet fisheries. There are large gaps in our understanding, however. Most turtle research has focused on the biology of nesting populations and hatchling production. Little is known about the long juvenile and subadult phases of development, in which the turtles are generally inaccessible. As a result, information on population age structure and survivorship is lacking.

Until much more is known about population structure and abundance, realistic mathematical models of turtle stock dynamics are unfeasible. However, numerical models of population dynamics based on preliminary data may be useful in pointing out critical assumptions, identifying data needs, and suggesting the possible magnitude of impacts.

A significant difficulty in modelling the response of a turtle population to driftnet fishing mortality is uncertainty about the population's resilience to increased mortality. It is reasonable to assume that a turtle population in relatively pristine state has some capacity for compensation, e.g., through increases in density-dependent growth rates or acceleration of reproductive schedules (Wilbur and Morin 1987; Frazer 1983). Faster growth at lower stock densities may shorten exposure to mortality risks and accelerate maturation. We are unaware of evidence of density-dependent growth in marine turtles, but the possibility is suggested by the wide variations in growth rates observed in many populations (Balazs 1982b; Crouse and Crowder 1987). As indicated above, however, any suggestion of density-dependent compensation is speculative. Growth rate variation may be due to factors independent of population density and food supply, such as heredity and ambient temperature. Further, populations already reduced well below pristine levels through harvesting of various life stages, environmental degradation, and other sources of increased mortality may have little remaining capacity for compensation.

### 1. Hawksbill Impacts

The estimated 1990 bycatch of hawksbills in the driftnet fisheries was 8 turtles, based on a single hawksbill identified in the monitored bycatch of the Japanese large-mesh fleet. No hawksbills have been identified in the squid fishery bycatches. This estimate suggests that the impacts of the driftnet fisheries on hawksbill populations are probably minor, barring serious biases in the monitoring programs, much larger bycatches of hawksbills prior to 1990, or the possibility that the turtles killed were offspring of a single, small, isolated nesting colony. In this regard, we note that in the endangered Hawaiian hawksbill population only about 15 females are thought to nest each year. Hawksbill nesting colonies throughout the central and western Pacific are typically small, and most have undergone severe declines from human harvesting for local consumption or international commercial trade.

### 2. Loggerhead Impacts

Some perspective on driftnet mortality impacts may be provided by computing the expected hatchling production and abundance of juveniles and subadult turtles under specific assumptions about stock origin and survivorship. In the case of loggerheads, it is reasonable to assume that most loggerheads taken in the driftnet fisheries originate from nesting colonies in Japan. While a comprehensive inventory of nesting is not available, some data on nesting activity have been reported. For example, Kajihara *et al.* (1991) reported that the number of loggerheads which "landed" on beaches in Kagoshima Prefecture in 1990 was 4,401. This statistic was 2,933 in 1989, 2,725 in 1988, and 2,296 in 1987. We assume that these figures do not refer to the total number of individual females nesting on these beaches, but rather to the aggregate number of emergences or crawls by a smaller number of females hauling out repeatedly during the nesting season. If so, then perhaps 500-1,000 loggerheads nested in Kagoshima Prefecture each year in recent years, assuming 3-6 emergences per nester. Loggerheads also nest in other regions of Japan, and we consider it likely that 2,000-3,000 loggerheads nest annually in Japan. Loggerheads are also known to nest in China and elsewhere in the western North Pacific outside Japan but we do not know the magnitude of these populations.

Nelson (1988) summarized the life history and environmental requirements of loggerheads and reviewed available information on mortality and reproductive biology. Based on his account, we would expect an annual nesting population of 2,000-3,000 loggerheads to produce approximately 600,000-900,000 hatchlings (300 per nesting female) each year. Roughly 0.3-0.4 percent of each brood, according to Nelson (1988), would have to survive to adulthood to maintain the stock at a constant level. Assuming such conditions, one can calculate steady-state, age-specific abundance and natural mortality levels that would prevail under various maturation schedules and survivorship curves. For example, Table 3 shows the expected relative size of the juvenile and subadult population ($X_{js}$), compared with an initial cohort of 600,000 hatchlings, under several combinations of first-year survival rate and age at maturity, assuming a 0.3 percent overall survival from hatchling to adult. The steady-state annual natural mortality levels of juveniles and subadults ($M_{js}$) are also given. The equilibrium abundance and mortality levels for juveniles and subadults are inversely related to first-year survival rate, as expected. Similarly, the steady-state abundance of juveniles and subadults is directly related to age at maturity, and the sustainable mortality rate in these age groups, $1-S_{js}$, is inversely related to age at maturity.

The wide range of outcomes in Table 3, together with our uncertainty about critical population parameters, point out the difficulty of assessing high-seas driftnet impacts. For example, if age at maturity were 25 yrs and survival during the first year were 25%, a geometric mean survival rate of 83% would be required in juvenile and subadult age classes to maintain the population at equilibrium with a 0.3 percent hatchling-adult survival rate. Under these conditions the steady state abundance of juveniles and subadults would be 1.45 times greater than the annual hatchling production. If 600,000-900,000 hatchlings were produced annually, a juvenile and subadult population of about 870,000-1,300,000 loggerheads would result. The annual mortality to juvenile and subadult loggerheads, under these equilibrium conditions, would be on the order of 150,000-225,000 turtles. On the other hand, if hatchling survival were only 10%, then the number of juveniles and subadults in a steady-state

Table 3. Annual survival rate for juvenile and subadult turtles ($S_{js}$), relative juvenile and subadult population size ($X_{js}$), and annual mortality of juvenile and subadult turtles ($M_{js}$), under various combinations of first-year survival rate and age at maturity, given a hypothetical steady-state hatchling production of 600,000 turtles and hatchling-to-adult survival of 0.3 percent.

| Age at Maturity | | First-year Survival Rate 10% | 25% | 75% |
|---|---|---|---|---|
| 15 yrs | $S_{js}$ → | 78% | 73% | 67% |
| | $X_{js}$ → | 0.44 | 0.91 | 2.26 |
| | $M_{js}$ → | 58,200 | 148,200 | 448,200 |
| 25 yrs | $S_{js}$ → | 86% | 83% | 79% |
| | $X_{js}$ → | 0.70 | 1.45 | 3.56 |
| | $M_{js}$ → | 58,200 | 148,200 | 448,200 |
| 30 yrs | $S_{js}$ → | 89% | 86% | 83% |
| | $X_{js}$ → | 0.88 | 1.77 | 4.39 |
| | $M_{js}$ → | 58,200 | 148,200 | 448,200 |

population would be considerably lower, as would be the annual mortality sustainable by the population.

The actual abundance and age structure of juvenile and subadult loggerheads in the North Pacific are unknown. The only pertinent information available appears to be the anecdotal report by Bartlett (1989) of an aggregation of immature (20-80 cm CL) loggerheads feeding on pelagic red crab (*Pleuroncodes planipes*) off Baja California Sur, Mexico. Bartlett speculated that there were more than 100,000 turtles involved. Based on tag-and-recapture data (Uchida and Teruya 1991; also see Balazs 1989), juvenile loggerheads in the eastern North Pacific are likely to be from Japanese nesting stocks.

Under some of the conditions given in Table 3, an annual mortality by driftnet fisheries of 1,500 loggerheads, or even 5,000 loggerheads, would have a relatively small impact compared with the total mortality in the population, provided driftnets killed turtles from the younger age groups rather than late subadults and the population compensated adequately. Carapace length data collected by driftnet program observers suggest that juvenile loggerheads were most at risk from driftnet fishing in 1990 (no data are available for earlier years of the large-mesh driftnet fishery). Under other conditions, however, the impacts of a 1,500-5,000 loggerhead kill in driftnets would be very significant. Sufficient data are not available to allow a reliable assessment of actual driftnet impacts. No reliable estimates of juvenile and subadult abundance or survival rates are available. Nor are there data to indicate recent trends in the loggerhead population or the capacity of the population to compensate for fishing mortality.

In any case, the available data indicate that the impacts of the squid driftnet fisheries on North Pacific loggerheads are probably negligible. The impacts of the large-mesh fisheries are greater, but their magnitude cannot yet be reliably determined.

### 3. Green Turtle Impacts

Parallel reasoning can be applied to green turtles to explore a range of possible driftnet fishery impacts. In the case of green turtles the likely sources of turtles taken in the driftnet fisheries include the nesting colonies in Hawaii (mainly at French Frigate Shoals) and Japan (principally in the Ogasawara Islands), each locale about equidistant from the driftnet fishing area where green turtles have been encountered. In the Hawaiian green turtle population, the number of nesting females at the key nesting beach has fluctuated during a 16-yr period of monitoring. But recently the state-wide population of nesting females has averaged about 300-400 females annually, producing about 150,000 hatchlings. The Ogasawara Islands green turtle nesting population has recently numbered about 200 females per year (Suganuma 1985). The combined annual hatchling production from the Hawaiian and Japanese stocks of green turtles may therefore be about 250,000 hatchlings. As with loggerheads, under certain assumptions the estimated 1990 driftnet kill of about 100 green turtles (perhaps 250 if all entangled turtles died), mostly early juveniles, would represent a relatively small fraction of the total juvenile mortality in the population. Again, under other sets of assumptions the impacts would be a great deal more severe.

As with loggerheads, the available observer data indicate that impacts of the high-seas squid driftnet fisheries on green turtles are probably negligible. Impacts of the large-mesh fisheries are greater, but cannot be reliably assessed without more information about population trends and natural mortality levels. Nevertheless, stocks of green turtles in Hawaii, Japan, and other locales have been severely reduced over the years. Thus any mortality by the driftnet fisheries will at the very least impede recovery of the populations.

### 4. Leatherback Impacts

The population dynamics of leatherback turtles are even less well understood than those of other marine turtle species. The stock origins of leatherbacks killed in the North Pacific high-seas driftnet fisheries are unknown. The possibilities include nesting colonies in Mexico, where an estimated 30,000 females may nest each year (Pritchard 1982); Irian Jaya, Indonesia, where some 13,000 nests (equivalent to about 2,000 nesters) were recorded in 1985 (Bhaskar 1985); Malaysia and China. The number of nesters in the Chinese population of leatherbacks is unknown. The nesting population in Terengganu, Malaysia, once substantial, has declined severely over the past 35 years, due primarily to heavy egg depredation. The estimate of beach landings by nesting leatherbacks at Terengganu dropped to only 280 in 1985, down from about 11,000 landings in 1956 (various sources cited by Eckert 1991). At any rate, the total Pacific leatherback hatchling production from these various sources is probably several million hatchlings per year.

The impacts of the driftnet mortality clearly depend on the stock origins of the leatherbacks encountered in the fisheries. If the leatherbacks killed in the driftnet fisheries are from the stocks nesting in Mexico or Indonesia, the driftnet fisheries would appear not to be a significant source of mortality to the population(s), compared to other sources. However, if the leatherback mortality in the driftnets involves turtles from the Malaysian stock exclusively the impact would be significant, since the driftnets appear to take mostly subadult or adult leatherbacks. Recovery of the Terengganu leatherback population will require protection of nests and a halt to egg depredation. But such measures would be ineffective without equal efforts to reduce mortality to the sharply declining numbers of adults and subadults (Crouse and Crowder 1987). There are no data to indicate whether the leatherbacks taken in the driftnet fisheries are from the depleted Terengganu population, from the more robust stocks in Mexico or Indonesia, or from a multitude of stocks. The issue cannot be resolved without information on leatherback stock structure and migration routes. Leatherback impacts appear to be of similar magnitude in the squid and large-mesh driftnet fisheries, probably because the species is distributed throughout the fishing grounds.

To summarize, a comprehensive, reliable assessment of the impacts of North Pacific high-seas driftnet fisheries on marine turtles is impossible without a better understanding of turtle population sizes, stock origins, exploitation history, and population dynamics. Under certain assumptions about stock origins, survivorship, and other parameters it may be argued that the mortality inflicted by driftnet fisheries in 1990, when all fisheries were monitored, had relatively little impact on marine turtle populations compared with other sources of mortality. Under other assumptions it may be concluded that driftnet fishing mortality was indeed significant.

Nevertheless, incidental mortalities of marine turtles in high-seas driftnet fisheries add to losses due to other factors, many of which have not abated or have even accelerated. Driftnet mortalities therefore impede national and international efforts to recover marine turtle populations, all of which are classified either as endangered or threatened by the IUCN.

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