Status of sea turtle stocks in the Pacific

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Abstract

Six species of sea turtles occur in the Pacific Ocean (green turtles, loggerheads, leatherbacks, hawksbills, olive ridleys and flatbacks). All species, except flatbacks, have transboundary distributions. The status of most sea turtle stocks in the Pacific Ocean is poorly understood. Some stocks are increasing, such as in eastern Australia and Hawaii. However, there is evidence that many stocks have been reduced significantly, which is mainly a result of overharvesting of eggs, subsistence or commercial harvest of large turtles and nesting habitat destruction. Incidental capture in coastal and pelagic fisheries can also be an important source of mortality for some stocks. Abundance trends for the six Pacific species of sea turtles are reviewed, using the best available quantitative information.

INTRODUCTION

The status of the sea turtle stocks in the Pacific Ocean basin is poorly understood (Spotila *et al.*, 1996; Meylan and Donnelly, 1999; Chaloupka and Limpus, 2001; Seminoff, 2002). Many stocks have been reduced significantly, which is mainly a result of overharvesting of eggs (Meylan and Donnelly, 1999; Chaloupka, 2001; Seminoff, 2002), subsistence or commercial harvest of large turtles (Horikoshi *et al.*, 1994; Meylan and Donnelly, 1999; Trinidad and Wilson, 2000; Gardner and Nichols, 2001; Limpus *et al.*, 2004) and nesting habitat destruction (Sharma, 2000; Matsuzawa *et al.*, 2002). Other sources of mortality can have local importance, such as fibropapilloma disease (Chaloupka and Balazs, n.d.) or tiger shark attack (Heithaus, Frid and Dill, 2002; Balazs and Chaloupka, unpubl. strandings data for Hawaii). Incidental capture in coastal and pelagic fisheries can also be an important source of mortality for some stocks (Chan, Liew and Mazlan, 1988; Cheng and Chen, 1997; Chaloupka, 2003b).

Most assessments of the status and trends of sea turtle populations have been based on monitoring the seasonal beach nesting activity of adult females (Chaloupka and Limpus, 2001). But monitoring only female nesting activity provides insufficient information for stock assessment because: (1) females skip breeding seasons, and (2) no information is provided on demographic structure because the immature, adult male and non-breeding female components are not sampled (Chaloupka and Limpus, 2001).

Reliable estimates of sea turtle abundance that would be suitable for stock assessment and conservation management planning depend on sampling the entire demographic structure of a population resident in the foraging grounds. Yet such foraging ground abundance estimates are only known for three Pacific sea turtle stocks – the southern Great Barrier Reef green turtle metapopulation (Chaloupka and Limpus, 2001; Chaloupka, 2002b), the Australian loggerhead metapopulation (Chaloupka and Limpus, 2001) and the Hawaiian green turtle metapopulation (Balazs and Chaloupka, 2004).

All previous regional assessments of sea turtle abundance have been based mainly on anecdotal or qualitative information (Spotila *et al.*, 1996; Meylan and Donnelly, 1999; Seminoff, 2002). Here we review briefly the abundance trends for the six species of sea turtle (green turtles, loggerheads, leatherbacks, hawksbills, olive ridleys, flatbacks) that occur in the Pacific Ocean basin using the best available quantitative information. However, most data are based on nesting beach monitoring and so must be viewed with extreme caution. Moreover, little is known about the spatial and temporal trends in coastal or pelagic fishing effort in the Pacific (Wetherall *et al.*, 1993; Robins, 1995; Poiner and Harris, 1996; Lu, Lee and Liao, 1998; Slater *et al.*, 1998; McCracken, 2000; Chaloupka, 2003b; Tuck, Polacheck and Bulman, 2003). Hence there is very little quantitative information available to support any robust risk analysis of fisheries impacts on sea turtle population viability (Slater *et al*., 1998).

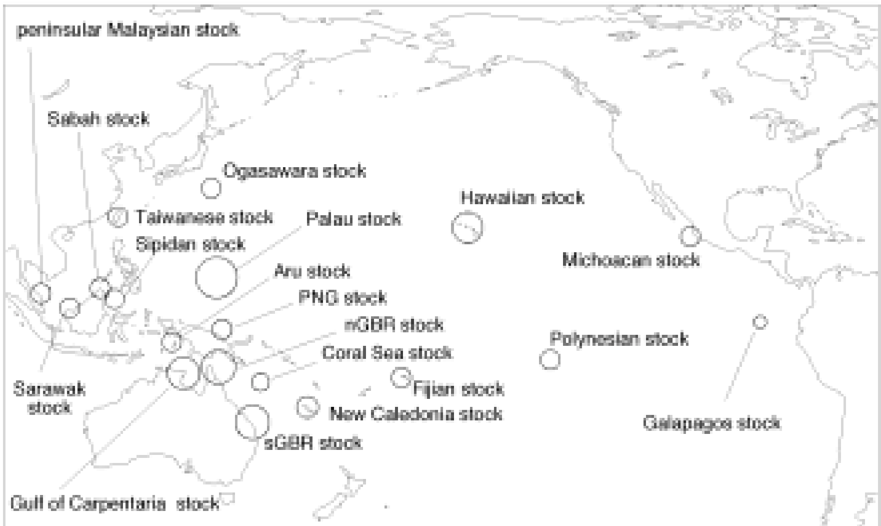

Figure 1. Location of the major regional rookeries for the Pacific green turtle stocks.
Source**:** Bowen, 1992; Dutton, Broderick and Fitzsimmons, 2002

Green turtles (*Chelonia mydas*)

Background

The green turtle comprises 20 management units or stocks in the Pacific (Dutton, Broderick and Fitzsimmons, 2002), which are shown in Figure 1. Many Pacific stocks are declining (Seminoff, 2002) but some are stable or increasing (Chaloupka and Limpus, 2001). Stable stocks include the Terengganu rookery (Liew, 2002), Ko Khram rookery (Charuchinda, Monanunsap and Chantrapornsyl, 2002), Sabah and Philippine Turtle Island rookeries in the Sulu Sea (Chaloupka, 2001; Basintal, 2002), Guam rookery (Cummings, 2002), Raine Island rookery of the northern Great Barrier Reef stock (Limpus *et al*., 2004), Heron Island rookery of the southern Great Barrier Reef stock (Chaloupka and Limpus, 2001), East Island rookery of the Hawaiian stock (Balazs and Chaloupka, 2004), Galapagos rookery (Seminoff, 2002) and the Playa Colola rookery of the Michoacan stock (Seminoff, 2002).

Table 1. Summary of nesting seasons for 20 Pacific green turtle stocks shown in Figure 1

Stock	Nesting location	Season (peak)	Source
sGBR	Heron Island	Oct–Jan	Chaloupka & Limpus (2001)
nGBR	Raine Island	Oct–Jan	Limpus *et al*. (2004)
Sipidan	Sipidan Island	year round (Oct–Jan)	Basintal (2002)
Sulu Sea	Philippine Turtle Islands	year round (Jul–Sep)	Chaloupka (2001)
Sarawak	Sarawak Turtle Islands	year round (Jul–Sep)	Chaloupka (2001)
Malaysia	Terengganu	year round (Jun–Jul)	Chaloupka (2001)
Taiwan (Prov. of China)	Wan-an Island	Jul–Aug	Cheng (2002)
Ogasawara	Ogasawara Islands	May–Aug	Suganuma (1985)
Hawaii	French Frigate Shoal	May–Jul	Balazs & Chaloupka (2004)
Michoacan	Playa Colola-Maruata	Sep–Jan	Alvarado-Diaz, Arias-Coyotl & Delgado-Trejo (2003)
Revillagigedo	Isla Clarion	Dec–April	Sarti, Roldan & Dutton (2002)
Galapagos	Isabella, St.Cruz, Fernandina	Dec–April	Zarate, Fernie & Dutton (2004)

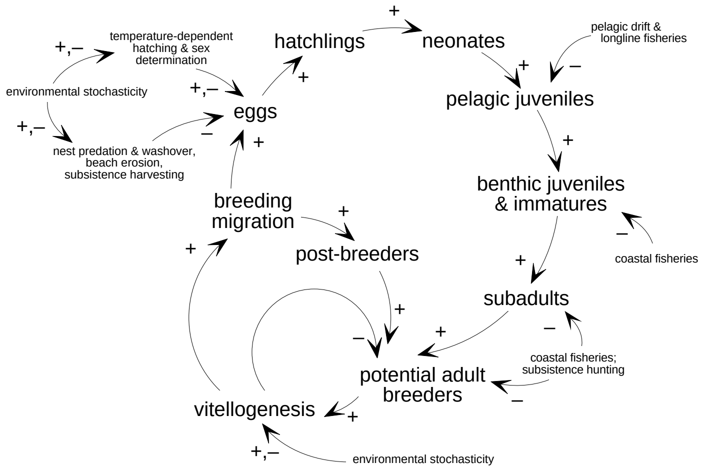

Figure 2. Lifecycle graph or causal loop model based on developmental phases and reproductive status (source: Puccia and Levins, 1985) for Pacific green turtles. The demographic structure and feedback mechanisms depicted here are included in the stochastic simulation model to explore Pacific green turtle metapopulation dynamics subjected to various hazards (e.g. nesting beach erosion, nest inundation by wave washover, egg and turtle harvesting, or incidental capture and drowning in coastal or pelagic fisheries) - see Chaloupka (2002a, 2004)

The main reason for the decline of some green turtle stocks in the Pacific Ocean is the overharvesting of eggs and large turtles (Horikoshi *et al.*, 1994; Limpus, Couper and Read, 1994; Chaloupka, 2002a; Seminoff *et al.*, 2003b – see Figure 3d). There is extensive demographic information available for the southern Great Barrier Reef stock (Limpus, Couper and Read, 1994; Limpus and Chaloupka, 1997; Chaloupka and Limpus, 2001; Chaloupka and Limpus, 2002; Chaloupka, 2002a; Chaloupka, 2002b). There is also extensive demographic information available for the Hawaiian stock including foraging ground abundance estimates (Balazs and Chaloupka, 2004; Balazs and Chaloupka, in press; Chaloupka and Balazs, n.d.). Some important demographic information such as survival probabilities and somatic growth dynamics is available for the Baja California population (Seminoff *et al.*, 2002; Seminoff *et al.*, 2003b). Demographic data are not available for any other Pacific green turtle stock.

A stochastic simulation model of the metapopulation dynamics of the Hawaiian stock was developed for National Oceanic and Atmospheric Administration (NOAA) Fisheries to help evaluate the impact of competing risks on green turtle population viability (Chaloupka, 2003, unpubl. – see Figure 2). A stochastic simulation model for the Australian stock was described in detail in Chaloupka (2002a) and a spatially explicit extension of that model was described in Chaloupka (2004). A more comprehensive stochastic simulation model was developed for the Great Barrier Reef Marine Park Authority to evaluate potential impacts of indigenous harvests on the viability of the southern Great Barrier Reef stock (Chaloupka, 2003a; see also Dobbs and Limpus, in press). A Bayesian surplus production stock assessment model has been developed recently for the Hawaiian green turtle metapopulation (Chaloupka, unpubl.).

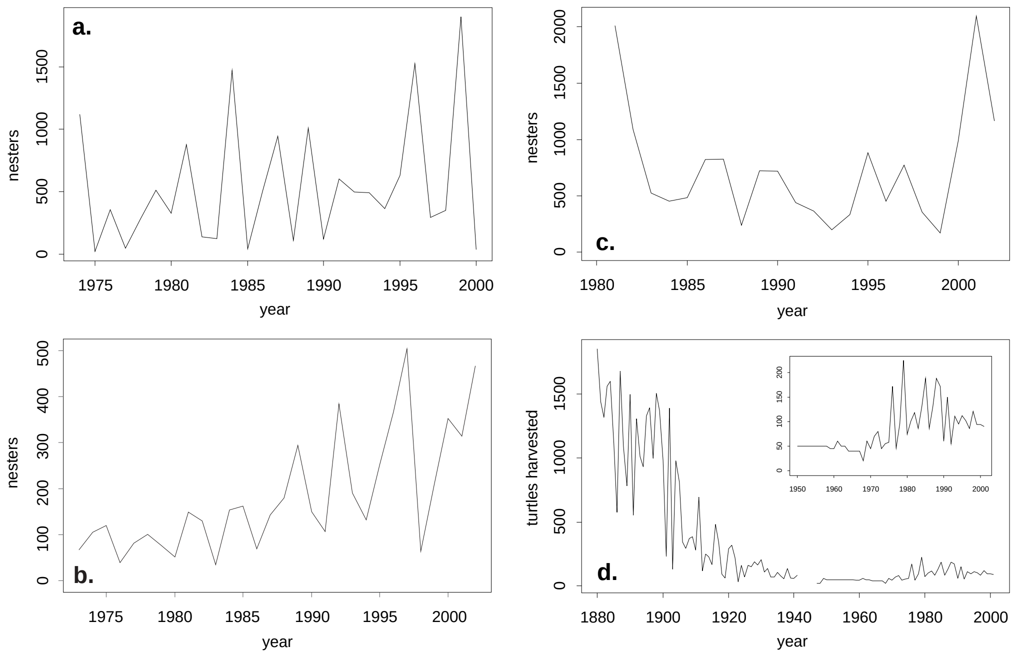

Figure 3. Trends in nesting abundance of three Pacific green turtle populations (a, b and c) and the harvest history of the Ogasawara population (d). Panel (a) shows the annual nesting census of green turtles at the Heron Island rookery, southern Great Barrier Reef (source**:** Chaloupka and Limpus, 2001; Limpus and Limpus, 2003). Panel (b) shows the annual nesting census of green turtles at the East Island rookery, French Frigate Shoals, Hawaii (source**:** Balazs and Chaloupka, 2004). Panel (c) shows the annual nesting census of green turtles at the Colola rookery, south Michoacan, Mexico (source**:** USA Biological Opinion, 2004). Panel (d) shows the number of adult green turtles harvested each year around the Ogasawara Islands, Japan (source**:** Horikoshi *et al*., 1994 with updates from Dr Suganuma, pers. comm.). The inset shows the same data for the period 1950–2000.

Hazards

Green sea turtles account for a small proportion of the incidental take in the Queensland east coast otter trawl (Robins, 1995; Slater *et al*., 1998) and Australian northern prawn fishery (Poiner and Harris, 1996). Green turtles are commonly caught in pelagic fisheries in the North Pacific (McCraken, 2000) and in some coastal fisheries off the California coast (Julian and Beeson, 1998).

Green turtles have also been the preferred target species for a wide range of subsistence harvests throughout the Pacific (Chaloupka, 2002a; Seminoff, 2002) and for egg collection (Chaloupka, 2001). The main hazards for the species are (Figure 2):

- egg harvesting;
- harvest of large turtles in the foraging grounds and on nesting beaches;
- nesting habitat destruction;
- incidental capture in coastal and pelagic fisheries.

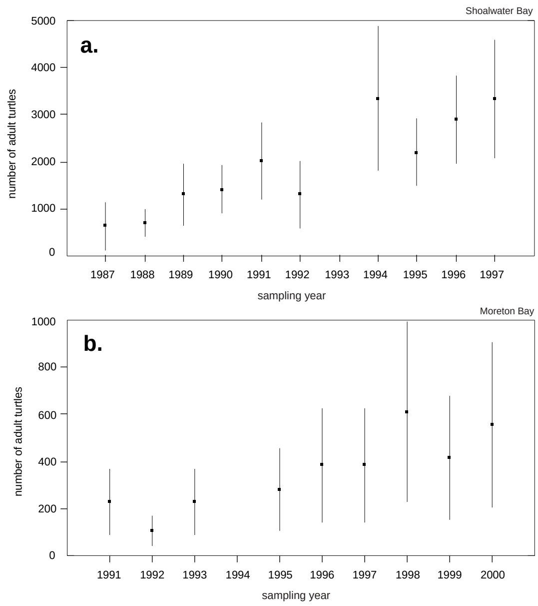

Figure 4. Trends in Horvitz-Thompson type population abundance (solid squares) for green turtles resident in two major foraging grounds of the southern Great Barrier Reef stock. Panel (a) shows adult abundance estimates for the Shoalwater Bay foraging ground population of the sGBR metapopulation. Panel (b) shows adult abundance estimates for the Moreton Bay foraging ground population of the sGBR metapopulation. Vertical bar = approximate 95 percent confidence interval. Source: Chaloupka, 2002b

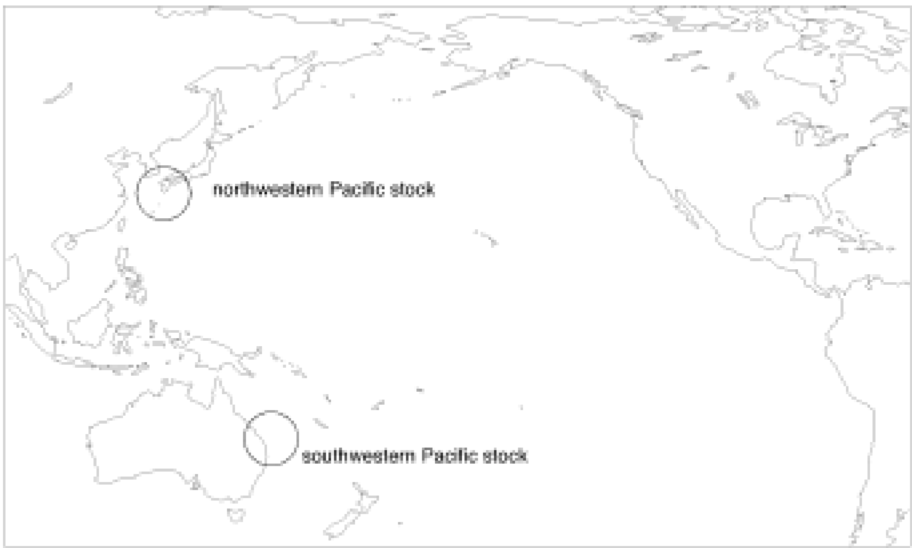

Figure 5. Location of the major regional rookeries for the Pacific loggerhead turtle stocks. Source: Bowen *et al.*, 1994; Kamezaki *et al.*, 2003; Limpus and Limpus, 2003

Loggerheads (*Caretta caretta*)

Background

The loggerhead sea turtles resident in Pacific waters comprise two distinct stocks (Figure 5). Ongoing genetic and tagging studies are beginning to define breeding stocks on a finer scale within these broad regions. Within Australia, the cluster of rookeries in the east and west is recognized as two distinct management units by genetic studies (see Dutton, Broderick and Fitzsimmons, 2002). Limpus and Limpus (2003) also suggest an additional unit, encompassing the small rookeries in New Caledonia (1 300 km distant from Australian nesting beaches). Similar genetic studies in Japan (Hatase *et al*., 2002) indicate the presence of at least four discernible management units and provide evidence that all loggerheads found in the northern Pacific originate in Japan. The transition from hatchling to young juvenile in this species occurs in the open ocean. Juvenile foraging areas occur off Baja California, Mexico, approximately 10–12 000 km from their nearest nesting beaches in Japan (Figure 6). Pacific loggerhead stocks have declined significantly over the last 50 years (Figure 7). This is apparent for all nesting populations (Figure 7a,c) and many foraging ground populations (Chaloupka and Limpus, 2001), but not for all foraging ground populations of the Australian stock (Figure 7b). There is extensive demographic information available for the Australian stock (Chaloupka and Limpus, 2002; Chaloupka, 2003b; Limpus and Limpus, 2003). There is very little demographic information available for the Japanese stock (Kamezaki and Matsui, 1997) but there are comprehensive nesting data available for this stock (Sato *et al*., 1997; Kamezaki *et al*., 2003). A stochastic simulation model of the population dynamics of the Japanese stock was developed for NOAA Fisheries to help evaluate the impact of competing risks on loggerhead population viability (Chaloupka, unpubl.). A stochastic simulation model for the Australian stock was described in detail in Chaloupka (2003b), which suggested the dramatic decline in the Australian loggerhead stock was a result of foxes feeding on nest contents at mainland rookeries and incidental capture in coastal and pelagic fisheries.

Table 2. Summary of nesting seasons for Pacific loggerhead turtle stocks shown in Figure 5

Stock	Nesting location	Season (peak)	Source
Southwest Pacific	New Caledonia, southern GBR/ Queensland	Oct–Mar (Dec)	Limpus & Limpus (2003)
Northwest Pacific	Southern Japan, Ryukyu Islands	Apr–Aug (Jul)	Kamezaki *et al*. (2003)

Hazards

Nearly 51 percent of sea turtles caught in the Queensland east coast otter trawl fishery were found to be loggerheads (Robins, 1995; Slater *et al*., 1998) while around 10 percent of the incidental capture of sea turtles in the Australian northern prawn fishery (Gulf of Carpentaria) was loggerheads (Poiner and Harris, 1996). Loggerheads are also commonly caught in pelagic fisheries in the northern Pacific (Wetherall *et al*., 1993; McCraken, 2000) and some coastal fisheries off the California coast (Julian and Beeson, 1998). The loggerheads caught in these high seas and coastal fisheries in the North Pacific all belong to the Japanese breeding stock (Figure 6). Recently, juvenile loggerheads of Australian stock origin have been found foraging in the southeast Pacific off the coast of Peru and Chile, suggesting that this stock is distributed across the entire southern Pacific Ocean (Dutton, in prep; see also Donoso *et al*., 2000, and Alfaro-Shigueto *et al*., in press) and is impacted by high seas and coastal fisheries operating in this region of the eastern Pacific (Donoso and Dutton, in press).

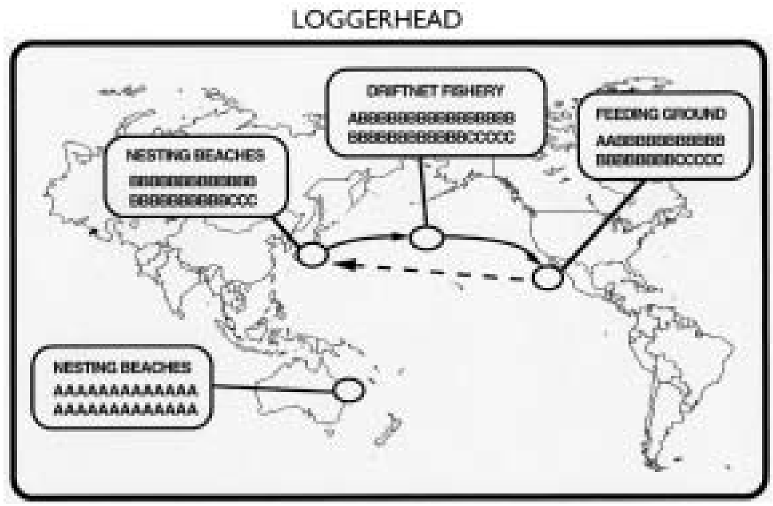

Figure 6. Genetic stock composition (based on mitochondrial DNA haplotypes) of loggerheads in the Pacific. Two regional nesting stocks are shown (Japan and Australia). The turtles in the North Pacific foraging areas belong to the Japanese nesting stock. Source: Bowen *et al*., 1995

The main hazards for loggerheads are (see also NMFS and USFWS, 1998a):

- incidental capture in coastal and pelagic fisheries;
- nesting habitat destruction, including beach armourment;
- feral animal predation on nests.

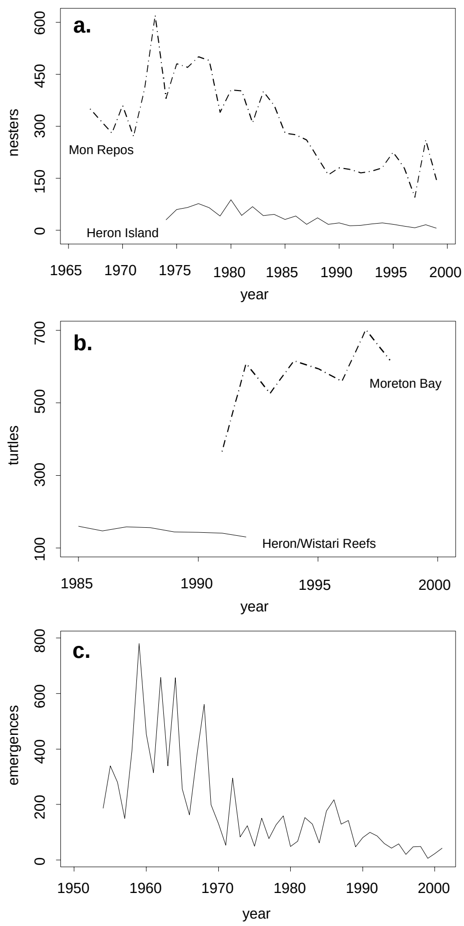

Figure 7. Trends in nesting abundance for the two Pacific loggerhead stocks. Panel (a) shows number of nesters recorded each year for the southwestern Pacific loggerhead rookeries at Mon Repos (source: Limpus and Limpus, 2003) and Heron Island (source: Chaloupka and Limpus, 2001). Panel (b) shows abundance estimates for loggerheads at two foraging ground populations of the southwestern Pacific stock based on Horvitz-Thompson type estimates using Cormack-Jolly-Seber capture probabilities (source: Chaloupka and Limpus, 2001). Panel (c) shows the number of female beach emergences or haul-outs recorded each year for the northwestern Pacific loggerhead rookery at Kamouda, Japan (source: Kamezaki *et al.*, 2003)

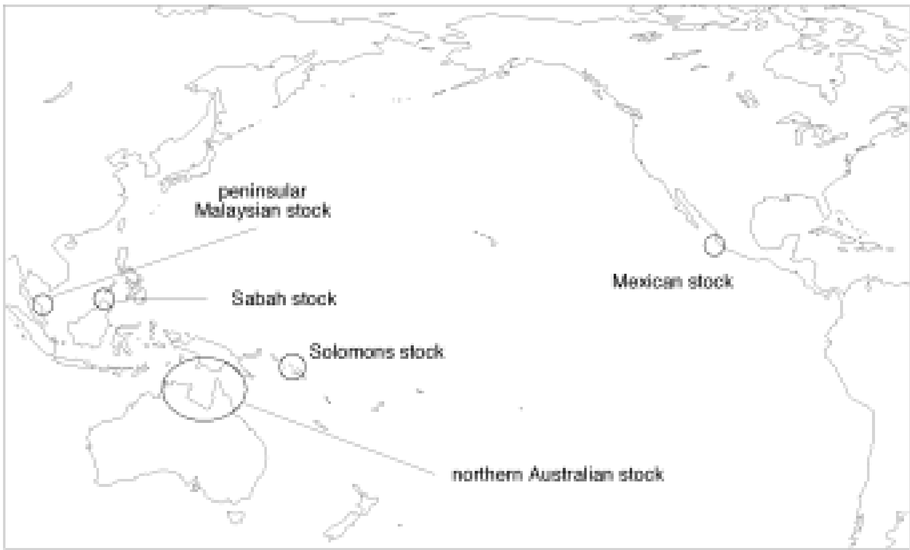

Figure 8. Location of the major regional rookeries for the Pacific hawksbill turtle stocks. Source: Broderick *et al*., 1994; Dutton, Broderick and Fitzsimmons, 2002

Hawksbills (*Eretmochelys imbricata)*

Background

The hawksbill turtle comprises five stocks or management units in the Pacific (Dutton, Broderick and Fitzsimmons, 2002), which are shown in Figure 8. The hawksbill is critically endangered with some Pacific stocks in decline (Meylan and Donnelly, 1999; Seminoff *et al*., 2003a). However, stable stocks include the Ko Khram rookery in the Gulf of Thailand (Charuchinda, Monanunsap and Chantrapornsyl, 2002) and the Sabah Turtle Islands rookery in the Sulu Sea (Basintal, 2002). The eastern Pacific stock was abundant but is now only occasionally found along the Baja and Pacific Mexico coast (Seminoff *et al*., 2003a). Long-term monitoring of nesting abundance is only available for the northern Australian stock (Figure 9a) and the Sabah stock (Figure 9b). The Australian stock has declined in recent years but there are no foraging ground abundance estimates for any Pacific population. There are only limited demographic data available for hawksbills (Chaloupka and Limpus, 1997; Pilcher and Ali, 1999). There are no reliable demographic models of hawksbill population dynamics (Chaloupka and Musick, 1997) but a stochastic simulation model is in development for the Western Pacific Regional Fishery Management Council (Hawaii).

Table 3. Summary of nesting seasons for Pacific hawksbill turtle stocks shown in Figure 8

Stock	Nesting location	Season	Source
Malaysian	Terengganu	Apr–Aug	Chan & Liew (1996)
Sabah	Gulisaan Island	Feb–Apr, Jun–Aug	Basintal (2002)
Australian	Milman Island	Dec–Apr	Loop, Miller & Limpus (1995)

A Bayesian surplus production stock assessment model has been developed for the Cuban hawksbill turtle population (Chaloupka, unpubl., for the IUCN review of the application of the Convention on International Trade in Endangered Species [CITES]), and this is being applied to the central Pacific hawksbill stock.

Hazards

Hawksbills appear to be rarely caught in either pelagic fisheries (Wetherall *et al*., 1993; McCracken, 2000) or coastal fisheries (Robins, 1995; Poiner and Harris, 1996; Slater *et al*., 1998). The main hazards for hawksbills are (Meylan and Donnelly, 1999; see also NMFS and USFWS, 1998c):

- commercial harvesting for *bekko* (tortoiseshell);
- egg harvesting;
- nesting habitat destruction.

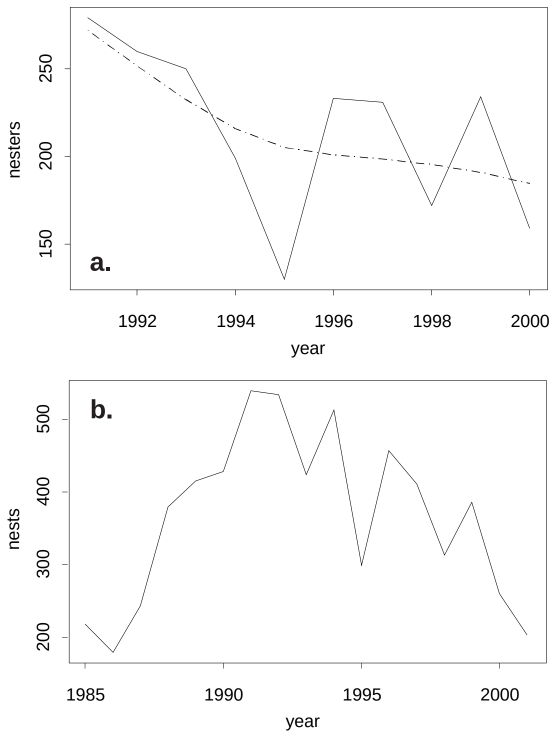

Figure 9. Trends in nesting abundance of two Pacific hawksbill populations. Panel (a) shows the estimated number of hawksbills nesting each year (solid curve) on Milman Island, northern Great Barrier Reef (source: Miller *et al*., in prep.). The underlying long-term trend in the nester series is shown by a robust cubic spline smooth fit (dashed curve), which suggests that the nester series declined most rapidly during the early 1990s and has since slowed. Panel (b) shows the estimated number of hawksbills nesting at the Gulisaan rookery in the Sabah Turtle Islands (source: Pilcher and Ali, 1999; Basintal, 2002)

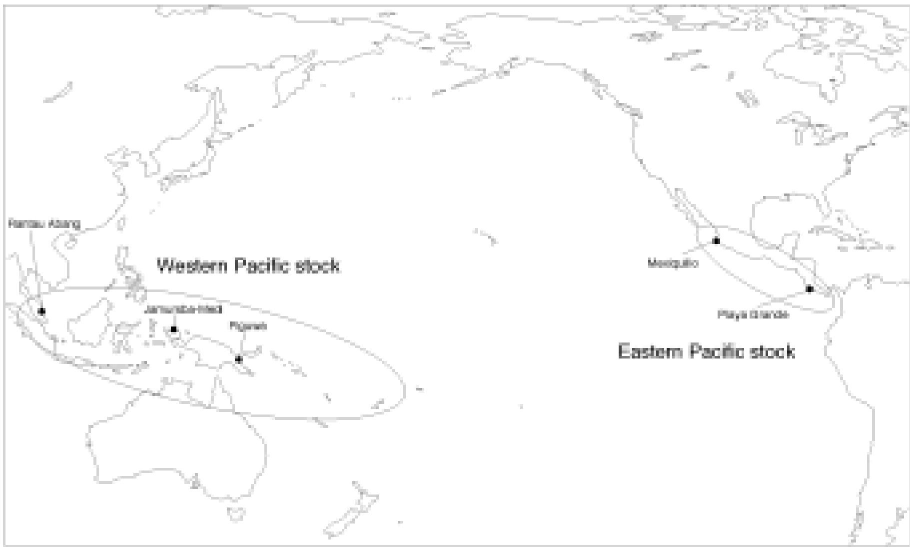

Figure 10. Location of the major rookeries for the Pacific leatherback turtle stocks. Source: Chua, 1988; Hirth, Kasu and Mala, 1993; Sarti *et al*., 1996; Spotila *et al*., 1996; Dutton *et al*., 1999; Suarez, Dutton and Bakarbessy, 2000

Leatherbacks (*Dermochelys coriacea*)

Background

The leatherback sea turtles resident in Pacific waters comprise two main distinct stocks (Figure 10), (with possibly a third “Indo-Pacific” stock whose status is unclear, in Malaysia). All stocks in the Pacific are apparently in decline (Sarti *et al*., 1996; Spotila *et al*., 1996) although perhaps not as seriously for the population that nests along the north Vogelkop coast of Papua near Jamursba-Medi (Hitipeuw and Maturbongs, 2002). However, there are no reliable estimates of the long-term status and trend in Pacific leatherback abundance. Many leatherbacks are apparently caught in coastal fisheries operating in Malaysian (Chan, Liew and Mazlan, 1988) and Californian waters (Julian and Beeson, 1998). Leatherbacks are also caught in pelagic fisheries in Chilean (Eckert and Sarti, 1997; Donoso and Dutton, 2000, and in press) and north Pacific waters (McCraken, 2000). A stochastic simulation model of the metapopulation dynamics of the western Pacific stock has been developed for NOAA Fisheries to help evaluate the impact of competing risks on leatherback metapopulation viability (Chaloupka, unpubl.).

Table 4. Summary of nesting seasons for Pacific leatherback turtle stocks shown in Figure 10

Stock	Nesting location	Season	Peak	Source
West Pacific	Terengganu (Malaysia)	Apr–Sep	Jul	Chua (1988)
	Jamursba-Medi (Papua)	Apr–Oct	Aug	Suarez, Dutton & Bakarbessy (2000)
	War Mon (Papua)	Nov–Feb	Dec	Suarez, Dutton & Bakarbessy (2000)
	Piguwa (Papua New Guinea, PNG)	Nov–Mar	Jan	Hirth, Kasu & Mala (1993)
	Kamiali-Huon Coast (PNG)	Nov–Mar	Dec	Dutton *et al*., unpubl
	Solomon Islands	Nov–Mar	Dec	Ramohia, Pita & da Wheya (2001)
East Pacific	Playa Mexiquillo (Mexico)	Oct–Mar	Dec	Eckert & Sarti (1997)
	Cahuitan (Mexico)	Oct–Mar	Dec	Sarti-Marinez (2002)
	Tierra Colorada (Mexico)	Oct–Mar	Dec	Sarti-Marinez (2002)
	Playa Grande (Costa Rica)	Oct–Mar	Dec	Steyermark *et al*. (1996)
	Playa Langosta (Costa Rica)	Oct–Mar	Dec	
	Chococente (Nicaragua)	Oct–Mar	Dec	Dutton *et al*., unpubl.

Although Atlantic populations appear to be stable or even increasing, leatherback populations are declining at all major Pacific basin nesting beaches, especially in the past two decades (NMFS and USFWS, 1998b; Spotila *et al*., 2000; Dutton, in press; Figure 14). The major decline of these nesting populations was probably brought about by a severe overharvest of eggs coupled with incidental mortality from fishing (Eckert and Sarti, 1997), especially the high seas driftnet fishery in the 1980s (Sarti *et al*., 1996).

Remaining breeding assemblages occur on both sides of the Pacific. In the western Pacific region they occur at low and scattered densities in Papua New Guinea, Solomon Islands, Fiji, Thailand, Vanuatu, China and Australia (east and northeast) (Limpus and McLachlan, 1996; Márquez, 1990; Hirth, Kasu and Mala, 1993). In the western Pacific the last remaining major rookery is limited to Papua (formerly Irian Jaya, Indonesia). Prior to 1990 a major rookery was located in Malaysia (Terengganu), but this population has collapsed in the last decade (Chan and Liew, 1996). In the eastern Pacific, the largest rookeries occur along the coasts of Mexico and Costa Rica. Scattered nesting has been reported in Panama, Colombia, Ecuador and Panama (Márquez, 1990; Spotila *et al*., 1996).

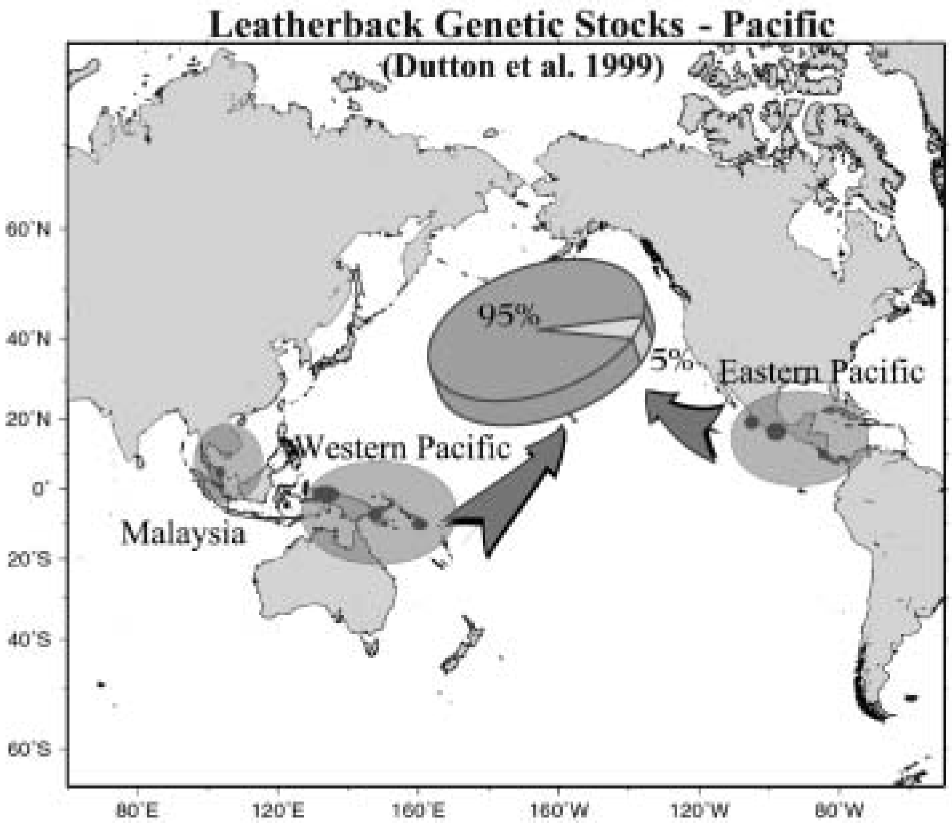

Figure 11. Stock composition of leatherbacks encountered in the north Pacific based on mitochondrial DNA (mtDNA) analysis (17 samples collected from the Hawaii-based longline fishery). The eastern Pacific genetic stock includes nesting populations in Costa Rica and Mexico, while the western Pacific stocks include populations in Papua (Indonesia), Papua New Guinea and the Solomon Islands, and a distinct stock in Malaysia. Source: Dutton *et al*., 1999

Mitochondrial DNA (mtDNA) sequences can be used to distinguish western Pacific from eastern Pacific genetic stocks (Figure 11). The eastern Pacific genetic stock includes Mexican and Costa Rican breeding assemblages, and the western Pacific stock contains populations in the Solomon Islands, Papua (Indonesia), and Papua New Guinea (Dutton, Broderick and Fitzsimmons, 2002). Genetic results, coupled with tag-recapture and satellite telemetry data suggest that the nesting stocks in the western Pacific primarily use the north Pacific for development and foraging, while animals from eastern Pacific stocks generally forage in the Southern Hemisphere, including the waters off Peru and Chile (Dutton, Broderick and Fitzsimmons, 2002). However, there are exceptions to this pattern, since animals of western Pacific stock origin have been found off Chile (Donoso *et al*., 2000), and likewise, some leatherbacks of eastern Pacific stock origin have been found in the north Pacific (Dutton, Broderick and Fitzsimmons, 2002).

Leatherbacks undertake some of the longest migrations of all sea turtles and can travel great distances between feeding and nesting areas (Figure 12). Although leatherbacks do not nest on the United States Pacific coast or territories, they forage in United States waters. Animals that are found in these forage areas are mainly from nesting beaches in the western Pacific, and undertake extraordinary migrations across the Pacific to return to nest in

Indonesia, Solomon Islands or Papua New Guinea (Dutton, Benson and Eckert, in press). This migratory behaviour exposes them to several United States and international high seas fisheries where they are taken as bycatch. While some eastern Pacific leatherbacks are found in the north Pacific, most animals that originate in Mexico and Costa Rica migrate south to feed in waters off Peru and Chile and further out in the southeastern Pacific (Dutton, Benson and Eckert, in press; Eckert 1999; Morreale *et al.*, 1996). The juvenile developmental areas remain unknown. Leatherbacks continue to be killed in the artisanal fisheries in Peru (Alfaro-Shigueto *et al.*, in press), and juveniles are caught in the Costa Rican artisanal fisheries (Arauz, unpubl.). Leatherbacks were killed in coastal swordfish gillnet fisheries in Chile (Eckert and Sarti, 1997). However, the size of this fishery has declined considerably since the early 1990s (Donoso and Dutton, in press). The extent of incidental take of leatherbacks by the international fleets that operate on the high seas in the eastern Pacific is unclear. The only data available are for the Chilean swordfish longline fishery, which indicate that leatherbacks are caught, although there have been no observed mortalities (Donoso and Dutton, in press).

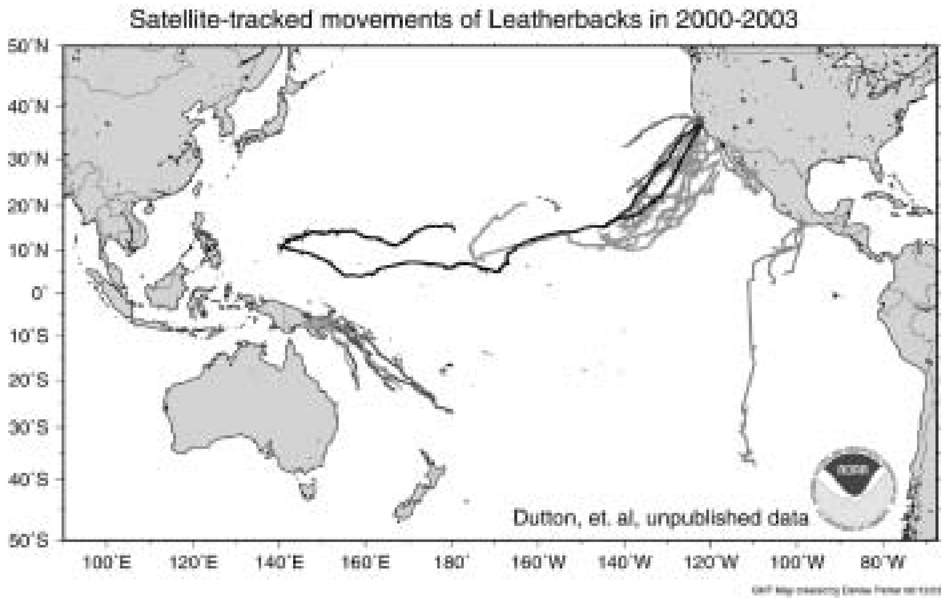

Figure 12. Satellite-tracked movements of adult leatherbacks in the Pacific. Tracks include turtles captured and released in a foraging area in Monterey Bay, California (Dutton, Eckert and Benson, unpubl.); females from nesting beaches in Papua New Guinea (Dutton, Benson, Rei and Ambio, unpubl.); and nesting females in Mexico (Sarti, Dutton and Eckert, unpubl.). Additional studies (not depicted here) have tracked southward post-nesting movements of female leatherbacks from Costa Rica passing by the Galapagos Islands (Morreale *et al.*, 1996), and females from Mexico that have travelled to waters off Peru and Chile (Eckert and Sarti, 1997)

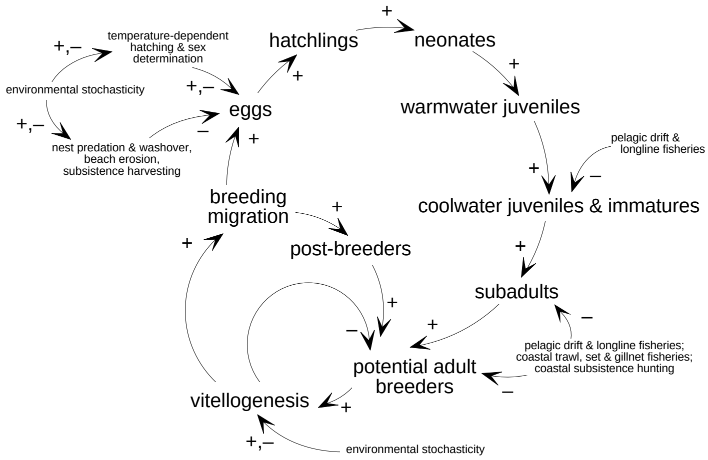

Figure 13. Developmental-phase-based and reproductive-status-based lifecycle graph or causal loop model (source: Puccia and Levins, 1985) for Pacific leatherback turtles constructed using information in Eckert (1999). The demographic structure and feedback mechanisms shown here are included in stochastic simulation models to explore western Pacific leatherback turtle metapopulation dynamics subject to various hazards, e.g. nesting beach erosion, nest inundation by wave washover, egg and turtle harvesting, or incidental capture and drowning in coastal or pelagic fisheries

Hazards

The main hazards for leatherbacks are (Figure 13, see also NMFS and USFWS, 1998b):

- egg harvesting;
- pig and veranid predation of eggs at coastal rookeries;
- incidental capture in coastal and pelagic fisheries;
- subsistence harvest of large turtles in the foraging grounds and on nesting beaches.

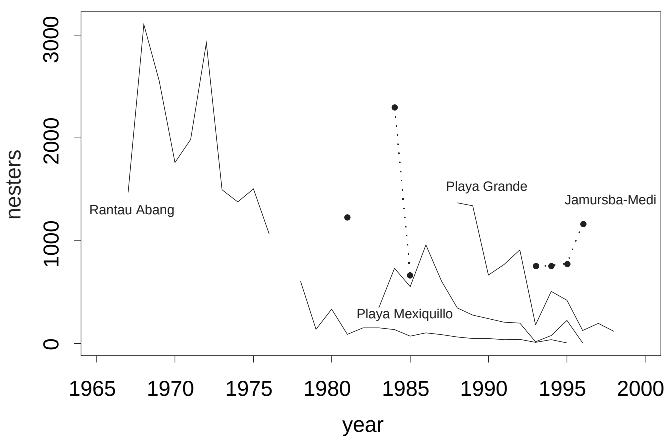

Figure 14. Trends in the nesting abundance of four major Pacific leatherback populations. The western Pacific stock comprises the Rantau Abang and Jamursba-Medi rookeries while the eastern Pacific stock comprises the Mexiquillo and Playa Grande rookeries. The data has been derived in various ways from Chua, 1988; Chan and Liew, 1996; Spotila *et al.*, 1996, 2000; Eckert and Sarti, 1997; Suarez, Dutton and Bakarbessy, 2000

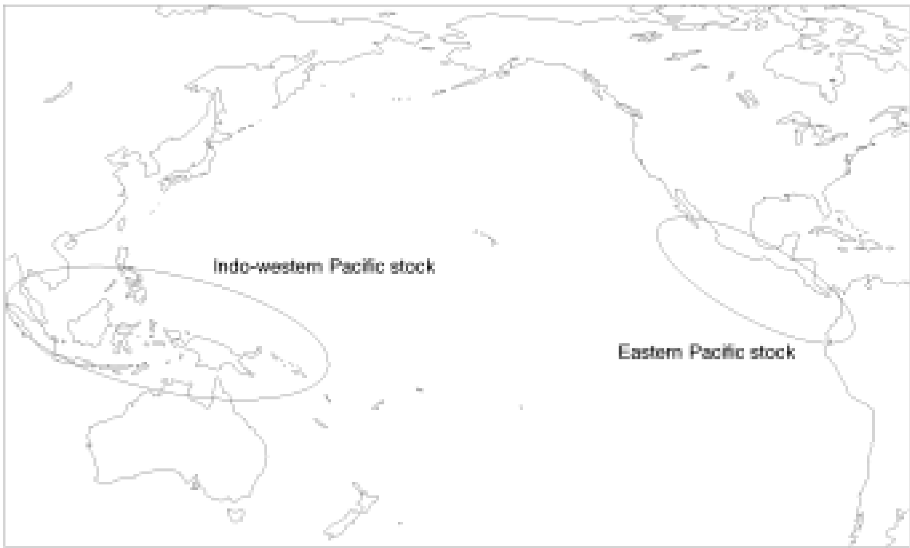

Figure 15. Location of the Pacific olive ridley turtle nesting stocks. Source: Bowen *et al*., 1998

Olive ridleys (*Lepidochelys olivacea*)

Background

The olive ridley turtle (*Lepidochelys olivacea*) has a circumtropical distribution and is probably the most abundant sea turtle species (Bowen *et al*., 1998). Olive ridleys resident in Pacific waters comprise two stocks (Figure 15) – an eastern Pacific stock that nests along the Pacific coast from Mexico to Colombia (Cliffton, Cornejo and Felger, 1982; Cornelius, 1982; Green and Ortiz-Crespo, 1982; Martinez and Paez, 2000) and a western Pacific stock that nests in coastal areas of southeastern Asia, New Guinea and northern Australia (Siow and Moll, 1982; Chantrapornsyl, 1992; Bowen *et al*., 1998; Putrawidjaja, 2000). Table 5 summarizes some of the nesting seasons for these two stocks.

Several major nesting populations of the eastern Pacific stock are increasing in abundance following protection from anthropogenic hazards (Figure 16) while some nesting populations in the eastern Pacific (Valverde, Cornelius and Mo, 1998) and Indo-western Pacific stocks are apparently in decline (Siow and Moll, 1982; Chantrapornsyl, 1992; Chantrapornsyl and Bhatia, 1993). The eastern Pacific stock was heavily exploited during the 1960s and 1970s for eggs, meat and skins (Green and Ortiz-Crespo, 1982; Trinidad and Wilson, 2000). Olive ridleys from both Pacific stocks are known to be caught incidentally in coastal fisheries (Cliffton, Cornejo and Felger, 1982; Robins, 1995; Poiner and Harris, 1996; Cheng and Chen, 1997; Slater *et al.*, 1998), which can be a major source of mortality (Poiner and Harris, 1996). Olive ridleys are also exposed to incidental capture in some Pacific pelagic longline fisheries (McCraken, 2000; Polovina *et al*., 2004). A stochastic simulation model of the population dynamics of the eastern Pacific stock has been developed for NOAA Fisheries to help evaluate the impact of various competing risks on olive ridley population viability (Chaloupka, unpubl.).

Table 5. Summary of nesting seasons for Pacific olive ridley turtle stocks shown in Figure 15

Stock	Nesting location	Season (peak)	Source
Eastern Pacific	Mexico	Jun–Dec (Aug–Oct)	Dash & Kar (1990)
	Costa Rica	year round (Aug–Nov)	Hughes & Richard (1974)
	Colombia	Aug–Dec (Aug–Dec)	Martinez & Paez (2000)
Indo-western Pacific	Northern Australia	Jun–Aug (Jun–Jul)	Limpus (2002 pers. comm.)
	Peninsula Malaysia	Oct–Jan	Siow & Moll (1982)
	West Thailand	Oct–Feb (Dec–Jan)	Chantrapornsyl (1992)
	Orissa	Dec–Apr (Dec–Apr)	Dash & Kar (1990)

Hazards

The main hazards for olive ridleys are (see also NMFS and USFWS, 1998d):

- egg harvesting;
- commercial harvest of large turtles in the foraging grounds and on nesting beaches;
- incidental capture in coastal and pelagic fisheries.

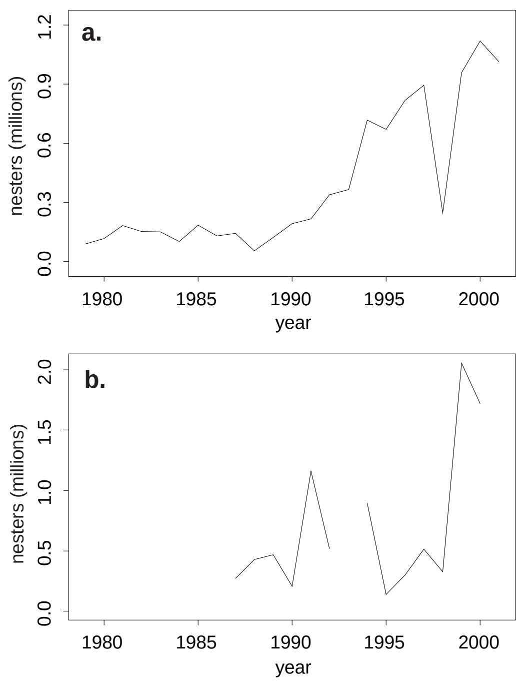

Figure 16. Trends in abundance of two major olive ridley nesting populations from the eastern Pacific stock. Panel (a) shows estimated nesting abundance at La Escobilla, Mexico. Panel (b) shows estimated nesting abundance at Ostional, Costa Rica — the nesting population at nearby Playa Nancite is apparently in decline (Valverde, Cornelius and Mo, 1998). Source: Chaves, 1998, 1999, 2002; Penaflores *et al*., 2000; F. Alberto Abreu, 2002, pers. comm.

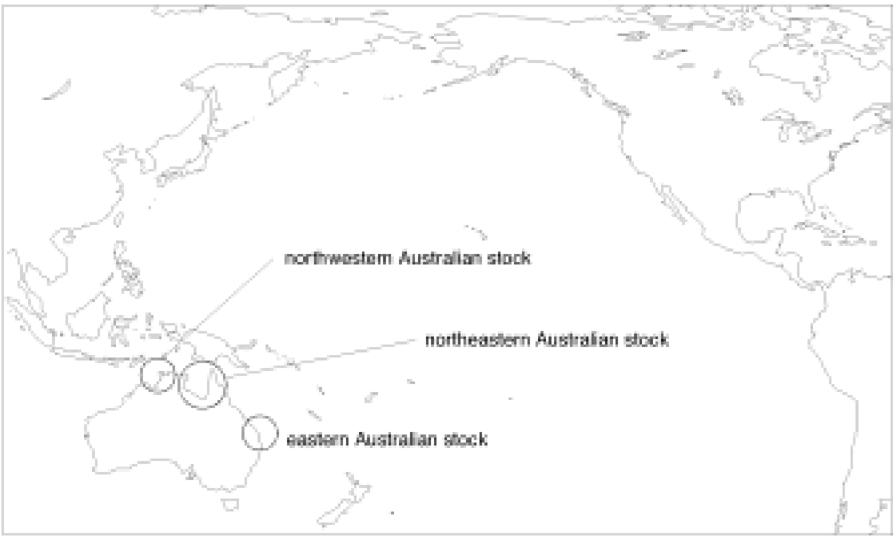

Figure 17. Location of the regional rookeries for the Pacific flatback turtle stocks. Source: Dutton, Broderick and Fitzsimmons, 2002; Limpus, 2002

Flatbacks (*Natator depressus*)

Background

The flatback is endemic to the northern Australian region with nesting restricted to Australia. Three management units are recognized in the Pacific (Dutton, Broderick and Fitzsimmons, 2002) – a northwestern Australian, a northeastern or Gulf of Carpentaria and an eastern Australian nesting stock (Figure 17). Crab Island in North Queensland (northeastern Australian stock) is the largest flatback rookery in the world (Limpus *et al*., 1983). Long-term monitoring of nesting abundance is only available for the eastern Australian stock that nests along central coastal Queensland (Mon Repos, Woongarra) and on offshore islands in the central Great Barrier Reef region such as Wild Duck (Limpus, 2002). All monitored nesting populations appear to be stable (see Figure 18) but there are no foraging ground abundance estimates for any population. There are only very limited demographic data available for the flatback turtle (Walker and Parmenter, 1990; Parmenter and Limpus, 1995; Limpus, 2002). There are no demographic models of flatback population dynamics available.

Table 6. Summary of nesting seasons for Pacific flatback turtle stocks shown in Figure 17

Stock	Nesting location	Season (peak)	Source
Northwestern Australian	Fog Bay	May–Jul	Guinea (1994)
Northeastern Australian	Crab Island	year round	Limpus *et al*. (1983)
Eastern Australian	Wild Duck Island	Oct–Jan	Slater *et al*. (1998)

Hazards

The eastern Australian stock might have been significantly reduced over the last century but there are no reliable data to confirm this view (Limpus, 2002). Extensive harvesting of eggs and turtles occurs in northern Australian waters (Limpus *et al*., 1983; Limpus, 2002). Nearly 60 percent of sea turtles caught in the Australian northern prawn fishery (Gulf of Carpentaria) are flatbacks (Poiner and Harris, 1996) while around 11 percent of the incidental capture of sea turtles in the Queensland east coast otter trawl fishery are flatbacks (Robins, 1995). The main hazards for flatbacks are:

- pig and veranid predation of eggs at coastal rookeries;
- egg harvesting;
- incidental capture in coastal otter trawl fisheries;
- indigenous harvest of large turtles in the foraging grounds and on nesting beaches.

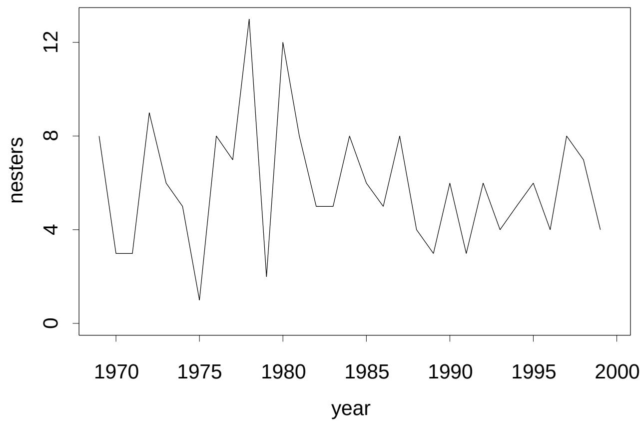

Figure 18. Trend in abundance of the Woongarra flatback nesting population from the eastern Australian stock. Source: Limpus, 2002

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A review of existing and potential longline gear modifications to reduce sea turtle mortality

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Abstract

Fisheries using pelagic longlines incidentally catch sea turtles and they may represent a serious threat to depleted sea turtle populations. The work to develop gear modifications to substantially reduce sea turtle bycatches in longlines has begun and this report presents a brief overview of the results obtained so far, with special emphasis on the efficiency of the measures tested. Furthermore, areas where further research is needed are identified.

INTRODUCTION

Sea turtles are a global resource and several anthropogenic activities have been identified to cause declines in sea turtle populations. One of these causes is harvest, either direct through the harvest of eggs and nesting females or indirect caused by incidental bycatches in fishing operations. Among fisheries that incidentally capture sea turtles, certain types of trawl, gillnet and longline fisheries generally pose the greatest threat. Several reports have documented incidental catches of sea turtles by these gear types, but unfortunately few studies have been conducted to develop and evaluate mitigation measures to reduce such bycatches.

The work to develop solutions to reduce the sea turtle bycatch in longlines and trawls has begun, however, and some promising mitigation measures have been identified, tested and in some cases implemented. This report describes the technological details of mitigation measures tested in longline fisheries. The efficiencies of these measures are reviewed and evaluated, and areas where further research is needed are identified.

Development of mitigation measures

Fishing gear and modifications

The most comprehensive work on development of mitigation measures to reduce sea turtle bycatch in longlining is a 3-year study conducted in the U.S. Atlantic pelagic longline fisheries (Watson *et al.*, 2004). This project has been carried out by NOAA Southeast Fisheries Science Center in cooperation with the U.S. pelagic longline fishing industry. The fishing experiments were conducted in 2001–2003 at Grand Banks, on board commercial longliners targeting swordfish.

In order to reduce incidental catch of sea turtles, circle hooks and mackerel bait were compared with the traditional J-hook and squid bait. The pooled results for the two last years of the project are given in Table 1.

Table 1. Percentage decrease in bycatches of loggerhead and leatherback turtles in the Grand Banks mitigation experiment (pooled data for 2002 and 2003). The treatments were compared with traditional J-hook baited with squid. (After Watson *et al*., 2004).

Treatment	Loggerhead	Leatherback
18/0 Circle hook with squid	74%	75%
18/0 Circle hook with mackerel	91%	67%

Circle hook with mackerel bait gave a 90% reduction in the bycatch of loggerhead turtle and the bycatch of leatherback turtle was reduced by 75% using circle hook with squid bait compared to the traditional J-hook baited with squid. When baited with mackerel, the circle hook gave catch increases (8–12%) for the targeted swordfish, but a decrease in target catch rate (29%) when baited with squid. The effectiveness of circle hooks has also been compared with that of the typical J-hooks in the swordfish longline fishery in the Pacific (Boggs in press.). Circle hooks were only 40% as effective as J-hooks at catching swordfish, but compared nearly equal (94%) with J-hooks at catching tuna.

Alternative types of mitigation measures were also tested in this project based on results from other studies. Blue-dyed squid bait, which is likely to be less visible, has been shown to reduce seabird bycatches (Boggs, 2001), and captive sea turtles ignored blue-dyed squid bait when presented with a choice between blue and normal baits (Swimmer and Brill, 2001; Swimmer *et al.*, 2002 cited in Boggs, in press.). Results of the fishing experiments conducted in the NOAA project, showed no effect of blue-dyed squid bait on incidental take of turtles. Furthermore, although historical data have indicated higher turtle bycatch on hooks nearest floats, moving the branch line 20 fathoms away from the buoy did not reduced the incidental catch of loggerhead or leatherback turtles.

Fishing practice modifications

Changing the way the fishing gear is operated is an alternative method to reduce incidental bycatch. There is a big difference in the operation of longline gear for swordfish and tunas. Swordfish is found in much shallower waters than tunas, and consequently the gear is set closer to the surface, whereas tuna longlines is set much deeper (down to 300–400 m when targeting bigeye tuna). Analysis of observer data collected by the Secretariat of the Pacific Community (SPC) indicates that shallow-set longline gear takes 10 times more sea turtles than deep-set gear (SPREP, 2001; Simonds, 2003). Turtles caught on deep-set gear were almost always taken on the shallowest hooks. The Japanese longline vessels, which is the dominant longline fleet in the Pacific, have gradually switched from shallow-set gear targeting yellowfin tuna and albacore to deep-set gear to catch bigeye tuna (Bjordal and Løkkeborg, 1996). This trend, which started in the 1970s, has probably lead to a sharp reduction in sea turtle bycatches in the Japanese longline fishery.

Sea turtle distribution has been shown to be dependent on surface water temperature, and the NOAA fishing experiments on the Grand Banks showed that fishing in colder water could reduce turtle interactions. Bycatches increased with temperature, especially for loggerheads, and this effect of temperature was reversed for swordfish catch rates. Thus fishing in temperatures below 20°C can reduce turtle interactions and increase target catch rates.

The results from the first year of the NOAA project also indicated that bycatches of loggerhead increased with increasing daylight soak time. The experiments conducted during the second year, however, did not give reduced catches of loggerhead by reducing the daylight soak time.

The Honolulu Laboratory of NMFS has conducted experiments in the Hawaii longline fisheries designed to complement similar research being conducted in the Atlantic Ocean (Boggs, in press.). However, permit has not been given to carry out the proposed fishing experiments due to the incidental sea turtle mortality such experiments will cause. This project has therefore been designed to test how modified fishing gear and fishing operations will affect target catches, i.e. to test for viability in maintaining target species catch rates. Two modifications were tested: (1) Stealth (camouflaged) gear that was designed to reduce the visibility by using narrow-frequency, yellow light-emitting diode-based, down-welling (shaded on the upper half) light sticks, dull blue painted lines and blue-dyed bait; and (2) Deep-set daytime gear using the same depth configuration as that for tuna gear, i.e. longer main line and more hooks between floats.

The stealth gear caught significantly fewer swordfish than the control gear reducing the revenue by 30%. The deep-set daytime gear gave a much more pronounced catch reduction than the stealth gear. The catch of swordfish was 85% less for this gear configuration compared with the control gear. The depth of the deep daytime sets averaged 244 m, whereas control and stealth sets averaged 19 m. These results may be improved by testing another colour of light stick and setting at greater depths, respectively.

De-hooking and release of captured turtles

In the NOAA sea turtle project “Careful Release Protocols” were developed with guidelines for releasing hooked and entangled sea turtles with minimal injury. New de-hooking and release techniques were developed to increase survival rates among the turtles that were incidentally caught. A dipnet used as a turtle elevator was used to bring larger turtles on board for de-hooking using different types of dehookers specially designed for removing hooks depending on location in the mouth cavity. Also line cutters were designed to assist in removing line from entangled sea turtles.

Records of hooking positions (hooked in the mouth versus ingestion) showed that a lower proportion of loggerhead turtles caught on circle hooks had ingested the baited hook compared to those caught on J-hooks. Consequently a higher proportion of turtles could be removed for circle hook (87%) compared with J-hook (36%). This is likely to reduce the post-hooking mortality associated with the interactions. Leatherbacks were most often foul hooked (i.e. external).

Also as a part of the NOAA project, behaviour observations were conducted in the laboratory to study the effects of hook size on ingestion of hooks by loggerhead turtles. Squid baited hooks of different sizes were presented to captive reared turtles, and the proportions of individuals attempting to swallow the hooks were recorded. These observations showed the loggerhead turtles had a much lower tendency to ingest hooks larger than 51 mm in width compared to hooks smaller than this size. Hooks smaller than 51 mm in width are predominantly used in the pelagic longline fisheries. Thus using larger hooks has the potential to reduce mortality of loggerhead turtles.

Future research

The Second International Fishers Forum (Honolulu, Hawaii, 19–22 November 2002) concluded that the major challenges standing in the way of finding a means to reduce sea turtle bycatches in longline operations include effective gear modifications and fishing tactics, research facilitation and dissemination, public awareness and industry incentives for action (Anon., 2002). Mitigation research should focus on bait types and size, hook design and size, and float design to make the gear more "stealthy". Also the use of sensors to determine when turtles and target species encounter the baited gear was suggested.

The International Technical Expert Workshop on Marine Turtle Bycatch in Longline Fisheries (Seattle, Washington, 11–13 February 2003) identified six overarching strategies as key elements to mitigate sea turtle bycatch in longline fisheries of which one was modifications of gear and fishery practices (Anon., 2003). Under this strategy highest priority was given to:

1. Deploy and implement items that have shown to be effective in reducing bycatch in shallow swordfish fisheries (reduced daylight soak time, leaders longer than float line, leaded swivels, circle hooks, mackerel baits, avoidance of areas of high turtle densities).
2. Direct additional and immediate research in the major ocean basins to fine tune recent findings (effects of circle hooks on target species, bait type, weighted leaders, repellents, branch line materials, attractiveness of gear, deep sets).
3. Establish an international fund for longline bycatch mitigation experiments.
4. Increase research on post-hooking mortality.

Most importantly, however, the encouraging mitigation measures tested in the comprehensive study conducted at the Grand Banks may prove to be a viable solution for longline operations in other regions. However, it is important to take into account that separate experiments are required because there are differences between the major ocean basins among species, in pelagic longline strategies and tactics, and in oceanic structure and ecology. Thus, bycatch-reduction techniques that have shown promise should be tested and evaluated by nations having longline fisheries where sea turtles are incidentally caught.

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A review of development, modification and implementation of TED (Turtle Excluder Device) to reduce sea turtle bycatch in trawl fisheries

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Abstract

Turtle Excluder Devices (TEDs), to reduce the capture of sea turtles in shrimp trawlers, were first developed in Western Countries from technology existing since the 1960s and designed to make towing more efficient (and hence called “trawling efficiency device”). Since the late 1980s, TEDs became compulsory in the United States (US) and their use spread to other countries following US regulations on shrimp imports that required nations exporting shrimp to the US to introduce TEDs in their shrimp trawlers. This paper reviews experiences in developing and implementing TEDs worldwide, including their main technical and operational features.

INTRODUCTION

In the 1970s, unwanted catch of fish and other species in shrimp trawling were perceived as a problem mainly in the southeastern United States (Seidel, 1975; Watson and McVea, 1977). In the shrimp trawl fisheries operated in the Gulf of Mexico, sea turtles were recognized as bycatch, in addition to jellyfish and fish species (Seidel, 1975). Sea turtles caught in the US shrimp trawl fisheries were the following five species: Kemp's ridley (*Lepidochelys kempii*), hawksbill (*Eretmochelys imbricata*), leatherback (*Dermochelys coriacea*), green (*Chelonia mydas*), and loggerhead (*Caretta caretta*). Time or area closures of fishing operations were first considered to prohibit fishing activities in areas or at times when the probability of interactions with sea turtles was highest. However, since this method caused substantial negative impact on fishermen’s income, further efforts were made in the 1980s to solve the problem through the development of appropriate technology that would reduce bycatch in fishing operations.

Against this background, the US National Marine Fisheries Service (NMFS), in collaboration with others, developed the Turtle Excluder Device (TED) (Seidel and McVea, 1982; Watson, Mitchell and Shah, 1986). In 1983, NMFS started a formal programme urging voluntary introduction of TEDs. However, in spite of this programme, in 1986 the number of shrimp trawlers that had introduced the TED was less than 3 percent of the total (Clark *et al.*, 1991). In 1987 the US Government required, under the Federal Register, fishing vessels of 25 feet length and over to install the TED, while vessels less than 25 feet length were restricted their towing time to only 90 minutes. Such regulations were applied to shrimp trawlers by season or by period, in some fishing grounds all year round, and consequently all the coastal fishing vessels were put under the regulations of either using the TED or limiting towing time to less than 90 minutes (Federal Register, 1987a; 1987b). In 1994 this regulation was applied all year round to shrimp trawl fisheries conducted in all areas, and also to the bottom trawl fishery operated as far north as Cape Charles in the winter season (Federal Register, 1992a, b, c).

The selective fishing gear, designed to separate fish in bottom or shrimp trawls, was developed mainly in the western countries since the 1960s. On the other hand, although the TED was designed to exclude mainly sea turtles, it had been originally developed for making towing effective and hence called “trawling efficiency device”. Actually, NMFS, which first developed the TED, had been originally working on the development of fishing gear designed to efficiently protect juvenile fish. The TED was developed on the hint of Nordmøre grid and is featured as a basic structure consisting of a ridged grid or "separator" with a large mesh net and the escape opening for sea turtles and/or large fishes. Shrimps enter the cod end through the grid and the mesh of the separator, while sea turtles and large fishes are led to the escape opening by being blocked by the separator (Watson, Mitchell and Shah, 1986).

TEDs have a history of various improvements (Clark *et al*., 1991). Besides the Standard NMFS TED (30-inch opening and 25-inch opening), various types of TEDs with entirely different shapes, sizes, bar intervals and installation angles were developed and used. Examples are the Georgia TED with an elliptical grid, the Cameron TED with a circle entrance, and square-shaped Matagorda (Bay) TED. Both the NMFS type and Cameron type have substantial depth, and for installing them part of the nets has to be cut and separated, while the other two are plain surface type and can be installed directly to the existing nets. The opening was attached to the upper part of the net for the NMFS TED and the Matagorda TED, and to the lower part for the Georgia TED.

In order to effectively encourage the use of TEDs, there is a need to show that TEDs can provide benefits also to the fishermen themselves by decreasing losses of shrimp catches and alleviating their work in sorting out shrimp, in addition to excluding sea turtles. For this reason, in the early 1990s experiments to assess the combined use of TEDs and other bycatch reduction devices (BRDs) were actively conducted (Watson *et al*., 1993). Christian *et al*. (1993) summarized the results of the approaches to the issue of fish bycatch in shrimp trawling and emphasized the effectiveness of the “fish-eye” (opening part attached to the net for escape of fish) and the importance of the installing angles of TEDs. Rogers *et al.* (1997) tested the combined use of TEDs and the fish-eye devised by fishermen and used for half a century in Louisiana to avoid fish bycatch. They pointed out that vibration of TEDs was related to losses in shrimp catch. Watson *et al.* (1993) carried out diving observations and experiments to examine the proportion of bycatch reduction to shrimp harvesting with the use of a pilot BRD, and 30 different combinations were tested in real fishing grounds. The most efficient among those combinations (achieving 50 percent reduction in bycatch of fish while harvesting 90 percent or more of shrimps) were those with a large mesh funnel net, extended funnel net and fish-eye type. Those with extended funnel net, large mesh funnel net and of HSB type showed the best proportion of shrimp harvest, while those attached with fish-eye proved most effective in reducing bycatch of fish.

Furthermore, during two shrimp fishing seasons (spring and autumn) in 1993, trawling experiments aimed at assessing BRD were carried out in three areas along the coast of Louisiana. As a result of using two devices designed by contracted agents (Authement-Ledet 2 and CJ Kiffe) and two NMFS-type designs (Extend Funnel, Skirted Extended Funnel), those using extended funnel nets, with some modifications, showed the best combination of reducing fish bycatch and shrimp loss (Mitchell *et al.*, 1995). Results of these experiments and research have been collated as a guide to more appropriate use of TEDs (Mitchell *et al.*, 1995). Subsequently, improvement and assessment experiments of TEDs were continued, and Rogers *et al.* (1997) tested two BRDs, one with a fish-eye in the back of the TED (upper part of cod end, bottom of extension, and side of the extension) and the other with an extended funnel. The former was easier to be attached but showed 3–7 percent losses of shrimps, while the latter with an extended funnel had a rather complex structure but showed no losses of shrimp catches. The Andrews 5-inch TED showed an effect of reducing bycatch of juvenile red snappers by over 70 percent while limiting the losses of shrimp catches.

In this way, the technological improvement of TEDs advanced as they were introduced to other countries in the world. However, it has recently been noted that the size of the opening of TEDs is too small for loggerhead turtles and green turtles to escape (both species are granted special protection) and thus enlargement of the opening has been proposed (Epperly and Teas, 2002). As a result, the US Government changed the size of the openings provided for offshore areas to 71 x 26 inches from 35 x 12 inches in the Atlantic and 32 x 10 inches in the Gulf of Mexico.

Soft-type TEDs

Soft-type TEDs consist of nets of different size, without metal frames and are used mainly for exclusion of jellyfish. One of the soft-type TEDs is the Morison Soft TED, which consists of exclusion nets with 203 mm mesh size attached inside the shrimp trawling net and an escape opening for large living species like sea turtles. In this device, jellyball jellyfish (*Stomolophus melagris*) and horseshoe crabs (*Limulus polyphemus*), as well as large living species like rays, sharks and sea turtles were excluded from the nets while, shrimps enter into cod end, passing through the net mesh (Kendall, 1990).

Development and improvement of SOFT-TED in Australia

The type of TEDs developed in the United States could not be directly introduced to the Australian shrimp fisheries. This was due to the fact that the size of NMFS-TED was too large for Australian trawl fishing gears and the fishing methods different (in the United States only the end tip of the net, including cod end, is retrieved on deck, while in Australia the entire net is retrieved onboard). In Australia, special consideration was given to the safety of the crew and to losses of shrimp catch. Consequently, with the aim of spreading soft-type TEDs, diverse experiments were carried out in Australia to verify the efficiency of soft-TEDs in reducing losses of shrimp harvest and reducing fish bycatch (Kendall, 1990; Kennelly *et al*., 1992; Andrew, Kennelly and Broadhurst, 1993; Robins-Troeger, 1994). Furthermore, a composite TED (AusTED) was developed with the aim of securing safety in fishing operations and improving bycatch exclusion functions (Mounsey, Baulch and Buckworth, 1995; Robins-Troeger, Buckworth and Dredge, 1995). AusTED consists of (i) flexible grid; (ii) net opening hoops; (iii) large mesh panels; (iv) escape gap cover; (v) accelerator funnel; (vi) grid support floats, and (vii) escape gap.

Flexible and soft grids were introduced to the AusTED, while retaining the characteristics of the conventional TED. Aus-TED was tested at the following five sites: shallow, estuarine, mud-bottom sites to deep-water, oceanic, and sand-bottom sites. No significant difference was observed in the shrimp catch rate between the control net and the nets equipped with AusTED, while sea turtles and short-tail stingray were excluded from the nets equipped with AusTED.

Brewer *et al*. (1998) assessed 16 types of BRDs developed for use in the northern Australian Shrimp Fisheries (NPF), in three experimental cruises in the Gulf of Carpentaria.

All four types with declination-type grids (Super Shooter, Nordmore grid, AusTED and NAFTED) proved very effective in excluding large sharks and rays as well as sea turtles. These were also effective in excluding some catch of unwanted small fish, when used in combination with other BRDs, especially with fish-eye and square-mesh windows. The rate of such fish exclusion was 0–39 percent. On the other hand, the escape rate of fish with the super shooter was only 2–12 percent in the scientific survey using research vessels and about only 4 percent in experimental operations using fishing vessels, respectively.

With the aim of further improving the bycatch-reduction features of the AusTED and of diffusing it among fishermen in Australia, AusTED II was developed through experiments and research by the Australian Fisheries Research and Development Corporation (FRDC Project 2000/170) and the Queensland Department of Primary Industries (McGilvray, Mounsey and MacCartie, 1999; Robins and McGilvray, 1999). The structure of the original AusTED was simplified (reducing the number of components), and the cover of the opening, the large mesh panel and net opening hoops were removed. Furthermore, square windows were installed at the back (front) of the grid. The accelerator funnel was changed into a guiding flap equipped with chains around it.

Diffusion of TEDs to other countries

A workshop was held in Mexico in 1986 that resulted in promoting the spread of TEDs to other countries. In Indonesia, more than 1 000 TEDs were employed in the fishing operations conducted by joint ventures with Japan in the western area, and fishing gear specialists were sent to NMFS for training (Watson, Mitchell and Shah, 1986).

In order to cope with the US regulation on shrimp imports, TEDs were also introduced to Southeast Asian countries including Thailand, Malaysia, and the Philippines, mainly by the initiatives of the Southeast Asian Fisheries Development Center (SEAFDEC). Bundit *et al.* (1997) tested two types of TEDs (Thai-Ku and Thai Turtle Free Device, TTFD) that had been jointly developed by Thailand and SEAFDEC, in addition to three types of US-developed TEDs (Anthony Weedless, super shooter, and Bent pipe) and two types of Mexican-developed TEDs (Georgia Jumper, Mexican). It resulted that TTFD was the best in terms of both sea turtle exclusion rate and positive effects on shrimp harvest. Similar experiments and training programmes aimed at promoting diffusion of TEDs among fishermen were carried out in Malaysia, the Philippines, Indonesia, and Brunei, and the effectiveness of TTFD was widely recognized. However, fishermen did not venture to use TEDs because: (i) little or no bycatch of sea turtles occur in ordinary shrimp trawling operations in the region; (ii) there is a danger in handling fishing gear due to the additional heavy-weight device, and (iii) large quantities of marine debris entering into the net block the grid mesh and thus lower the shrimp catch rate. Actually, no sea turtles entered into the nets during the experiments. For this reason, along with the efforts to diffuse TEDs, those countries are now carrying out, jointly with the Kyoto University of Japan (SEASTAR 2000 project), follow-up studies on sea turtle behaviour in order to study the differences between distribution/migration areas of sea turtles and shrimp trawling grounds in the region. Matsuoka and Kan (1991) carried out a series of experiments near Yule Island in Papua New Guinea, using experimental shrimp trawling nets attached with a TED designed to have a passive function, using an inner funnel for harvesting only shrimp and excluding finfish as well as side windows to exclude finfish bycatch. They reported that, with the attachment of this type of TED, 75.8 percent of javalinfish was excluded with no reduction of shrimp catches.

In the early 1980s, India conducted experiments for assessing the effectiveness of TEDs at Orissa beach (Silas, Rajagopalan and Bastian Fernando, 1983; Silas *et al.*, 1983). In the mid-1990s activities were expanded to include development and diffusion of TEDs, which lead to the development of the CIFT-TED by the Central Institute of Fisheries Technology (CIFT) (Dawson and Boopendranath, 2003). About 500 sets of CIFT-TED were distributed for free to fishermen in the surrounding areas (Sankar and Raju, 2003).

In addition, activities to encourage the use of TEDs have been promoted in Mexico, Belize, Guatemala, Honduras, El Salvador, Nicaragua, Costa Rica and Panama in Latin America, as well as Kenya, Nigeria and other countries in Africa. However, sufficient and detailed data and information are not available as yet on the actual use, diffusion and types of TEDs.

Meanwhile, for further improvement and refinement of TEDs, the survival of sea turtles that escape should be examined and clarified. Although some indirect estimates are available based on stranded turtles during the shrimp trawling season (Crowder *et al.*, 1994; Caillouet *et al., 19*96), more detailed studies are necessary as basis for future improvements.

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Reducing turtle mortality in shrimp-trawl fisheries in Australia, Kuwait and Iran

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Abstract

The work achieved to date to prevent the capture of turtles in Australia's Northern Prawn Fishery, the Iranian Shrimp-trawl Fishery and the Kuwait Shrimp-trawl Fishery is described. Attention is given to the design and operational performance of TEDs used in these studies and the steps taken to extend the results to fishermen. A framework for the development and introduction of these devices into a shrimp fishery is also discussed.

INTRODUCTION

In recent years there has been increased global concern over the impacts of fishing activity on turtle populations, in particular, shrimp-trawl fisheries in tropical waters have come under increased scrutiny due to the capture and drowning of turtles caught in trawl nets. In many countries this scrutiny has resulted in the introduction of stringent legislation requiring the implementation of measures to prevent turtle capture. These measures may include temporal or spatial closure of fishing grounds, particularly where the risk of turtle interaction is high, such as adjacent to turtles nesting sites, although the most commonly favoured option seems to be the development of gear modifications known as turtle excluder devices.

The development of turtle excluder devices (TEDs) probably originated in the United States in the 1980s following concerns over the impact of shrimp trawling on turtle populations in the Gulf of Mexico and southwestern Atlantic shrimp fisheries. News of these developments spread quickly to other countries, particularly where turtle populations were also thought to be threatened by similar fishing activity. In Australia this work commenced in the early 1990s, following the listing of all six species of turtles recorded in shrimp-trawl catches as either threatened or endangered in the Endangered Species Protection Act 1992. This led to major efforts in all of Australia's tropical shrimp-trawl fisheries to develop suitable TED designs, and currently all require, or are in the process of requiring, the mandatory use of these devices in all trawl nets. In Australia's Northern Prawn Fishery (NPF) for example, TED-related research has resulted in almost total elimination of turtle catches, with nearly 100 percent of turtles that enter a trawl being excluded by these devices. Other countries with tropical shrimp-trawl fisheries, such as those in Southeast Asia, the Persian Gulf and the Caribbean, have also been addressing the issue of turtle capture. Some of these countries have made substantial progress towards developing and testing suitable devices, and a few have made their use mandatory. However, in many cases progress towards the adoption of these devices has been slow and some of these countries have been impacted by a United States embargo on shrimp imports from fisheries where approved TED designs are not being used. Reasons for the lack of progress include the absence of incentives for fishermen to use and adopt TEDs, inadequate extension programmes, poor collaboration between fishermen, scientists, managers and government officials, inadequate management or poor enforcement of fishery regulations.

This paper presents experiences in reducing sea turtle mortality in shrimp fisheries fisheries in Australia, Kwait and Iran.

Australia – The Northern Prawn Fishery

In the early 1990s fishermen in the Northern Prawn Fishery (NPF) were under considerable pressure to reduce the capture of turtles and other bycatch from trawl operations. During this time the estimated annual mortality of turtles caught in this fishery ranged between 500 and 1 000 individuals (Poiner and Harris, 1996). Records indicated the capture of six turtle species and all were listed as either endangered or vulnerable under Australia’s Endangered Species Protection Act 1992. Under the Act shrimp trawling was listed as a “key threatening process” to turtles, this essentially meaning that trawling could be prohibited if a suitable threat abatement plan to mitigate their capture was not introduced into the fishery. During this period additional pressure on NPF fishermen included the mandatory requirement by the year 2000 for all nets to be fitted with an approved TED (plus a bycatch reduction device (BRD) to reduce the capture of small fish bycatch), and the introduction of the shrimp embargo by the United States on fisheries not using approved turtle excluder devices. Despite the majority of exports from the NPF being destined for Asian markets the desire to maintain access to the US market was strong.

The Northern Prawn Fishery is Australia's largest and most valuable shrimp fishery, landing approximately 10 000 tonnes of shrimp per year valued at an estimated A$150 million. The fishery covers a large geographical area of some one million square kilometres extending across much of the northern coastline from Queensland to Western Australia. The main target species are *Penaeus semisulcatus*, *P. esculentus*, *Fenneropenaeus merguiensis*, and *F. indicus*. The fishery presently supports 95 boats with an average length around 24 m. Each boat is permitted to tow two trawls measuring between 11 and 29 m (headline length) each. The mesh size in the main part of the trawl is typically around 63 mm and the codend mesh around 50 mm. The fishery has two fishing seasons; during the first season fishing can occur during the night and day while only night operations are permitted in the second season. Fishing depth is typically less than 40 m.

Attempts to introduce both TEDs and BRDs into this fishery have been extensive and overall very successful. These attempts began in 1995 when 16 TED and BRD combinations were tested in the fishery using a 65-m research vessel. This was followed by testing the best performing devices onboard a 24-m shrimp trawler. The TEDs tested included a Super Shooter TED (Figure 1), a Nordmore grid (Figure 2) and the AusTED. The Super Shooter was originally developed for the Gulf of Mexico and southwestern Atlantic shrimp fisheries. The grid has an oval shape and is constructed from aluminium rod or pipe. The bars of the grid are bent near the escape opening to facilitate the removal of weed that may foul the bars and prevent the entry of shrimp into the codend. In this study bar spacing was 100 mm. A guiding panel ahead of the grid was used to guide animals towards the top of the codend. Large animals are then guided by the bars towards the escape opening in the bottom of the codend. These animals then push aside a netting escape panel (cover) located over the escape opening and are excluded from the trawl net. Small animals exit the guiding panel, pass through the bars and into the codend. The escape cover sits tightly against the escape opening and prevents the escape of small animals. The Nordmore grid used in this study was a hybrid of a larger grid of the same name that originated from Norway. This grid is rectangular in shape and is designed to exclude large animals through an escape opening located on top of the codend. It was also constructed from aluminium but the bars were not bent near the escape opening. Bar spacing was 100 mm. A guiding funnel ahead of the grid guides animals away from the escape opening towards the bottom of the codend. An escape cover was not fitted over the escape opening. The AusTED was a unique design with the grid being constructed from steel wire rope encased in plastic. In this way the grid was flexible thus avoiding claims by fishermen that TEDs were a safety hazard to crew when hauled aloft. Bar spacing was also 100 mm and an escape cover was not fitted. Detailed construction details of these devices are provided in Eayrs and Prado (1998).

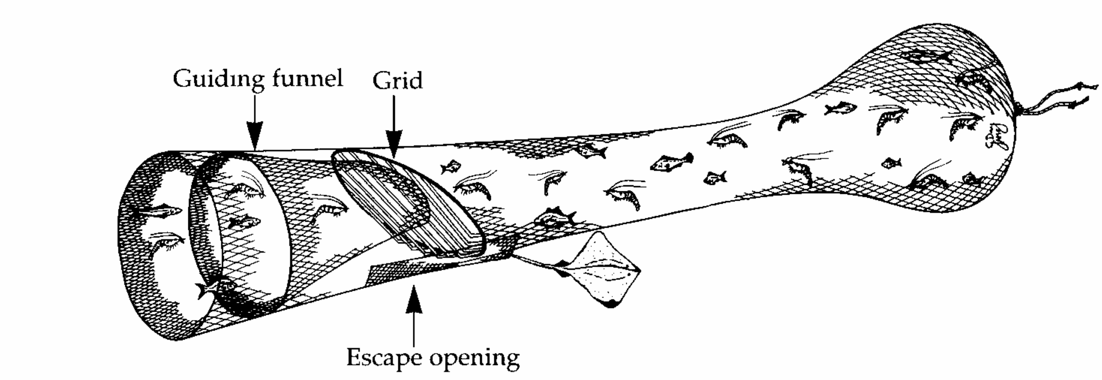


Figure 1 The Super Shooter TED has an inclined oval grid to exclude animals through an escape opening in the bottom of the codend. The guiding funnel guides shrimp away from the escape opening.

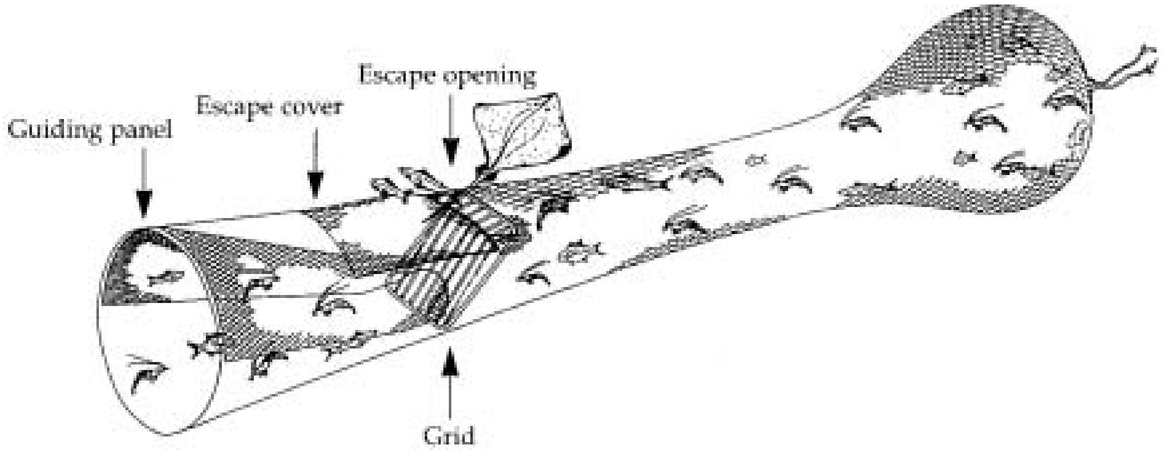


Figure 2 The Nordmore grid is a rectangular TED designed to exclude animals through an escape opening in the top of the codend.

All three TEDs tested in this study performed well and excluded large animals such as turtles, sharks and stingrays (Table 1). Shrimp loss was a problem with some devices, particularly when a BRD was added to the codend to reduce catches of small fish bycatch. In many instances this loss was due to inexperience and incorrect location of the BRD. A detailed description of the catch results from all devices are reported in Brewer *et al.*, 1998. The Super Shooter was deemed the best performing TED in this study and was subsequently selected for further testing onboard a commercial shrimp trawler under normal operating conditions (Table 2). There were several reasons for conducting the initial tests onboard a research vessel, including greater control over the testing environment and difficulties gaining voluntary involvement from fishermen. This difficulty was mainly linked to fears that the TED would cause massive shrimp loss and pose a safety hazard to the crew during onboard handling of the net.

Table 1. Summary results of TED performance during two research cruises. Catches are compared to a standard trawl. Tow duration in the initial cruise was 30 minutes and in the second cruise it was 120 minutes

TED	**No. tows**	**No. turtles**	**No. sharks & stingrays (>5kg)**	**Small fish excluded (% wt.)**	**Wt. shrimp caught (%)**
30 minute tows					
Super shooter	19	1#	1	0	90
Nordmore grid	17	0	0	4	88
Standard trawl	20	2	1		
120 minute tows					
Super shooter + fisheye	36	0	3	15	94
Nordmore + fisheye	37	0	2	30	85
Nordmore + sq.mesh window	37	0	2	35	73
AusTED	15	0	3	27	75
Standard trawl	39	7	24		

turtle caught ahead of grid and released alive

Table 2. Summary results of TED performance onboard a commercial shrimp trawler under normal operating conditions. Catches are compared to a standard trawl. Fish bycatch was not recorded due to constraints on operating practices. No. of tows in brackets

	Super shooter	**Standard**	**Super shooter + sq. mesh window**	**Standard**
Turtles (nos.)	0 (13)	0 (13)	0 (24)	0 (24)
Sharks (nos.)	6 (13)	16 (13)	3 (24)	12 (24)
Stingrays (nos.)	0 (13)	15 (13)	0 (24)	2 (24)
Shrimp (kg)	289 (8)	280 (8)	855 (23)	945 (23)

The completion of the initial study was followed by a major three-year extension programme to help prepare fishermen for the mandatory introduction of these devices in 2000. This programme included the following:

- practical workshops and fishing-gear displays at major fishing ports;

- production of bi-annual newsletters to provide performance results and information updates;
- production of videos including underwater footage of TEDs and BRDs in operation;
- awarding two tied travel grants valued at A$10 000 to fishermen identified by their peers as having made a major contribution towards TED and BRD development;
- providing a range of TEDs and BRDs free of charge to fishermen wishing to test a device onboard their boat;
- the production of a practical guidebook to bycatch reduction, and
- a fishing technologist "boat-hopping" between the fleet over a three-year period.

The practical guidebook was written to provide fishermen and other stakeholders with a guide to the type, design, use and operation of these devices. It also included technical details for their construction and maintenance. The guidebook was small in size, wire-bound and printed on water resistant paper so that it could be safely used on the deck of a trawler. The task of the fishing technologist was to demonstrate the performance of TEDs and BRDs. Armed with a range of devices the technologist would board a boat and initially describe their design and operation. If the skipper was amenable to the idea, one of the devices would be fitted to a trawl to assess operating and catching performance. Depending on the willingness and enthusiasm of the skipper (which was often linked to the ability of the device to retain shrimp as opposed to excluding bycatch) the device would be tested over several days. Catch data was recorded and preliminary assessment of the devices possible (lack of control over the fishing environment precluded more scientific assessment). The detailed assessment of a TED was not the main priority of this study; the priority being to provide the fisherman an opportunity to test a device onboard his own boat and thus gain confidence in its use and operation. A detailed description of this extension programme and associated results are reported in Robins *et al.*, 2000.

As the date for the mandatory introduction of these devices neared, it became necessary to provide training for netmakers in the design, construction and specification of these devices. In addition compliance officers needed to be trained so they could identify approved designs and measure them against approved specifications. These specifications were also promulgated to the fishermen, both formally via official documents provided by the Australian Fisheries Management Authority (AFMA) and informally via a brochure using simple language and diagrams. The specifications were not only designed to reduce bycatch, but to provide fishermen with an opportunity to be innovative and develop new, more effective designs. For example, the specifications for a TED only prescribe limits on bar spacing, the attachment of the grid to the codend, the minimum size of the escape opening and the rigidity of material used to construct the grid. There are no specifications for the use of a guiding panel or funnel ahead or behind the grid, the placement of floats nor the size of the grid. Incorrect use of these modifications will result in excessive shrimp loss and they have little or no impact on turtle escape. The use of these modifications is therefore self-regulating yet simultaneously allows fishermen some opportunity to be innovative and optimize the performance of their devices.

As a result of these efforts the introduction and use of both TEDs and BRDs into this fishery has been very successful. Recent assessment from an observer programme, in which five observers on 24 boats recorded catches from over 1 600 trawl shots, indicated that turtle exclusion rates are 99 percent, with the rare capture of a turtle as the net is hauled (Table 3). Random at-sea inspection by compliance officers have found compliance rates nearing 100 percent and fishermen are well aware of the financial implications of poorly operated and maintained TEDs. The successful adoption of these devices by NPF fishermen and their demonstrable commitment towards reducing the threat of trawling on turtle populations, resulted in the lifting of the US embargo soon after TEDs became mandatory in this fishery. The introduction of TEDs has also had wider ecological benefits, including exclusion rates of large animals such as sharks and stingrays nearing 100 percent and to a lesser degree some large fish species. Damage rates to shrimp by these large animals has also dropped markedly, hence overall catch value has improved. This value was estimated at A$750 per week to each boat by one study, but this is dependant upon catch volume, trawl duration, size and type of large animal caught.

Table 3. Summary results from observer programme in Northern Prawn Fishery in 2002 comparing the performance of a net with a TED fitted against a net without a TED. Shark and stingray data include individuals of all lengths. No. of tows = 1 612

Animal group	Difference (%)	Animal group	Difference (%)
Turtles	-99	Damaged prawns	> -41
Sharks	-21	Sea snakes	No difference
Stingrays	-39	Sawfish	No difference
Large sponges	-91	Fish bycatch (small)	> -8

Kuwait shrimp-trawl fishery

Attempts to reduce catches of turtles in the Kuwait shrimp-trawl fishery commenced in earnest in 2003 when the Australian Maritime College and the Kuwait Institute for Scientific Research (KISR) began a one-year collaborative bycatch reduction programme that included practical training workshops and at-sea tests of several TED and BRD designs.

The at-sea tests occurred on the commercial fishing grounds adjacent Kuwait Bay. This fishery extends along much of the Kuwait coast and is typical of many tropical shrimp fisheries worldwide, being characterized by a wide variety of bycatch species and variable but often high bycatch to shrimp ratios. Bycatch to shrimp ratios up to 15:1 (by weight) have been recorded in this fishery (Ye, Alsaffar and Mohammed, 2000). The main bycatch species in this fishery are juvenile fish or species of low commercial value. Catches of turtles do not appear to have been documented, but the US embargo is in place and has affected shrimp exports.

The Kuwait shrimp-trawl fishery occurs along much of the Kuwaiti coastline in depths to about 40 m. The main shrimp species caught are *Penaeus semisulcatus, Metapenaeus affinis* and *Parapenaeopsis stylifera.* The fishery supports two types of fishing vessels: large steel trawlers measuring around 25 m and smaller timber or fibreglass dhows. The fishing gear used by the steel trawlers usually comprises of two flat, semi-balloon or balloon shrimp trawls measuring around 27 m (headline length) towed simultaneously in a double rig configuration. The mesh size in the main part of the trawl (body) is typically 51 mm and codend mesh size is typically 45 mm. The smaller vessels usually tow a single net of similar design. The headline length of these nets are usually around 32 m and mesh size in the main part of the trawl (body) is typically 45 mm. Codend mesh size is typically 38 mm. Fishing occurs both at night-time and day-time, although until recently regional conflict necessitated a ban on night trawling.

The collaborative programme included pre-sea training workshops and three five-day periods at sea testing the performance of one TED and several BRDs. During the workshops

KISR staff had the opportunity to assist in construction of fishing gear in preparation of the at-sea tests, and in this way gain knowledge of the design, rigging and operation of these devices. This was then complemented by participation in the at-sea tests. These tests occurred on both steel trawlers and the smaller dhows. The specific location of the tests was selected by the skipper of the vessel as per normal commercial practice. The catching performance of these devices was compared against a standard trawl.

The TED used in these tests was constructed by Popeye Netmaking (Cairns, Australia) and is known in the local industry as the Popeye TED. To suit the larger trawl nets used in the fishery the overall size of the TED was increased to match the circumference of the codend, otherwise, no other changes were made to this TED. The grid used in the construction of the TED was oval in shape, measuring 1.8 m high and approximately 4.8 m in circumference, and was designed with a bar spacing of 120 mm. The entire grid was constructed from stainless steel bars to provide adequate strength.

The performance of the TED and other devices tested in this study have not been assessed in detail as the final at-sea tests were only recently completed. However, the overall performance of the TED was satisfactory; no turtles were caught in the net fitted with this device and shrimp catches were little different to the standard net (Table 4). The standard net did catch one turtle (during the second trip) however after a period of recovery onboard the boat it was released alive into the water. The TED did not pose a safety hazard to the crew and they very quickly developed the skill to safely and correctly handle this device.

Table 4. Summary results of TED performance onboard commercial shrimp trawler in the Kuwait shrimp-trawl fishery. Catches are basket numbers and are compared to a standard trawl. No. of tows in brackets

	Trip one (8)		**Trip two (8)**	
	Popeye TED	**Standard**	**Popeye TED**	**Standard**
Turtles (nos.)	0	0	0	0
Fish	360	544	465	538
Shrimp	47	53	56	55

At this stage little additional progress has been made towards the removal of the US embargo.

Iranian shrimp-trawl fishery

In October 1997, the Food and Agriculture Organization of the United Nations (FAO), the Ministry of Jehad - E-Sazandegi, Fisheries Company of Iran (Shilat) and the AMC conducted a bycatch reduction workshop in Bandar-Abbas, Iran. The objectives of this workshop were to test a TED (the NAFTED) and several bycatch reduction devices, and demonstrate to fishery officers from the Gulf region the installation, operation and performance of these devices under commercial fishing conditions.

The at-sea tests occurred on commercial fishing grounds that are part of the Iranian shrimp-trawl fishery. This fishery extends along much of the Iranian coast and is typical of many tropical shrimp fisheries worldwide with regard to the variety of bycatch species caught and variable but often high bycatch to shrimp ratios. The main species caught in this fishery are

Penaeus merguiensis, *P. semisulcatus*, *Metapenaeus affinis* and *Parapenaeopsis stylifera.* There was little information available regarding the impact of shrimp-trawling on turtle populations and despite the export of some shrimp from this fishery there was little concern for the US embargo. The main bycatch species in this fishery was juvenile fish and fishing activity occurred mainly in daylight hours.

The fishery supports three types of fishing vessels: small fibreglass trawlers measuring about 7 m in length dominate the fishery and number approximately 1 500. The largest vessels are constructed from steel and measure between 20 and 25 m and they total 39 in number. Approximately 850 timber dhows also operate in this fishery averaging around 16 m in length. The fishing gear used by the steel trawlers usually comprises of two flat, semi-balloon or balloon shrimp trawls measuring 29.3 m (headline length) towed simultaneously in a double rig configuration. The smaller vessels usually tow a single net of similar design. The mesh size in the main part of the trawl (body) measured 40 mm while codend mesh size measured 30 mm.

The NAFTED was initially designed by the Australian Maritime College (AMC) to exclude large animals such as turtles, sharks and stingrays from trawl operations in the NPF. This device was similar to the Nordmore grid tested in Australia but with bent bars near an escape opening located at the top of the codend. The grid was constructed from aluminium and grid angle was 45 degrees. This device is typically designed with a bar spacing of 100 mm, however, in this instance a bar spacing of 60 mm was used to improve exclusion rates of smaller animals. A panel of netting located ahead of the grid was used to guide all animals to the bottom of the codend. Large animals are then guided by the grid towards an escape opening on top of the codend while smaller animals pass through the bars and into the codend. No escape cover was fitted to the TED because it was feared this would reduce fish exclusion rates.

Due to the structure of the testing programme, catches from a trawl fitted with the NAFTED was compared against a trawl with a square-mesh window BRD. The NAFTED reduced bycatch by 34 percent and maintained shrimp catches (Table 5). The reduction in commercial fish was 50 percent and it is likely these fish were excluded through the large escape opening. The catch of large stingrays was reduced by 95 percent.

Table 5. Catch comparison (number of full baskets) between a net fitted with a NAFTED and a net with a square-mesh window and fish cone stimulator attached. No. of tows = 3. The numbers in brackets indicate the number of large stingrays caught in each net

	Shrimp	**Commercial fish**	**Bycatch**
NAFTED	15.0	0.75	3.4 (4)[2]
SMW + Cone	15.25	1.5	5.25(85)[2]

The workshop participants and crew were most impressed with the performance of the NAFTED, particularly as the hazardous operation of removing stingrays from the catch was virtually eliminated and sorting times were substantially reduced. The loss of commercial fish was of some concern but this was offset by the benefits of stingray exclusion. The NAFTED posed no handling problems for the crew although it did require correct deployment from the trawler. This simply entailed making sure the codend was not twisted and the grid was sitting upright in the water prior to shooting the gear away. At no stage did the large aluminium grid pose a safety hazard to the crew.

Lesson learnt

The development and testing of TEDs in these shrimp-trawl fisheries has provided some valuable lessons useful for consideration to those about to embark on similar work.

Extension and enforcement

The successful introduction of TEDs into the Northern Prawn Fishery is in part due to the willingness of fishermen to adopt new technology. Although in most instances they initially regarded these devices with suspicion, the initiatives used to extend the results of the testing programmes on both research and commercial boats played a major role in this success. In particular the use of underwater cameras to film TEDs and associated shrimp and fish behaviour was tremendously successful. In many instances fishermen had never observed their fishing gear in operation, and the attraction of observing this video was strong and useful for stimulating new ideas and demonstrating the importance of correct rigging and operation. Gear workshops at the fishing ports were also very successful and provided fishermen an opportunity to ask questions about the design and operation of these devices. The provision of literature for fishermen to take to sea was useful because it allowed them to learn about recent developments at their leisure. This approach provided fishermen the opportunity to test and learn about TEDs before their mandatory introduction, thus giving them time to become suitably prepared, although a few fishermen made no such attempts and paid the price accordingly.

It is unclear how effective this extension work would have been in an environment whereby checking of gear by compliance officers was inadequate. In the NPF up to 80 percent of the fleet is boarded in any one year and the penalties for infringements can be severe. This serves as a suitable inducement to comply with the specifications. However, it is probable that the fear of shrimp loss and associated income in an export-orientated fishery served as an even greater inducement to comply with the specifications and optimize TED performance.

Selecting the correct TED

Probably the most important aspect to TED selection is the decision to orientate the grid either upwards to exclude large animals through the top of the codend or downwards to exclude these animals through the bottom of the codend. While grids orientated in either direction seem equally effective in excluding turtles, orientation plays a major role in the ability of the TED to exclude rocks, sponges or heavy debris from the trawl. In locations where these items are present a bottom excluding TED is required so that they can roll towards the escape opening and be excluded. In locations where the seabed is largely devoid of these items, an upward excluding TED can be used.

The overall size of the grid is arguably the next most important aspect of TED selection because it influences the ability of the escape cover to sit tightly over the escape opening. The size of the grid should be sufficiently large to slightly distort and increase the circumference of the codend. This in turn prevents shrimp loss by allowing the trailing edge of the escape cover to make good contact with codend netting adjacent the escape opening.

Grid angle also influences the ability of the TED to exclude turtles and other large animals. Typically a grid angle of 45–55 degrees is required for both upward and downward orientated grids to rapidly exclude turtles and other large animals from the trawl. Such angles also reduce the likelihood of shrimp loss. If grid angle is excessive, irrespective of grid orientation, the rapid exclusion of turtles is delayed, thus increasing their potential to be drowned. Excessive or high grid angle may also result in blockage by rocks, sponges etc., and hamper the rapid passage of shrimp into the codend. They may also partially push the escape opening aside and cause massive shrimp loss. If grid angle is inadequate the escape cover may not sit tightly over the escape opening and shrimp loss is likely. The shape of the escape opening may also become distorted. Low grid angles do not seem to have a negative impact on the exclusion of turtles from the trawl.

The distance between the bars of the grid is important because it influences exclusion rates of small or juvenile turtles and the passage of shrimp into the codend. In the United States and Australian fisheries bar spacing is typically 100–120 mm. Greater distances between bars is thought to increase the potential for the head or flippers of large turtles to become fouled in the grid. Lesser distances will have little effect on turtle exclusion and may increase escape rates of fish and other animals. Increased shrimp loss may also result from smaller bar spaces.

Other factors to consider when selecting a TED is the use of guiding panels or funnels of netting ahead of the grid. These are usually constructed from netting material and are designed to guide shrimp away from the escape opening. In Australia some shrimp fishermen have decided to do away with these funnels with seemingly little impact on shrimp catches. Another factor is the use of a netting (escape) cover over the escape opening. These are always used in bottom excluding grids to prevent shrimp near the bottom of the codend from escaping. With a top excluding grid they do not seem to be as important – studies in Australia and Iran indicated that the NAFTED lost few shrimp – but many fishermen do not like to operate a trawl with the escape opening exposed. Grids are typically constructed from aluminium or stainless steel rod or tubing, the latter material often being preferred in large grids for additional strength. Several floats are usually always attached to the TED irrespective of grid orientation. Floats serve to provide buoyancy and stability, particularly to large, heavy grids. They can also be useful when the gear is at the sea surface to indicate the orientation of the grid prior to deployment.

Over-tuning of TEDs

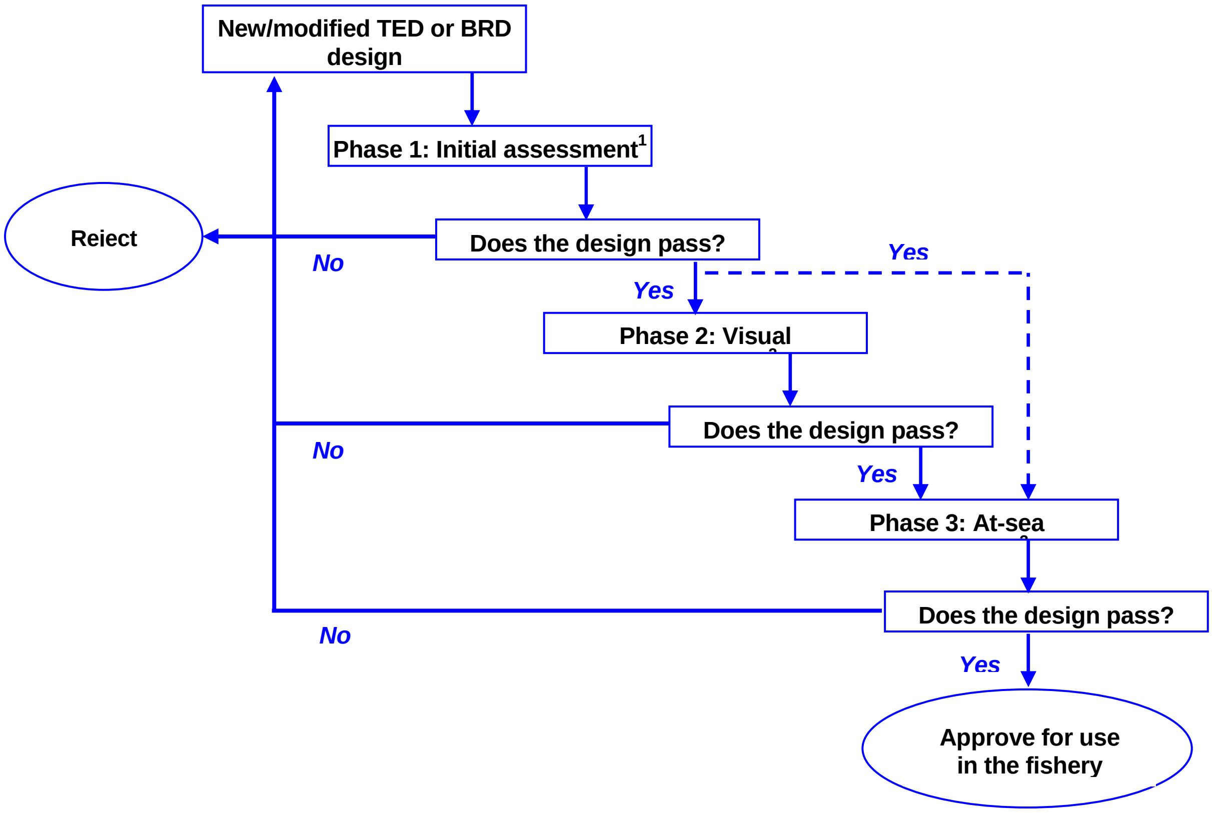
Over-tuning of TEDs is a term coined to describe excessive or inappropriate modifications to the TED to reduce shrimp loss. This loss typically arises from poor design, rigging or maintenance of a TED, or the poor selection of a TED for a particular fishing ground. Examples include incorrect grid angle or orientation, and the use of small grids in grounds with high sponge numbers. Many fishermen inexperienced in the use of TEDs are then tempted to modify their device to ameliorate the problem. The temptation is particularly high if two nets are towed simultaneously and the shrimp catch from one net is substantially smaller than that of the other – this being colloquially known in Australia as being "TED-ed" because the TED is blamed for the loss. It is very common for these fishermen to attempt to solve the problem by making the escape cover sit tighter over the escape opening. This can be achieved by the use of excessively long escape covers, heavy weights attached to the trailing edge of the cover (on a top opening TED), or the use of floats on the cover (of a bottom opening TED). However, in many instances the unfortunate outcome of these modifications is to increase the frequency of being TED-ed because large animals now struggle to push aside the escape opening. This in turn increases the period that the cover is not seated tightly over the opening thus providing shrimp a greater opportunity to escape. The answer to this problem often seems counter-intuitive; that is, to loosen the escape cover to increase the speed and ease with which turtles and other large animals can escape. A well-designed and tuned TED will rapidly exclude these animals from the trawl, thereby reducing blockage of the grid or escape opening. The escape cover will then be seated against the codend for longer periods and the opportunity for shrimp to escape will be minimized.

Testing protocol

Following the mandatory introduction of these devices in the NPF it became clear that a testing protocol was required that allowed innovative fishermen the opportunity to test and develop their own TEDs (and BRDs). A TED and BRD committee, with membership including a fisherman, a fishing technologist and the fishery manager, was established by AFMA to develop the protocol and monitor progress. This protocol was designed to provide fishermen with a quick and simple means of developing new devices and measuring their performance whilst providing sufficient rigour to demonstrate the achievement of bycatch reduction targets and satisfy the concerns of other stakeholders. Underpinning the design of the testing protocol was the desire to encourage and foster the development of innovative bycatch reduction devices and to provide flexible testing requirements that accommodate the difficulties of testing these devices onboard commercial fishing boats.

The TED and BRD testing protocol has three main assessment phases: an initial assessment phase, a visual assessment phase and an at-sea testing phase (Figure 3). The initial assessment phase involves the operator providing members of the TED and BRD committee for review and comment written details of the device to be tested, including technical details and specifications, and a description of how the device will reduce bycatch. Approval (or otherwise) of the device is usually made within 48 hours of receipt of the application. The criteria for initial approval of the device are based on the expected likelihood of reducing bycatch to a level at least commensurate with approved devices and the potential threat the device may pose to endangered or threatened species. The judgement of this device and ability to meet these criteria relies almost exclusively on the collective experience of the three committee members (although additional advice may occasionally be sought). The recommendation for the next phase of assessment may include a request for visual assessment of the device and/or at-sea testing.

The visual assessment phase involves one or more of the committee members either physically viewing the device or briefly (~1 day) testing it in a flume tank at the Australian Maritime College. The aim of this phase is to gain a better appreciation of the device, its operation and likelihood of achieving the claimed reduction in bycatch. This phase is only expected to be required when an entirely new or complex bycatch reduction device is developed or if the details submitted in the initial assessment phase are inadequate or inconclusive. In most instances a device will not require this assessment phase. The criteria for visual approval of the device is similar to that of the initial assessment phase, but with the possible additional expectation that the shape and orientation of the device in the flume tank is as claimed. The cost of transportation and flume tank testing is borne by AFMA.



1. Initial assessment of TED or BRD design, including rigging details, specifications and location in the codend.
2. Visual assessment of actual device fitted to a codend.
3. At-sea assessment initially by fisher, then by TED/BRD expert if required.

Figure 3: The TED and BRD testing protocol used by fishermen in Australia's Northern Prawn Fishery to develop and test their own devices.

The final assessment of the device involves at-sea testing onboard a commercial fishing boat. The fisherman is provided with a scientific permit from AFMA to test the device under normal commercial fishing conditions, but which may include specific requirements related to the location fished (e.g. region of relatively high bycatch density), data collection methodology and the period of assessment. In the case of a new TED being tested a permit is initially granted for four to six weeks. During this time the fisherman operates as per normal commercial practice but if two turtles are caught in the net with the new device the permit is revoked and the device fails the assessment. In this way an allowance is made for the exceptional or fluky capture of a turtle, such as when a turtle has had insufficient time to escape from a TED during haul-back (steps are currently being taken to reduce this figure to zero).

Following completion of the initial at-sea testing phase the fisherman is required to provide a report with shot by shot catch details. If a new or modified TED is being tested then details of turtle catches in the net fitted with this device is required. Following receipt of this report, the members of the committee may then decide to either approve the device or request further testing and assessment. In most instances where a TED is tested a trained observer is required to board the boat and independently assess the performance of the device. The observer may spend several weeks onboard the boat and if two turtles are caught during this time the device fails the assessment. While onboard the observer will collect relevant catch data and provide a detailed report analysing the performance of the device over the test period. Importantly, the costs of the assessment by an observer are borne by AFMA.

The members of the committee then review the observer's report and decide whether the device is acceptable for inclusion as an approved TED. The absence of turtle catch in the net fitted with the TED may simply reflect the absence of these animals in the area fished. The TED may therefore be given approval subject to further monitoring by the fisherman and/or by another observer at a later date if in the region. The approval of this device is then indicated to AFMA, other NPF fishermen and stakeholders.

TEDs in Iran and Kuwait

The TEDs tested in Iran and Kuwait originated in Australia and they successfully excluded large animals from the trawl with little shrimp loss. This suggests that TEDs originating from one country can be a suitable starting point for other countries about to embark on similar research. The testing framework applied to introduce these devices in each country has proven successful and can be confidently applied with little alteration to other fisheries (Figure 4). As fishermen become more adept at using these devices they can begin to modify or develop their own devices to better suit their fishing operation. In both Iran and Kuwait catch rates of shrimp are often highly variable due to their schooling behaviour, and this makes assessment of shrimp loss difficult unless an extensive testing programme is undertaken. In both countries fishermen were pleased with the exclusion of hazardous large animals and reduced catch sorting times. Increased leisure time is a good incentive for fishermen to adopt these devices, and there were indications that a small loss of shrimp was an acceptable price to pay. This was no doubt driven by the fact that the income of these fishermen was not totally derived from shrimp alone.

However, the at-sea testing of TEDs in these countries is only the first step in the process of successfully introducing these devices to the satisfaction of all stakeholders. Research organizations alone cannot follow the entire process to its logical conclusion, and government involvement is usually required to provide relevant funding for extension programmes, the training of fishermen, netmakers and compliance officers. It is unlikely that fishermen will fully develop, test and adopt these devices on a voluntary basis alone, particularly in a competitive environment where the testing of innovative fishing gear is fraught with risk of shrimp loss. The removal of the US embargo requires a detailed data-set of trawl and turtle interactions. Ideally this needs to be from both fishery dependent and independent sources to verify that fishermen are reducing turtle capture as claimed. Such efforts take substantial time and effort, and requires a major commitment by fishery managers and others. There also needs to be an extensive monitoring programme to confirm the uptake and effective compliance of these devices by fishermen. Such programmes are expensive and usually require funding and assistance from governments or other sources. Since the workshop in Iran, for example, there seems to have been little documented progress in TED development in the region. Anecdotal reports suggest that this is partly due to lack of political will, indifference by various stakeholders and insufficient resources to fund further research. Clearly these issues need to be addressed to effectively protect turtle populations.

Identify the bycatch problem
- capture of threatened or endangered animals
- discarding of bycatch/trash fish
- capture of juveniles

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Consider techniques to eliminate the problem
- review literature
- contact experts from similar fisheries
- seek ideas and related information from fishermen

↓

Construct devices for local fishery
- collect details of trawl design, handling and fishing operation
- coordinate activity with fishermen, netmakers
- use flume tank (if available)

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At-sea tests
- onboard research boat or commercial fishing boat (preferable)
- assess performance of device under normal operating conditions

↓

Extend results to fishermen and other stakeholders
- talks, videos, articles, papers and other media
- boat-hopping with devices for testing
- fishermen exchanging ideas, information
- specifications developed

↓

Mitigate the problem
- adoption of devices by fishermen
- reduced pressure by other stakeholders
- mandatory introduction of devices
- removal of US embargo

Figure 4: A framework for the development of an effective TED (or BRD) into a shrimp-trawl fishery (adapted from Kennelly, 1996)

Future research

The use and operation of TEDs in a shrimp-trawl fishery is only the first step towards protecting turtle populations. There is wide-spread consensus that contact with a TED and subsequent exclusion does little harm to these animals providing that the TED is well tuned and escape occurs quickly. However, it is not known if there are any long-term health repercussions associated with repeated exclusion of an individual over a short time period. This might occur in a fishery where several boats using TEDs are operating in close proximity to one another. It is also not known to what extent escape from a trawl can be delayed by a poorly designed or tuned TED without causing mortality. Further work is required to evaluate the effect of such incidents on turtle health.

TEDs have also demonstrated good capacity to exclude other animals from the trawl, including large sharks, stingrays and fish. In many instances the exclusion of these animals can also approach 100 percent. Moreover, in some instances these devices can be modified to exclude smaller animals using a narrower bar spacing, although the risks of shrimp loss are increased. The use of underwater cameras can be a valuable tool to observe the behaviour of animals as they approach a TED, and this information help identify other species suitable for exclusion from the trawl. Where the exclusion of these animals is a desirable outcome, further work is required to modify TEDs to optimize exclusion rates while maintaining catches of shrimp.

In many countries there is a need to identify the extent of turtle populations, including timing and location of migrations be they diel or otherwise. This information is useful because it can help predict times when turtles are most vulnerable to capture from shrimp trawling. The potential introduction of temporal or spatial closures can then be used as an additional (or alternative) technique to prevent turtle mortality in trawl nets. Those countries attempting to overcome the US embargo will also need to collect additional information, including demonstrable uptake and use of TEDs by fishermen, proven ability to exclude turtles and a demonstrable means of ensuring fishermen are abiding by the TED specifications and associated regulations.

CONCLUSION

Over the past few decades major strides have been made in many shrimp-trawl fisheries to prevent the capture and mortality of turtles. A well-designed and maintained TED can exclude almost 100 percent of turtles that enter the trawl, with individuals usually only being caught immediately prior to hauling of the gear. In such instances the turtle can be released safely with little ill-effect. Other large animals can also be excluded at similar rates, including sharks, stingrays, sponges and fish.

The at-sea testing of these devices is a step in the right direction, however, if not supported by a well-funded extension programme to provide fishermen with important design, operational and performance information then the effective uptake and adoption of these devices is hampered. Moreover, compliance rates are likely to be less than would otherwise be achieved with such a programme, thus increasing the threat of trawling to turtle populations. Every effort should be made to encourage the voluntary testing and use of these devices and addressing the needs and concerns of fishermen is an essential requirement towards the successful uptake of these devices. This work should also be coupled with a strong monitoring and compliance programme to ensure all fishermen are complying with TED specifications and related regulations.

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Management experiences in implementing sea turtle avoidance and mitigation measures in commercial fisheries

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Abstract

This paper describes some of the experiences of Governments and fisheries managers in implementing measures to reduce the impact of commercial fishing on sea turtles that may be incidentally caught or otherwise adversely affected by those fisheries. This paper primarily uses the experiences of the United States in implementing such programmes for certain fisheries, as well as those of some other countries, and is not intended to be an exhaustive description of all such actions everywhere. Rather, it uses selected cases to demonstrate experiences that may be common to various fisheries or important for future policy considerations.

BACKGROUND

The incidental catch of or interaction with sea turtles in fisheries has been a concern for decades. Given the life cycle of these animals, and in particular their frequent proximity to or co-location with various fisheries, sea turtles are particularly vulnerable to interactions with certain fishing methods such as coastal trawl and gillnet fishing and pelagic longline fishing. This factor, in combination with their status as threatened or endangered species under national laws or international regimes, presents fisheries managers with a serious policy problem: how to reduce or mitigate the impact of fisheries on sea turtles without unduly reducing the viability of the fisheries themselves.

Many countries have statutory or regulatory regimes which guide fisheries managers on the protocols or procedures to use in developing management policies for fisheries that interact with endangered or protected species. In other countries, however, no such protocols or procedures exist, and managers must make difficult choices on an ad hoc basis.

Relevant laws in the United States, including the Endangered Species Act (the ESA), call upon the United States Government to take steps to address human activities that have a negative impact on the survival of species that are threatened or endangered. Under certain circumstances this law requires the Government to stop the activities that are affecting the protected species unless or until those activities can be adjusted or modified to reduce the effect they have to a level that does not prevent the recovery of the species in question.

Six species of sea turtles occurring in areas under US jurisdiction are protected under the ESA: (green turtle (*Chelonia mydas*); hawksbill turtle (*Eretmochelys imbricata*); Kemp's ridley turtle (*Lepidochelys kempii*); leatherback turtle (*Dermochelys coriacea*); loggerhead

[1] The views expressed in this paper are solely those of the author and do not necessarily reflect those of the US Department of State or of the US Government generally.

turtle (*Caretta caretta*); olive ridley turtle (*Lepidochelys olivacea*)). Through coordination within the Government under specific provisions of the ESA, sea turtles are the subject of consultations among several agencies and entities to protect against multiple threats or circumstances. Such consultations have been conducted with the Minerals Management Service for oil and gas activities, the US Army Corps of Engineers for dredging activities, the US Navy for explosives testing, the Environmental Protection Agency for the designation of dredged material disposal sites, and many other Federal agencies for activities ranging from nuclear power plant construction to scientific research. Consultations have also been conducted with agencies which manage and regulate state fisheries and with private individuals who conduct activities that pose a threat to sea turtles.

The responsibility for addressing activities that affect these species in the marine environment lies with the US National Marine Fisheries Service (NOAA Fisheries), an agency within the National Oceanic and Atmospheric Administration in the US Department of Commerce. The United States has taken significant action to address bycatch or incidental capture of sea turtles in a variety of fisheries. In particular, two types of fisheries, coastal shrimp trawl fisheries in the southeast Atlantic Ocean and Gulf of Mexico region, and pelagic longline fisheries in both the Atlantic and Pacific Oceans, have been the subject of recent and comprehensive actions.

Development and introduction of turtle excluder devices (TEDs)[2]

Coastal shrimp trawl fisheries in the United States employ standard or "otter" trawl nets at or near the sea floor along inshore and offshore coastal waters. For those shrimp fisheries in tropical or sub-tropical waters, these fisheries are often conducted in areas that also serve as foraging, breeding or migratory habitats for sea turtles. Trawl fishing for shrimp at an industrial level uses multiple trawl nets that can be deployed for up to 2-3 hours, with the risk of capturing and drowning sea turtles that cannot come to the surface to breathe.

All species of sea turtles that occur in the southeastern United States became listed as threatened or endangered under the ESA by 1978. Several studies, including a report by the US National Academy of Sciences, National Research Council (1990), found that the penaeid shrimp fishery was the single largest anthropogenic source of sea turtle mortality. The implications of the ESA represented potentially severe consequences for the economically valuable shrimp fishery, including closure of the fishery. To recover the affected sea turtle populations, as required by the ESA, significant efforts were directed toward reducing the incidental capture and mortality of sea turtles.

The US Government initiated a research effort in 1978 to develop potential solutions. Alternatives considered included area and seasonal closures, restricted tow times, and gear modifications. Widespread area and seasonal closures were considered politically and economically unacceptable at that time, and tow time restrictions were not effective or easily enforceable.

An intensive gear development programme was conducted between 1978 and 1980, resulting in the development of the "turtle excluder device" (TED). The TED was developed by gear technologists, working with ideas developed by commercial fishers to exclude

[2] This section was prepared in part based on material provided by Dr John Watson, NOAA Fisheries Harvesting Systems Laboratory, Pascagoula, MS, USA.

jellyfish, an unwanted but abundant bycatch component, from their catch. The original TED design was a metal grid installed in the trawl extension that separated and excluded sea turtles and other large bycatch objects and organisms. In 1981 US fishery managers initiated a programme to encourage the voluntary use of TED technology by the shrimping industry. A technology transfer programme was developed which included industry workshops and demonstrations. TEDs were manufactured by commercial companies under Government contracts and distributed to fishers for trials. However, fishers did not readily accept the technology. They expressed concerns that the gear was too large, cumbersome and complicated.

Research and development continued between 1980 and 1984 to improve the handling characteristics of the gear, and modifications were made to reduce fish bycatch as an incentive to encourage voluntary use. In 1985 and 1986, technology transfer efforts were increased and successful demonstrations of the technology were conducted. However, widespread voluntary use of the technology did not occur.

In 1986, environmental organizations in the United States threatened to sue the US Government on this issue, arguing that the voluntary TED programme was not effective and sea turtles were not being adequately protected. In response, federal regulators called for a mediation meeting between representatives of the shrimping industry and environmental protection groups. The results of the mediation meetings formed the basis for regulations requiring the mandatory use of TED technology by a large segment of the shrimping industry. The proposed mandatory regulations superceded the programme promoting voluntary use of TEDs and resulted in a strong campaign from segments of the industry in opposition to mandatory use of TEDs.

The proposed mandatory use of TEDs also resulted in the development of alternative designs by fishers. The new designs were cheaper, less complicated and easier to use, but were less effective in retaining shrimp catch. The incorporation of TED technology into the shrimp industry through mandatory regulations was met with intense opposition from the shrimp industry that included political pressure, litigation, personal confrontation and civil disobedience. The industry resistance and opposition resulted from several factors which included fear of reduced revenue through loss of target catch and the related economic hardship, denial and disbelief of the magnitude of the sea turtle conservation issue, general opposition to industry regulation, and distrust of federal regulators precipitated by an effective propaganda campaign from industry organizations.

In 1989, after three years of litigation, industry opposition, political pressure, and curtailed attempts to enact regulations, federal regulations requiring the mandatory use of TEDs by US shrimp fishers became effective.

Effective implementation of TED technology required intensive enforcement efforts, including criminal and civil prosecution, fines and catch seizures. This was facilitated by the availability of resources and infrastructure to conduct enforcement activities on a regular and comprehensive basis. Vessel boarding and inspections were conducted by NOAA Fisheries enforcement officers, the US Coast Guard, and state marine enforcement authorities. Often the boardings occurred in conjunction with shrimp fishery area or season openings. The constant presence of enforcement assets and the deterrent effect of significant fines and penalties for TED violations were key to achieving high rates of compliance with the new regulations and ensuring that sea turtle bycatch would be decreased.

Widespread use of TEDs resulted in the identification of operational and technical problems with some designs that, combined with poor construction and installation, resulted in significant revenue loss for many vessels. Cooperative efforts between fishers and gear technologists, which began in earnest in 1990, led to the identification of and solutions to technical problems and the development of more efficient designs. The improved TED design was a simple grid design constructed from aluminum tubing or pipe, which increases strength and durability. The new design employed a curved bar style which provided improved efficiency, effective floatation, improved angle of attack, effective guiding funnels and exit flaps and improved installation and operating instructions.

Effective transfer of technological improvements resulted from intensive technical training of law enforcement officers (who were in turn able to advise fishers on technical problems), dissemination of technical manuals and summary placards, and an intensive technical training programme for fishers which included a multimedia training presentation and hands-on demonstrations by gear technologists. Cooperation between fishers and gear technologist resulted in efficient and effective technological improvements, better communication, a more effective technology transfer programme, compliance with mandatory regulations, recovery of threatened and endangered sea turtle species, and sustainability of the valuable penaeid shrimp fishery. In addition, over time shrimp fishers began to appreciate increased efficiencies in their fishing operations, as the TEDs also served to remove unwanted bycatch of non-target species and debris, which also had a positive effect on overall quality of the catch.

The conservation benefit of the use of TEDs is probably most clearly demonstrated by the progress toward recovery of the Kemp’s ridley populations in the Gulf of Mexico. Over time, scientific studies and stock assessments of the sea turtle populations of this species determined that the population grew at a rate of around 11 percent per year, from the year of the lowest level of nesting activity in 1985 to 1999. The models used for the stock assessment indicated that this growth rate was due largely to the introduction and use of TEDs after 1990, with a likely reduction in total mortality of 45-50 percent[3].

The TEDs programme in the United States continues to evolve. Recently, new regulations were developed to address concerns over the ability of the original TED designs to exclude large turtles, including leatherback turtles. New larger minimum dimensions for the TED escape opening went into effect in 2003 for the Gulf of Mexico and Atlantic fisheries, and this new regulation brought many of the same difficulties and challenges for managers that the original TED rule created. However, the new designs approved for use in achieving exclusion for the larger turtles also have tested well for shrimp retention, equaling or in some cases improving shrimp catch retention compared to the smaller openings. This has eased the expected concerns by industry over potential shrimp loss.

International experience with the adoption of TEDs

Since 1990 the United States has worked with other countries to promote the adoption of regulatory programmes that require the reduction of the incidental capture of sea turtles. US law has, since that time, also prohibited the importation of shrimp and shrimp products

[3] This information derived from NOAA Fisheries stock assessments (TEWG, 1998; 2000).

that have been harvested in ways harmful to sea turtles, US Public Law 101-162 (Section 609).

Many of the other countries that have implemented TED programmes in response to the requirements of Section 609 have had experiences similar to those of the United States. The main technical issue for fisheries managers in many of these countries was the resistance to the development and adoption of TED programmes by local fishers, based on the belief that the use of TEDs would significantly reduce shrimp production due to a loss of shrimp catch through the turtle escape opening in the TEDs. Arguments were also made that the United States was promoting the use of TEDs by other countries as a protectionist measure designed to disadvantage foreign producers in the US markets. Arguments were also made in many countries that sea turtle interactions did not occur or were infrequent, and that TEDs were too expensive to purchase or maintain. Many industries also had no mechanism for public comment or input on the development of the new programmes, and felt that their views were being ignored or disregarded by managers or the Governments. In the implementation of the international programme to promote the use of TEDs, the United States worked with foreign fishery managers and industries to address these arguments where possible.

Data from testing in the United States on TED catch performance for target shrimp species was shared, though in many cases immediately reproducing the low levels of shrimp loss (average of 3 percent loss) achieved in US testing and in use in fisheries was difficult for foreign shrimp fishers. The catch rates depended on specific construction, installation and adjustment of the TEDs, factors that were not always taken into account by fishers new to the devices. In time, with additional technical assistance from fishery managers and advice and assistance from US technical experts, many foreign fishers were able to take their specific fishing environments, sea bottom and debris conditions, and gear configurations into account to make the necessary adjustments to improve target species catch rates.

The issue of the cost of the gear was more difficult to address. In addition to the cost of the material to construct the TED and labour costs to construct and install the gear, fishers also had continuing maintenance costs, replacement costs, and initially (until they were able to make adjustments) costs due to shrimp loss from the TED. The United States made it clear in its discussions with foreign Governments that were considering the adoption of a TED programme that the only requirement for the TEDs in terms of construction was consistency with approved designs and functionality. TEDs were not required to be purchased from the United States, but could be constructed locally. Although this did reduce costs for some countries, materials for the construction of TEDs varied in price and availability from country to country, as did fabrication methods. There is also a scale of costs to take into account. TEDs that cost US$150-300 could be purchased easily by owners or operators of large vessels fishing in productive areas with easy access to strong markets, but that same price was more difficult for owners or operators of small vessels during seasons of low production with markets requiring high transportation costs or suffering from depressed prices.

Concerning the argument that sea turtle bycatch did not occur in certain areas and that TEDs were not necessary in some foreign countries, the United States provided flexibility in its implementing guidelines and provided a channel for exemption to the TED requirement by offering to consider scientifically sound studies on sea turtle interactions with shrimp trawl fleets. The studies should be based on data collected through an independent observer programme covering a significant portion of a given fleet throughout a fishing year.

However, the countries that were determined by the United States to be subject to the requirements of Section 609 were all tropical or sub-tropical countries where turtles were known to nest, migrate, forage or breed, and the outcome of any such study for a country in the affected group would likely demonstrate some level of sea turtle interaction. Also, the costs and efforts to conduct such studies were significant. Thus, no countries pursued such a study for the purpose of seeking an exemption from the TED requirements of the United States. Only one country, Costa Rica, conducted an observer-based study on the size composition of turtles interacting with their Pacific coast shrimp trawl fleet, though that study was done in order to seek an exemption to the bar spacing specification in the TED design requirements and not an exemption to the TED requirement itself.

Though foreign Governments were able to overcome these arguments, implementation of TED programmes carried additional challenges. Technology transfer to the fishing industry and training and education in the construction, use and installation of the gear was difficult for countries where there traditionally was no cooperative relationship between fishery managers and industry, or where the framework to carry out such activities did not exist. Also, many fishery managers had no experience or practical knowledge of TEDs and had to rely on outside sources to develop their capacity, such as training or information from the United States. For its part the United States conducted technical training and technology transfer for each country that requested it, but for a number of reasons it was difficult to ensure that this information was disseminated throughout each country’s industry.

Another challenge to implementation was enforcement of the new regulations. As with many fishery management regimes, strong fisheries enforcement is a necessary component of an effective conservation and management scheme. This is especially true in the circumstance of Governments promulgating new TED programmes for resistant industries. Many Governments have limited or inadequate resources to support the level of enforcement activity, such as frequent boarding and inspection dockside and at sea, that is necessary to provide the level of enforcement presence that would be considered adequate to achieve good compliance. In some cases, the operating budgets of the fishery management or maritime enforcement authorities were inadequate even to provide enforcement vessels with fuel to conduct at-sea inspections. Even a minimal increase in costs to such Government agencies could not easily be absorbed, and many Governments were initially incapable of securing adequate financial support from the central Government until the industry raised the issue politically as necessary for their continued access to the US market.

In addition, TED programmes require that fishery managers and enforcement officials be proficient in TED specifications, installation and use. The challenges of disseminating and transferring information about TEDs to the industry are also applicable to the process for training personnel and agencies responsible for enforcing TED regulations.

Based on the experiences of the United States and other Governments, one of the best ways to promote good compliance and maintain good relations between the Government or fishery managers and the fishing industry is to build the capacity of fishery managers and enforcement officials to provide advice and assistance to fishers when conducting enforcement activities. If fishers only receive negative reinforcement from Government officials, especially regarding management measures or programmes that they object to or are dissatisfied with and under circumstances where the only direct contact they have with managers or other officials is during enforcement activities, achieving successful conservation benefits becomes more difficult over time and the conservation and management programmes erode, as does the relationship between managers and the fishers. Instead, it is extremely productive to encourage managers and enforcement officials to work cooperatively with the industries during enforcement activities and to approach the fishers in a positive manner, inform them of both the requirements and the objectives of the programme and, when appropriate, make observations or recommendations regarding adjustments or refinements to the fishing gear that could address the concerns or problems of the fishers and possibly improve target catch rates, which in turn reduces the substantive dissatisfaction with the TED programme.

As with the experience of the United States, many countries required years to develop and fully implement programmes, and in some cases widespread compliance among their fleets took even longer. A factor that proved to be useful in many cases was the engagement of the fishing associations or collectives by the fishery managers in order to promote the use of TEDs through education and training. The associations usually understood the implications for their industry and had a broader perspective than individual fishers. They served as good conduits between managers and the industry and often facilitated training and assistance by the Government, and represented the views of the fishers to the Governments in order to more effectively influence management policies. In many cases the constructive feedback from the industry on how to make the TED programmes more effective, or the gear itself more efficient for local fishing conditions, would only have been successfully communicated to fishery managers through the associations or collectives.

Efforts to address sea turtle bycatch and interactions in pelagic longline fisheries[4]

In addition to the issue of bycatch of sea turtles in trawl fisheries, a second fishing method, longline fishing, has recently been identified as having significant negative impacts on sea turtles.

This fishing method, employed in fisheries around the globe, uses multiple baited hooks strung from long main lines. Each longline set can have hundreds of hooks. The lines are set to fish at varying depths, according to the target species (tunas and swordfish) and fishing conditions.

In the United States, NOAA Fisheries determined that longline fishing for swordfish, which uses longline gear set at shallow depths down to 120 feet or less, resulted in the highest rates of interactions and significant mortality. The mortality resulted from the fishing gear itself, both from direct catch on hooks or by entanglement or foul-hooking, and in addition turtles that were released alive from the gear experienced delayed mortality due to the problems caused by the hooks and line that remain in the animal. The post-release mortality is of significant concern, as there is a large degree of uncertainty about such mortality and it must be estimated based on the best available information.

Given that the longline fisheries that had an impact on sea turtles were conducted by US vessels in both the exclusive economic zones and on the high seas in both the Pacific and Atlantic Oceans, steps were required to address this bycatch over broad geographic areas. The status of the sea turtle populations that interacted with the US longline fleets differed by ocean as well. Populations of leatherback turtles in the Pacific Ocean were and are considered

[4] The longline and gillnet sections were prepared based in part on information provided by NOAA Fisheries Office of Protected Resources.

to be critically endangered, and required more immediate and comprehensive management measures for the longline fisheries to reduce incidental capture.

Within this context, one of the significant differences between the trawl and longline bycatch issues emerged. Unlike the trawl bycatch situation, which was resolved through the development of the TED as an alternative to reducing fishing effort or closing fisheries altogether, there was no potential longline gear modification readily available for implementation within the time frame allowed for the actions called for pursuant to the ESA. At that time little was known about the specific nature of sea turtle interactions with longline gear, and specifically about what could be done in the short term to reduce interactions. However, observer data did provide information on rates of sea turtle bycatch as well as time and areas where bycatch levels were most significant.

Beginning in late 1999, NOAA Fisheries implemented temporary seasonal time/area closures for the US Hawaii-based longline fishery to reduce the bycatch of endangered and threatened sea turtles. In June 2002, NOAA Fisheries implemented permanent regulations prohibiting fishing for swordfish in the Pacific by US vessels north of the equator and prohibiting all longline fishing during April and May in waters south of Hawaii to the equator. These time/area closures were based on at-sea observer data identifying areas of high sea turtle interactions with the longline fishery. These closures were shown to be highly effective in reducing sea turtle/longline interactions. Prior to the closures, the Hawaii-based US longline fleet was estimated to take over 850 turtles each year. With the closures in place, the estimated annual take is approximately 100 turtles – almost a nine-fold reduction.

For the Atlantic Ocean, NOAA Fisheries implemented seasonal time/area closures for the US Atlantic longline fishery to reduce the bycatch of endangered and threatened sea turtles beginning in late 2000. In July 2002, a final rule was implemented to reduce sea turtle take in longline gear which prohibited fishing with longline gear in an area encompassing over 2 600 000 square nautical miles in the Northwest Atlantic. The closure was based on at-sea observer data identifying this area as having high levels of sea turtle interactions. Prior to the closure, the US Atlantic longline fishery was estimated to take over 3 000 turtles per year. With the closure in place, the estimated annual take is approximately 875 turtles – almost a four-fold reduction.

The closure of the Hawaii-based fishery had serious impacts on the industry. Given the geographic isolation of the Hawaiian Islands, and since the fleet is federally permitted in Hawaii, vessels could not easily move to other fishing areas as they might have if they were based along the coast of the US mainland. However, historically many Hawaii-based longliners would fish around Hawaii in the spring and summer and California in the autumn and winter. With the swordfish closure off Hawaii, about 20 vessels gave up their Hawaii-based permit and moved their operations to California. This became a problem for managers because these vessels continued to impact sea turtles which are highly migratory and occur off the west coast of the United States. Some vessels that did not relocate to California were able to change their gear and practices in order to target tuna, but most Hawaii-based swordfish vessels remained inactive. This led to lawsuits and litigation by the industry and environmental groups to challenge the measures put in place by the fisheries management authorities.

While the time/area closures were put in place as an immediate measure, NOAA Fisheries was exploring whether a long-term solution could be found which was based on gear modifications and other management measures that, if effective, could lead to a re-opening of the closed fisheries and a resumption of fishing effort under a regulatory regime that required strict measures to control bycatch. For such a programme to work, research on methods to reduce sea turtle bycatch was necessary.

In 2003, two studies were completed to evaluate whether changes in commercial longline fishing gear and practices could reduce sea turtle bycatch. The first was conducted in the eastern Atlantic Ocean by the University of Florida in partnership with the University of the Azores (initiated in 2000). The other was conducted in the northwestern Atlantic by NOAA Fisheries in partnership with an industry group, the Bluewater Fishermen's Association (initiated in 2001). These studies were successful in identifying modifications that can help to reduce sea turtle bycatch in longline fisheries for swordfish. Large circle hooks in combination with specific bait types were shown to reduce sea turtle take in longline gear (large circle hooks alone were shown to significantly reduce sea turtle take regardless of bait type, and mackerel bait in combination with large circle hooks had the highest reduction for loggerhead turtles). Based on these results, NOAA Fisheries is considering allowing the use of large circle hooks (18/0 or greater) with specific bait and offset configurations, on an experimental-fisheries basis in the Pacific to evaluate their effectiveness in overall sea turtle bycatch reduction under normal operating conditions. Regulations are being developed to require circle hooks in the Atlantic and Gulf of Mexico fisheries, and to re-open the north Atlantic fishery for US vessels.

One of the concerns expressed by US and international fishers is the uncertainty over the effect of such gear modifications on target catch rates. This echoes the concerns expressed by the shrimp trawl industry at the inception of the TED regulations. It is clear that such concerns need to be addressed if gear modification measures that may eventually become part of a regulatory programme are to be easily and quickly adopted by the industry, and additional studies are planned to determine target catch rates for tuna and swordfish based on the modifications that showed the most promise for reducing sea turtle interactions (the effects of large circle hooks on swordfish catch have been documented in the Atlantic study – when used with mackerel bait there is a statistically significant increase in swordfish catch, when used with squid there is a statistically significant decrease in swordfish catch).

In order to implement safe handling practices which could reduce mortality for turtles that are hooked or entangled in longline gear, NOAA Fisheries, in partnership with industry, developed a number of tools that can improve the survival for turtles after release. These tools include de-hooking devices to remove hooks in a more efficient manner, line cutters to reduce the amount of fishing line that might be attached to hooks that cannot be removed, and dip nets to aid in bringing smaller turtles on board vessels for gear removal or resuscitation. Such measures, in combination with gear modifications, are considered to comprise the suite of management measures that so far hold the most promise to reduce sea turtle bycatch in commercial longline fisheries, and may allow the easing of time and area closures if proven to be effective in the long term. However, given the serious population status of certain sea turtle species, such as the Pacific leatherback and Pacific loggerhead, additional measures may continue to be necessary to achieve species recovery.

Measures to reduce sea turtle bycatch in gillnets

Gillnet gear is also highly problematic for sea turtles and is known to be a significant source of mortality in coastal areas and on the high seas. In the US, NOAA Fisheries has implemented several management measures to address turtle bycatch resulting from fishing with gillnets along the US east coast, including time/area closures and prohibitions of large-mesh gillnets. These measures were established based on at-sea observer data and enforcement records, sea surface temperature data (predicting sea turtle seasonal migrations), and records of sea turtle strandings.

These restrictions have been effective at reducing sea turtle interactions in gillnets. Beginning in 2001, NOAA Fisheries closed Pamlico Sound, North Carolina, to fishing with gillnets greater than 4 1/4 inch stretched mesh from 1 September through 15 December each year. Sea turtle strandings in the area decreased by over 50 percent relative to the same time period in previous years. Also in 2001, NOAA Fisheries implemented time/area closures to fishing with drift gillnets in US waters off California and Oregon to protect sea turtles. Waters from Monterey Bay north to Oregon were closed from 15 August through 15 November each year to protect leatherbacks. In addition, in any year where El Niño conditions are forecast for southern California, drift gillnets are prohibited during the summer months along the west coast to protect loggerheads. These time/area closures are anticipated to reduce sea turtle interactions by over 70 percent.

CONCLUSIONS

The experiences of the United States and other countries in the introduction and implementation of new gear modifications and management actions to reduce the impact of fisheries on sea turtle populations demonstrate the difficulties inherent to the challenge of reconciling economic activities such as coastal or pelagic fishing with the statutory requirements or policy directives to conserve and recover sea turtles and other protected resources. In the case of commercial fisheries that have direct impacts on endangered species such as sea turtles through bycatch, there were different approaches available to or required of resource managers. However, not all of these approaches or options were easily accepted by user groups, and they require significant commitment of resources, including financial and human resources, to research, develop and refine the management measures and gear modifications necessary to achieve the conservation objective. Some of the important lessons learned include:

- voluntary acceptance of new gear modifications or technologies may be difficult and may not provide the conservation benefit or meet conservation goals established by managers or regulatory/statutory guidelines;
- technologies that result in increased costs and/or decrease in target catch (and subsequently loss of revenue) will likely be resisted by users, especially where there is no clear communication to or education of users about the nature of the bycatch problem and the responsibilities of managers or policy-makers;
- user groups should be active participants in the planning, development and evaluation of new technologies or management measures, as the impact on their activities can be significant, but also because of the positive contributions user groups can make to finding or developing gear or management solutions in cooperation with fisheries managers;
- mandatory use of new sustainable technologies requires effective enforcement commitment;
- technical training of enforcement personnel can be a cost-effective technology transfer technique, and helps to maintain positive relationships between managers/enforcement officials and user groups;

- planning for new technology development should include major commitment for technology transfer activities;
- regulations implementing new mitigation technologies should be flexible and easily modified to allow modifications necessary to adapt gear to different conditions encountered during commercial operations and to allow for technological improvements while maintaining enforceability, and
- successful development and acceptance of sustainable technologies requires effective communication and cooperation between users and fishery researchers, regulators and the public.

However difficult implementing measures to reduce the bycatch and mortality of sea turtles may appear, the management experiences related to the TED programme and the develop-ment of bycatch solutions for other fisheries may serve as an example of how political commitment and technology transfer to fishing industries can result in a programme that reduces the impact of fisheries on sea turtles while maintaining the sustainability of the fisheries themselves and the livelihoods of those participating in every associated stage of the use of marine resources.