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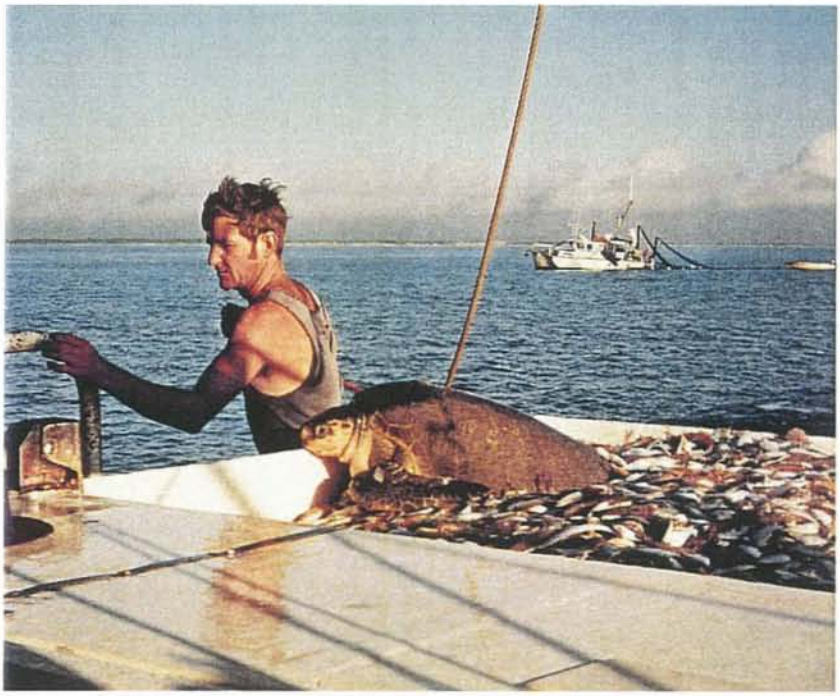
Project Report Series

Monitoring the Impact of Trawling on Sea Turtle Populations of the Queensland East Coast

J.B. Robins and D.G. Mayer



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T93/229 Monitoring the Impact of Trawling on Sea Turtle Populations of the Queensland East Coast

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OBJECTIVES

1. To provide detailed information on turtle-trawl interactions over an extended period along the Queensland east coast and in Torres Strait.
2. To determine the fate of turtles that suffer repeated trawl capture.
3. To liaise with industry on the issue of turtle-trawl interactions and to educate fishers on the treatment of trawl-captured turtles.
4. To investigate an alternative population monitoring method for sea turtles using catch and effort information from the trawl fleet.

NON-TECHNICAL SUMMARY

Six species of sea turtle inhabit the waters of northern Australia. Significant trawl fisheries for penaeid prawns and scallops also occur in these areas. The overlap between the distribution of sea turtles and the distribution of trawling effort allows sea turtles to be caught in trawl nets. Catching a turtle in a trawl net is a relatively infrequent occurrence with overall catch rates averaging less than 1 turtle per 20 days of trawling. Low frequency of capture and ethical considerations limit the research of turtle bycatch to observational studies. The most feasible approach to measure turtle catch rates under current research budgets is to monitor turtle bycatch through participants in the commercial fishery. This can take the form of a logbook program (either compulsory, voluntary or selective) or an observer-based sampling program. Most Australian fisheries use compulsory logbooks to monitor the effort expended to take commercial catch. Research trawls, though limited in time and space, can be used to validate logbook information. The wide geographic distribution of trawl fisheries in Australia makes voluntary monitoring the only feasible method, in terms of both cost and coverage, to obtain information on the number of turtles caught and killed in these fisheries.

Turtle bycatch data are limited for trawl fisheries in New South Wales and Torres Strait. However, even less is known about the size or extent of turtle bycatch in trawl fisheries of Western Australia, including the North West Shelf. Information on turtle bycatch has been collected for limited periods of time within the Northern Prawn Fishery. About 6,000 turtles are estimated to be caught annually in the tiger prawn sector of the Northern Prawn Fishery, of which an estimated 350 die. A program to monitor the incidental capture of sea turtles in the Queensland Trawl Fishery was initiated in 1991 by the Queensland Department of

Primary Industries. The Queensland Fisheries Management Authority funded the program between 1991 and 1993. It utilised voluntary data recording by selected commercial fishers. The project was extended until 1996 with funding from the Fisheries Research and Development Corporation. The extension of the project aimed to provide a long-term database on turtle-trawl interactions throughout the Queensland east coast by collecting information continuously for 6 years.

The success of the voluntary turtle monitoring program relied heavily on the participation of individual commercial fishers. Over the 6 years, 106 different vessels took part in the program, representing the involvement of 12% of the Queensland trawling industry. In total 1,527 turtles were reported caught over 23,906 days fished. Stratified, weighted analysis of the data resulted in an annual estimated turtle catch of 5,901 for the Queensland Trawl Fishery (95% Confidence Interval 5,199 - 6,604) given an average total fleet effort of 84,876 days fished. The catch was comprised of 2,938 loggerhead turtles (95% C.I. 2,390 - 3,487), 1,562 green turtles (95% C.I. 1,223 - 1,902), 80 hawksbill turtles (95% C.I. 42 - 119), 323 Pacific Ridley turtles (95% C.I. 240 - 406) and 968 flatback turtles (95% C.I. 770 - 1,165). A similar analysis for the Torres Strait Prawn Fishery resulted in an annual estimated catch of 652 turtles (95% C.I. 537 - 788), given an average total fleet effort of 8,634 days fished. This was comprised of 85 loggerhead turtles (95% C.I. 50 - 131), 145 green turtles (95% C.I. 95 - 203), 6 hawksbill turtles (95% C.I. 0 - 15), 18 Pacific Ridley turtles (95% C.I. 6 - 32) and 400 flatback turtles (95% C.I. 304 - 518).

Greater than 90% of all turtles reported caught in the Queensland Trawl Fishery were healthy when first landed on the boat. Four percent were reported as comatose and 1% were reported as dead. Mortality rates of trawl-caught turtles were similar in the Torres Strait Prawn Fishery, where 96% of turtles were reported as healthy. Three percent were reported as comatose and 1% were reported as dead. These mortality rates translate to an estimated trawl related mortality of between 72 and 94 turtles for the Queensland Trawl Fishery. If comatose turtles are considered to die as a consequence of a trawl capture (i.e. dead + comatose turtles) then between 306 and 468 turtles are estimated die as a consequence of a trawl capture. Trawl related mortality for the Torres Strait Prawn Fishery was estimated to be between five and eight turtles per year (i.e. dead turtles only) or between 21 and 32 turtles if comatose turtles are considered to die as a consequence of a trawl capture. These mortality rates are considerably lower than that reported for the Northern Prawn Fishery, which were 10% dead in 1989 and 18% dead in 1990, and 39% if comatose turtles were assumed to die in 1990.

There are a number of factors that may explain the difference in mortality rates between the Northern Prawn Fishery and the two fisheries reported here. It has been suggested that mortality rates in a fishery are the consequence of the average duration of the trawls as well as the susceptibility to drowning of the dominant species caught. It has been speculated that flatback turtles have a greater tolerance to trawl-capture than other species. Flatback turtles were the dominant species caught in the Torres Strait (66%) and this combined with an average tow duration of 144 minutes may account for the lower mortality rates in the Torres Strait Prawn Fishery than in the Northern Prawn Fishery, where average tow duration has been reported as 186 minutes. Mortality rates of turtles in the Queensland Trawl Fishery are markedly lower than the Northern Prawn Fishery most likely as a consequence of short tow durations (i.e. 60 to 90 minutes) in the areas where turtles are caught predominantly, i.e. the Moreton Bay fishery. Another possible cause of the low mortality rates in this study could be under-reporting of dead turtles by fishers involved in the program. However, the incidence of a low mortality rate of trawl-caught turtles is supported by tow duration data and levels of mortality similar to the Northern Prawn Fishery were reported in some areas of the Queensland Trawl Fishery where tow durations are longer (i.e. 129 minutes, tiger and endeavour prawn fisheries of north Queensland). The degree of inaccurate reporting should be variable, as different fishers would report differently. It would take a concerted effort from the majority of commercial fishers involved in this study (some 106 individuals) to have a major effect on data accuracy.

It is difficult to speculate what impact the estimated turtle bycatch has on sea turtle populations of eastern Australia. There is limited quantitative information available about the population status of the six species of sea turtle that inhabit the waters of eastern Australia. The exception to this is the loggerhead turtle, for which a 50% to 80% decline in the number of nesting female turtles has been observed since the mid 1980's. Determining the numbers and the status of sea turtle populations has intrinsic difficulties because of: i) the paucity of census data, ii) the difficulties in estimating abundance and determining trends in localised feeding grounds, iii) the mixture of stocks in feeding grounds, iv) the lack of quantification of life history parameters and the longevity of turtle life cycles, and v) the dispersed nature of the population between feeding grounds and nesting beaches and our incomplete understanding of the migration patterns. Sea turtles are long-lived, have delayed sexual maturity and high survivorship of adults. Species with these life history traits are particularly susceptible to human impacts that can result in population declines. Hypothetical modelling of the Queensland east coast loggerhead turtle population suggests that an annual loss of only a few hundred adult and sub-adult female turtles would have a profound effect on the population and would result in a declining population size.

The turtle bycatch and trawl related mortality estimated for the Queensland Trawl Fishery and the Torres Strait Prawn Fishery would contribute to a decline in the loggerhead turtle population, if the model reflects the true situation. It is likely that bycatch in trawl nets is only one factor contributing to the declining numbers of sea turtles in eastern Australia. This is especially so for species such as green and hawksbill turtles, that are the target of commercial and traditional harvest, or flatback turtles whose eggs are at risk to feral animal predation in northern Australia. Nevertheless, measures that the trawl industry can take to minimise its impact upon sea turtle populations of eastern Australia should be investigated.

The fate of turtles post-release from a trawl capture was also investigated during the research project. Seven trawl-caught turtles were monitored after release from the trawler using real-time tracking systems and data-logging equipment. The data-logging equipment (Temperature Depth Recorders or TDRs) provided the most complete picture of dive profiles of trawl-caught turtles. All turtles displayed a distinctive "escape" response upon release. The data recorded indicates that trawl capture resulted in appreciable behavioural changes, i.e. an increased number of surfacings. It appeared that small turtles took longer to recover than large turtles. No delayed post-trawl mortalities were observed, as would be expected with the small sample size and a reported trawl mortality of 0.6% in Moreton Bay, the location where field work was undertaken.

The participation of commercial fishers in the voluntary turtle monitoring program had a significant impact on raising the industry's awareness of the issues associated with the incidental capture of turtles in trawl nets. Visits by research staff to the ports and wharfs of the Queensland east coast resulted in energetic discussions on these issues between boat owners, skippers, deckhands and research staff. Recovery treatments for trawl-caught turtles and a code of fishing ethics, covering turtle captures, were developed in conjunction with the Queensland Commercial Fisherman's Organisation. A four page leaflet, including recovery procedures, species identification guide and code of fishing ethics was produced with support from the Queensland Commercial Fisherman's Organisation, the Australian Fisheries Management Authority, the Australian Prawn Promotion Association and the Australian Nature Conservation Agency (= Environment Australia). It was distributed to all master fishermen from the Queensland East Coast, Torres Strait and the Northern Prawn Fishery. Anecdotal reports from commercial fishers provide encouraging information that these recovery techniques are being employed in the industry and that many turtles can recover from trawl captures.

Limited quantitative information is available about the current status of turtle populations from the Queensland east coast. Current indices of population trends (i.e. nesting beach surveys) are only available for loggerhead turtles. Turtle catch per unit effort (CPUE) was investigated as an alternate means of monitoring turtle populations only in areas where sampling effort and turtle catch were continuous throughout time. Only two of the 133 QFISH grids in which turtle bycatch occurred, had sufficient data to provide a continuous picture of abundance. These grids were Moreton Bay (W88) and Bundaberg (U32). Turtle CPUE was still highly variable in these grids. It is likely that unless sampling effort is highly concentrated and continuous throughout time, turtle CPUE will not be able to detect changes in population size unless dramatic changes occur. The use of turtle CPUE as an index of abundance may be possible if accurate turtle bycatch is recorded by the majority of the trawl fleet as information collected through the compulsory trawl fishery logbooks. Turtle CPUE was most useful as an overall, wide-scale, in-water survey of the distribution of sea turtles throughout Queensland waters. The turtle CPUE by species has provided insights into potential areas where sea turtles are aggregated and may provide fruitful areas for research into sea turtle biology and population dynamics by conservation agencies.

The assessment of sea turtle bycatch in Australian prawn trawl fisheries is necessary to support the conservation of threatened sea turtle species. The voluntary turtle monitoring program has developed a long-term database on the frequency and location of turtle captures. The data is being used in fisheries management for the identification of priority areas where the issue of how to abate threats to turtles from trawling is being negotiated. This includes the identification of areas where TEDs are to become compulsory. The commercial fishing industry has input to these negotiations through the Queensland Trawl Management Plan via TrawlMAC. The Queensland Department of Environment and the Great Barrier Reef Marine Park Authority also have input into determining these priority areas through the joint analysis of the turtle CPUE data via a collaborative risk assessment.

The process of conducting a voluntary turtle monitoring program over 6 years has helped to develop a responsible attitude by commercial fishers to environmentally sensitive issues such as sea turtle conservation. The positive relationship established between commercial fishers and research staff has been of considerable value in assisting with the introduction and adoption of measures to mitigate turtle bycatch (i.e. Turtle Excluder Devices) in Queensland east coast trawl fisheries. This project has demonstrated the value of involving commercial fishers in research projects, especially when there is continuity in the research staff. This enables contacts with the fishing industry to be established and developed over an extended period of time.

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BACKGROUND

Six species of sea turtle inhabit the waters of northern Australia. All six species are protected within Australian waters from direct and unintentional harvest under the Commonwealth *Endangered Species Protection Act 1992*. Indigenous harvest for non-commercial purposes is permitted. Environment Australia has classified the conservation status of sea turtles in Australia. Four species are *vulnerable*, one is *endangered* and the status of one species is undetermined (Table 1). In most Australian states, sea turtles are also protected under State conservation or fisheries legislation (Table 1). On a global scale, the International Union for the Conservation of Nature lists all sea turtles as being threatened.

Table 1 Conservation status of sea turtles
(c = critically endangered, e = endangered, t = threatened, v= vulnerable, nl = not listed)

Species		Conservation status					
		IUCN[A]	C'wealth[B]	Qld[C]	NT[D]	WA[E]	NSW[F]
Chelonia mydas	Green turtle	e	v	v	v	nl	v
Caretta caretta	Loggerhead turtle	e	e	e	e	t	v
Natator depressus	Flatback turtle	v	nl	v	nl	nl	nl
Eretmochelys imbricata	Hawksbill turtle	c	v	v	v	nl	nl
Lepidochelys olivacea	Pacific Ridley turtle	e	v	e	v	nl	nl
Dermochelys coriacea	Leatherback turtle	e	v	e	v	t	v

[A] International Union for the Conservation of Nature Red List of Threatened Animals 1996, [B] Commonwealth *Endangered Species Protection Act 1992*:schedule 1, [C] Queensland *Nature Conservation Act 1994*, [D] no specific State listing Commonwealth listings adopted, [E] Western Australian *Wildlife Conservation Act* 1950, [E] NSW *Threatened Species Conservation Act 1995*

Sea turtles can be entangled in all types of fishing gear, including discarded netting and twine. Incidental capture of turtles occurs primarily in commercial fishing activities, of which, trawling for prawns catches the greatest number of turtles (Magnuson *et al.* 1990). Captures of turtles in prawn trawl nets have been reported in Australia, Colombia, French Guinea, Malaysia, Mexico, Surinam and the USA (Hillestad *et al.* 1981). Estimates of the number of turtles caught and killed in trawl nets have been made for prawn trawl fisheries in southeastern USA (Henwood and Stuntz 1987), Malaysia (Chan *et al.* 1988), northern Australia (Poiner *et al.* 1990), the Caribbean (Henwood *et al.* 1992) and eastern Australia (Robins 1995). These studies provide baseline data about when, where and how many turtles are caught and directly killed in trawl nets (Table 2). Catch and mortality of sea turtles is not always consistent between fisheries because factors such as the species caught and the average tow duration of the fishery can influence catch and mortality rates. It is difficult to draw conclusions about the interaction between a fishery and sea turtles based on information from other experiences. It is thus necessary to document catch and mortality in each fishery.

Most programs have been based on observer or survey information from commercial fishers as large-scale trawl fisheries are particularly difficult to sample adequately via research trawling. Most studies suggest that the incidental capture of sea turtles in trawl nets is a function of the amount and distribution of effort within a fishery and the distribution and density of sea turtles. Estimates of turtles caught and killed in USA trawl fisheries initiated major concern for the impact of trawling on sea turtles worldwide (Magnuson *et al.* 1990). In some countries trawl nets now incorporate turtle excluder devices (TEDs) to reduce the number of turtles caught and killed in their trawl fisheries. Countries using TEDs include the USA, Mexico, Trindidad and Tobago, Belize, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, Panama, Colombia, Venezuela, Guyana, Surinam, Brazil, Ecuador, Nigeria, Kenya, Tanzania, Mozambique, India, Thailand, Indonesia and the Philippines (Robins 1997).

Table 2 Worldwide annual estimates of turtles caught and killed by trawling operations

Fishery location	Prawn catch (t)	Sampling method	Turtles caught (± s.e.)	Turtles killed (± s.e.)	Comments
Terengganu, Malaysia [A]	-	interviews	742	742	assumes all turtles killed
SE Atlantic, USA [B]	13,000	observers	33,881 ± 3,522	7,115 ± 740	704,376 standard net hours, 1.4% sampled
Gulf of Mexico, USA [B]	122,000	observers	12,497 ± 6,042	3,755 ± 1,752	4,315,698 standard net hours, 0.38% sampled
SE Atlantic, USA [C]	13,000	observers & interviews	26,075	not estimated	500,000 hours fished
Gulf of Mexico, USA [C]	122,000	observers & interviews	3, 135	not estimated	5,000,000 hours fished
Mexico [D]	87,106	desktop study	48,779	11,324	
Central America [D]	27,132	desktop study	15,195	3,528	
South America [D]	82,217	desktop study	46,042	10,628	
Northern Prawn Fishery, Australia [E]	6,267	research surveys, voluntary logbook	5,730 ± 1,907	344 ± 125	1.1% sampled
Northern Prawn Fishery, Australia [F]		voluntary logbook	5,357	777	
Queensland east coast, Australia [G]	7,000	voluntary logbook	5,295 ± 1,231	58 ± 14	7.6% sampled

[A] (Chan *et al.* 1988), [B] (Henwood and Stuntz 1987), [C] (Renaud *et al.* 1990), [D] (Henwood *et al.* 1992), [E] (Poiner *et al.* 1990), [F] (Poiner and Harris 1996), [G] (Robins 1995)

In response to the world wide concern that trawl fisheries may be having a detrimental impact on sea turtle populations, a program to monitor the incidental capture of sea turtles in the Queensland Trawl Fishery (QTF) was initiated in 1991 by the Queensland Department of Primary Industries. The program was funded by the Queensland Fisheries Management Authority between 1991 to 1993 and utilised voluntary data recording by selected commercial fishers.

Turtle capture in trawl nets is a relatively infrequent occurrence with catch per unit effort averaging less than 0.0487 turtles per hour of trawling[1] (Henwood and Stuntz 1987; Poiner *et al.* 1990; Robins 1995). Low frequency of capture and ethical considerations limit the research of turtle bycatch to observational studies. High costs of vessel charter generally prevent the sole use of research trawls to document the spatial and temporal nature of turtle bycatch in the trawl fisheries. The only feasible approach under current fisheries research budgets is to monitor turtle bycatch through participants in the commercial fishery. This can take the form of a logbook program (either compulsory, voluntary or selective) or an observer-based sampling program. Most Australian fisheries use compulsory logbooks to monitor the effort expended to take commercial catch. Research trawls, though limited in time and space, can validate logbook information. The wide geographic distribution of the Queensland Trawl Fishery made voluntary monitoring the only feasible method, in terms of both cost and coverage, to obtain information on the number of turtles caught and killed in this fishery.

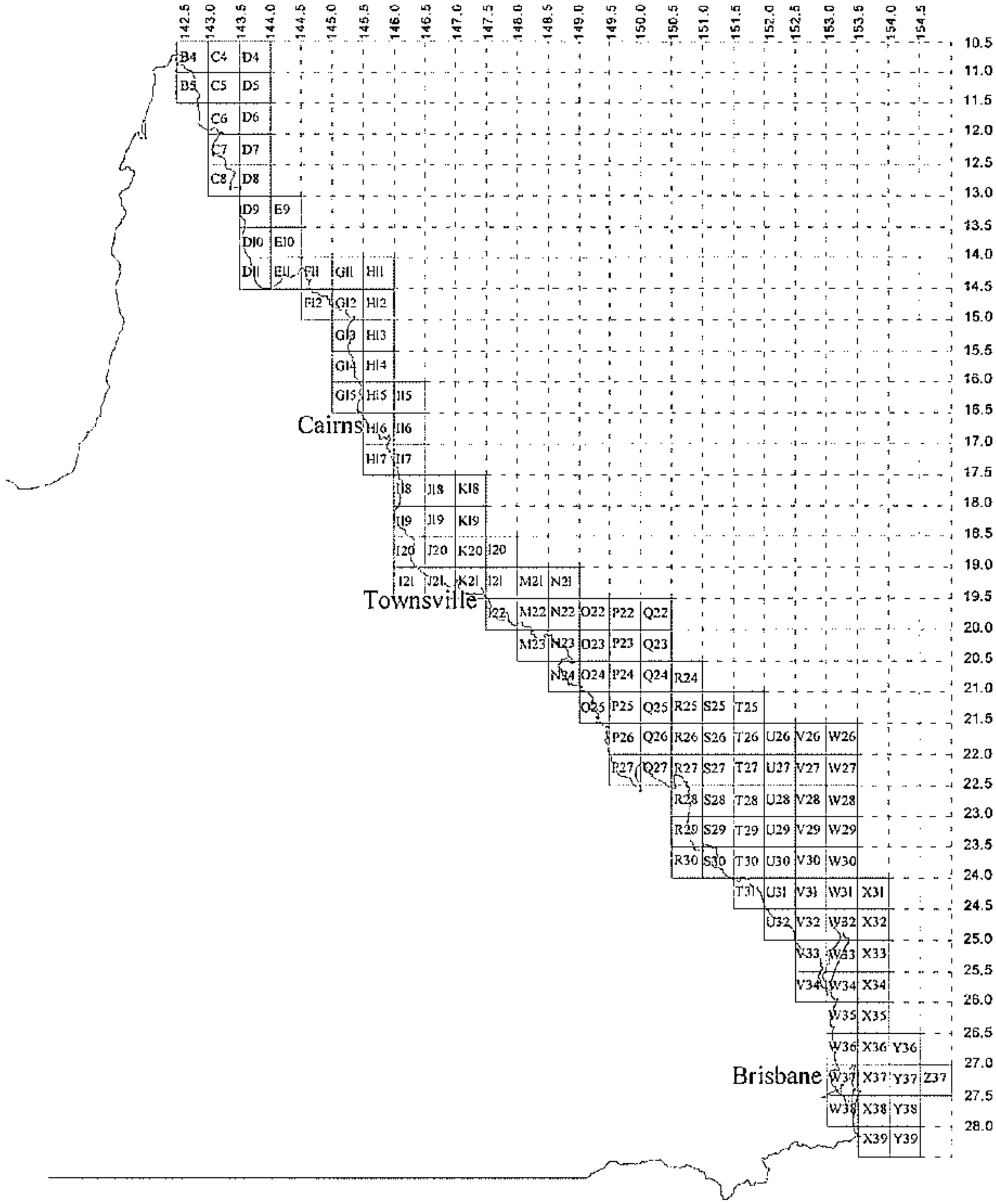
[1] Standardised to catch per hour of a 30.5 m headrope length prawn trawl net

Figure 1 Queensland Trawl Fishery, QFISH grids

QFISH grids, lattitude ⁰ S, longitude ⁰E indicated

QFISH grids identified by minimium lattitude and minimium longitude

eg B4 = 10.5⁰E, 142.5⁰S



The Queensland east coast supports a complex multi-species trawl fishery. Boats endorsed for the Queensland Trawl Fishery may work along the Queensland coastline, southeast of Cape York Peninsula (10°30'S, 142°30'E) to the Queensland/New South Wales border (Figure 1). This area includes several major estuaries and bays, a wide continental shelf and the Great

Barrier Reef World Heritage Area. Some fishing also occurs over the continental shelf. There are several seasonal and spatial trawl closures within the boundaries of the fishery.

About 800 vessels are licensed to use otterboard trawls in the Queensland Trawl Fishery. The primary target species are penaeid prawns and scallops. Annually the fleet lands about 7,000 tonnes of prawns (wet weight, heads on), 1,200 tonnes of scallop meat and smaller quantities of sand crabs (*Portunus pelagicus*), scyllarid lobsters (*Thenus* spp.), squid (*Photololigo* spp., *Sepioteuthis* spp.), and certain fish species. The annual value of landings from the Queensland Trawl Fishery is about $120 million (ABARE 1997). The composition of the catch varies from year to year because most boats are highly mobile and will readily move along the coast switching target species depending upon abundance and market value of the catch. The fishery can be divided into nine sub-component fisheries based on primary target species and the spatial and depth distribution of these species (Table 3).

Table 3 Sub-component fisheries of the Queensland Trawl Fishery

Sub-component fishery and target species	Main geographic locations	Main fishing season [A]	Average tow duration (mins)	Tow depth (m), as % of total effort[B]		Additional comments
Tiger prawn	northern Qld	March,	129 ± 44[B]	*0- 9*	60%	shallow, inshore trawl
Penaeus esculentus	(north of	April,		*10-19*	35%	grounds, near seagrass areas
P. semisulcatus	19°30'S)	May		*20-29*	4%	
P. monodon				*≥ 30*	1%	
Endeavour prawn	northern Qld	March,	129 ± 44[B]	*0- 9*	60%	shallow, inshore trawl
Metapenaeus ensis	(north of	April,		*10-19*	35%	grounds, often overlapping
M. endeavouri	19°30'S)	May		*20-29*	4%	with the tiger-prawn fishery
				≥ 30	1%	
Red spot king prawn	northern Qld	May	128 ± 51[B]	*0- 9*	6%	offshore fishery, mostly in
P. longistylus	(north west of	to		*10-19*	8%	waters deeper than 30 m
P. latisulcatus	23°S, 152°E)	September		*20-29*	9%	
				≥30	67%	
Eastern king prawn	southern Qld	September	1. < 90	*0- 9*	4%	1. inshore waters to 20 m,
P. plebejus - 2 spatially	(south east of	to		*10-19*	8%	targeting small prawns
separate fisheries	23°S, 152°E)	May	2. > 120	*20-29*	18%	2. offshore waters to 200 m,
				≥ 30	70%	targeting large prawns
Moreton Bay	mostly	September	76 ± 29[B]	*0- 9*	43%	shallow, inshore waters,
M. bennettae	Moreton Bay	to		*10-19*	40%	targets small size prawns
P. esculentus	(27°S, 153°E)	May		*20-29*	17%	including endeavours
P. plebejus						prawns
Banana prawn	adjacent to	February	55 ± 28[B]	*0- 9*	82%	associated with the major
P. merguiensis	rivers &	to	"short"	*10-19*	15%	wet season of Qld; targets
P. indicus	estuaries	May		*≥ 20*	3%	spawning aggregations of
						prawns in inshore waters
School prawn	southern Qld	February,	"short"	unquantified		seasonal, localised fishery
M. macleayi	(25°S,153°E)	March,				in shallow waters, occurs
		April				only in some years
Scallop	central Qld	November	155 ± 49[B]	*0- 9*	0%	trawl fishery for scallops
Amusium balloti	(19°S to 25°S)	to		*10-19*	9%	occurring offshore, mostly
A. pleuronectes		April		*20-29*	6%	in deeper waters
				≥ 30	85%	
Stout Whiting	southern Qld	April to				developmental fishery, 5
Sillago robusta	(23°S to 30°S)	December				endorsees

[A] taken from Trainor (1990), [B] taken from Dredge and Trainor (1994)

These sub-component fisheries are a useful way of looking at the Queensland Trawl Fishery as each fishery can be defined easily in both space and time, and within each sub-component fishery, operating characteristics such as tow duration, tow speed and gear characteristics are broadly similar. Commercial catch and effort is not uniformly distributed throughout the fishery. Four areas along the Queensland east coast show a concentration of effort. They are Moreton Bay, Princess Charlotte Bay, the Townsville region and the Bundaberg/Hervey Bay region. Of these areas, only Hervey Bay and Moreton Bay are outside the Great Barrier Reef World Heritage Area. As such, a major proportion of the catch from trawl fisheries of the Queensland east coast is taken from within the Great Barrier Reef World Heritage Area (Tanzer *et al.* 1997).

All Queensland Trawl Fishery trawlers are required to complete a daily logbook of catch and effort. Logbook information is recorded by the Queensland Fisheries Management Authority (QFMA) on a database known as QFISH, previously known as CFISH and SUNFISH. The daily catch (by weight) of each boat is recorded usually within 30 nautical-mile grids, with more recent data being recorded on a tow-by-tow basis or a 6 nautical-mile grid basis. The QFMA does not cross validate information submitted in the compulsory logbooks with other sources of information e.g. processor records. As such, it is difficult to assess the reliability of QFISH effort data. Anecdotal reports suggest that some mis-reporting of commercial catch and effort does occur but the scale and direction (under-reporting versus over-reporting) of the potential error is unknown.

Results from the voluntary monitoring in 1991 and 1992 estimated that 5,295 (± 1,231 s.e.) were caught annually by the Queensland Trawl Fishery (Robins 1995). About 1% of captured turtles were reported dead when landed. If comatose turtles are assumed to die, then the mortality rate of trawl-caught turtles could be as high as 7%. Loggerhead, green and flatback turtles were the main species caught (Table 4).

Table 4 Species composition of turtles caught in trawl nets in the Queensland Trawl Fishery

Species	Percent of total turtles caught
Loggerhead turtle	50.4%
Green turtle	30.1%
Flatback turtle	10.9%
Pacific Ridley turtle	5.3%
Hawksbill turtle	1.5%
Leatherback turtle	not recorded caught
Unidentified	1.8%

data from Robins (1995)

The Torres Strait Prawn Fishery (TSPF) is a separate and distinct fishery from both the Northern Prawn Fishery and the Queensland Trawl Fishery. The Torres Strait Prawn Fishery was formed when the Torres Strait Treaty was ratified in 1985. As at January 1996, the fleet comprised 94 licensed vessels (including six inactive licences) assigned a potential 13,570 fishing days (Turnbull 1997). All vessels are required to hold Queensland east coast trawl endorsement and 31 hold entitlements to fish the Northern Prawn Fishery. The fleet is highly mobile and most vessels operate in Torres Strait on a part-time basis. The fishery is closed for three months, between December and March. Most effort in this fishery occurs in the first half of the fishing season (March to August), with lesser effort in the remainder of the fishing season (September to November). Annual catch is usually between 1,500 and 2,000 tonnes of prawns, comprised of brown tiger prawns (*P. esculentus*), blue endeavour prawns (*M.*

endeavouri) and red-spot king prawns (*P. longistylus*, Table 5). The catch has an annual value of around $18 to $23 million (ABARE 1997).

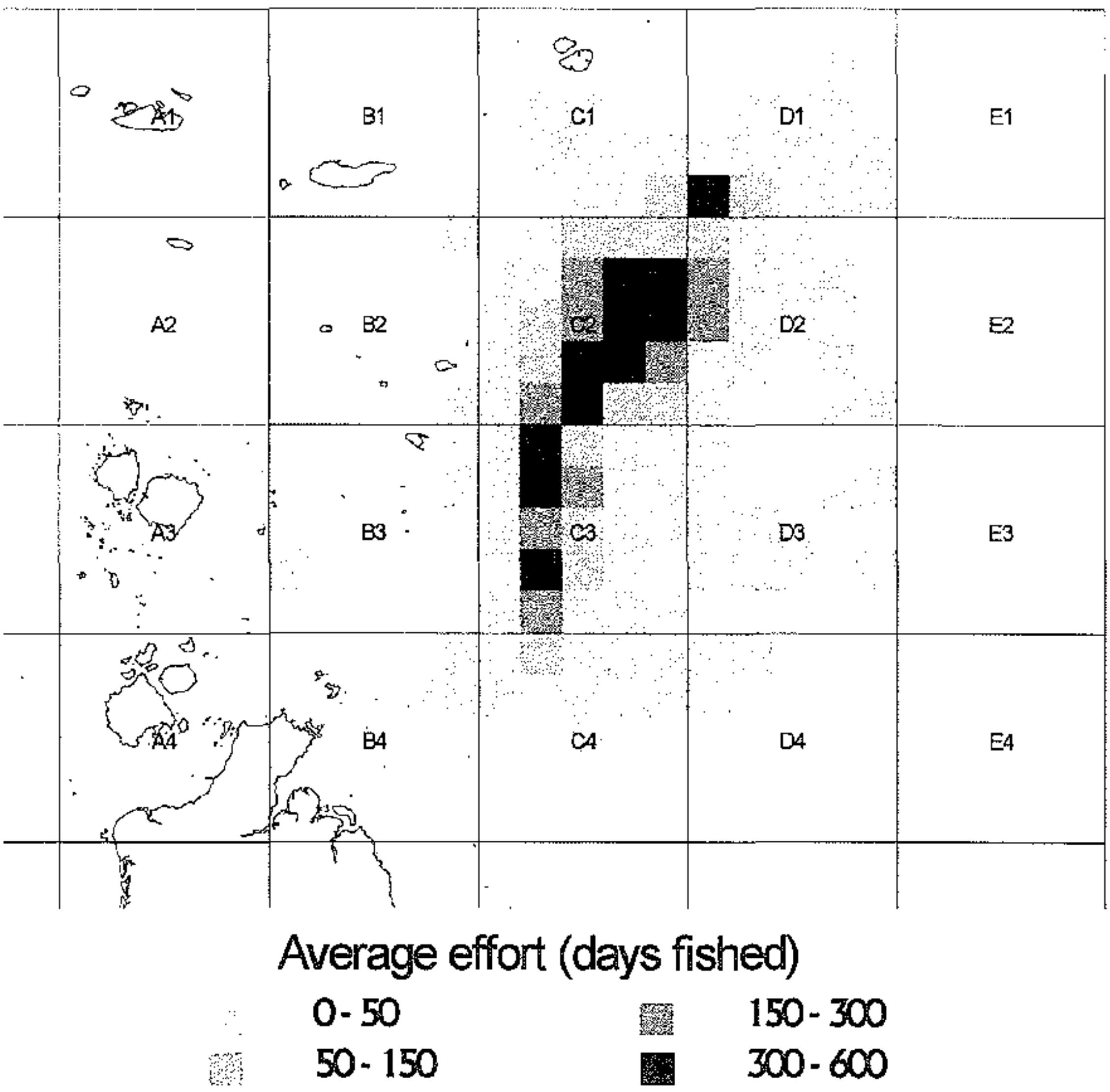
Table 5 Annual catch and effort within the Torres Strait Prawn Fishery

	1991	1992	1993	1994	1995	1996
Prawn catch (tonnes)	1,871	2,048	1,417	1,528	1,861	1,516
Total effort (hours)	100,683	123,618	89,077	97,261	86,594	85,210
Nights fished	9,983	11,907	8,525	9,244	8,158	7,893

data from the Turnbull (1997)

The fishery is restricted to a relatively small area (about 20% or 8,000 km²) of the Torres Strait Protected Zone (Turnbull 1997). The fishing grounds are bounded to the west by the Warrior Reef complex, the east by the reefs surrounding Darnley Island, the north by the border of the Torres Strait Protected Zone and the south by the border of the 'outside but near' area (Figure 2). The main fishing ground is to the east of the Warrior Reef complex with a focus around Yorke Island.

Figure 2 Location and distribution of effort within the Torres Strait Prawn Fishery



NEED

Trawling for penaeid prawns and scallops has been suggested as the main factor causing the decline of some sea turtle populations in Australian waters. Trawling was nominated in 1995 for Schedule 3 (= *Key Threatening Process*) of the Commonwealth *Endangered Species Protection Act 1992* for its bycatch of sea turtles, sea snakes, teleosts and other native species (Anonymous 1996). The nomination suggests that trawling "threatens or may threaten the survival or abundance" of sea turtles of northern Australia. Quantitative data on the species and number of turtles caught and killed in northern Australian trawl fisheries was needed to assist in the assessment of the nomination. Interim advice to the Minister for the Environment from the Endangered Species Scientific Subcommittee (Environment Australia) has yet to reach a final conclusion regarding this nomination. The assessment committee is seeking to obtain more information before providing further advice.

The initial QFMA funded study provided preliminary data on the extent of turtle-trawl interactions (Robins 1995). The extension of the study has resulted in a long-term database on turtle-trawl interactions throughout the Queensland east coast.

OBJECTIVES

The objectives of the research project were to:

1. Provide detailed information on turtle-trawl interactions over an extended period along the Queensland east coast and in Torres Strait.
2. Determine the fate of turtles which suffer repeated trawl capture.
3. Liaise with industry on the issue of turtle-trawl interactions and to educate fishers on treatment of trawl-captured turtles.
4. Investigate an alternative population monitoring method for sea turtles using catch and effort information from the trawl fleet.

METHODS

1. DETAILED INFORMATION ON TURTLE-TRAWL INTERACTIONS

Recording of turtle catches

A selective logbook program was set up in January 1991 to monitor the capture of sea turtles in trawl nets of the Queensland Trawl Fishery. It was expanded subsequently to the Torres Strait Prawn Fishery in 1994. Commercial fishers were approached individually to assist the program. Only those fishers who expressed keen interest in recording information were selected to participate. Chosen fishers were supplied with a turtle data kit that included standardised data sheets, a species identification chart (based on taxonomic features, with assisting photographs), a flexible tape measure and guidelines on measuring the curved carapace length of sea turtles. Using this kit, fishers recorded the date, time, location, tow duration, tow depth, species and curved carapace length (CCL, optional) of captured turtles. Fishers were instructed how to identify different turtle species using the identification chart but if unsure of the species were instructed to record the species as "unidentified". Fishers reporting more than five turtles per year were given disposable cameras so that their species identification could be checked and verified. The physical condition of the turtle upon capture was also recorded and classified as either healthy, injured externally, comatose or dead (Table

6). Classifications were derived from discussions with Dr Ian Poiner (CSIRO), Mr Aubrey Harris (BRS) and Dr Colin Limpus (Queensland DOE).

Table 6 Classification of turtle condition upon capture

Physical condition	Signs and symptoms
Healthy	moving, flapping aggressively
Injured externally	wounded externally but otherwise healthy
Comatose	dazed; few movements; slight signs of breathing
Dead	no movement; head limp, extended and flops to ground; no sign of breathing; eyes do not respond to touch

Recording and allocation of effort

Catch and effort data for commercial fishers in the monitoring program (hereafter referred to as the "sample fleet") were retrieved from QFISH as were the catch and effort data for the whole commercial trawl fleet (hereafter referred to as the "total fleet"). Data retrieved from QFISH were cleaned to remove invalid records (e.g. land-locked records of fishing effort). Effort was in boat-days fished and was allocated to each sub-component fishery based upon which target species made up the largest proportion of each days total catch. The sub-component fisheries (Table 3) were used with one modification and one exception. The school-prawn fishery is sporadic between years and fewer than 400 days per year could be allocated to this fishery during the study. The school-prawn fishery was therefore incorporated into the eastern-king-prawn fishery because it occurs in the same location. The stout whiting fishery only had five endorsees when the program began and only limited effort was expended in this sub-component fishery. As such, only seven sub-component fisheries were used to assess turtle catch and mortality. The spatial and temporal distribution of sample fleet effort was compared to total fleet effort between sub-component fisheries over months and years using an analysis of variance (ANOVA), which showed a reasonably constant sampling fraction across all strata.

Estimation procedures

The variable of interest is turtle captures, both by species and in total. Our main objective was to estimate the average annual turtle catch and associated 95% confidence interval. Hence, annual fleet effort, whilst being a known quantity, was treated as a random variable for the purposes of inferring future annual turtle catches. Annual catch was estimated by the product of the two available variables, namely turtle catch per unit effort (turtle CPUE) by total fleet effort (in boat-days). This product of two independent parameters gives an unbiased estimator of the total (Pollock *et al.* 1994). Each individual boat record was allocated to one of the seven sub-component fisheries of the Queensland Trawl Fishery (Table 3) based jointly on the listed locations and captures of target species. Within these fisheries, the database of sample fleet turtle captures and effort were summed into monthly values and used to calculate turtle CPUE per QFISH grid over the six years 1991 to 1996. Monthly data were used in preference to individual daily records to i) minimise variability and ii) reduce the dataset to a size amenable for analysis. The data for analysis were thus stratified as seven sub-component fisheries by six years by twelve months within years. Data for the Torres Strait Prawn Fishery analysis were stratified as one fishery by three years by nine months within years.

Total fleet effort data were distributed approximately normally. The stratum main effects for this variable were determined by unweighted and untransformed parametric analysis of variance.

Turtle CPUE data tended to be skewed, with the degree of skewness varying between sub-component fisheries. A weighted analysis of variance of turtle CPUE, with the weights for each observation being the number of sample fleet boat-days used in its calculation, was used to determine the relative importance of each of the main strata. Numerous transformations were trialed to correct for departures from normality, with a view to using bias-corrected back-transformed means (Kendall and Stuart 1967) and confidence intervals. However, these methods did not give consistent results, due in part to the presence of a reasonable number of true zero turtle CPUEs throughout the data.

These preliminary analyses demonstrated both large differences and heterogeneous variances between sub-component fisheries for both total fleet effort and turtle CPUE. The year and month effects in the preliminary analysis of turtle CPUE were not large and were interpreted as indicative of random variation, giving 72 independent observations of turtle CPUE for each sub-component fishery. Both the year and month effects in the preliminary analysis of total fleet effort were significant ($p < 0.01$). The month effect within each sub-component fishery was reduced to a single degree-of-freedom contrast between 'high season' and 'low season'. Fishing seasons were derived from the months in which the majority of the target species was caught (Table 3). Hence, the strata for estimation of Queensland Trawl Fishery total fleet effort consisted of seven sub-component fisheries by six years by two seasons, with six random observations within each strata. Similarly, the strata for estimation of total fleet effort within the Torres Strait Prawn Fishery was one fishery by three years by two seasons, with six random observations for "high season" and three for "low season".

The weighted means and standard errors (using pooled variation from analyses within each sub-component fishery) were used to calculate the parametric estimates of total captures and confidence limits about these estimates, via the basic methods of Buonaccorsi and Liebhold (1988) and Poiner and Harris (1996), for each of the defined fisheries. Independence between these means was assumed. We incorporated one refinement above that of Poiner and Harris (1996), as we were interested in the variance of the direct product of the two means (giving total annual captures for each fishery in each year), rather than in the variance of the population of products. The unbiased estimate of this variance is as listed in Goodman (1960), equation nine. Whilst approximately correct, these methods give symmetrical confidence limits about the estimated means, which may be questionable, given the skewness of turtle CPUEs and hence total turtle captures.

An alternate approach for data that are non-normal is the bootstrap (Efron and Tibshirani 1993). For each replicated bootstrap, the captures for each strata (on a fishery by year by season basis) were estimated by multiplying bootstrapped mean turtle CPUE by bootstrapped mean total fleet effort, with the number of resamplings (with replacement) for each being the number of observations available (Efron and Tibshirani 1993), i.e. six for total fleet effort and 72 for turtle CPUE. Similar to the parametric analyses, bootstrap resamplings from the turtle CPUE data were weighted according to the sampling fleet effort of each observation. We were guided by DiCiccio and Efron (1996), who recommends the use of 2,000 or more bootstrap replicates for the more difficult estimation of confidence intervals. We chose to use 5,000 replicates to estimate the mean catch and associated distribution per strata and overall because of the variability in the data.

Total annual turtle captures were estimated from the distribution generated by summing the 5,000 bootstrap estimates from each strata. Non-parametric confidence intervals from these ordered replicates were estimated using the standard percentile method. This method has been shown to be asymptotically valid (Young 1994). Whilst advanced bootstrap alternatives have been proposed, Smith (1997) found that the percentile method was superior to both the bias-corrected and accelerated bootstrap methods for estimating confidence limits using similar trawl data.

Estimating turtle mortality

Previous studies estimated the number of turtles killed by trawling from observed dead turtles (Henwood and Stuntz 1987). This has been criticised as being a minimum estimate of trawl mortality because comatose turtles are not included (Murphy and Hopkins-Murphy 1989). Comatose turtles returned to the water after a trawl capture probably die and should be included in calculations (Kemmerer 1989). Two estimates of mortality have been made in the present study:

1. a minimum estimate was based on reported dead turtles (hereafter referred to as observed mortality = dead turtles/total turtle captures); and
2. an upper estimate of mortality has been made assuming that all comatose turtles die (hereafter referred to as potential mortality = (dead turtles + comatose turtles)/total turtle captures).

The relationship between tow duration and mortality was analysed using a conditional weighted bent-stick linear regression (GENSTAT) for (a) observed mortality and (b) potential mortality. Sufficient data were available to analyse the relationship for all species pooled and for the following individual species: loggerhead turtles, green turtles, Pacific Ridley turtles and flatback turtles. Data were grouped into 15-minute tow time intervals, except for tows longer than 240 minutes which were pooled (Kemmerer 1989). Significance of the bent-stick linear regression was tested using sum of squares corrected for the mean rather than the unadjusted sums of squares.

2. DETERMINING THE FATE OF TRAWL-CAUGHT TURTLES

The original project proposal suggested that the fate of turtles taken by trawl would be estimated using a mark-recapture experiment of trawl-caught turtles. Moreton Bay was selected as the study site due to the reliable catch of loggerhead turtles in trawl nets. It is also a fishery where turtles may suffer repeated trawl capture due to the intensity of trawling. Turtles caught by trawlers in Moreton Bay were to be marked with short-term paint and released. The experiment was to be publicised, with fishers and volunteer beach-monitoring personnel reporting marked turtle carcasses. "Stored" live turtles would also be used as controls in the experiment.

After careful consideration (including discussions with Professor Helene Marsh, James Cook University, Dr David Die, CSIRO Division of Marine Research and Dr Colin Limpus, Queensland Department of Environment), the methodology to determine the fate of trawl-caught turtles was modified. The success of a mark-recapture study of trawl-caught turtles would be highly dependent upon the response from commercial fishers and the general public in reporting the recapture of marked turtles. Given the controversial nature of the issue of trawl-caught turtles, support from the majority of commercial fishers in Moreton Bay for the mark-recapture study could not be guaranteed. The degree of under-reporting of marked turtles (both alive and dead) would be extremely difficult to quantify. This "error" would seriously effect the accuracy of any measure of survival from the mark-recapture experiment (Pollock 1982; Burnham *et al.* 1987). As an alternative, trawl-caught turtles were monitored using ultrasonic, biotelemetry equipment. Such work has been conducted successfully for several years in the USA. Using biotelemetry equipment would ensure that precise information about the fate of trawl-caught turtles could be obtained.

Technical specifications of tracking equipment

Two tracking systems were used for monitoring the turtles post-release from commercial trawlers. The initial system (real-time module) only allowed real-time monitoring of the turtle. Data was logged at-sea and did not require the retrieval of the transmitters. This system was used initially as we were unsure of the probability of equipment retrieval after its timed release from the turtle. The second system (data-logging module) was used after preliminary tracking episodes suggested a high probability of equipment retrieval. This allowed the use of archival data-logging equipment. The equipment setup is described below (Table 7).

1. Real-time module

This system consisted of an ultrasonic transmitter connected to a radio transmitter (Figure 3). The radio transmitter and ultrasonic transmitter were sleeved together by a 70 mm x 30 mm (diam.) piece of PVC tubing. The transmitters were enclosed within a custom-made float using *Pour-In-Place Syntactic Foam*™ (Flotation Technologies) so as to provide slightly positive buoyancy to the complete modules. Floats were cylindrical in shape being 38 mm in diameter and 115 mm (module 1) or 140 mm (module 2) in length. The transmitters were connected via a tether of 0.87 mm monofilament with a breaking strength 45 kg, to a galvanic timed release (GTR) fuse.

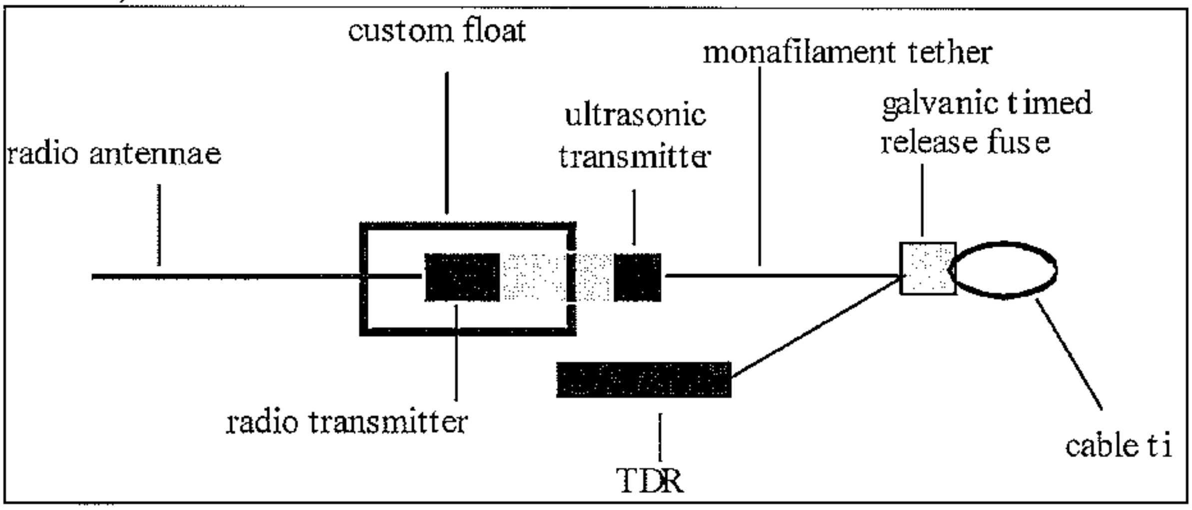
2. Data-logging module

A second method of monitoring trawl-caught turtles was used to ensure that data was recorded continuously from the time of release. Temperature Depth Recorders (TDRs) were attached to the real-time monitoring system using a second monofilament tether. Temperature and depth were recorded each 35 seconds. The TDRs had a memory of 64 kbytes, allowing 8,128 recordings of both temperature and depth over 3 days. TDRs were purchased through an additional contribution to the project by the Reef Cooperative Research Centre.

Table 7 Specifications of biotelemetry equipment used to monitor trawl-caught turtles

System	Manufacturer	Model	Specifications
Radio	Advanced Telemetry Systems	3pn standard transmitter (201) Fieldmaster Receiver 4 element Yagi antenna	60 day life span, weight 12 grams
Ultrasonic	Sonotronics	DT-88 depth tags USR5-W receiver DH-2 directional hydrophone DR-92 data decoder	17 mm x 80 mm, 60 day life span
TDR	Vemco	MiniLog-TDR MiniLog-PC computer interface	21 mm diam x 100 mm, 34 m depth tolerance, 0.2m resolution ± 1m accuracy, 5 year life span

Figure 3 Schematic diagram of biotelemetry equipment
(not to scale)



Field methods

Field work was carried out in Moreton Bay during the main prawning seasons of spring and summer, 1995-1996 and 1996-1997.

Moreton Bay was an appropriate study site because:

- of the frequent capture of the endangered loggerhead turtle,
- turtle catches are a reliable event for trawlers in this area, with an average of one turtle caught for every three days trawled,
- annually the catch is estimated to be 3,187 ± 1,074 (s.e.) turtles (Robins 1995), accounting greater than 50% of the turtles caught in the Queensland Trawl Fishery,
- reported mortality for this fishery is 0.6% and warrants verification as any additional delayed post-trawl mortality could significantly change current mortality estimates.

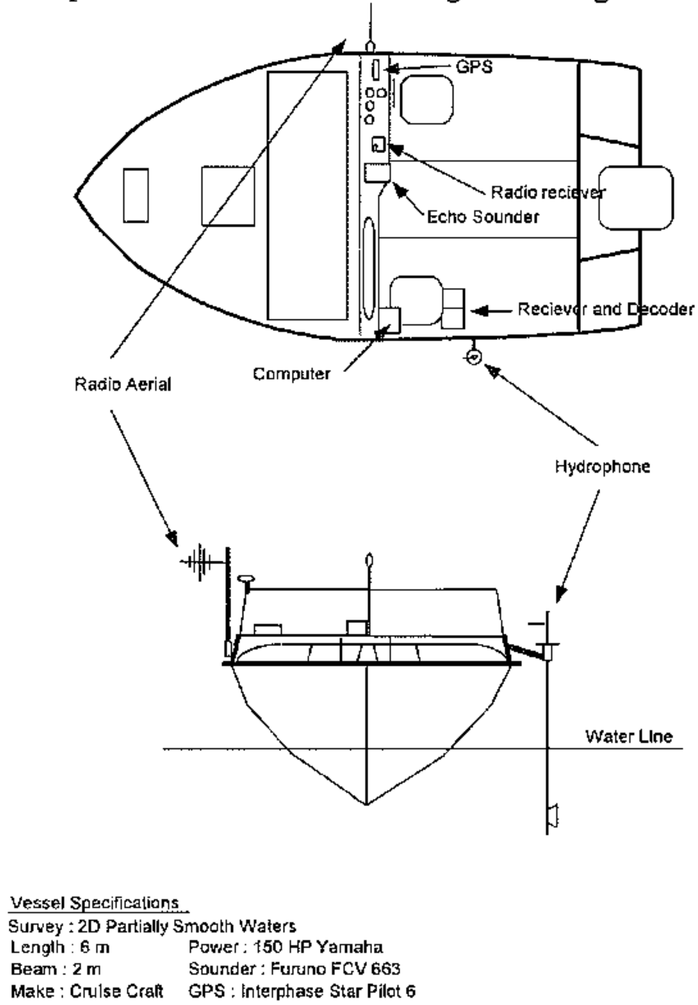
The following is a summary of the methods for monitoring trawl-caught turtles.

Wait on a trawler until a turtle is caught - An integral and time consuming part of monitoring trawl-caught turtles was acquiring a turtle that had been caught in a trawl net. Two commercial fishers in Moreton Bay assisted in this task. Fishers would undertake normal trawling operations with one research staff member waiting onboard the trawler. The other researcher would wait in a small semi-enclosed vessel that was set up for ultrasonic and radio tracking (Figure 4). When a turtle was caught during normal trawling operations, the turtle was fitted with an ultrasonic and radio transmitter before release.

Attach transmitters and TDR - Tags were attached to the sea turtle via 7 kg breaking strength cable-tie inserted through a 3 mm hole drilled into a marginal scute adjacent to the post-central scutes. Benzocaine (1/1000 of stock) was applied to the marginal scute before and during drilling to numb the area. Antifungal cream was smeared into the hole to assist in the prevention of infection before the turtle was released into the water.

Release turtle into the water - This was the easiest of the tasks.

Figure 4 Equipment setup on a 6 m vessel for tracking trawl-caught turtles



Follow the turtle in a small boat, relocating the turtle each day to maintain contact - Turtles were monitored as soon after release as possible from the tracking vessel. The vessel was equipped with depth sounder and a Global Positioning System (GPS). Real-time monitoring required constant contact with the ultrasonic signal, which was decoded and recorded by an onboard computer. The GPS position of the boat and water depth was recorded at 15 minute intervals to allow interpretation of the depth recordings within the context of the location of the turtle. Real-time tracking of trawl-caught turtles was limited by weather conditions, with strong winds (i.e. > 20 knots) or thunderstorms ending tracking. When the weather permitted, the tagged turtle was relocated each day subsequent to its release until the Galvanic Timed Release fuse corroded and the transmitter modules were located. Locating the turtle was essential when using the real-time tracking system, but not so when the TDRs were used.

Find the tag module after it has released from the turtle – Initially, this was something akin to looking for a needle in a haystack when the size of Moreton Bay (26 km wide by 55 km long) was compared to that of our tracking equipment. However, the radio and ultrasonic technology proved itself in this instance with only one module being lost. (The lost module was found and returned by a member of the public some 28 months after its disappearance.) Data recorded by real-time tracking and data-logging were plotted to determine visual trends in behaviour of trawl-caught turtles after release from the trawler. The number of surfacings per hour were calculated and plotted against time since release as an indication of the "stress" and recovery of the turtle after the trawl-capture.

3. INDUSTRY LIAISON AND EDUCATION

Information returned by fishers formed a key part of the turtle monitoring program and access to commercial trawlers was essential to complete the monitoring of trawl-caught turtles in Moreton Bay. All fishers who participated in the voluntary turtle monitoring program were sent a quarterly newsletter summarising issues and results to assist in industry liaison and education. Fifteen newsletters were sent to fishers over the duration of the project. Issues relating to turtle captures in trawl nets were also discussed during wharfside interviews with fishers.

Basic information on ways of handling stressed and moribund turtles was reinforced through the development and publication of *Turtle Recovery Procedures* and *Code of Fishing Ethics: The Capture of Sea Turtles*. This work was undertaken in conjunction with the Queensland Commercial Fisherman's Organisation. This leaflet is included in Appendix 1.

4. POTENTIAL USE OF CATCH PER UNIT EFFORT INFORMATION

It is difficult to detect declines in the population size of sea turtles unless dramatic changes occur. Determining numbers and the status of sea turtle populations has intrinsic difficulties because of i) the paucity of census data, ii) the difficulties in estimating abundance and determining trends in localised feeding grounds, iii) the mixture of stocks in feeding grounds, iv) the lack of quantification of life history parameters and the longevity of turtle life cycles, and v) the dispersed nature of the population between feeding grounds and nesting beaches and our incomplete understanding of the migration patterns (Marsh *et al.* 1993).

Current methods of monitoring turtle populations

The most common method of monitoring the trends in the size of sea turtle populations is nesting beach surveys (Richardson *et al.* 1978; Meylan 1981; Bjorndal *et al.* 1993). These are undertaken by counting nesting females or their tracks by vehicular or foot patrols at known turtle rookeries during the nesting season. Survey methodology is not consistent between different survey programs. Most nesting beach studies also use tag-recapture methods where individual turtles are marked using a metal tag or a PIT tag. Recaptures provide information on growth and movement (Frazer 1983; Limpus 1992) as well as limited information on survival (Chaloupka and Musick 1996). Nesting beach surveys have documented the decline of turtle populations in Costa Rica (Bjorndal *et al.* 1993), the USA (Frazer 1983), south east Asia (Limpus *et al.* 1994) and Australia (Limpus and Reimer 1994). The main advantage of nesting beach surveys is the relative ease with which the animals can be accessed. The main disadvantage of nesting beach surveys is that this method does not account for male, sub-adult and non-breeding female turtles in the population.

Population trends based on nesting surveys assume that the number of nesting females is proportional (and remains constant) to the total population. Few studies attempt to validate this assumption by documenting the annual proportion of adult females within the population migrating to nest (Bjorndal *et al.* 1993; Limpus *et al.* 1994). As such, the species being monitored must nest in predictable patterns through time and in space. The method is invalid for species whose nesting patterns fluctuate due to environmental factors (Ehrhart 1989). For example, nesting surveys for green turtles would be a poor indicator of the overall population status because annual numbers of nesting turtles fluctuate dramatically due to environmental factors such as the El Nino effect (Limpus and Nicholls 1988). Whether other sea turtle species are influenced by environmental factors (short or long term) is unknown. Also, sea turtles have remigration intervals that vary between species, locations and individuals. This makes it difficult to monitor the nesting patterns of individuals or to estimate the survival of tagged individuals without long term data.

Most sea turtle tag-recapture programs have limited recapture success which can be attributed to tag loss (McDonald and Dutton 1995), non-reporting of tagged turtles (Frazer 1983), high post-nesting mortality or simply tagged turtles not being recaptured. Few studies have attempted to use tag-recapture information to estimate population size because the populations under study are generally not closed (i.e. they are opening to migration, mortality and recruitment) and there is a lack of knowledge regarding sea turtle ecology.

Some preliminary work has investigated the feasibility of aerial surveys as indices of distribution and density of sea turtles (LeBuff and Hagan 1978; Marsh and Saalfeld 1989; Thompson *et al.* 1991; Shoop and Kenney 1992; Epperly *et al.* 1994; Epperly *et al.* 1995). Aerial surveys basically involve flying strip transects at a predetermined height with observers counting animals or nests that fall within a defined width of water or land. Correction factors are then applied to the counts to compensate for visibility (availability) and observer (perception) biases. Most aerial surveys for sea turtles are flown in conditions of low sun-glare, good weather and minimal water turbidity to increase the sightability of turtles. Density estimates derived from aerial surveys of rare animals, such as sea turtles, have large variability associated with estimates but this can be reduced with more intensified sampling. The main advantage of aerial surveys is their ability to cover large and remote areas and to identify areas of high turtle density (LeBuff and Hagan 1978; Marsh and Saalfeld 1989; Epperly *et al.* 1994; Musick *et al.* 1994).

Aerial surveys are not suitable for estimating population size as not all turtles will be sighted due to water turbidity or observer bias. This results in an underestimate of turtle densities (Marsh and Saalfeld 1990). Information from aerial surveys can be used for planning conservation measures or identifying seasons and areas where sea turtles are at risk from human activities such as trawling (Epperly *et al.* 1995).

Catch per unit effort as an alternate method

Catch per unit effort (CPUE) has been used as an index of fish stock abundance for many years. The majority of studies where CPUE has been calculated have been undertaken on the species that are the target of the fishery. The simplest model of commercial catch and abundance is that catch rate (CPUE) is directly proportional to abundance i.e.

Catch = **N** (stock abundance) x **E** (fishing effort) x **q** (catchability coefficient)

For catch rate to be proportional to abundance, fishing effort must be distributed at random with respect to the fish. CPUE data must be spatially stratified to overcome the spatial concentration of fishing effort in areas of high target catch abundance (Hilborn and Walters 1992). Also, Hilborn and Walters (1992) recommend using an adjusted index of abundance instead of using catch/effort because effort is usually not constant or well defined.

CPUE might be an alternate measure of populations trends in sea turtles because i) turtles are not the target species of commercial fishing effort, therefore there are no targeted areas of turtle catch where density is high, ii) turtles in some feeding grounds are known to have relatively stable home ranges, so the animals are not continually moving, and iii) commercial trawl effort provides a "cheap", large-scale sample of inwater turtle densities, that can be stratified spatially and temporally (i.e. CPUE weekly, monthly). This may overcome the problems associated with seasonal trends in effort or turtle abundance.

The potential disadvantages of using CPUE as an index of turtle abundance include i) recaptures of individual turtles - without some means of flagging recaptures, turtle abundance will be overestimated, ii) sampling is limited to commercially trawlable areas, but it is known that turtles also inhabit areas outside the commercial trawl grounds, iii) catchability of turtles in trawl nets may not be constant, varying with factors such as water visibility, species and trawl speed, and iv) if catch rates are low, then estimates of total catch will have inherently large confidence intervals.

Trawl surveys are suitable for estimating turtle densities over short time periods when immigration and emigration of turtles from an area are negligible and are less appropriate to estimate total turtle population size (Meylan 1981). The cost of using research trawling to undertake simultaneous, wide-scale trawl surveys of turtle densities would be prohibitive and could only be considered as a feasible method if undertaken as part of normal fishing operations.

Catch and effort data have been used to estimate the density of sea turtles in localised areas (Butler *et al.* 1987; Schmid 1995) and in some fisheries (Poiner and Harris 1996). Butler *et al.* (1987) used a depletion experiment to estimate the number of loggerhead turtles in selected channels and inlets in eastern Florida, USA. Repetitive trawling effectively 'removed' turtles from an area (by marking), thus identifying repeated captures. The catch efficiency of the sampling gear was also estimated. The probability of turtle capture was estimated for each area and was based on the supposition that catch-per-tow decreased as turtles were 'removed' from the area. Regression of the cumulative turtle catch against catch per sample was used to estimate the original population size in the area. The method assumes that the turtle population within an area is closed and that each tow was an equal unit of effort with the probability of capture remaining constant. The catch rates were variable across season and month with differing categories of turtles (i.e. adult males, adult females and sub-adults) being more prevalent in different seasons. Butler *et al.* (1987) also suggested that turtles used preferred habitats in these channels and inlets.

Poiner and Harris (1996) used catch per unit effort data (CPUE) to estimate the total number of turtles in the Northern Prawn Fishery, Australia. CPUE requires effort to be well defined and constant throughout time (Robson 1966) but this seldom occurs in real fisheries. The method also assumes that turtles are uniformly distributed unless CPUE data can be highly stratified (i.e. for depth or habitat type). Trawls are usually made along specific paths within the marine environment so to extrapolate fine-scale sampling to a large area introduces many unquantifiable errors. Observed trawl catches were not evenly distributed throughout the Northern Prawn Fishery (Poiner and Harris 1996) and this was partially adjusted for by stratifying the CPUE data into two depth categories, 10-40 m and 41-90 m. However, it is unlikely that the depth stratification adjusted adequately for the density of sea turtles across such a large area as the Northern Prawn Fishery (783,000 km^2).

The current study calculated turtle CPUE for each 1666.8 km^2 (= 900 nm^2) QFISH grid, pooled for each month within the sampling period. This gave 72 potential estimates of turtle density for any one of the 133 grids in which turtle captures were recorded. Turtle CPUE was calculated for each species. Total turtle CPUE was not an appropriate index of the status of turtle populations as pooling across species may mask subtle declines in any one of the species.

CPUE for each turtle species was plotted for each degree of latitude to determine which areas of the Queensland east coast had sufficient data to undertake an investigation of the usefulness of CPUE over time. Many grids had incomplete sampling over the 72 months or had recorded true zeros as the predominate estimate of CPUE.

DETAILED RESULTS

ASSESSMENT OF OUTCOMES VS OBJECTIVES

Objective 1. To provide detailed information on turtle-trawl interactions over an extended period along the Queensland east coast and in Torres Strait.
A voluntary turtle monitoring program recorded turtle captures in trawl nets between 1991 and 1996. The success of the program relied heavily on the participation of individual commercial fishers. Over the 6 years, 106 different vessels took part in the program, representing the involvement of 12% of the Queensland trawling industry. In total 1,527 turtles were recorded caught over 23,906 days fished. Stratified, weighted analysis of the data resulted in an annual estimated turtle catch for the Queensland Trawl Fishery of 5,901 (95% confidence interval 5,199 - 6,604) given an average total fleet effort of 84,876 days fished. This was comprised of 2,938 loggerhead turtles (95% C.I. 2,390 - 3,487), 1,562 green turtles (95% C.I. 1,223 - 1,902), 80 hawksbill turtles (95% C.I. 42 - 119), 323 Pacific Ridley turtles (95% C.I. 240 - 406) and 968 flatback turtles (95% C.I. 770 - 1,165). A similar analysis resulted in an annual estimated turtle catch for the Torres Strait Prawn Fishery of 652 (95% C.I. 537 - 788), given an average total fleet effort of 8,634 days fished. This was comprised of 85 loggerhead turtles (95% C.I. 50 - 131), 145 green turtles (95% C.I. 95 - 203), 6 hawksbill turtles (95% C.I. 0 - 15), 18 Pacific Ridley turtles (95% C.I. 6 - 32) and 400 flatback turtles (95% C.I. 304 - 518).

Greater than 90% of all turtles reported caught in the Queensland Trawl Fishery were healthy when first landed on the boat. Four percent were reported as comatose and 1% were reported as dead. Mortality rates of trawl-caught turtles were similar in the Torres Strait Prawn Fishery, where 96% of reported turtles were healthy. Three percent were reported as comatose and 1% were reported as dead. These mortality rates translate to an estimated trawl related mortality of between 72 and 94 turtles for the Queensland Trawl Fishery. If comatose turtles are considered to die as a consequence of a trawl capture (i.e. dead + comatose turtles) then between 306 and 468 turtles are estimated die as a consequence of a trawl capture. Trawl related turtle mortality for the Torres Strait Prawn Fishery was estimated to be between five and eight turtles per year (i.e. dead turtle only) or between 21 and 32 turtles if comatose turtles are considered to die as a consequence of a trawl capture. These mortality rates are considerably lower than that reported for the Northern Prawn Fishery, which were 10% dead in 1989 and 18% dead in 1990, and 39% if comatose turtles were assumed to die in 1990 (Poiner and Harris 1996).

There are a number of factors that may explain the difference in mortality rates between the Northern Prawn Fishery and the two fisheries reported here. It has been suggested that mortality rates in a fishery are the consequence of the average duration of the trawls as well as the susceptibility to drowning of the dominant species caught. It has been speculated that flatback turtles have a greater tolerance to trawl-capture than other species. Flatback turtles were the dominant species caught in the Torres Strait (66%) and this combined with an average tow duration of 144 minutes may account for the lower mortality rates in the Torres Strait Prawn Fishery than in the Northern Prawn Fishery, where average tow duration has been reported as 186 minutes. Mortality rates of turtles in the Queensland Trawl Fishery are markedly lower than the Northern Prawn Fishery most likely as a consequence of short tow durations (i.e. 60 to 90 minutes) in the areas where turtles are caught predominantly, i.e. the Moreton Bay fishery. Another possible cause of the low mortality rates in this study could be under-reporting of dead turtles by fishers involved in the program. However, the incidence of a low mortality rate of trawl-caught turtles is supported by tow duration data and levels of mortality similar to the Northern Prawn Fishery were reported in some areas of the Queensland Trawl Fishery where tow durations are longer (i.e. 129 minutes, tiger and endeavour prawn fisheries of north Queensland). The degree of inaccurate reporting should be variable, as different fishers would report differently. It would take a concerted effort from the majority of commercial fishers involved in this study (some 106 individuals) to have a major effect on data accuracy.

The assessment of sea turtle bycatch in Australian prawn trawl fisheries is necessary to support the conservation of threatened sea turtle species. The voluntary turtle monitoring program has developed a long-term database on the frequency and location of turtle captures. These data are being used in fisheries management for the identification of priority areas where the issue of how to abate threats to turtles from trawling is being negotiated. This includes the identification of areas where TEDs are to become compulsory. The commercial fishing industry has input to these negotiations through the Queensland Trawl Management Plan via TrawlMAC. The Queensland Department of Environment and the Great Barrier Reef Marine Park Authority also have input into determining these priority areas through the joint analysis of the turtle CPUE data via a collaborative risk assessment.

Objective 2. To determine the fate of turtles which suffer repeated trawl capture.
Seven trawl-caught turtles were monitored post-release using real-time tracking systems (incorporating radio and ultrasonic transmitters) and data-logging equipment (temperature-depth recorders TDRs). The TDR's provided the most complete picture of dive profiles of trawl caught turtles. All turtles displayed a distinctive "escape" response upon release. The data recorded indicates that trawl capture resulted in appreciable behavioural changes, i.e. an increased number of surfacings. Small turtles appeared to take longer to recover than large turtles. No delayed post-trawl mortalities were observed, as would be expected with the small sample size and a reported trawl mortality of 0.6% in Moreton Bay. Determining the fate of trawl caught turtles was an extremely difficult task, given the range of conditions under which captures occur. This topic warrants further research.

Objective 3. To liaise with industry on the issue of turtle-trawl interactions and to educate fishers on treatment of trawl-captured turtles.
The participation of commercial fishers in the voluntary turtle monitoring program had a significant impact on raising the industry awareness of the issues associated with the incidental capture of turtles in trawl nets. Visits by research staff to the ports and wharfs of the Queensland east coast, resulted in energetic discussions on these issues between boat owners, skippers, deckhands and research staff. In conjunction with the Queensland Commercial Fishermans Organisation, recovery treatments for trawl-caught turtles and a code of fishing ethics regarding turtle captures were developed. With support from the current project, the Queensland Commercial Fishermans Organisation, the Australian Fisheries Management Authority, the Australian Prawn Promotion Association and the Australian Nature Conservation Agency (= Environment Australia), jointly produced a four page leaflet, including recovery procedures, species identification guide and code of fishing ethics. It was distributed to all master fishermen from the Queensland east coast, Torres Strait and Northern

Prawn fisheries. Anecdotal reports from commercial fishers provide encouraging information that these recovery techniques are being employed in the industry and that many turtles can recover from trawl captures.

Objective 4. To investigate an alternative population monitoring method for sea turtles using catch and effort information from the trawl fleet.

Limited quantitative information is available about the current status of turtle populations from the Queensland east coast. Current indices of population trends (i.e. nesting beach surveys) are only available for loggerhead turtles. Turtle catch per unit effort (CPUE) was most useful as an overall, wide-scale, in-water survey of the distribution of sea turtles throughout Queensland east coast waters. The turtle CPUE by species has provided insights into potential areas where sea turtles are aggregated and areas that may be fruitful for further research into the biology and population dynamics of sea turtles by conservation agencies.

CPUE was investigated as an alternate means of monitoring turtle populations only in areas where sampling effort and turtle catch were continuous throughout time. Of the 133 QFISH grids in which turtle bycatch occurred, only two had sufficient data to provide a continuous picture of abundance. These grids were Moreton Bay (W88) and Bundaberg (U32). CPUE was still highly variable within these grids, and it is likely that unless sampling effort is highly concentrated and continuous throughout time, trends suggested by trawl CPUE will not be detected unless the population size changes dramatically. Turtle CPUE may be a useful alternate index of population trends if turtle bycatch was recorded by the majority of the trawl fleet as information collected by the compulsory logbook associated with trawl fisheries.

1. DETAILED INFORMATION ON TURTLE-TRAWL INTERACTIONS

General results

The voluntary monitoring program relied on the participation by commercial fishers. Over the six years, 106 different boats took part in the program. Some fishers consistently returned information over the whole six years, others assisted the program for varying amounts of time (Table 8). This gave diversity to the data set, ensuring that a wide range of geographic locations were sampled as well as involving over 12% of the Queensland trawling industry in a research program.

Table 8 Duration of participation by fishers in the voluntary monitoring program

	6 years	5 years	4 years	3 years	2 years	1 year
Number of Fishers	9	2	6	14	23	42

In total 1,527 turtles were reported caught in Queensland Trawl Fishery nets during the six years. By themselves, these figures mean little as they are influenced by the location of the fishing effort expended. Between 1991 and 1993, turtles reported caught were dominated by loggerhead and green turtles as a consequence of sampling effort being concentrated in southern Queensland. In contrast, sample fleet effort was more concentrated in northern Queensland in 1994 to 1996 and this is reflected in the higher reported frequency of flatback turtles and reduced reporting of loggerhead turtles.

The species composition of reported trawl-caught turtles varied between years with three species (loggerhead, green and flatback turtles) always dominating the catch (Table 9). Pooled across years, 40% of the turtles caught were identified as loggerhead turtles (range per year: 25% to 53%), 28% were green turtles (range per year: 21% to 41%) and 20% were flatback turtles (range per year: 7% to 31%). Pacific Ridley turtles accounted for 6% of turtles caught and hawksbill turtles accounted for 2% of turtles caught. Only one small leatherback turtle (47 cm CCL) was reported captured off Townsville during the program. It was released alive into the water. The capture of leatherback turtles in trawl nets on the Queensland east coast is such a rare event that this capture has not been included in the analyses in the remainder of the report.

Table 9 Reported turtle captures in the Queensland Trawl Fishery

Species	1991	1992	1993	1994	1995	1996	Total
Loggerhead turtles	206	125	94	90	39	63	617
Green turtles	89	112	43	91	50	48	433
Leatherback turtles	0	0	0	0	0	1	1
Hawksbill turtles	9	1	2	3	3	5	23
Pacific Ridley turtles	26	12	7	14	15	18	92
Flatback turtles	54	18	40	84	49	67	312
Unidentified	5	2	2	9	0	31	49
Total	389	270	188	291	156	233	1,527

A total of 151 turtles were reported caught in trawl nets in Torres Strait Prawn Fishery during the monitoring program. Between 1991 and 1993, Torres Straits operators were not targeted by the monitoring program. However, from 1994 to 1996, greater emphasis was placed on sampling boats that worked in the Torres Strait Prawn Fishery. This explains the dramatic increase in recorded turtle captures in these latter three years. Pooled across years, flatback turtles dominated the captures in Torres Strait, accounting for 66% of reported captures (range per year: 55% to 78%). Green turtles and loggerhead turtles were the other species caught commonly, accounting for 21% and 10% of turtles caught respectively, pooled across years (Table 10).

Table 10 Reported turtle captures in the Torres Strait Prawn Fishery

Species	1991	1992	1993	1994	1995	1996	Total
Loggerhead turtles	2	0	0	5	5	3	15
Green turtles	3	4	3	14	6	2	32
Leatherback turtles	0	0	0	0	0	0	0
Hawksbill turtles	1	0	0	0	1	0	2
Pacific Ridley turtles	0	0	0	0	1	0	1
Flatback turtles	15	4	10	23	30	18	100
Unidentified	0	0	0	0	1	0	1
Total	21	8	13	42	44	23	151

Estimated turtle catch per year

The bootstrap means were virtually the same as the means from the weighted untransformed parametric analysis, indicating the overall estimates of turtles caught are quite stable. However, the confidence limits were notably different, as also found by Buonaccorsi and Liebhold (1988) in their entomological studies. The bootstrap 95% confidence intervals were tighter, as well as non-symmetrical (as expected). The estimated means and confidence limits of total turtle captures from the standard, unweighted untransformed parametric analysis and from the replicated bootstrap, stratified on fishery by year by season, are compared in Figure

5. Similar variability was observed about the estimates for each species, which are listed by fisheries in Table 11.

Figure 5 Comparison of total turtle captures (means and 95% confidence intervals) for standard and bootstrap analyses, stratified on a fishery by year by season basis

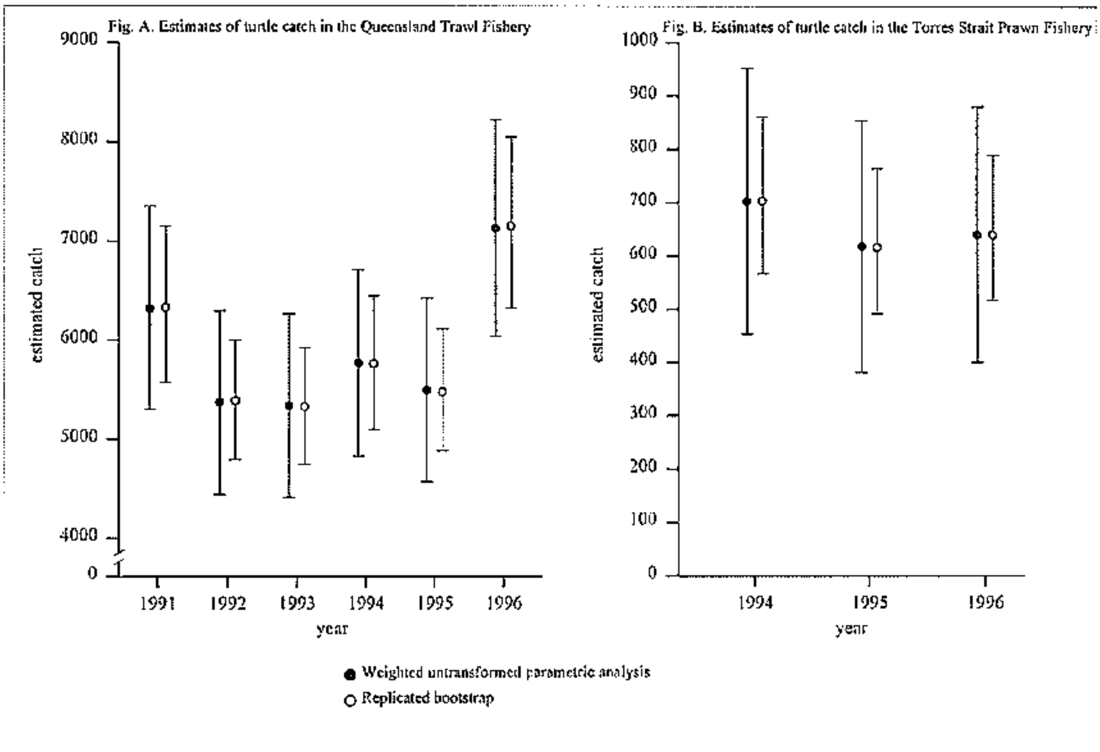


Table 11 Variability (95% confidence intervals) of estimates of turtle captures

Year	Fishery		Loggerhead turtles	Green turtles	Hawksbill turtles	Pacific Ridley turtles	Flatback turtles
1991	QTF	p	2573-4074	1203-2128	36-121	206-404	648-1164
		b	2808-3818	1347-1950	50-106	210-344	683-1058
1992	QTF	p	2131-3436	1017-1799	32-107	182-365	572-1052
		b	2373-3150	1165-1623	46-92	191-304	621-929
1993	QTF	p	2019-3272	1033-1785	31-114	197-393	630-1130
		b	2247-2969	1168-1623	46-99	206-342	672-1028
1994	QTF	p	2084-3350	1164-1949	37-126	224-455	767-1324
		b	2310-3048	1276-1795	52-112	235-411	794-1235
	TSPF	p	29 – 153	70 – 242	0 – 18	0 – 39	248 – 611
		b	51 – 142	101 – 222	0 – 17	7 – 35	317 - 565
1995	QTF	p	1983-3207	1090-1835	34-126	226-440	736-1276
		b	2169-2924	1202-1684	50-110	235-378	781-1153
	TSPF	p	24 – 136	59 – 215	0 – 16	0 – 34	209 – 546
		b	44 – 124	83 – 197	0 – 15	5 – 31	273 - 504
1996	QTF	p	2775-4367	1391-2355	47-150	270-510	855-1459
		b	2990-4076	1532-2163	63-132	275-447	889-1344
	TSPF	p	26 – 140	62 – 222	0 – 17	0 – 35	219 – 563
		b	48 – 129	92 – 205	0 – 15	6 – 32	284 – 525

p = standard parametric analysis, b = bootstrap analysis

Given that the bootstrap means were similar to parametric means, but that bootstrap confidence limits were tighter and non-symmetrical, results presented in the remainder of the report are from the bootstrap analysis. Estimates of CPUE, total effort and turtle captures are summarised in the tables below. Estimated CPUE was not consistent across sub-component fisheries (Table 12). This was not surprising, given the heterogenous distribution of sea turtles throughout waters of the Queensland east coast.

Table 12 Estimated CPUE of turtles in the Queensland Trawl Fishery and the Torres Strait Prawn Fishery and observed CPUE during research trawls

	Commercial CPUE						Research CPUE
Fishery	**Loggerhead turtles**	**Green turtles**	**Hawksbill turtles**	**Pacific Ridley turtles**	**Flatback turtles**	**All species**	**All species[A]**
Tiger prawn	0.0060	0.0230	0.0020	0.0090	0.0240	0.0645	0.0854 (82)
Endeavour prawn	0.0070	0.0130	0.0008	0.0050	0.0260	0.0498	-
Red spot king prawn	0.0050	0.0050	0.0006	0.0030	0.0120	0.0213	-
Eastern king prawn	0.0090	0.0070	0.0003	0.0010	0.0020	0.0155	0.0000 (137)
Moreton Bay	0.2030	0.0550	0.0016	0.0020	0.0020	0.2754	0.0733 (150)
Banana prawn	0.0260	0.0280	0.0005	0.0030	0.0110	0.0682	0.0714 (84)
Scallop	0.0060	0.0040	0.0000	0.0010	0.0040	0.0159	0.0000 (213)
Torres Strait Prawn	0.0098	0.0168	0.0007	0.0021	0.0463	0.0757	0.3125 (16)

[A](n) indicates the total number of days fished from which the weighted research CPUE is derived

Validation of the turtle CPUE derived from the voluntary turtle monitoring program is very difficult given the large spatial and temporal distribution of the Queensland Trawl Fishery and the Torres Strait Prawn Fishery. The limited data on turtle bycatch derived from research observers offers little in the way of validation of the voluntary logbook data recorded during commercial trawling operations (Table 12). A mean turtle CPUE, weighted by the number of days fished, was calculated from a variety of research work undertaken by QDPI including benthic community surveys, prawn tagging research and TED trials, as well as from research work during commercial trawling operations. The research turtle CPUE is similar to that of the commercial turtle CPUE in some sectors, but is very different in others i.e. Moreton Bay and Torres Strait. This is likely to be due to small scale differences in the geographic locations of research trawls versus commercial trawls or to small sample size (e.g. Torres Strait).

Annual catch of turtles was estimated to be 5,901 in the Queensland Trawl Fishery and 652 in the Torres Strait Prawn Fishery (Table 13). The 95% confidence intervals of these estimates were 5,199 to 6,604 for the Queensland Trawl Fishery and 537 - 788 for the Torres Strait Prawn Fishery. Turtle captures were not evenly distributed across sub-component fisheries. In particular, the Moreton Bay fishery dominated estimates, accounting for 54% of turtles captured. The tiger-prawn sub-component fishery caught 23% and the banana prawn sub-component fishery caught 6%. All other sub-components of the Queensland Trawl Fishery caught less than 5% of observed turtles. The majority of loggerhead turtles were caught in the Moreton Bay fishery (Table 13). Green turtles were caught throughout the Queensland east coast, although higher numbers were caught in fisheries associated with seagrass e.g. Moreton Bay and tiger prawn. Hawksbill turtles were an infrequent capture in trawl nets and this is reflected in the relatively low number of turtles estimated to be caught trawl fisheries. Pacific Ridley turtles were caught predominantly in the tiger prawn fisheries of northern Queensland.

About 970 flatback turtles were estimated to be caught each year. Captures of this species occurred predominantly in the fisheries of north Queensland and Torres Strait.

Table 13 Estimated average annual catch of turtles in the Queensland Trawl Fishery and the Torres Strait Prawn Fishery

Fishery	Effort[A]	Loggerhead turtles	Green turtles	Hawksbill turtles	Pacific Ridley turtles	Flatback turtles	All species[B]
Tiger prawn	20,928	126	481	42	188	502	1,350
Endeavour prawn	5,736	40	75	5	29	149	286
Red spot king prawn	12,936	65	65	8	39	155	276
Eastern king prawn	15,900	143	111	5	16	32	246
Moreton Bay	11,616	2,358	639	19	23	23	3,199
Banana prawn	5,016	130	140	3	15	55	342
Scallop	12,744	76	51	0	13	51	203
Queensland Trawl	**84,876**	**2,938**	**1,562**	**80**	**323**	**968**	**5,901**
Torres Strait Prawn	**8,634**	**85**	**145**	**6**	**18**	**400**	**652**

[A] effort presented as days fished , [B] includes turtles not identified to species

Physical condition of turtles upon capture

Five categories of physical condition upon capture were reported during the six year program. These were:

- *healthy* which included externally injured turtles. In all cases of turtles reported injured the descriptions suggested that the external injuries were not the result of the immediate trawl capture, but were scars or damage from previous events, so externally injured turtles were included in the healthy category. Fishers who participated in the program were unable to detect any internal injuries and were not trained to do so.
- *dead* (as per Table 6)
- *comatose* (as per Table 6)
- *carcase* which were turtles that had been dead for some time and were in various stages of decomposition. These captures were not included in the estimation of total captures but are provided here for information.
- *undetermined* which includes those turtles whose condition upon capture was not recorded and as such their fate is unknown.

Pooled across all species, greater than 90% of all turtles were reported as healthy when first landed on the boat (Table 14). Four percent were reported as comatose and 1% were reported dead.

Table 14 Physical condition of upon capture in the Queensland Trawl Fishery

	Loggerhead turtles	Green turtles	Hawksbill turtles	Pacific Ridley turtles	Flatback turtles	All species[A]
Healthy	582	406	21	79	298	1430
Comatose	25	22	1	9	7	64
Dead	7	4	1	3	6	21
Carcase	2	1	0	0	1	4
Undetermined	0	0	0	1	0	8
	617	433	23	92	312	1527

[A] includes turtles not identified to species

Ninety-four percent of loggerhead turtles were reported as healthy upon capture, 4% were reported as comatose and 1% were reported dead. This was fairly consistent across years, and is probably due to most loggerhead turtles being caught in trawl fisheries with short tow durations. The majority of green turtles were reported as healthy upon capture (93%) with 5% reported as comatose and 1% as dead. The hawksbill turtle had the highest rate of reported deaths in trawl nets, with 4% of captured hawksbills being dead, 91% as healthy and 4% as comatose. Some caution is needed in extrapolating these figures beyond the sample data due to a small sample size. However, higher trawl related mortality has been speculated for small turtles (Lutcavage and Lutz 1996). Eighty-six percent of Pacific Ridley turtles were reported as healthy upon capture. Comatose turtles accounted for 10% of captures while 3% were reported dead. This is higher than that reported for loggerhead or green turtles and may be a consequence of both the smaller size of Pacific Ridley turtles and the longer tow durations of fisheries where they were caught most commonly. Ninety-five percent of flatback turtles were reported in a healthy condition. Few were reported as either comatose (2%) or dead (2%). In total, 49 turtles were not identified to species. Of these, 43 were reported to be healthy upon capture while the remaining six had undetermined physical conditions upon capture.

The majority of turtles caught in Torres Strait (96%) were reported in a healthy condition upon capture. About 3% were reported comatose and less than 1% were reported dead. These proportions were similar for flatback turtles (99% healthy, 1% comatose and 0% dead) and green turtles (91% healthy and 9% comatose). The proportions of healthy (87%), comatose (7%) and dead (7%) were again similar for loggerhead turtles but with a small sample size (n=15) caution should be used in extrapolating the data. For the other species caught in Torres Strait, all were reported in a healthy condition.

These reported mortality rates were directly applied to the estimates of total turtle catch to estimated the average annual trawl related mortality of sea turtles. Between 72 and 94 turtles are estimated to drown in trawl nets of the Queensland Trawl Fishery. If comatose turtles are considered to die as a consequence of a trawl capture (i.e. dead + comatose turtles) then between 306 and 468 turtles are estimated die as a consequence of a trawl capture. Trawl related turtle mortality for the Torres Strait Prawn Fishery was estimated to be between five and eight turtles per year or between 21 and 32 turtles if comatose turtles are considered to die as a consequence of a trawl capture. These mortality rates are considerably lower than that reported for the Northern Prawn Fishery, which were 10% dead in 1989 and 18% dead in 1990, and 39% if comatose turtles were assumed to die in 1990 (Poiner and Harris 1996).

There are a number of factors that may explain the difference in mortality rates between the Northern Prawn Fishery and the two fisheries reported here. It has been suggested that mortality rates in a fishery are the consequence of the average duration of the trawls (Watson and Seidel 1980; Kemmerer 1989; Robins 1995) as well as the susceptibility to drowning of the dominant species caught (Poiner and Harris 1996). It has been speculated that flatback turtles have a greater tolerance to trawl-capture than other species (Poiner and Harris 1996). Flatback turtles were the dominant species caught in the Torres Strait (66%) and this combined with an average tow duration of 144 minutes may account for the lower mortality rates in the Torres Strait Prawn Fishery than in the Northern Prawn Fishery, where average tow duration has been reported as 186 minutes (Poiner and Harris 1996).

Mortality rates of turtles in the Queensland Trawl Fishery are markedly lower than the Northern Prawn Fishery most likely as a consequence of short tow durations (i.e. 60 to 90 minutes) in the areas where turtles are caught predominantly, i.e. the Moreton Bay fishery. Another possible cause of the low mortality rates in this study could be under-reporting of dead turtles by fishers involved in the program. However, the incidence of a low mortality rate of trawl-caught turtles is supported by tow duration data and levels of mortality similar to the Northern Prawn Fishery were reported in some areas of the Queensland Trawl Fishery where tow durations are longer (i.e. 129 minutes, tiger and endeavour prawn fisheries of north Queensland). The degree of inaccurate reporting should be variable, as different fishers would report differently. It would take a concerted effort from the majority of commercial fishers involved in this study (some 106 individuals) to have a major effect on data accuracy.

Species geographic distribution

The distribution of sea turtles in Queensland waters is poorly understood (Dr Col Limpus personal communication 1998). Current knowledge of sea turtle distribution is based on nesting and feeding grounds studies undertaken by the Queensland Turtle Research Group (Queensland Department of Environment).

Loggerhead turtles dominated the catches in trawl fisheries of southern Queensland, as reported in Robins (1995). Flatback turtles dominated the captures in fisheries in northern Queensland and Torres Strait, while green turtles were commonly caught along the whole length of the Queensland east coast. Figures 6 to 10 give the distribution of turtle captures (as recorded by latitude and longitude by commercial fishers) for each species along the Queensland east coast. These figures have not been adjusted for the effort in each area but rather represent the geographic location of turtle captures. In themselves, they do not indicate the rate at which turtles are caught in particular area.

Figure 6 Distribution of reported captures of loggerhead turtles in trawl nets

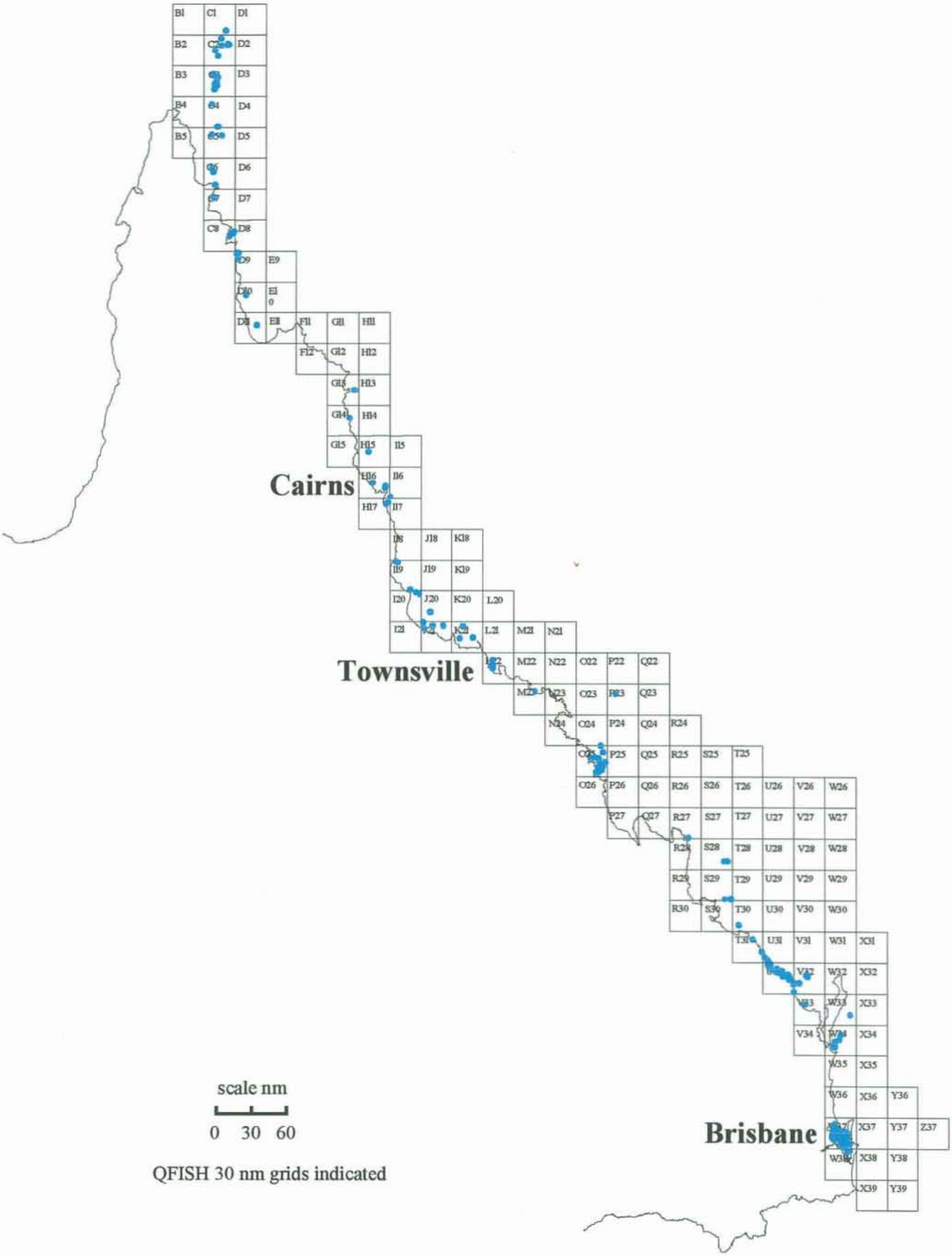


Figure 7 Distribution of reported captures of green turtles in trawl nets

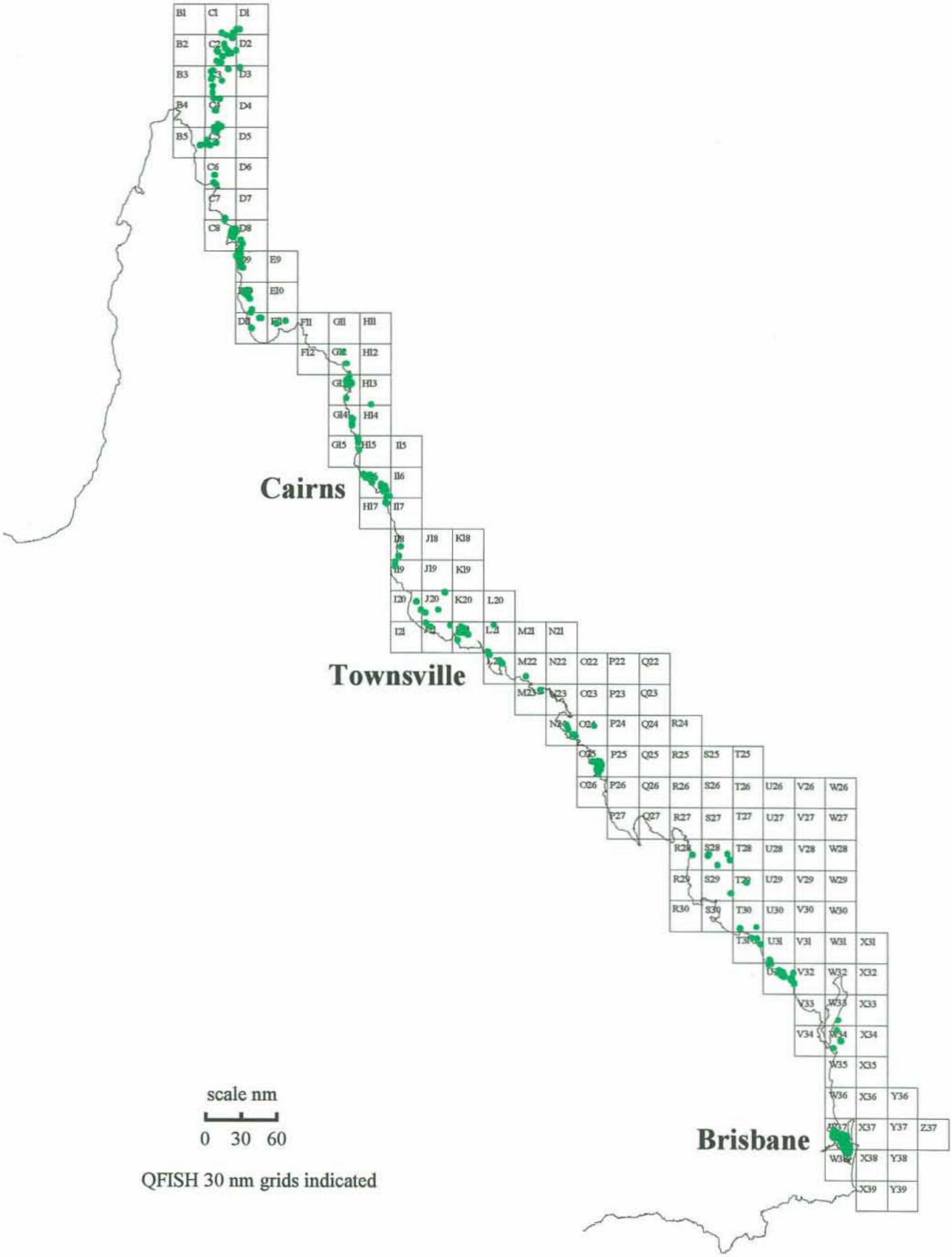


Figure 8 Distribution of reported captures of hawksbill turtles in trawl nets

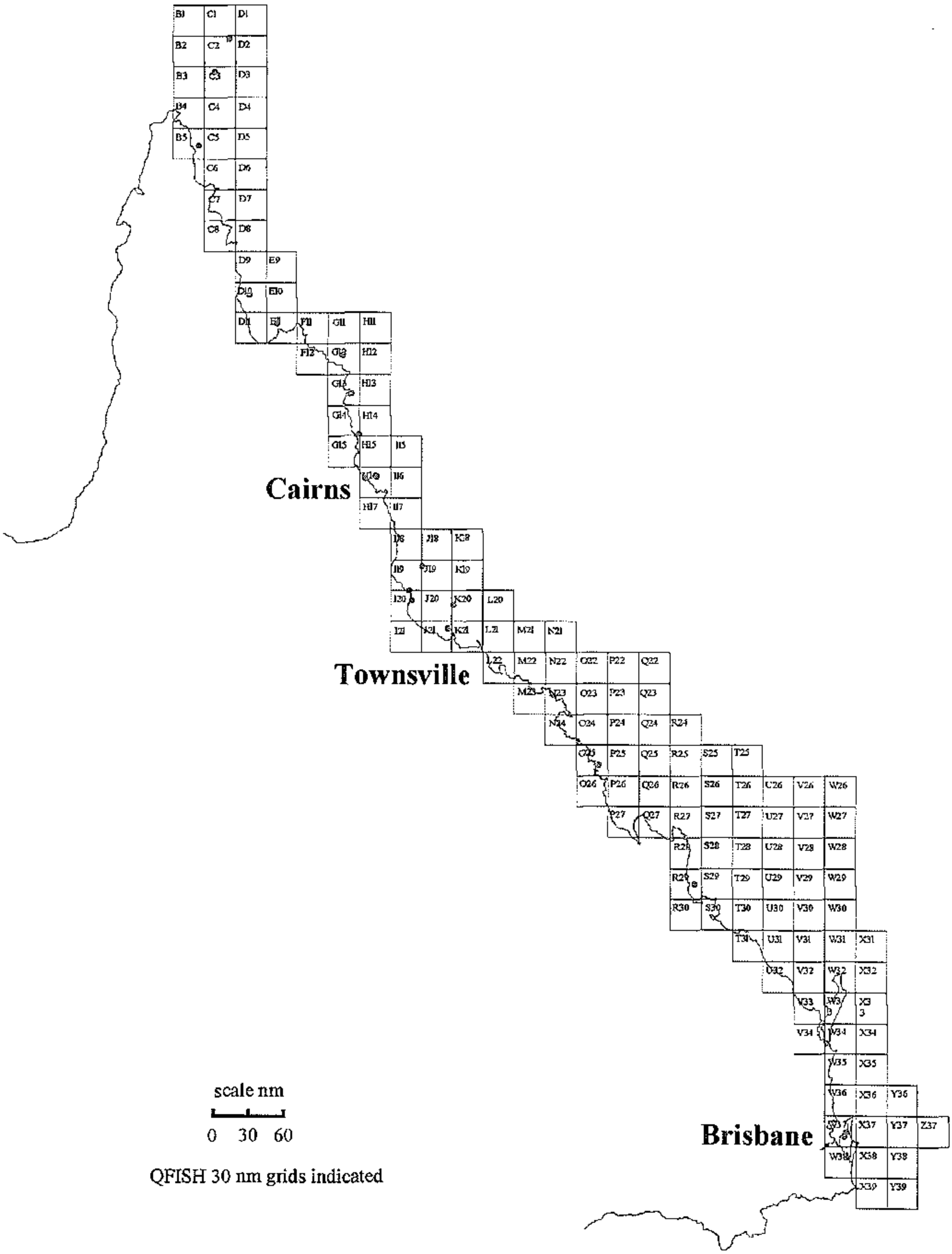


Figure 9 Distribution of reported captures of Pacific Ridley turtles in trawl nets

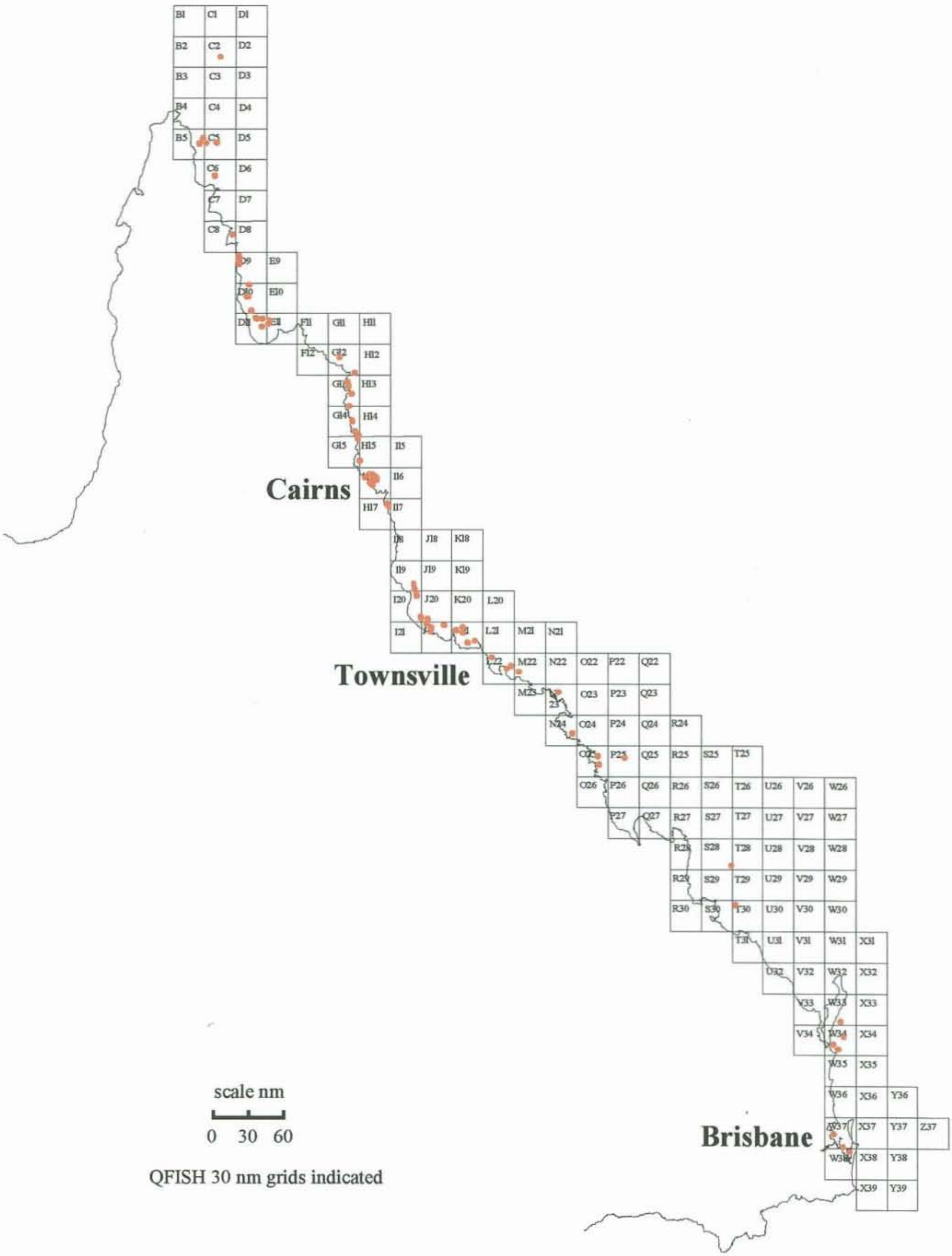
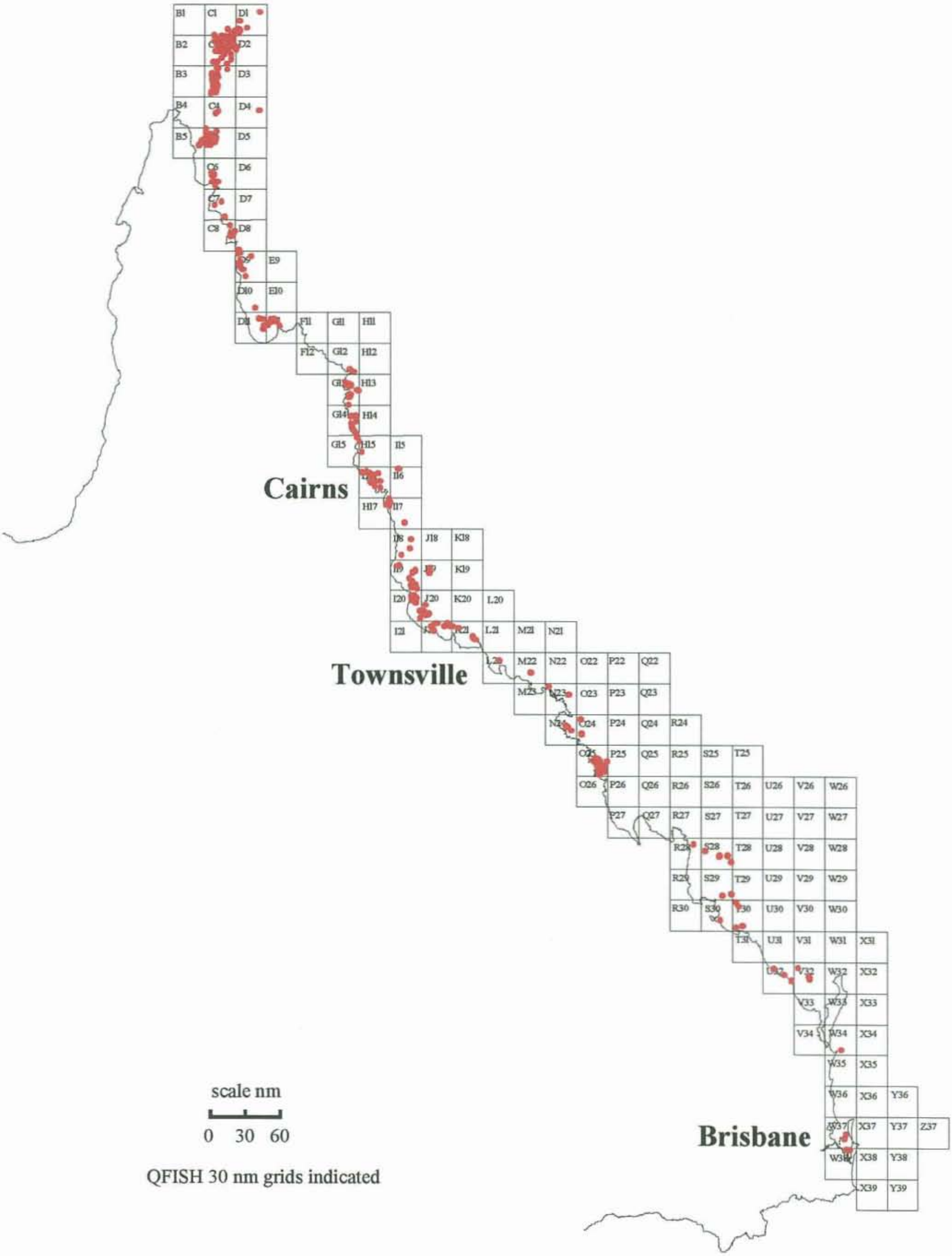


Figure 10 Distribution of reported captures of flatback turtles in trawl nets



Depth distribution of turtle captures

Of the 1,527 turtles reported caught in the Queensland Trawl Fishery, 1,495 had information on water depth. Ninety-five percent of turtles were reported caught in trawls undertaken in waters less than 30 m (Table 15). There appeared to be slightly different depth distribution of capture between species. Loggerhead and green turtles were most frequently caught in waters between 6 and 20 m, while hawksbill, Pacific Ridley and flatback turtles were caught most frequently in slightly deeper waters, i.e. 11 to 25 m. While this is only a slight change in depth distribution, this may represent true differences in preferred depth of habitat for these species respectively. Little is known of the wide-spread depth preferences of turtles in Australia and the data in this report is probably the most comprehensive set currently available.

Table 15 Depth distribution of trawl-caught turtles in the Queensland Trawl Fishery

	Depth (m)												
Species	**0-5**	**6-10**	**11-15**	**16-20**	**21-25**	**26-30**	**31-35**	**36-40**	**41-45**	**46-50**	**51-55**	**56-60**	**Total**
Loggerhead turtles	60	225	129	109	31	29	11	3	0	0	1	1	599
Green turtles	13	159	122	66	25	21	9	2	6	2	1	2	428
Hawksbill turtles	0	3	2	9	4	1	1	1	1	0	0	0	22
Pacific Ridley turtles	2	11	20	31	15	7	3	1	1	0	0	0	91
Flatback turtles	3	42	72	95	36	44	12	2	1	3	1	0	311
unidentified	0	15	14	10	1	1	2	0	0	0	0	0	43
Total	78	455	359	321	112	103	38	9	9	5	3	3	**1495**

Of the 151 turtles reported caught in the Torres Strait Prawn Fishery, 149 had associated trawl-depth information reported. Ninety percent of turtles were caught in trawls undertaken in waters depths between 15 and 35 m (Table 16). This may be an attribute of this fishery, where trawling occurs between reefs and sandbanks that form Torres Strait. There is little opportunity for shallow water trawling. Flatback and green turtles were the dominant species captured in the Torres Strait Prawn Fishery, with captures occurring most frequently in water depths of 20 to 30 m.

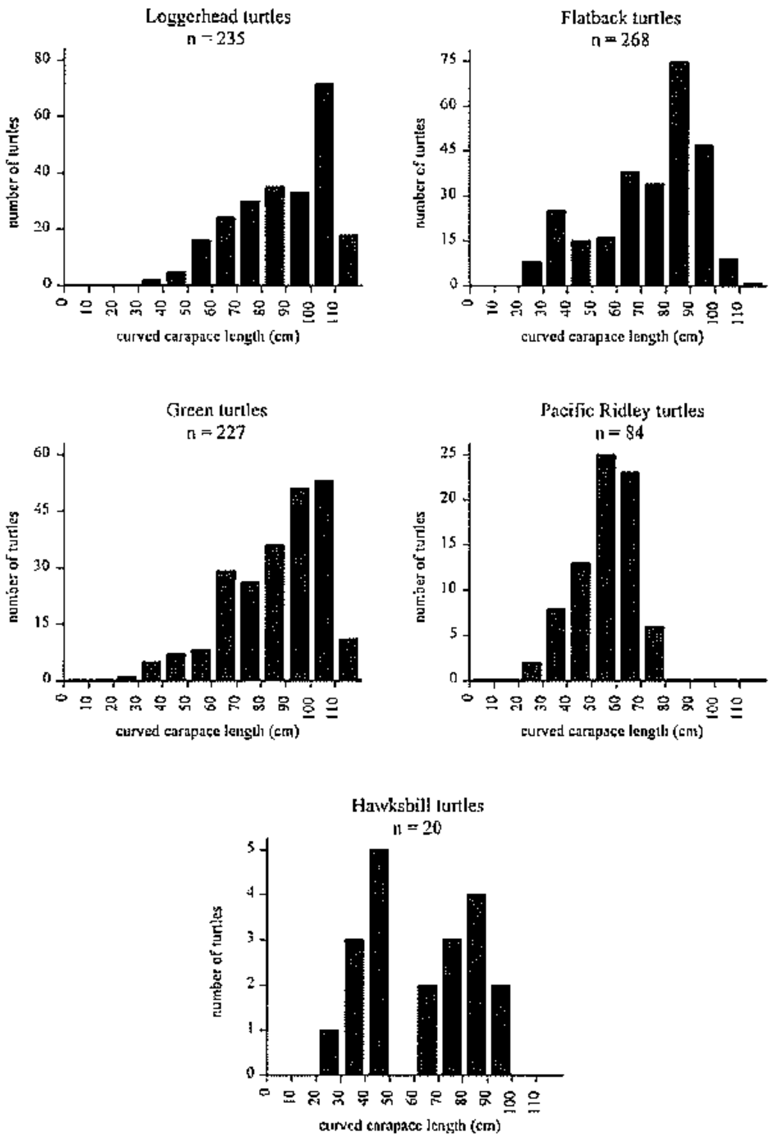
Table 16 Depth distribution of trawl-caught turtles in Torres Strait Prawn Fishery

	Depth (m)									
Species	**0-5**	**6-10**	**11-15**	**16-20**	**21-25**	**26-30**	**31-35**	**36-40**	**41-45**	**Total**
Loggerhead turtles	0	0	0	2	4	6	2	1	0	15
Green turtles	0	0	0	2	5	13	7	4	0	31
Hawksbill turtles	0	0	0	0	0	1	1	0	0	2
Pacific Ridley turtles	0	0	0	0	0	1	0	0	0	1
Flatback turtles	0	0	2	10	31	37	12	4	3	99
unidentified	0	0	0	0	1	0	0	0	0	1
Total	0	0	2	14	41	58	22	9	3	149

Size of turtles caught

A wide size range of turtles were reported caught in the Queensland Trawl Fishery (Figure 11). The size of a sea turtle does not consistently reflect its age or maturation stage (Musick and Limpus 1996). However, information on the size of sea turtles caught in trawl nets may assist in the understanding the impact of trawling of the population as a whole.

Figure 11 Size distributions of turtles caught in trawl nets of the Queensland Trawl Fishery

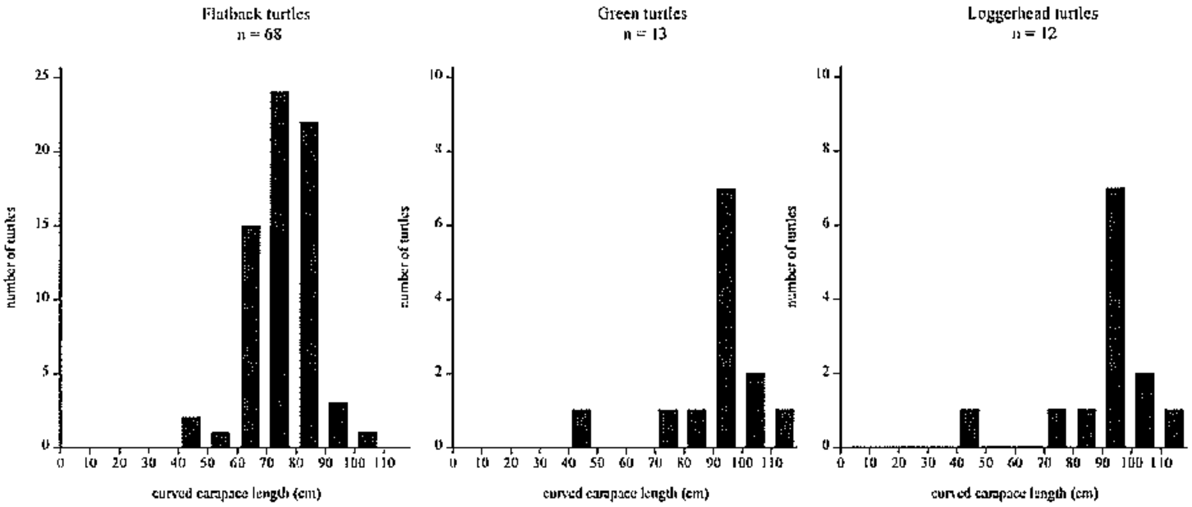


Small loggerhead turtles (less than 70 cm curved carapace length, CCL) are an unusual catch within studies by the Queensland Turtle Research Project (Musick and Limpus 1996). However, small turtles (25 to 35 cm CCL) have been recorded in Chesapeake Bay (USA) in developmental habitat (Musick and Limpus 1996). In the monitoring program, 39 turtles smaller than this size were reported as loggerhead turtles, with many being caught in Moreton Bay. This inconsistency with that reported by the Queensland Turtle Research Project could arise from two sources, firstly mis-identification and incorrect measuring by fishers or secondly, limited sampling of turtle habitats by the Queensland Turtle Research Project. As such, these smaller size classes reported in the monitoring program should be treated with some caution until further corroborative studies can be completed.

Captures of green turtles were dominated by large turtles, although the smallest recorded individual green turtle was 27 cm CCL. Small individuals such as these are rare in the studies undertaken by the Queensland Turtle Research Project. The minimum recruitment size of hawksbill turtles to coral reefs has been estimated at 35 cm CCL, but the smallest hawksbill turtle reported during the voluntary turtle monitoring program was 28 cm CCL, caught adjacent to Cairns. The sample size was relatively small (n=20). The trawl captures were dominated by turtles between 30 and 50 cm CCL and 80 to 90 cm CCL. The largest individual reported was 91 cm CCL. Flatback turtles reported caught were usually greater than 60 cm CCL, although 27% were smaller than 60 cm CCL. Five Pacific Ridley turtles were reported with a CCL greater than 85 cm. This is larger than previous reported maximum values for Pacific Ridley turtles (Marquez 1990). These animals may have been mis-identified and were treated as unidentified.

Turtles caught in the Torres Strait Prawn Fishery were dominated by large flatback and green turtles (Figure 12). This may be a reflection of the size of turtles inhabiting the slightly deeper waters in Torres Strait where most trawling occurs. Loggerhead turtles were of a similar size to those caught in the Queensland Trawl Fishery.

Figure 12 Size distributions of turtles caught in trawl nets of the Torres Strait Prawn Fishery

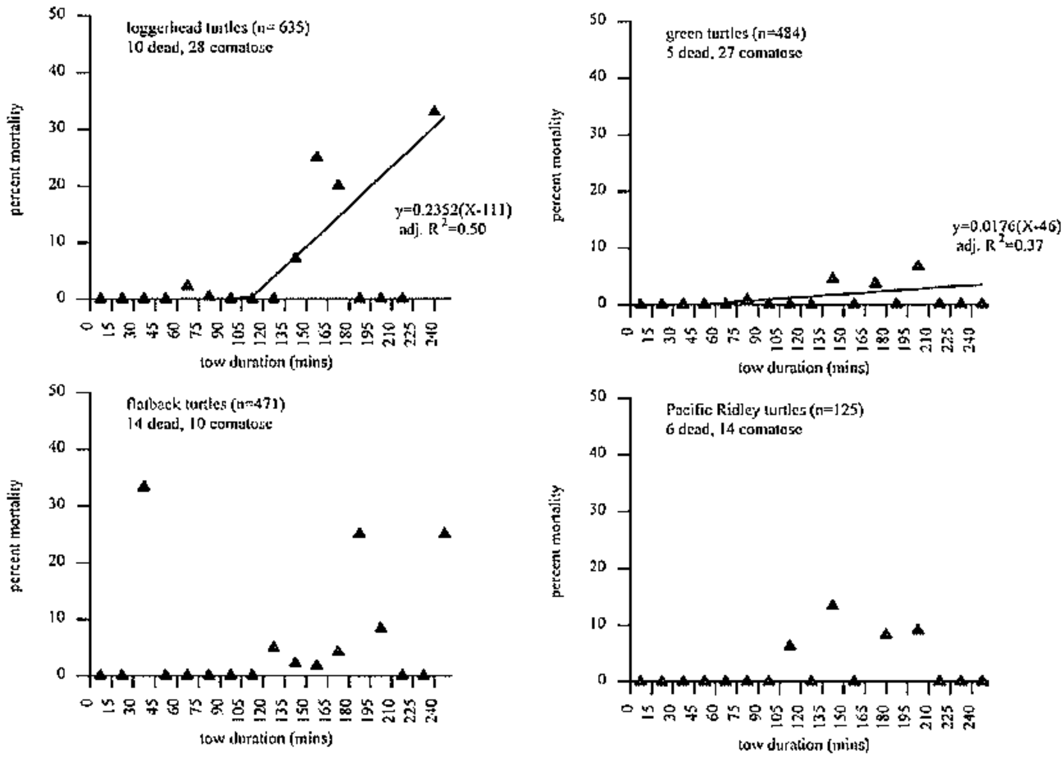


Tow time versus mortality

Turtles were caught in tows ranging in duration from 10 to 285 minutes, but the majority of captures (70%) occurred in tows of less than 135 minutes. A total of 1,515 trawl-caught turtles were reported with condition-upon-capture information recorded. Of these, 21 were reported as dead and 64 as comatose. This resulted in limited sample sizes upon which to base the analysis of tow-time versus mortality. Additional information recorded during the voluntary monitoring program by fishers from the Northern Prawn Fishery was incorporated into the tow-time versus mortality analysis as such quantitative information is extremely limited and there has been some suggestion that some species may tolerate trawl capture better than others. Pooling the data increased the sample size to 1,799 captures with a total of 38 being reported dead and 81 reported as comatose. The data are presented for all species excepting hawksbill turtles. Only 23 hawksbill turtles were reported caught, of which one was dead and one was comatose. The relationship between tow-time and mortality should be interpreted with caution as sample sizes are still relatively small.

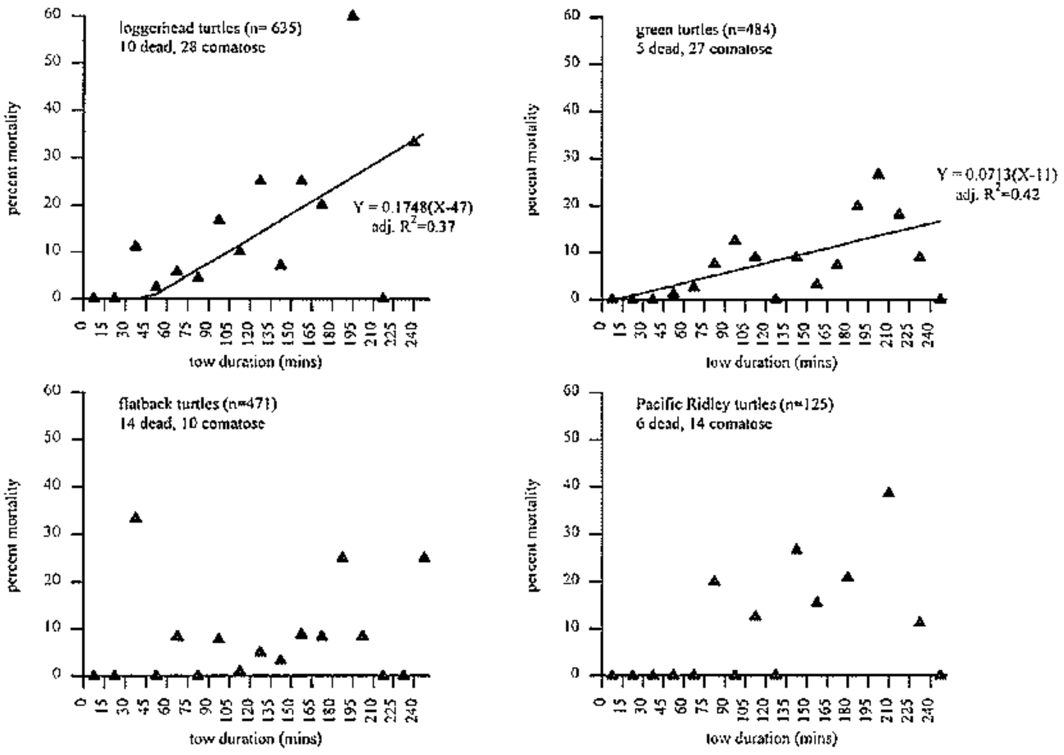
The plots of observed mortality (dead only) versus tow duration are presented in Figure 13. A conditional weighted bent-stick linear regression of tow time against percent mortality was statistically significant for all species pooled ($p < 0.007$), loggerhead turtles ($p < 0.001$) and green turtles ($p = 0.040$), but was not significant for Pacific Ridley turtles ($p = 0.404$) or flatback turtles ($p = 0.291$). This latter result may be due to the possible outlier at low tow duration (30-45 minutes), as mortality appears to increase at the upper end of this dimension (Figure 14). Despite being statistically significant, the regression lines accounted a limited amount of the variance. Adjusted R^2 values were less than 50%.

Figure 13 Observed mortality of trawl-caught turtles as a function of tow duration



The plots of potential mortality (dead plus comatose) versus tow duration are presented in Figure 14. The conditional weighted bent-stick linear regression of tow time against percent mortality was statistically significant for all species pooled ($p < 0.001$), loggerhead turtles ($p = 0.002$), and green turtles ($p = 0.003$), but not for Pacific Ridley turtles ($p = 0.089$) or flatback turtles ($p = 0.413$). The fitted regression lines accounted for slightly more of the variance, with adjusted R^2 values of 53%, 37%, and 42% respectively.

Figure 14 Potential mortality of trawl-caught turtles as a function of tow duration



The relationship between tow duration and mortality is complex and difficult to model as the condition of a trawl-caught turtle is influenced by several factors, including what oxygen reserves the turtle had when it became caught in the net, how long the turtle had been struggling within the net, and whether the turtle was still recovering from previous captures. As such, it would be unreasonable to expect a linear regression to have a close fit to the data unless these factors could be quantified and incorporated into the analysis.

General conclusions that can be drawn from the analyses suggest that for most species there is a positive correlation between tow duration and turtle mortality. Lutcavage and Lutz (1996) speculated that mortality rates of trawl-caught turtles would differ between geographic areas and between turtle species, due to physiological capacities and size differences. Poiner and Harris (1996) noted that flatback turtles had the lowest mortality rates of trawl-caught turtles in the Northern Prawn Fishery, although sample sizes for species other than flatback turtles were small. Current findings in this study support the speculation that flatback turtles appear to have a greater tolerance to trawl-capture. Trawl-captures are still potentially lethal for flatback turtles, but limitations to tow duration may not lower their mortality rate, as it is proposed to do so for other species.

It is difficult to speculate what impact the estimated turtle bycatch has on sea turtle populations of eastern Australia. There is limited quantitative information available about the population status of the six species of sea turtle that inhabit the waters of eastern Australia. The exception to this is the loggerhead turtle, for which a 50 to 80% decline in the number of nesting female turtles has been observed since the mid 1980's (Limpus and Reimer 1994). Sea turtles are long-lived, have delayed sexual maturity and high survivorship of adults. Species with these life history traits are particularly susceptible to human impacts that can result in population declines. Hypothetical modelling of the Queensland east coast loggerhead turtle population suggests that an annual loss of only a few hundred adult and sub-adult female turtles would have a profound effect on the population and would result in a declining population size (Heppell *et al.* 1996).

The turtle bycatch and trawl related mortality estimated for the Queensland Trawl Fishery and the Torres Strait Prawn Fishery would contribute to a decline in loggerhead turtle population numbers, if the model reflects the true situation. It is likely that bycatch in trawl nets is only one factor contributing to the decline in of sea turtle numbers in eastern Australia. This is especially so for species such as green and hawksbill turtles, which are the target of commercial and traditional harvest or flatback turtles, whose eggs are at risk to feral animal predation in northern Australia. Nevertheless, measures that the trawl industry can take to minimise its impact upon sea turtle populations of eastern Australia should be investigated.

Possible sources of error

This study is based on the voluntary participation of commercial fishers of the Queensland Trawl Fishery and the Torres Strait Prawn Fishery. The turtle CPUE of the sample fleet was assumed to be representative of the turtle CPUE of the total fleet. It is possible that this assumption is incorrect as turtle CPUE for each commercial fisher was variable. It is possible that fishers who caught or killed many turtles did not participate in the program due to the perception that the information was controversial. It is also possible that fishers who rarely caught or killed sea turtles did not participate in the program due to the perception that this non-capture information was not useful or of interest to the program. As such, any biases in the data due to the non-random representation of the whole fleet are unquantified, and their direction of effect is unknown.

An inherent source of error in trawl fishery logbook data is the geographic scale at which catch and effort information is recorded. Much for the information recorded by commercial fishers in the Queensland Trawl Fishery is logged at a geographic scale of 1666.8 km^2, while the logbook data for the Torres Strait Prawn Fishery is recorded in 66.7 km^2 grids. Average turtle CPUE had to be estimated for grids of 1666.8 km^2. It is unlikely that sea turtles are distributed uniformly across this geographic scale. It is possible that pooling data at this geographic scale may mask some of the small-scale differences in the fishing behaviour of individual fishers that may influence how many turtles are caught during trawling operations.

A criticism of voluntary logbook information is the accuracy of the data reported to government agencies. If fishers did not accurately record the details of turtles caught, then catch and mortality will be under-estimated. Low mortality rates recorded in the program are supported by short tow durations in fisheries where turtle captures were frequent. It is difficult to validate the accuracy of turtle CPUE. Limited information on turtle CPUE was retrieved from QDPI research work, but offered little in the way of validating the reported turtle CPUE. Over 100 individuals participated in the voluntary turtle monitoring program. It would take a concerted effort by the majority of these fishers to have a major effect on the accuracy of the data and the subsequent estimates. A broad-scale, labour intensive observer program in the Queensland Trawl Fishery and the Torres Strait Prawn Fishery would be required to validate the estimates of this study.

2. DETERMINING THE FATE OF TRAWL CAUGHT TURTLES

Seven turtles were tagged and monitored post-release to a trawl capture (Table 17). Real-time monitoring with radio and ultrasonic transmitters was labour intensive and weather dependent (i.e. wind must be less than 20 knots). Initial work with real-time monitoring tags indicated a high chance of retrieving the equipment within Moreton Bay, provided the geographic location of the turtle was monitored regularly. The probability of equipment retrieval lead to the use of Temperature Depth Recorders (TDRs), which have recorded complete dive profiles over three days. TDRs compensated for data "gaps" that occurred as a result of bad weather or equipment failure. Future monitoring will benefit from TDR use, although it is inevitable that the equipment will be lost. Results from tracking trawl-caught turtles are presented below

Table 17 Details of trawl-caught turtles that were monitored post-release

Date	Species	CCL (cm)	Tow (mins)	Condition upon capture	QNPWS tag	Release position	GTR fuse	Monitoring equipment
26/09/95	loggerhead turtle	87.5	120	healthy	T85226 (L3)	27°19.33'S 153°16.44'E	3 days	real-time 5 field days
17/10/95	loggerhead turtle	83.0	90	healthy	T85227 (L3)	27°21.72'S 153°17.17'E	6 days	real-time
08/11/95	loggerhead turtle	79.0	120	healthy	T85246 (L3)	27°18.11'S 153°18.55'E	5 days	real-time no data
21/01/96	loggerhead turtle	-	90	healthy	T85228 (L3)	27°28.53'S 153°16.98'E	4 days	real-time
05/02/96	green turtle	>95	90	healthy (slow to start)	T85242 (L3)	27°28.79'S 153°19.66'E	6 days	real-time tag not retrieved
22/01/97	loggerhead turtle	76	90	healthy	T85249 (L3)	27°19.0'S 153°08.0'E	8 days	real-time, TDR
19/03/97	Pacific Ridley turtle	56	90	healthy	T85240 (L3)	27°19.3'S 153°09.0'E	8 days	real-time, TDR

Turtle 1, 25th - 30th September 1995: A loggerhead turtle (87.5 cm CCL) was caught on the 26th September during a trawl of 120 minutes tow duration. A QNPWS Tag (T85226) was applied in the L3 position. The turtle was released at 27°19.33'S, 153°16.44'E at 19:42. The turtle was located immediately upon release and tracked for about 20 minutes before the signal was lost. Strong winds (20 to 25 knots) and choppy seas (1.5 to 2.0 metres) made tracking the animal extremely difficult and unfortunately tracking had to be abandoned until the morning of the 28th September, about 36 hours after the turtle was released from the trawler. The turtle was then relocated and monitored using real-time tracking equipment for the next six hours (Figure 15). Tracking then stopped but resumed 58 hours after capture. The ultrasonic and radio transmitter was retrieved successfully on the 30th September.

Figure 15 Dive profile of trawl-caught turtle (no 1)

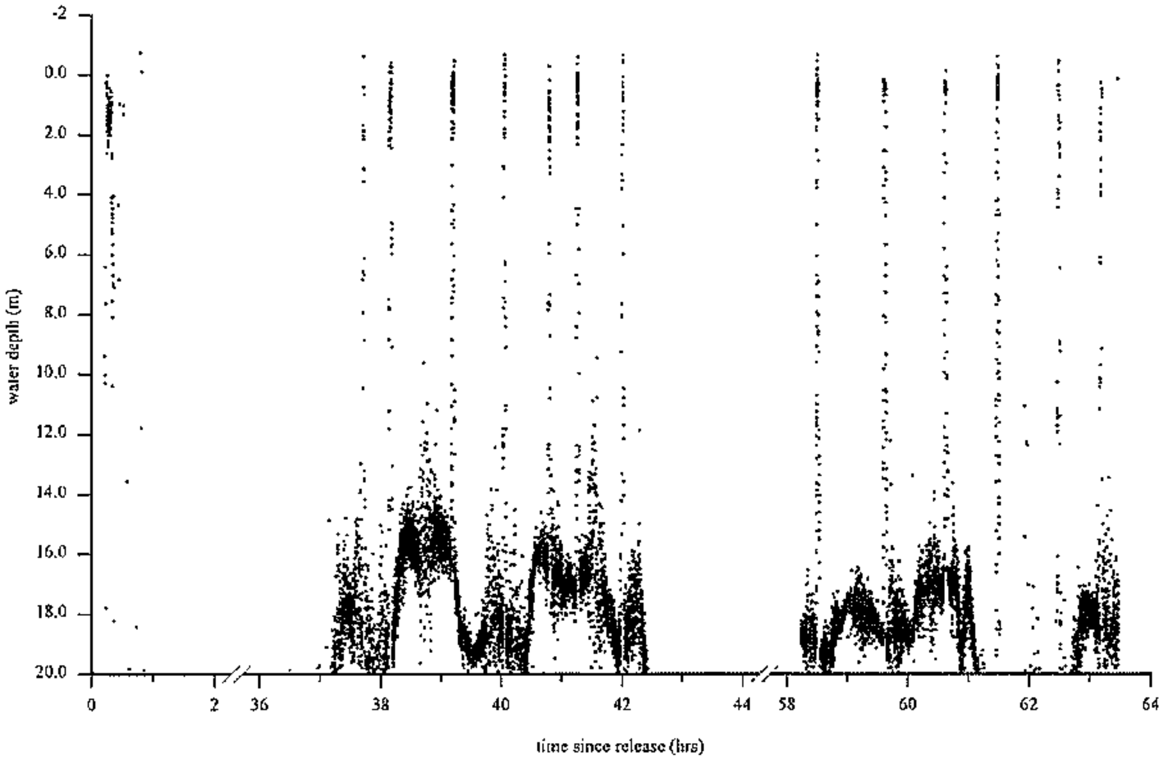
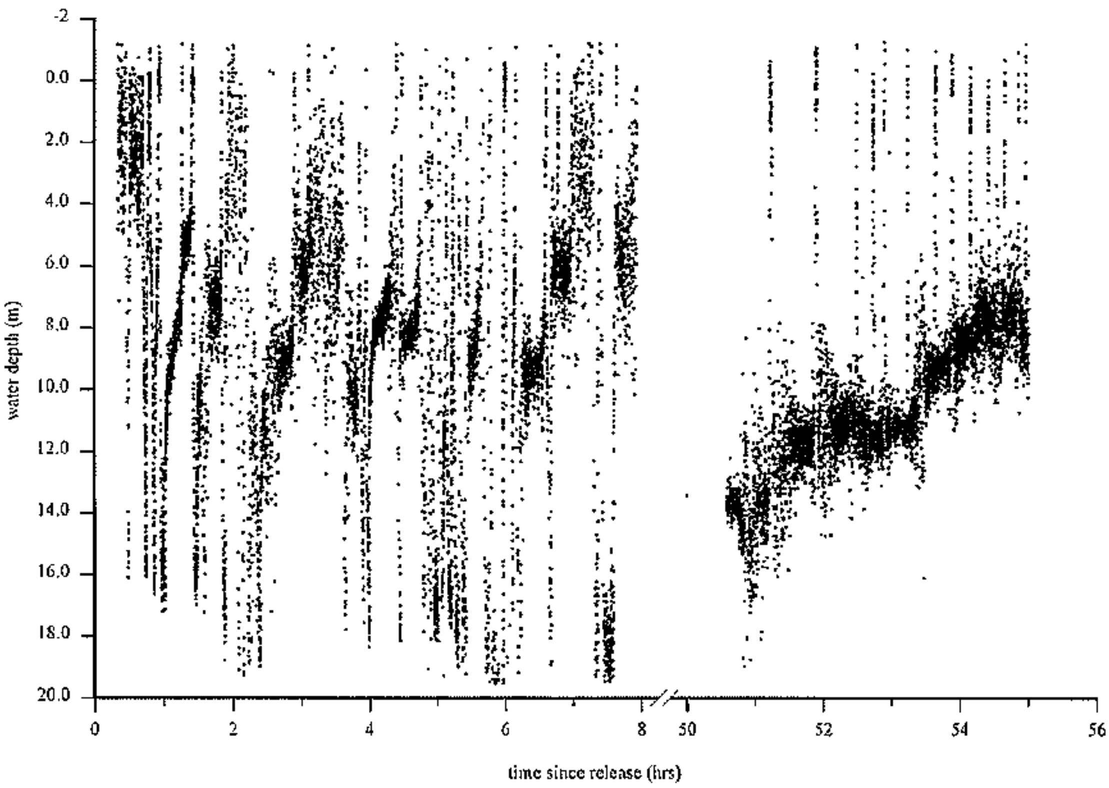


Figure 16 Dive profile of trawl-caught turtle (no 2)



Turtle 2, 17th to 21st October 1995: A loggerhead turtle (83.0 cm CCL) was caught on the 17th October in a trawl of 90 minutes duration. The turtle was located immediately upon release and tracked continuously for next 8 hours (Figure 16). Tracking was resumed 12½ hours after release, but without success and at 24 hrs after release without success. The tagged turtle was finally relocated 50 hours after release, having moved 2 nautical-miles from its last known position. It was tracked for the next 6 hours.

Turtle 3, 31st October to 14th November 1995: After 4 nights trawling a loggerhead turtle was caught in the trawl net (Table 17). The turtle was released, but tracking was not undertaken until 2 hours later when winds had eased. When tracking was commenced, the outboard motor seized within the next 5 minutes and tracking was abandoned. Strong winds and mechanical problems with the boat prevented the collection of any tracking data associated with this turtle. The ultrasonic and radio transmitters were washed ashore 3 days after the GTR fused corroded and was returned by a member of the public to the Southern Fisheries Centre.

Turtle 4, 21st to 25th January 1996: After 2 nights trawling a loggerhead turtle was caught in the trawl net (Table 17). The turtle was released but was unsuccessfully tracked until 8½ hours after release (Figure 17). It was tracked for the next 4 hours before staff required sleep. Tracking recommenced 31 hours after release and continued until equipment failure at 36 hours after release. Poor weather prevented further tracking of this trawl-caught turtle before the GTR fuse corroded. The transmitters were successfully retrieved.

Figure 17 Dive profile of trawl-caught turtle (no 4)

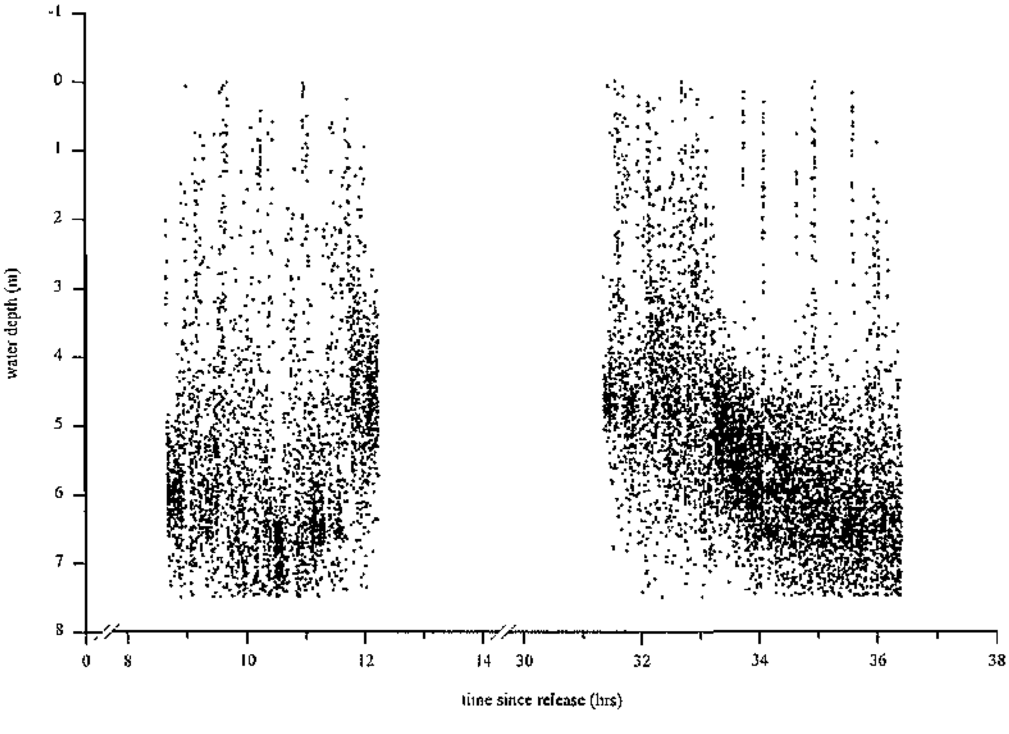
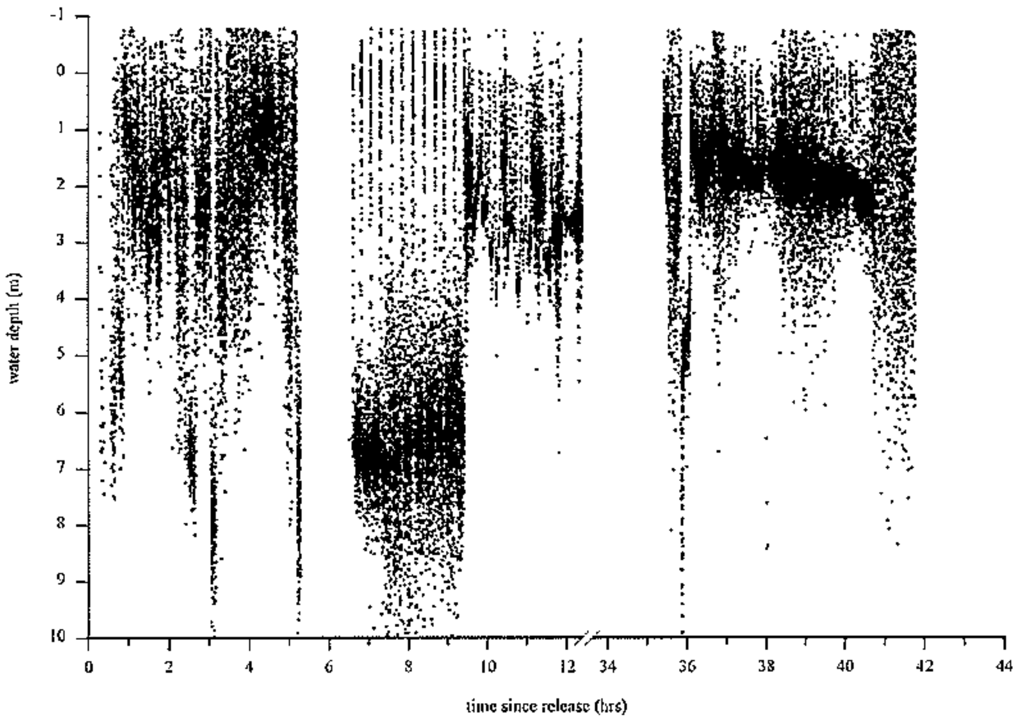


Figure 18 Dive profile of trawl-caught turtle (no 5)



Turtle 5, 5th to 12th February 1996: A green turtle was caught in a trawl of 90 minutes duration (Table 17). The turtle was released and tracked successfully for the next 12 hours (Figure 18). Tracking then recommenced some 36 hours after release and continued for a further 8 hours. Poor weather prevented subsequent tracking before the GTR fuse corroded.

Unpredictable weather, gear failure and human limitations meant that a full picture of the post-trawl response of sea turtles could not be gathered continuously. The high frequency of tag retrieval lead to the decision to use equipment that could automatically record data for an extended period and then be retrieved. This equipment was the Temperature-Depth Recorders (TDRs). Radio and ultrasonic equipment enabled us to locate tagged turtles as well as the transmitter when released from the turtle. Data recorded by the TDRs provides the most complete picture of dive profiles of trawl-caught turtles.

Turtle 6, 9th to 26th December 1996: A loggerhead turtle was caught after four nights of trawling (Table 17). The turtle was released and tracked successfully for the next six hours. For the last three hours of this tracking session, the turtle remained near a sub-surface rock formation in Moreton Bay (Otter Rock) around which 14 trawlers were trawling intensively. The turtle was relocated on the next two days and the tags retrieved on the third successive day. The dive profile of this turtle was monitored mostly using a data logging TDR that allowed the continuous information to be recorded for 54 hours after release (Figure 19). Note the presence of a "tidal-like" cycle within the dive profile. This possibly represents the turtle spending the majority of its time at a particular depth (e.g. the bottom), with water depth changing as a result of the flood and ebb of the tide.

Figure 19 Dive profile of a trawl-caught turtle (no 6) monitored using a TDR
(solid line at the bottom of the graph indicates the tidal cycle)

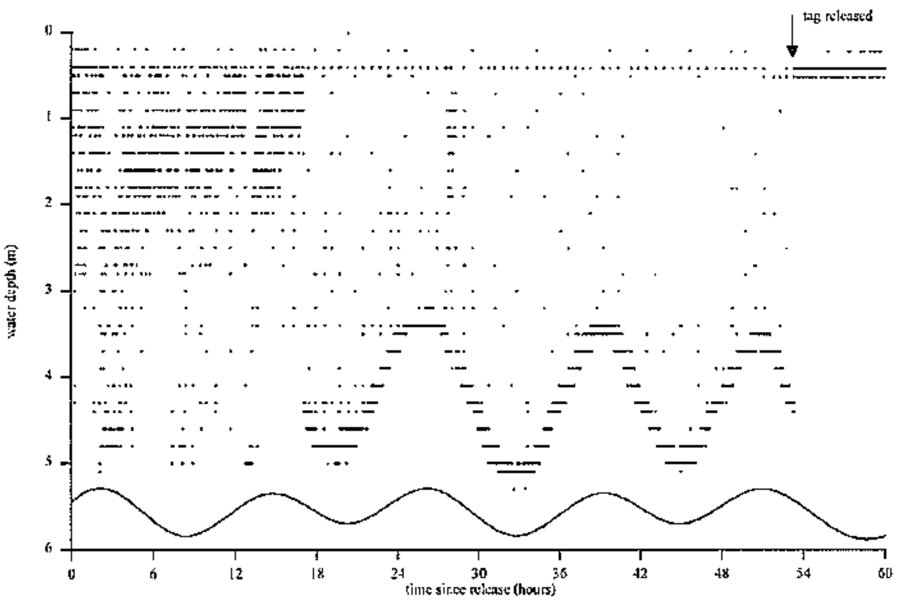
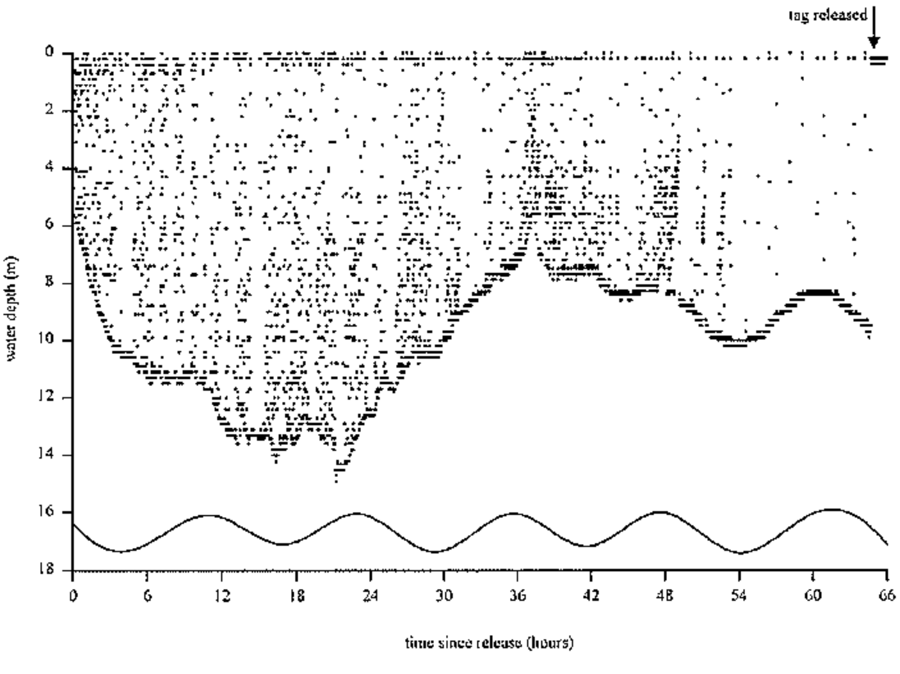


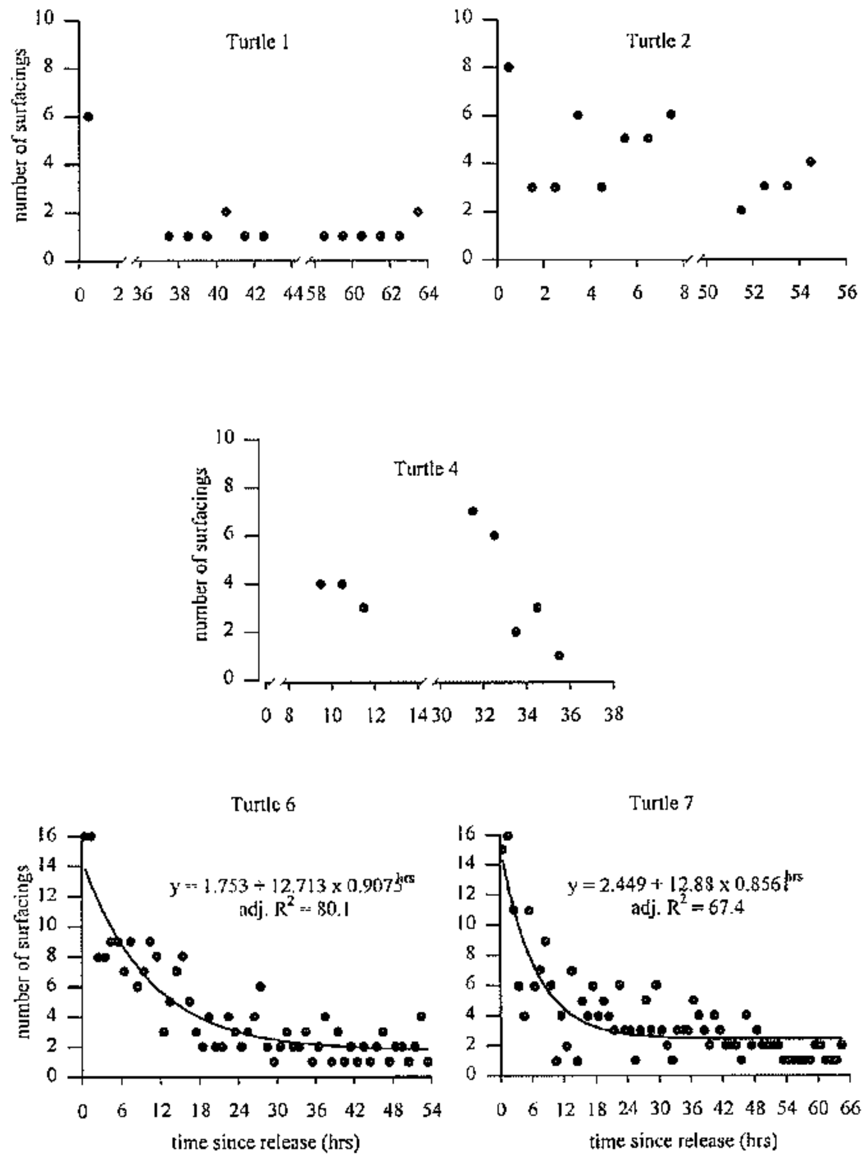
Figure 20 Dive profile of a trawl-caught turtle (no 7) monitored using a TDR
(solid line at the bottom of the graph indicates the tidal cycle)



Turtle 7, 16th to 23rd March 1997: A Pacific Ridley turtle was caught after four nights of trawling. The turtle was released and tracked for the next 45 minutes. Interference on the same frequency as the ultrasonic tag (40 kHz) prevented real-time tracking of the turtle. Fortunately, the TDR was retrieved after its release from the turtle and the logged data from the TDR provided dive profiles of this trawl-caught turtle for about 66 hours after capture (Figure 20). The influence of tide on water depth can also be seen in this dive profile.

All turtles displayed a distinctive "escape" response upon release, swimming rapidly away from the trawler. Visual assessment of the dive-profiles and observations from field experience suggested that an index of the "stress" of a trawl capture could be the number of surfacings versus time since release from the trawler. When analysed using non-linear regression, the number of surfacings a turtle made was significantly inversely related to time since release (Figure 21). The regression explained 80.1% and 67.4% of the variation in surfacing patterns for Turtle 6 and Turtle 7 respectively (Figure 21). Turtle 6, a loggerhead turtle, settled into a steady dive-surface-dive pattern 17 hours after the trawl capture (Figure 19). Once into this pattern, the turtle surfaced on average every 35 minutes. Turtle 7, a Pacific Ridley turtle, settled into a steady dive-surface-dive pattern about 42 hours after the trawl capture (Figure 20). This turtle surfaced on average every 24 minutes.

Figure 21 Number of surfacings versus time since release



The data recorded indicates that trawl capture resulted in appreciable behavioural changes, i.e. an increased number of surfacings. It appears that small turtles take longer to recover than larger turtles. This is consistent with current hypothesis that small turtles are more susceptible to drowning in trawl nets than larger turtles. No delayed post-trawl mortalities were observed, as would be expected with the small sample size and a reported trawl mortality of 0.6% in Moreton Bay.

Small turtles have been released into a trawl net fitted with a TED during TED testing in the USA. Turtles caught in a trawl net for less than eight minutes developed blood acidosis. Blood acidosis was caused mostly by the intense activity shown by the turtle within the trawl net and when these turtles reached the surface they hyperventilated (Stabenau *et al.* 1991). Hyperventilation of trawl-caught turtles is consistent with the behaviour observed during the current study, whereby turtles remained near the surface immediately after release. It would also be consistent with the elevated number of surfacings recorded for turtles post-release from the trawl. This type of behaviour has lead to some speculation that turtles stressed by a trawl capture are probably unlikely to undertake extended dives (Caillouet *et al.* 1996) and therefore are unlikely to be recaptured in another trawl net. This may reduce the chance of individual turtles being repeatedly caught in trawl nets and would decrease the possibility of high mortalities of turtles in areas where fishing effort is intensive. Trawl-aught turtle number six in this study was not recaptured in a trawl net immediately after it release from a trawler, despite 14 trawlers working intensively in the area in which the turtle remained. Small increases in the estimated trawl mortality of sea turtles could have significant implications for loggerhead turtle populations that nest in Queensland.

3. INDUSTRY LIAISON AND EDUCATION

The voluntary turtle monitoring program had a significant impact on raising industry awareness about the community concerns over the incidental capture of sea turtles in trawl nets. Many fishers became aware that there are six different species of turtles that occur in Queensland waters and that grouping them as "turtles" did not address some of the community concerns for endangered species. Fifteen newsletters were distributed to fishers participating in the turtle monitoring program and provided information of the distribution of turtles, turtle catches in other trawl fisheries, possible implications of turtle captures and "best treatment" for trawl-caught turtles. Visits to ports and wharfs along the Queensland east coast were undertaken to identify fishers willing to participate in the monitoring program. Wharfside discussions with many boat owners, skippers and deckhands raised the industry's awareness of turtle catch and mortality in trawl nets. Field work tracking trawl-caught turtles also assisted in the education of commercial fishers to the biology and behaviour of turtles. The presence of research staff on commercial boats always triggered radio conversations.

Project staff assisted the Queensland Commercial Fishermans Organisation to develop a code of practise for commercial fishers who encounter sea turtles (Appendix 1). This was successfully adopted by the Queensland trawling industry and was copied and used in several other Australian trawl fisheries where sea turtle captures occur. The *Turtle Recovery Procedures, Code of Fishing Ethics: The Capture of Sea Turtles, Guide to Sea Turtle Identification* (taxonomic) and *Sea Turtle Identification Chart* (photographic) was distributed to about 3,000 master fishers through the industry publication *Queensland Fisherman*. This four page leaflet was also incorporated into Commonwealth prawn trawl fisheries logbooks in

1996. The leaflet was amended and reprinted in late 1996 with the support of Queensland Commercial Fishermans Organisation, Queensland Department of Primary Industries, Australian Prawn Promotion Association, Australian Fisheries Management Agency, and Australian Nature Conservation Agency. It was included in the 1997 and 1998 Northern Prawn Fishery logbooks. Anecdotal reports from commercial fishers provide encouraging information that these recovery techniques are being employed in the industry. However, it is difficult to determine what proportion of the northern Australian trawling industry adhere to the recovery procedures and code of fishing ethics.

The effectiveness and respect the project held with the Queensland trawling industry can be ascertained from the following awards. Staff from the project were nominated for the 1994 QDPI Achievement Award and were the 1997 Winner of the Queensland Seafood Awards, *Award for Excellence in Promotion of the Commercial Fishing Industry and the Marine Environment* recognising innovation and leadership in promoting the commercial fishing industry and the marine environment on which it depends.

4. POTENTIAL USE OF CATCH PER UNIT EFFORT INFORMATION

A total of 133 grids, of 1666.8 km^2 in size, were fished during the collection of turtle catch rates from 1991 to 1996. Monthly turtle CPUE for the majority of grids was usually zero, even for the three species most commonly caught, i.e. loggerhead, flatback and green turtles. There were only a handful of grids in which sampling effort was consistent throughout years and where the turtle CPUE was not dominated by true zeros. These areas were U32 (Bundaberg coastline) and W88 (Moreton Bay). The monthly turtle CPUE for the 72 months between 1991 and 1996 are presented for loggerhead turtles in the Figures 22 and 23. Turtle CPUE within QFISH grid U32 shows some seasonality but no distinct trend (Figure 22). As can be seen from the graph, it would be difficult to detect trends in the abundance of loggerhead turtles given the variable nature of their CPUE within this grid, even though it is a known area where turtles congregate.

Figure 22 Monthly CPUE for loggerhead turtles in QFISH grid U32 (Bundaberg)

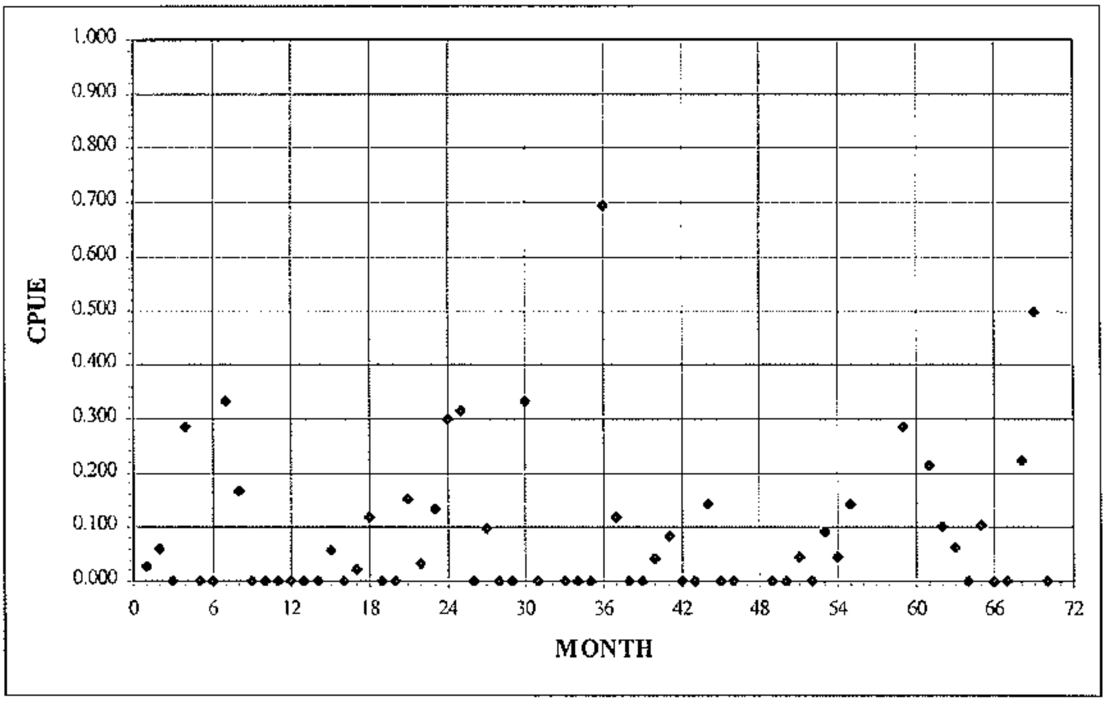
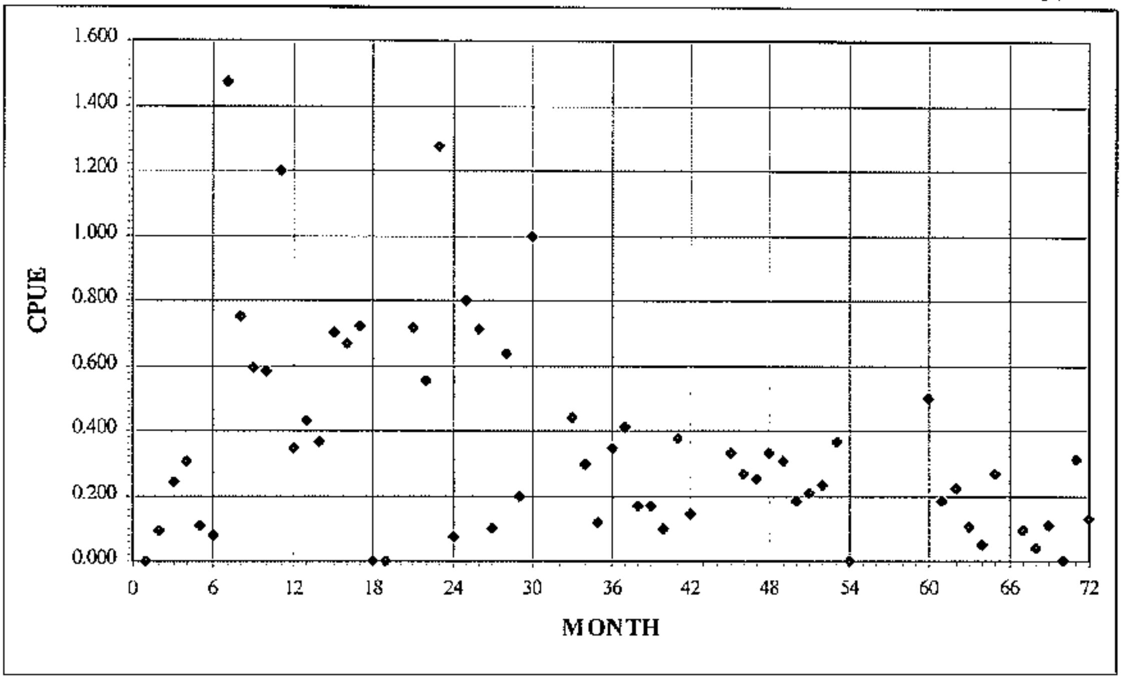


Figure 23 Monthly CPUE for loggerhead turtles in QFISH grid W88 (Moreton Bay)



Likewise, the loggerhead turtle CPUE within QFISH grid W88 (Moreton Bay, including W37 and W38) was also highly variable between months. CPUE in the latter months of the study were notably lower than CPUEs in the early months of the study (Figure 23). This would be consistent with declines in loggerhead turtle nesting numbers recorded along the Queensland east coast by the Queensland Turtle Research Project. However, it is more realistic that the data reflects the activities of fishers participating in the monitoring program. Some individual fishers had high catch rates of sea turtles. The data warrant further investigation into CPUE trends based on information from individual fishers. For each fisher, their fishing method is probably reasonably constant over time and may alleviate some of the problems inherent when pooling catch and effort across fishers.

It is likely that unless sampling effort is highly concentrated and continuous throughout time, trends suggested by turtle CPUE in trawl nets will be beyond detection of the "limits of acceptable change". The use of turtle CPUE as an index of abundance may be possible when turtle bycatch is recorded by the majority of the trawl fleet as compulsory information collected by the logbooks associated with trawl fisheries. The collection of such obligatory data is often more prone to misreporting than that collected from volunteers.

Turtle catch per unit effort (CPUE) was most useful as an overall, wide-scale, in-water survey of the distribution of sea turtles throughout Queensland east coast waters. The turtle CPUE by species has provided insights into potential areas where sea turtles are aggregated and may provide fruitful areas for research by conservation agencies into sea turtle biology and population dynamics. This information has been forwarded onto the Queensland Department of Environment.

BENEFITS

The assessment of the impact of trawling on sea turtle populations in Australian prawn trawl fisheries is necessary to ensure the conservation of threatened sea turtle species. The voluntary turtle monitoring program has developed a long term database on the frequency and location of turtle captures. These data are being used in fisheries management for the identification of priority areas where the issue of how to abate threats to turtles from trawling is being negotiated with the commercial fishing industry through the Queensland Trawl Management Plan and the TrawlMAC process. This has resulted in the management intervention of the compulsory use of TEDs in the following areas:

a) Moreton Bay (defined in the Queensland *Fisheries Regulations 1995*).
b) Inshore trawl grounds from Wreck Rock to Hervey Bay (along the parallel of 24°20'S, from low water mark to 6 nm offshore, southward, at a distance of 6 nm from shore to the parallel of 25°15'S, from low water mark to 6 nm offshore).
c) Inshore trawl grounds – Repulse Bay (along the parallel of 20°30'S, from low water mark to 6 nm offshore, southward, at a distance of 6 nm from shore, to the parallel of 21°00'S, from low water mark to 6 nm offshore).
d) Inshore trawl grounds – Townsville (inshore of a line drawn between the mouth of Cattle Creek [18°52'S, 146°18'E] to the tip of Cape Cleveland).
e) Inshore trawl grounds – Cape Flattery to Cairns (along the parallel of 15°00'S, from low water mark to 6 nm offshore, southward, at a distance of 6 nm from shore, to the parallel of 17°00'S, from low water mark to 6 nm offshore).
f) Inshore trawl grounds – Portland Road to Princess Charlotte Bay (along the parallel of 12°30'S, from low water mark to 6 nm offshore, southward, at a distance of 6 nm from shore to the parallel of 14°30'S from low water mark to 6 nm offshore), plus
g) Inshore waters south of Cape Moreton (a voluntary agreement by the QCFO Southport Branch fishers).

The data are also being used by the Queensland Department of Environment and the Great Barrier Reef Marine Park Authority in planning their policy and management objectives regarding the incidental capture of turtles in trawl nets. The executive summary of the information supplied to the GBRMPA turtle working group appears in Appendix 2.

The continuity of the voluntary monitoring program over six years has helped to develop a responsible attitude by commercial fishers to environmentally sensitive issues such as sea turtle conservation. This project has assisted in changing industry perceptions towards the use of TEDs in Queensland waters and has played a significant role in progressing the smooth transition towards compulsory TED usage on the Queensland east coast.

Information on the catch and mortality of sea turtles on the Queensland east coast has not assisted the Queensland fishing industry in retaining access to the USA shrimp market. Despite capture and mortality of sea turtles in Queensland being considerably lower than in the USA, the USA has taken the stance that all shrimp products from a country will be banned from importation into the USA unless turtle excluder devices are fitted to vessels within the prawn trawl fisheries of that country

INTELLECTUAL PROPERTY

Intellectual property resulting from this study relates to the turtle capture information that was collected from commercial fishers on a confidential basis. The data have been summarised, analysed and interpreted to provide the Fisheries Research and Development Corporation with this Final Report. Published papers will allow access by industry and other interested persons to the summarised data.

FURTHER DEVELOPMENT

1. The collection of turtle bycatch information on a long-term basis would benefit any commercial fishery, especially those that have interactions with threatened species. As such, further research or monitoring the incidence of turtle bycatch in trawl nets of the Queensland east coast is recommended as changes in turtle catch may occur as a consequence of proposed fishery management measures i.e. TEDs or reductions in effort.
2. In addressing the impact of commercial fisheries on threatened sea turtles, the incidence of turtle bycatch should be quantified in those fisheries for which data are sparse i.e. net, line and pot fisheries.
3. Further work may need to consider the effect of a trawl capture on sea turtles post-release. Currently there is speculation that even with gear that allows turtles to escape the trawl net while underwater (i.e. TEDs) that the event is so stressful that post-capture mortality occurs at some later stage. Field studies of this issue are difficult and as such, laboratory manipulations of sea turtles may provide more information on their ability to recovery from a trawl capture.

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Assisting Vessels

Turtle Monitoring Program:
FV *Ali Star*, FV *Alinga*, FV *Annhilator*, FV *Assailant*, FV *Austral Star*, FV *Avalon II*, FV *Avenger*, FV *Barrook*, FV *Battlestar*, FV *Bay Raider*, FV *Bindi*, FV *Born Free*, FV *Break Away II*, FV *C King*, FV *Cachalot*, FV *Captain Alex*, FV *Captain Senrab*, FV *Cooloola Star*, FV *Coral II*, FV *Coral Sea*, FV *CP Jane*, FV *Craig Lenn Anne*, FV *Daisy J*, FV *Damarla*, FV *Darden Star*, FV *Dawsonia*, FV *Debbie B*, FV *Del Maree*, FV *Dhikarr*, FV *Eastern Mist*, FV *Ella Mae*, FV *Eva W*, FV *Evening Star*, FV *Exodus*, FV *Farsund*, FV *Fay Jan*, FV *Gemini Star*, FV *Glen Joy*, FV *Gypsy*, FV *Highcatcher*, FV *Hobo Too*, FV *Illusion*, FV *Karabella*, FV *Karool*, FV *Kathleen II*, FV *Katie M*, FV *Kenandale*, FV *Kia Orana*, FV *Leisa T*, FV *Lorna Jan*, FV *Magani*, FV *Makara*, FV *Mar Jean*, FV *Margram*, FV *Marina*, FV *Matano*, FV *Melissa Joy*, FV *Midnight Fox*, FV *Milana J*, FV *Moccasin*, FV *Moonraker*, FV *Moreton Mist*, FV *Mystery Bell*, FV *Nessodden*, FV *North Queen*, FV *Patrica M*, FV *Peg II*, FV *Pioneer*, FV *Pisces Star*, FV *Popeye*, FV *Providence*, FV *Queenslander*, FV *Reality II*, FV *Rebecca Mae*, FV *Reflect*, FV *Restless*, FV *Robian*, FV *Roger Lee*, FV *Rolinda*, FV *Sassenach*, FV *Sea Raker*, FV *Shamrock*, FV *Shane*, FV *Sharon Lee*, FV *Shimer Jean*, FV *Shiralee*, FV *Siren III*, FV *Sonya M*, FV *Stardancer*, FV *Starwatch*, FV *Susan M*, FV *Swan*

Song II, FV *Tafura*, FV *Talley Ho*, FV *Three Rivers*, FV *Tracey Anne*, FV *Uannjo*, FV *Upstart Raider*, FV *Wandering Star*, FV *William Kelf*, and FV *Zodiac*.

Tracking Trawl Caught Turtles:
FV *Sonya M*, FV *Rolinda*

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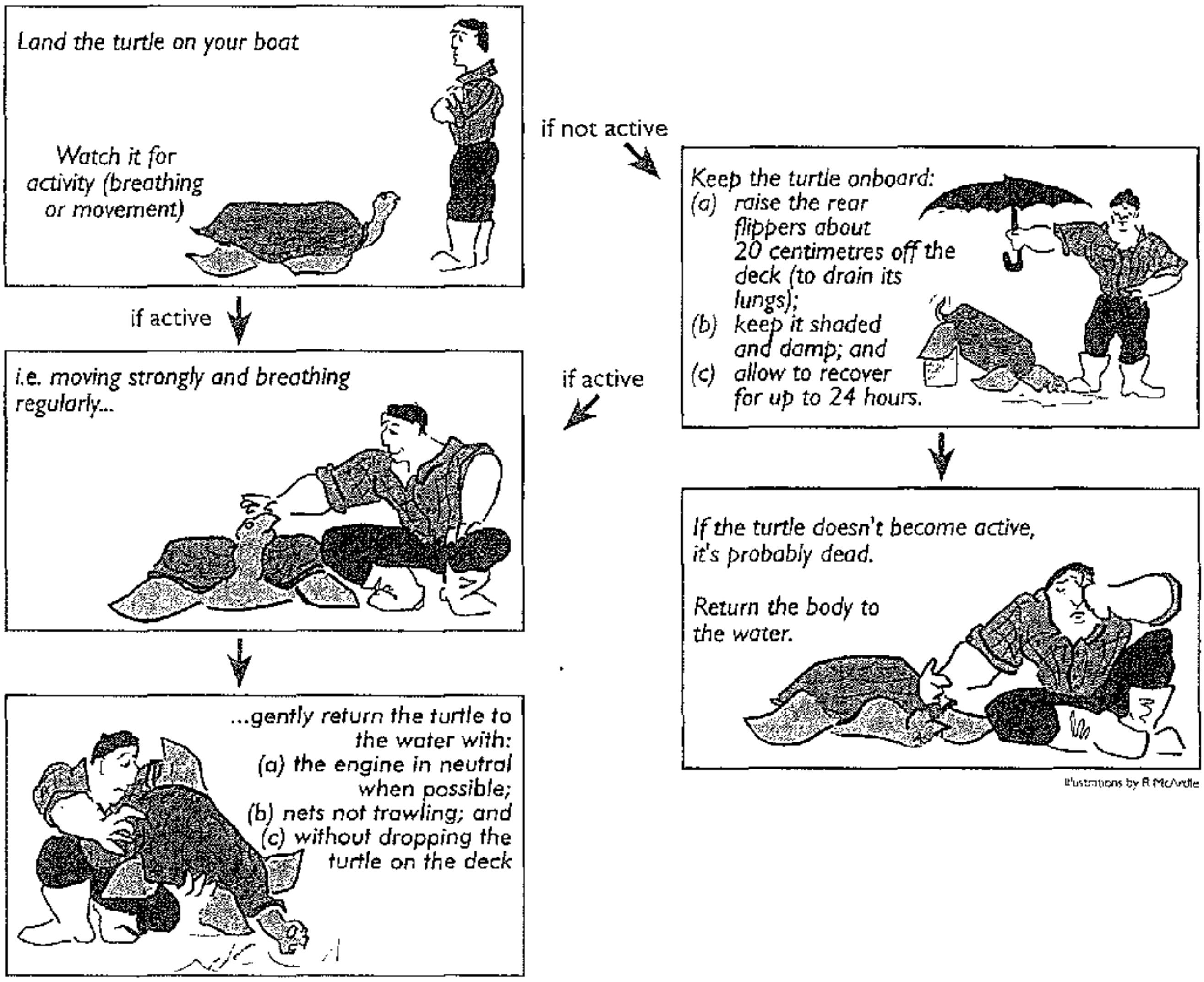
APPENDICES

1. Turtle Recovery Procedures and Code of Fishing Ethics

Turtle Recovery Procedures

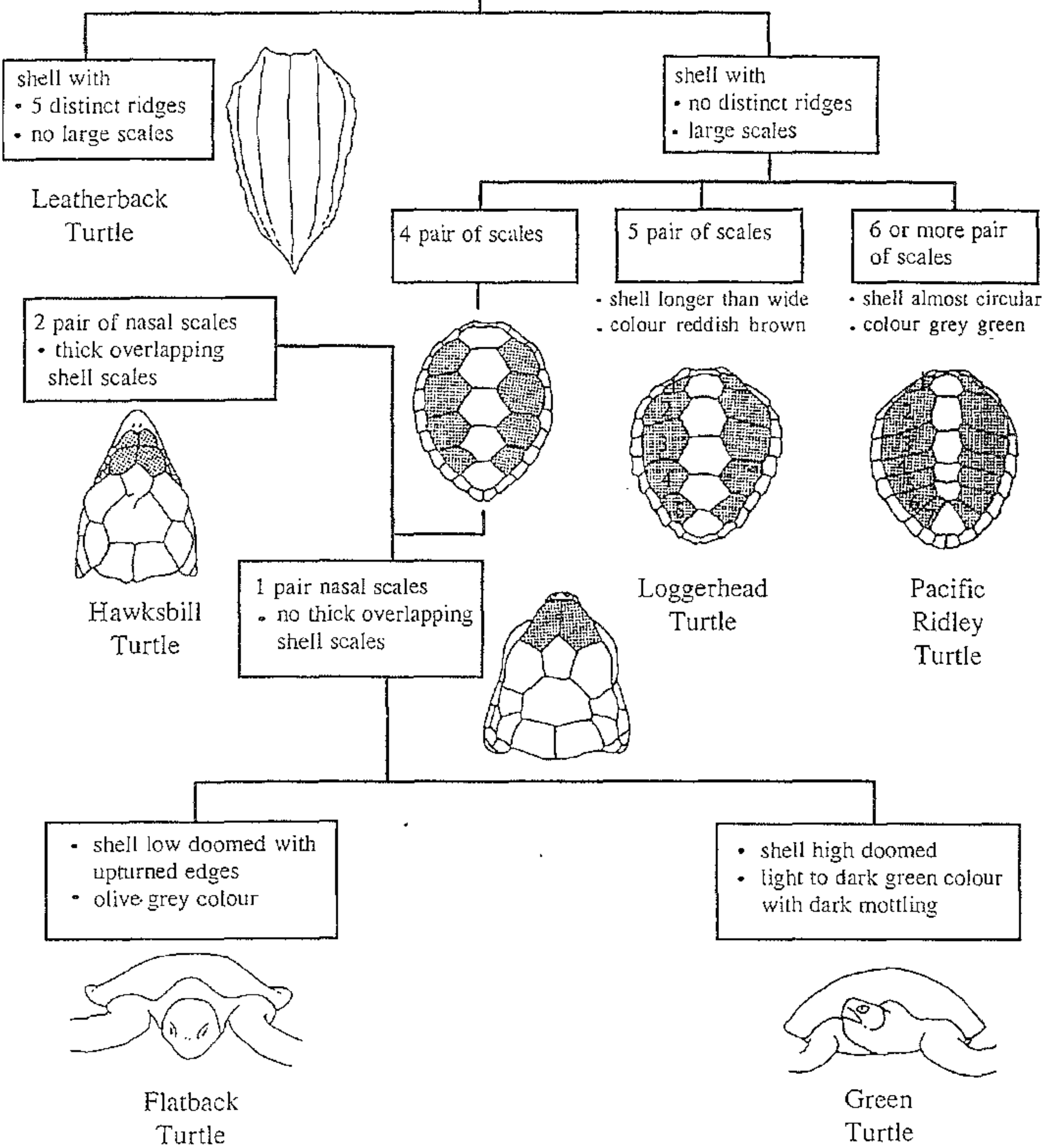
Sea turtles caught in trawl nets may be stressed. Most are conscious and able to swim away after removal from the net, but some may be tired or appear lifeless. Turtles that appear lifeless are not necessarily dead. They may be comatose. Turtles returned to the water before they recover from a coma will drown. A turtle may recover on board your boat once its lungs have drained of water. This could take up to 24 hours. By following these steps you can help to prevent unnecessary turtle deaths:



Additional information

All records of turtle catches and deaths are important. If you catch a sea turtle record when, where, what species and what condition it was in when released. Record any tag numbers that may be on the front flippers of the turtle. This information should be recorded on your compulsory fishing log book or passed on to the Southern Fisheries Centre, telephone: (07) 3817 9500.

Guide to Sea Turtle Identification

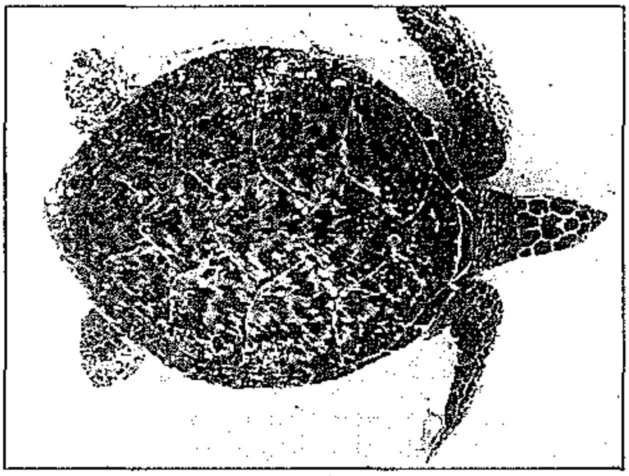


Note: The colour of the shell may vary within species.

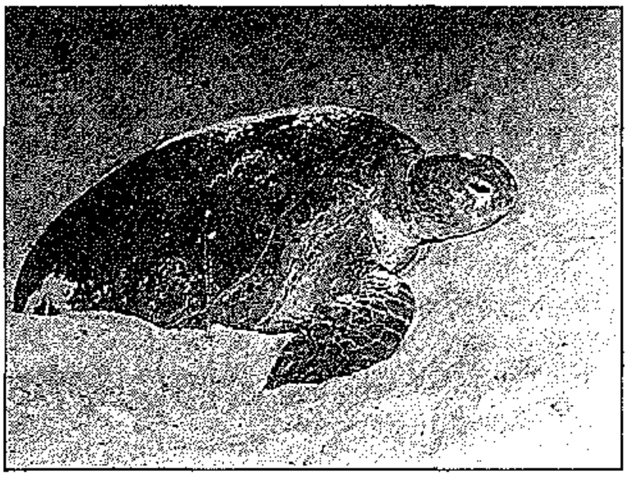
For more information contact the Southern Fisheries centre on (07) 3817 9500

Sea Turtle Identification Chart

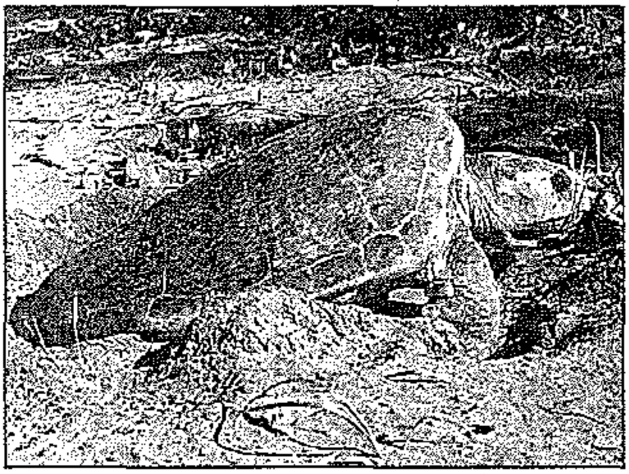
(Photos courtesy of Department of Environment)



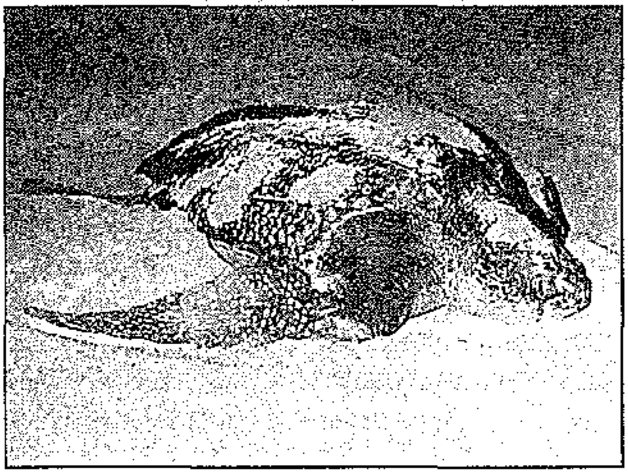
Hawksbill Turtle



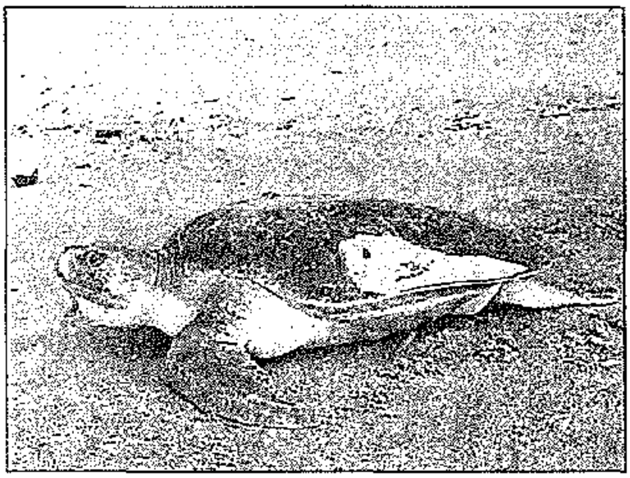
Green Turtle



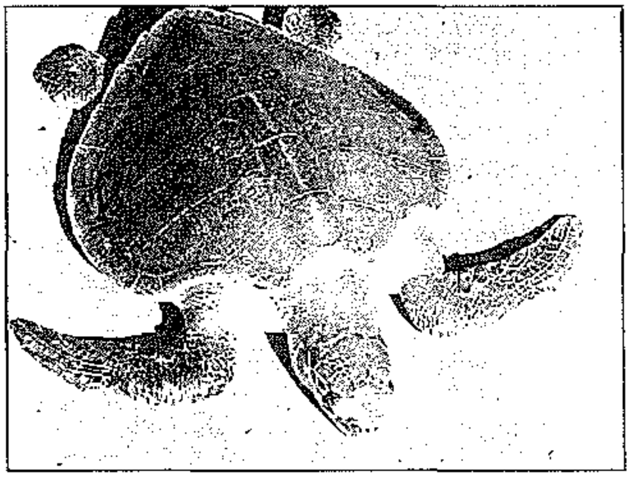
Loggerhead Turtle



Leatherback Turtle



Flatback Turtle



Pacific Ridley Turtle

QCFO
QUEENSLAND COMMERCIAL FISHERMEN'S ORGANISATION

DPI
QUEENSLAND
DEPARTMENT OF PRIMARY INDUSTRIES

Code of Fishing Ethics: The Capture of Sea Turtles

Sea turtle mortality is caused by a number of factors including direct harvest by indigenous people, ingestion of marine debris, predation by introduced animals, fungal and bacterial infections of eggs, entanglement in shark nets, boat propellor strikes and incidental capture in fishing gear. Although trawl related mortality is minimal, the commercial fishing industry still needs to assist in the conservation of endangered sea turtles.

By following this code of fishing ethics, fishers can assist in minimising the impact of their trawling operations on sea turtles. Individual fishers are encouraged to adhere to the code of fishing ethics.

Refrain from trawling within 2 to 3 nautical miles of 'major' turtle nesting beaches during turtle nesting season.
Why: to minimise the possibility of nesting turtles being caught in trawl nets.

Limit trawl shots to less than 90 minutes in areas of high turtle numbers.
Why: to minimise mortality of turtles caught in trawl nets. Turtles caught in trawl nets have better chance of surviving if trawl shots are less than 90 minutes.

Apply recovery procedures when appropriate. Return lively turtles to the water as soon as possible. Why: to help the recovery of turtles accidentally caught in trawl nets thereby minimising unnecessary mortality.

Forward information on tagged or marked turtles caught to Southern Fisheries Centre.
Why: to help find out about basic turtle biology such as distance moved and life spans.

Participate in research programs monitoring the incidental capture of turtles in trawl nets. Why: to assist the collection of data to determine if trawling does/does not affect sea turtles.

Participate in research programs trialing by-catch excluding equipment. Why: through fishers participating in these trials an excluder device which is most suitable to your fishing grounds is more likely to be developed, something which will advantage fishers and turtles.

For further information contact:
QCFO (07) 3262 6855
or
Southern Fisheries Centre (07) 3817 9500

Australian Fisheries Management Authority

FISHERIES RESEARCH & DEVELOPMENT CORPORATION

Australian Nature Conservation Agency

2. Supplementary Report to the Queensland Department of Environment

Executive Summary: This supplementary report was compiled upon verbal request from the Queensland Department of Environment to have access to information from the QDPI turtle monitoring program. This information has been provided on the understanding that it is used for policy purposes in collaborating with the Queensland Fisheries Management Authority's TrawlMAC. One of TrawlMACs' objectives is to determine appropriate areas for the introduction of TEDs in the Queensland East Coast Otter Trawl Fishery.

To assist in this objective, estimates of the frequency of turtle capture by 30^2 nautical mile grids are presented. The scale at which the data are presented is limited by the information returned by commercial fishers into the otter trawl catch and effort database, QFISH, which is managed by the QFMA. The frequency of turtle captures is estimated as turtle catch per unit effort (CPUE) where the unit of effort is days fished. Average CPUE (± standard deviation) per QFISH grid is presented for all species pooled as well as by species (ie loggerhead turtles, *Caretta caretta*, flatback turtles, *Natator depressus*, green turtles, *Chelonia mydas*, Pacific Ridley turtles, *Lepidochelys olivacea*, hawksbill turtles, *Eretmochelys imbricata* and unidentified).

To allow estimates of turtles caught per QFISH grid, average effort (days fished ± standard deviation) is also presented. If calculated, 6243 turtles are estimated to be caught annually in the Queensland East Coast Otter Trawl Fishery. This is comprised of 3,325 loggerhead turtles, 1,021 flatback turtles, 1,393 green turtles, 289 Pacific Ridley turtles, 45 hawksbill turtles and 170 unidentified turtles. It should be noted that these figures are based on simple calculations of annualised CPUE and have wide confidence intervals. Continuing work by QDPI in analysing the raw data (using complex data stratification, weighting observations and bootstrap resampling) results in estimates that are overall, lower and that have tighter confidence intervals: total turtles – 5,901; loggerhead turtles – 2,938; flatback turtles - 968; green turtles – 1,562; Pacific Ridley turtles – 323; hawksbill turtles - 80 and unidentified turtles - 30. This information will be available in the FRDC Final Report, which is still in preparation. Despite the discrepancies, for the purposes of policy formation, the relative frequency of potential turtle captures (CPUE) and the relative number of turtles caught remains reasonably constant.

As requested, average tow duration per QFISH grid has also been provided. The relationship between tow duration and turtle mortality is complex, with the condition of a captured turtle being influenced by several factors, including what oxygen reserves the turtle had when it became caught in the net, how long the turtle had been struggling within the net, and whether it was still recovering from previous captures. Despite the lack of a definitive relationship between tow time and mortality, it is generally assumed that the longer the tow duration of a fishery, the greater the potential for turtle mortality to occur. Average tow durations provided in this report should be viewed as that - an average which may vary considerably at certain times in the year or that which may vary considerably between the spatial locations within the 30^2 nautical miles that comprise a QFISH grid. Also included in this report, is an updated version of the preliminary analysis of the turtle monitoring data to identify areas of "appreciable" turtle captures. This analysis was initially completed in May 1996 for the QFMA's TrawlMAC, based mainly on data from 1993 to 1995. The full 6 years data, 1991 to 1996 have been included in the current analysis in the identification of areas of "appreciable" turtle captures.