A BIOLOGICAL REVIEW OF AUSTRALIAN MARINE TURTLES.

1. LOGGERHEAD TURTLE *Caretta caretta* (Linnaeus)

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Cover photographs: Clockwise from top left: nesting female *Caretta caretta* from eastern Australia; Mon Repos Beach, a mainland rookery with brown siliceous sand; Post-hatchling *Caretta caretta*, carapace length = 13 cm; Erskine Island, a Great Barrier Reef rookery with white coralline sand.

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PREFACE

This review of the loggerhead turtle provides the first comprehensive collation of biological data for the species. While peer reviewed scientific publications are the most significant source of information for the species, there is a large body of additional information available from many other sources within Australia. In particular, I have drawn together data contained in many unpublished reports on file in various government and non-government agencies. In addition, relevant information has been obtained from newspaper reports and from books and journals describing the early exploration and natural history of Australia. The review provides a comprehensive summary of information available up to August 2004.

To provide a more comprehensive summary of available information, previously unpublished data drawn from the Queensland Environmental Protection Agency (EPA) Turtle Conservation Project database have been summarised and included. These data are a collation of the results of private research undertaken by myself since 1968 and turtle research undertaken by EPA staff and trained volunteers within foraging and nesting populations in Queensland and adjacent areas within Australia and neighbouring countries.

My understanding of sea turtle biology has been greatly enhanced through collaborative studies with Dr John Parmenter, Dr Craig Moritz, Dr David Owens and Dr Joan Whittier and their respective post-graduate students.

Many folks have assisted in the preparation of this review both directly and indirectly. I am particularly indebted to the assistance and support that I received from Queensland Parks and Wildlife Service staff, in particular Dr Jeff Miller and Duncan Limpus and others who worked in our field studies: Barry Lyon, David Walters, Valonna Baker, Annette Fleay, Phillip Read, Emma Gyuris, Darryl Reimer, Mark Deacon, Ian Bell, Cathy Gatley and John Meech. Keith Morris, Dr Bob Prince and Kelly Pendoley provided guidance regarding turtles in Western Australia. Dr Mick Guinea, Dr Scott Whiting, Ray Chatto and Dr Rod Kennett assisted with information regarding turtles in the Northern Territory.

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This assistance is gratefully acknowledged.

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A BIOLOGICAL REVIEW OF AUSTRALIAN MARINE TURTLES

LOGGERHEAD TURTLE, *Caretta caretta* (Linneaus)

1. THE SPECIES

1.1 TAXONOMY

Loggerhead turtle, *Caretta caretta*.

CLASS: REPTILIA
ORDER: TESTUDINES
FAMILY: CHELONIIDAE
SPECIES: *Caretta caretta* (Linnaeus, 1758)

There is one extant species for the genus and there are no valid subspecies currently recognised (Cogger, 1992; Dodd, 1988; Pritchard and Trebbau, 1984; Bolten and Witherington, 2003) (Figure 1).

1a. Nesting female

1b. Hatchling

1c. Post-hatchling, carapace length = 13 cm

1d. Post-hatchling, 18 month captive reared.

Figure 1. *Caretta caretta* from eastern Australia.

1.2 GLOBAL DISTRIBUTION

The monospecific genus *Caretta* has a worldwide circumtropical and subtropical distribution (Dodd, 1988; Bolten and Witherington, 2003). *C. caretta* breeds primarily in subtropical to tropical regions of each ocean. In the Indian Ocean there are breeding aggregations in South Africa-Mozambique, Oman, Sri Lanka and Western Australia (Baldwin *et al.* 2003) (Figure 2). In the Pacific Ocean there are breeding aggregations centred on Japan and south Queensland-New Caledonia (Limpus and Limpus, 2003a) (Figure 2). There is no known *C. caretta* breeding in Papua New Guinea, Indonesia or Malaysia.

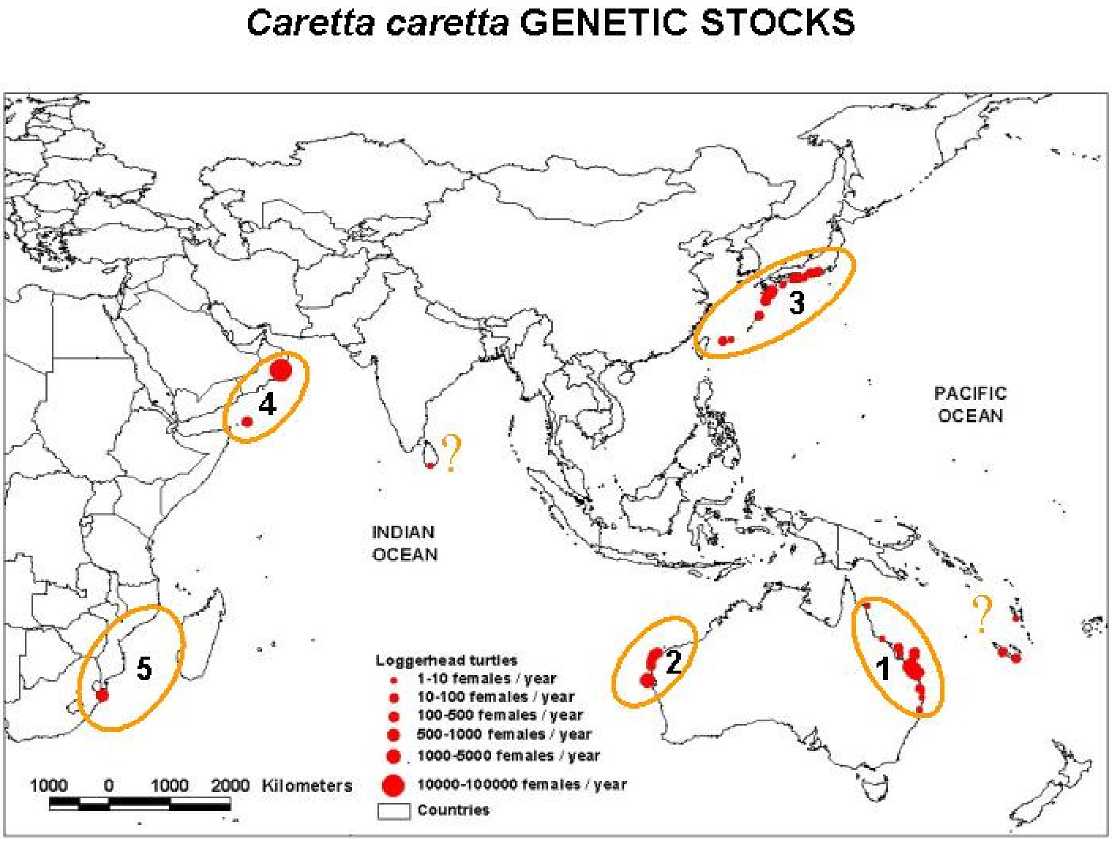


Figure 2. Distribution of *Caretta caretta* breeding sites in the Indian Ocean – Western Pacific Ocean region. Identified genetic stocks: 1 = Eastern Australian; 2 = Western Australian; 3 = Japanese; 4 = Arabian Peninsula; 5 = East African. The nesting populations of Sri Lanka and New Caledonia have yet to be genetically tested.

Genetic studies on the global scale have demonstrated that there is little or no female-mediated interbreeding between the major breeding aggregations (Bowen *et al.* 1993, Bowen, 2003 (Figure 2). In management terms, this means that should there be a significant population decline at one of the major breeding units, there is little probability of it being repopulated from other stocks in the time frame of human management. The breeding populations in Australia are therefore unique.

1.3 IDENTIFICATION

The carapace scutes of *C. caretta* are non-imbricate (= non-overlapping) with typically five pairs of costal scutes; three or four enlarged inframarginal scutes on the bridge and no large inframarginal pores within the inframarginal scutes (Cogger 1992; Limpus, 1992) (Figure 3).

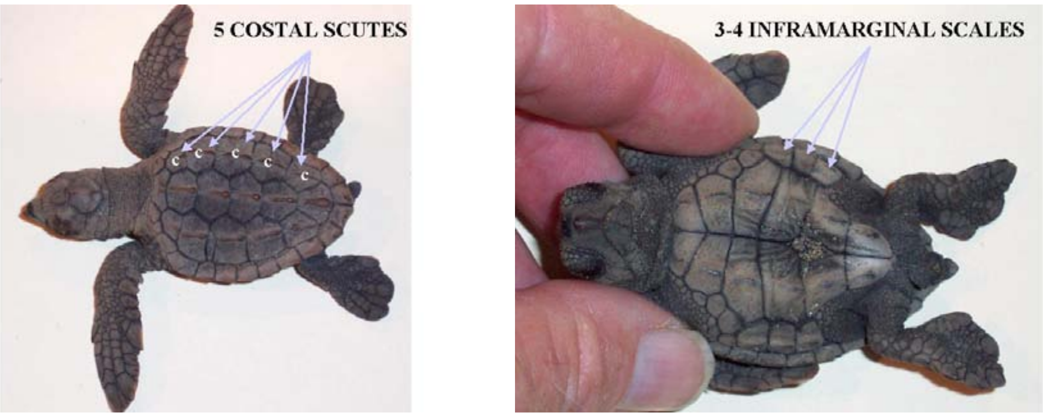


Figure 3. Diagnostic feature for identifying *Caretta caretta.*

C. caretta eggs are distinct in size (average egg diameter = 4.04 cm) and the clutches rarely contain yolkless eggs (Limpus, 1985). When ashore on the nesting beach, *C. caretta* moves with an alternating gait, leaving distinctive tracks up to ~1 m wide (Limpus, 1985).

The morphology of *C. caretta* has been described by Wyneken (2001).

2. BIOLOGY OF THE LOGGERHEAD TURTLE *Caretta caretta* (Linnaeus), IN AUSTRALIA.

Where possible, data are derived from studies of *C. caretta* within the Australian stocks. Where relevant data are not available from these stocks, data are derived from studies on *Caretta* stocks elsewhere (Dodd, 1988; Bolten and Witherington, 2003) or extrapolated from appropriate studies with other turtle species. Because the most comprehensive data for the species in Australia are available from the eastern Australian stock, this stock is described in detail. Where the general biological characteristics have not been described for other stocks in the region, the eastern Australian stock data are used as indicative or representative.

2.1 GENETIC CHARACTERISTICS / STOCK IDENTIFICATION

The *C. caretta* nesting populations of south Queensland have been proposed to encompass two stocks, based on isosyme electrophoretic studies (Gyuris and Limpus, 1988):

- those that nest on the mainland coast and the islands of the Capricorn-Bunker Groups.
- those that nest on the Swain Reef cays, which lie about 100 km further to the northeast.

However, these populations were not differentiated during studies that included mtDNA sequencing and microsatellite analysis (Dutton *et al.* 2002).

The *C. caretta* population that breeds in south Queensland (represented by Mon Repos specimens) is genetically different from the population that breeds in southern Japan (Bowen *et al.* 1994). This is consistent with similar findings for other major populations in the Atlantic basin (Bowen *et al.* 1993). Therefore the *C. caretta* populations of the north and south Pacific Oceans need to be managed as independent stocks. The Queensland population also has fixed genetic differences from both the South African and Oman populations of the western and northern Indian Ocean that represent about a million years of genetic isolation (Bowen, 2003). Preliminary genetic analyses of the *C. caretta* populations of eastern and western Australia indicate that they constitute separate stocks (Dutton *et al.* 2002).

Apart from a small nesting population of a few hundred *C. caretta* annually in southern New Caledonia and Vanuatu, there is no predictable nesting by the species elsewhere in the South Pacific Ocean basin (Limpus and Limpus, 2003a). This breeding population has yet to be genetically assessed.

There are no records of *C. caretta* nesting from across northern Australia between Lizard Island in Queensland and the Ashmore Reefs in north-western Australia.

2.2 EASTERN AUSTRALIAN STOCK

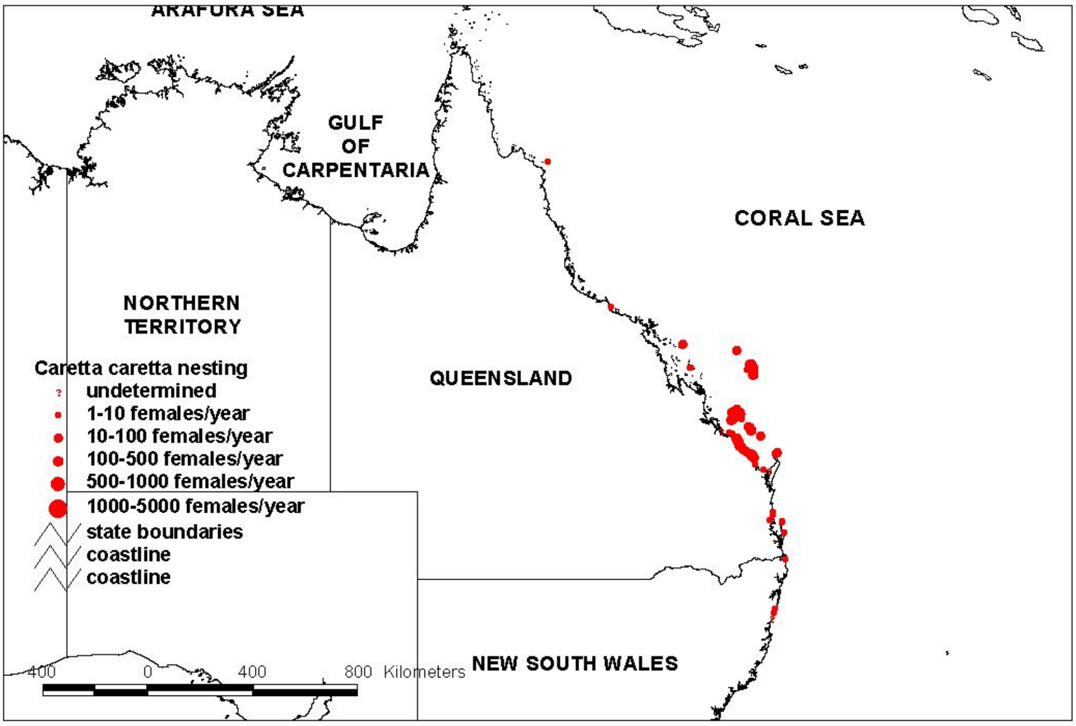
2.2.1 ROOKERIES

The major eastern Australian breeding aggregations occur in three concentrations (Bustard, 1972; Limpus, 1985; Limpus and Reimer, 1994) (Figure 4a):

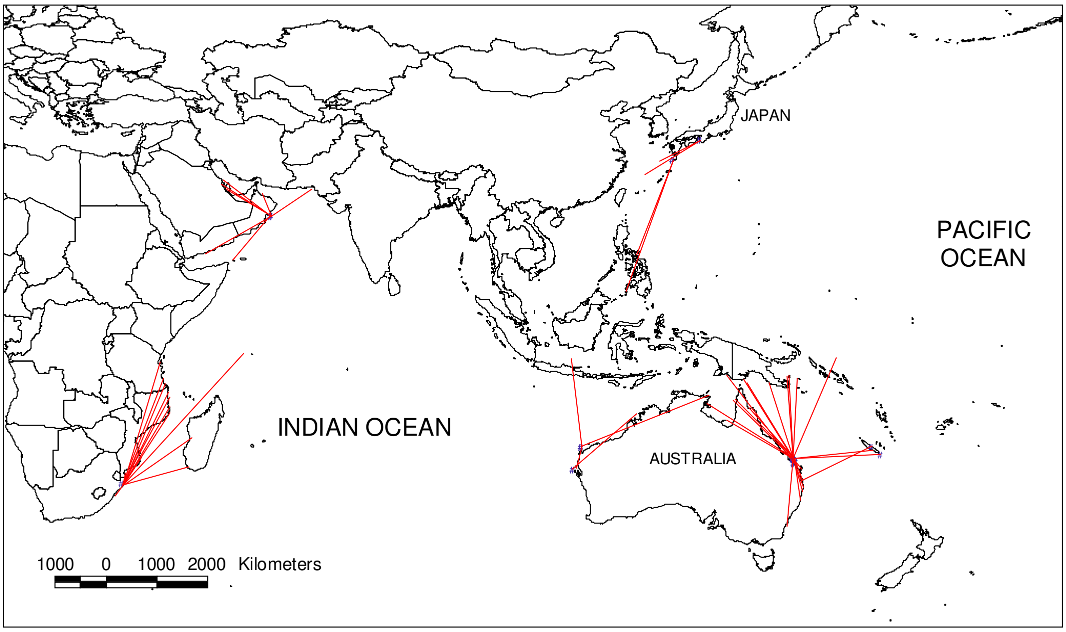
- On the mainland coast of southeast Queensland (especially Mon Repos and adjacent beaches of the Woongarra Coast and Wreck Rock Beach). Minor breeding aggregations occur at other sites on the mainland coast south from Bustard Head to the Sunshine Coast and on northern ends of Fraser, Moreton and North Stradbroke Islands;
- On the 13 islands of the Capricorn-Bunker Groups of the southern Great Barrier Reef (especially Wreck, Tryon and Erskine Islands);

- On the islands of the Swain Reefs (especially Pryce Island, Frigate, Bylund, Thomas and Bacchi Cays) and at Bushy Island off Mackay. These are mostly small aggregations.

Isolated nesting crawls have been recorded beyond this central-south Queensland area, including in northern New South Wales.

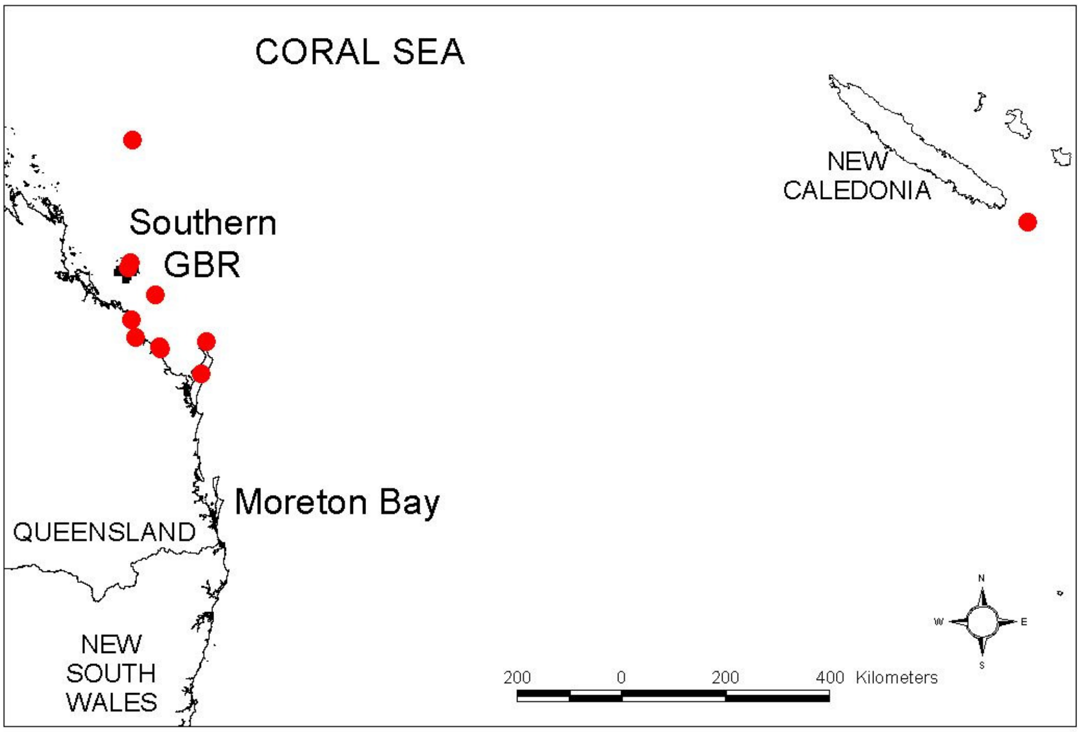


4a. Distribution of *Caretta caretta* rookeries in eastern Australia.

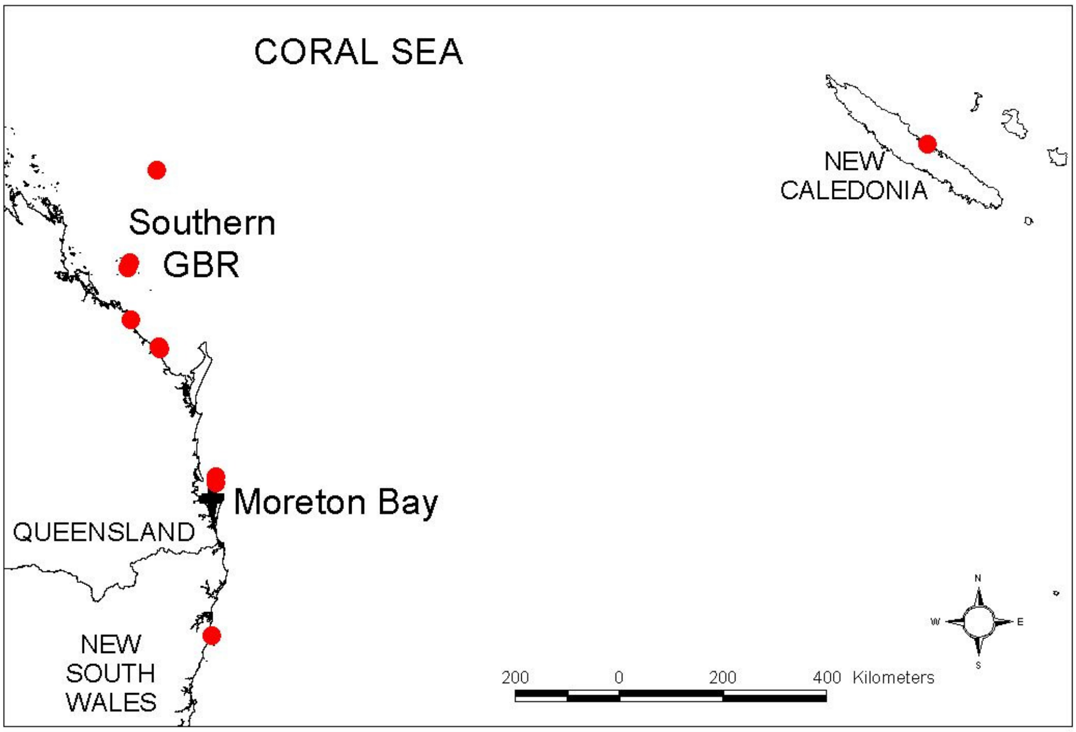


4b. Post-nesting dispersal of *Caretta caretta* from Indian Ocean - Western Pacific Ocean rookeries to their respective foraging areas. Lines have been used to denote end points, not migration pathways.

Figure 4. Distribution of nesting and migration for *Caretta caretta*, in eastern Australia.



4c. Distribution of breeding sites for *Caretta caretta* (dots) migrating from feeding sites within the Capricornia Reefs of the southern Great Barrier Reef.



4d. Distribution of breeding sites for *Caretta caretta* (dots) migrating from feeding areas in Moreton Bay.

Figure 4. Continued

Greater than 80% of all *C. caretta* nesting in Queensland occurs within the protected habitat of Conservation Parks and National Parks. These Parks are listed by the Office of the Queensland Parliamentary Council (2003).

Major rookeries:

- Mon Repos Conservation Park (Figure 5a)
- Capricornia Cays National Park and Capricornia Cays National Park Scientific (Wreck Island, Erskine Island (Figure 5b), Tryon Island) (Anon, 1999)

Minor rookeries:

- Capricornia Cays National Park and Capricornia Cays National Park Scientific (North West Island, North Reef Island, Wilson Island, Heron Island, Masthead Island, Hoskyn Island, Fairfax Island, Lady Musgrave Island) (Anon, 1999)
- Great Sandy National Park (Fraser Island)
- Swain Reefs National Park (Pryce Island, Frigate Cay, Byland Cay, Thomas and Bacchi Cays)
- Bushy Island National Park
- Barubbra Island Conservation Park
- Mouth of Baffle Creek Conservation Park 1 and 2
- Mouth of Kolan River Conservation Park

5a. Mon Repos Beach, a mainland rookery with brown siliceous sand.

5b. Erskine Island, a Great Barrier Reef rookery with white coralline sand.

Figure 5. *Caretta caretta* nesting habitat in eastern Australia.

Nesting census

The size of the annual breeding population (females only) has been monitored at numerous rookeries for the eastern Australian stock for varying periods since 1968 (Limpus and Limpus, 2003a). Those data provide the primary measure of the stability of the *C. caretta* population(s) in the South Pacific Ocean basin:

- The total nesting population for Queensland was estimated at approximately 3500 females for the 1976 and 1977 breeding seasons (Limpus, 1985; Limpus and Reimer, 1994).
- The annual nesting population was estimated at less than 500 females in the 1999–2000 breeding season (Limpus and Limpus, 2003a).
- At all sites monitored since the mid 1970s there has been a marked decline in the number of females breeding annually, with an estimated 50–80% decline in the number of breeding females at various rookeries up to 1990 (Limpus and Reimer, 1994) and a decline of approximately 86% by 1999 (Limpus and Limpus, 2003a) (Figure 6).

Internesting habitat

The nesting female utilises marine habitat adjacent to her rookery called the internesting habitat. She occupies this habitat only during the breeding season while she is preparing each of her successive clutches for laying. In coral reefs, the internesting habitat may be very restricted in area for individual turtles, being less than 1 kilometre from the nesting beach for some females (Limpus and Reed, 1985). In internesting habitat with less structure, the internesting female may range up to 24 km from the nesting beach. During the first 3 days of preparing for the next clutch, the internesting female is less active (slower swimming, shorter displacement distances) than during the remainder of the internesting period (Tucker *et al.* 1996). The first 3 days of preparation for the next clutch encompass the period during which ovulation, fertilisation, first cleavage of the embryo and commencement of shelling of the egg occurs (Miller, 1985). There is little or no feeding by the breeding females while in the internesting habitat (Limpus *et al.* 2001).

A significant proportion of the internesting habitat adjacent to the *C. caretta* rookeries of Mon Repos and the Woongarra Coast are contained within the Woongarra Marine Park. This Marine Park zoning specifically provides for a seasonal closure to trawling and for control of tourist activities on Mon Repos beach during the turtle breeding season (1 October to 31 January).

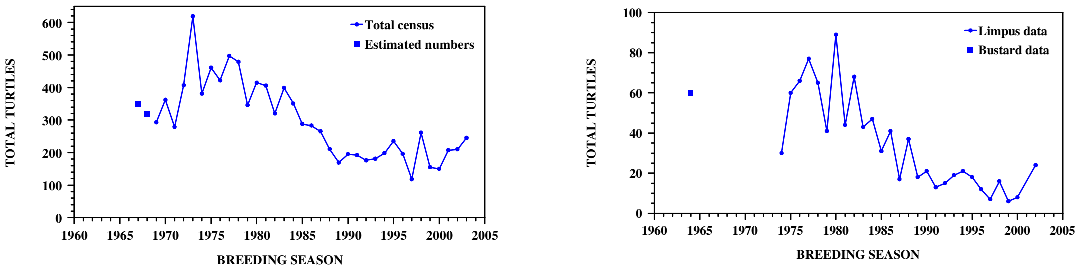
The Great Barrier Reef Coast Marine Park (Queensland) and the adjacent Great Barrier Reef Marine Park (Federal) zoning of the waters adjacent to Wreck Rock and the Capricornia and Swain Reefs rookeries of the southern Great Barrier Reef provides substantial protection of the internesting habitat for the majority of the eastern Australian *C. caretta* nesting population.

2.2.2 FIDELITY TO NESTING SITES

The adult female displays a high degree of fidelity to her chosen nesting beach, with most females returning to the same small beach for their successive clutches within a nesting season and in successive nesting seasons (Bustard, 1972; Limpus, 1985; Limpus *et al.* 1984, 1994).

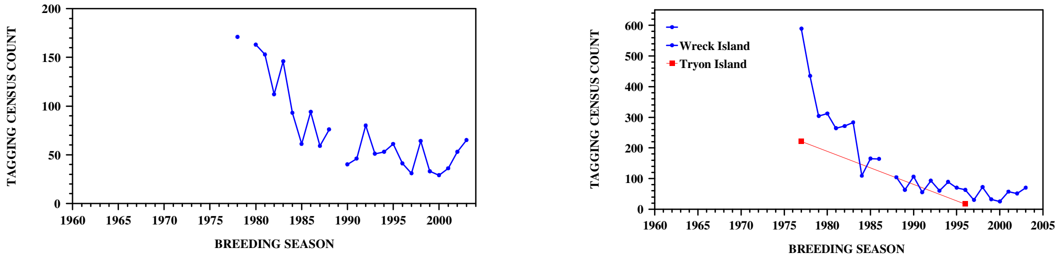
The genetic studies provide convincing evidence that the breeding female is returning to the region of her birth (Bowen *et al.* 1993, 1994; Bowen, 2003). It remains to be demonstrated whether this fidelity is the result of imprinting to the natal beach during the egg or hatchling phase or whether the hatchling is first imprinted to the region of her birth and is later imprinted to her rookery(s) as an adult during her first breeding season.

Mainland beaches   Great Barrier Reef coral cays



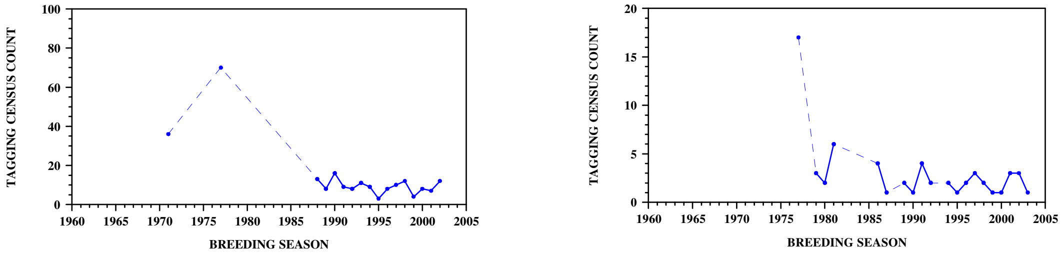
6a. Woongarra coast, including Mon Repos. Total tagging census for the entire breeding season for five beaches between Burnett and Elliott Rivers.

6b. Heron Island. Total tagging census for the breeding season.



6c. Wreck Rock beaches. Five-week total tagging census from mid December to late January on the 22 km beach from Red Rock to Broadwater Creek.

6d. Wreck Island and Tryon Island. Two-week mid-season tagging census for the last two weeks of December.



6e. Lady Musgrave Island. Two-week mid-season tagging census for the last two weeks of December.

6f. Northwest Island. Two-week mid-season tagging census for the last two weeks of December.

Figure 6: Nesting census data for *Caretta caretta* index beaches in eastern Australia.

2.2.3 MIGRATION

There is no one path followed by all turtles on their breeding migrations. Each adult migrates with a high degree of faithfulness between its particular feeding area and its rookery (Limpus, 1985, 1989, 1994; Limpus *et al.* 1992; Limpus and Limpus 2001, 2003b). While some migrate more than 2600 km, the majority migrate less than 1000 km to their rookeries. Turtles nesting at the one rookery will have migrated from numerous foraging areas (Limpus and Limpus 2003a). Similarly, turtles that live within the same foraging area can be expected to disperse to widely scattered breeding sites (Limpus and Limpus, 2001, 2003b. Figures 4c–d).

Females tagged at the southeast Queensland rookeries have been recorded from feeding areas in Indonesia, Papua New Guinea, Solomon Islands, New Caledonia, Northern Territory, Queensland and New South Wales (Figure 4b). There have been unconfirmed reports of tagged loggerhead turtles being trawled in northern New Zealand (Limpus, 1985). If so, there is a high probability that they originated from the Queensland rookeries.

2.2.4 BREEDING SEASON

In south Queensland (Limpus, 1985):

- Mating commences in about late October, reaches a peak in November and ceases by about early December;
- Nesting commences in late October, reaching a peak in late December and ends in about early March; and
- Hatchlings emerge from nests from late December until about May with a peak of hatching in February and early March.

2.2.5 BREEDING ADULTS

Adult *C. caretta* (Figure 1a) are large-headed; brown dorsally; the carapace is usually variegated with light brown, reddish-brown and black areas; and the ventral plastron is whitish or cream. They have distinct horny scales on a smooth domed carapace. Breeding males are similar in appearance to the females in carapace size and colour (Limpus, 1985). Sizes of adults are summarised in Table 1.

2.2.6 BREEDING CYCLES

The endocrine cycles associated with maturation and the breeding cycles of male and female *C. caretta* have been reviewed by Hamann *et al.* (2003). The morphology of the male and female reproductive system for *C. caretta* has been summarised by Miller and Limpus (2003). *C. caretta* breeding cycles are summarised in Table 2.

Yolk deposition associated with the maturation of ovarian follicles is completed prior to commencement of the breeding migration from the distant foraging areas (Hamann *et al.* 2003). The breeding female does not feed, or does so infrequently, during the internesting period offshore from the nesting beach (Limpus and Limpus, 2003b). While in the egg production phase of her life, the breeding female relies on stored fat reserves to meet her nutrient and energy needs (Hamann *et al.* 2003).

The circulating hormone profiles of the breeding female when she crawls ashore and enters the nesting habitat indicate that she is physiologically prepared for oviposition and is not on a pre-ovulatory exploratory crawl (Whittier *et al.* 1997). This study concluded that unsuccessfully nesting females are individuals that experience unsatisfactory situations that cause them to return to the sea without oviposition of eggs.

Breeding females show a reduced corticosterone stress response compared to non-breeding females that enables females to maintain behavioural and physiological commitment to reproduction, even when she has been severely traumatised (Jessop *et al.* 2003). Nesting turtles are unlikely to experience elevated levels of corticosterone when exposed to ecological stressors such as disturbance by other nesting turtles, failure to find a suitable nesting site, elevated body temperatures or even human disturbance during nesting (Jessop *et al.* 2003).

Table 1. Summary of the sizes of breeding adult *Caretta caretta* from eastern Australia.

		Measurement				**References**
		mean	**SD**	**Range**	**n**	
Curved carapace length (cm)						
Female	Mon Repos	95.76	4.42	80.0–113.5	2207	Limpus, 1985
	Heron Island	95.70	4.68	84.0–108.0	380	Limpus *et al.* 1984
Male	Capricorn Reefs	96.64	1.32	95.0–99.5	7	Limpus, 1985
Weight (kg)						
Female	Mon Repos	100.65	13.99	70.3–146.1	112	Limpus, 1985

Table 2. Summary of eastern Australian *Caretta caretta* breeding cycles.

		Measurement				**References**
		Mean	**SD**	**Range**	**n**	
Renesting interval (d)						
	Mon Repos	13.90	1.71	9–23	2959	Limpus, 1985
	Heron Island	14.50	3.48	13–20	37	Limpus *et al.* 1984
Remigration interval (yr)						
Female:	Mon Repos	3.82	1.84	1–10	325	Limpus, 1985
Male:	Southern GBR			Mostly annual		Wibbels *et al.* 1990

2.2.7 EGGS

The eggs are cleidoic, white and spherical and they must be laid in 25°C–33°C, well ventilated, low salinity, high humidity nest substrate not subjected to flooding, for successful incubation (Ackerman, 1980; Limpus, 1985; Limpus *et al.* 1985; Miller, 1985). There is no parental care of the eggs or hatchlings (Miller, 1985). Nesting behaviour has been described by Bustard *et al.* (1975).

Embryos can be killed by rotation of the eggs during incubation (Limpus *et al.* 1979). For optimal hatching success, eggs should not be rotated if they are more than three hours and less than three weeks post-oviposition.

Measurements of *C. caretta* eggs and nests are summarised in Table 3.

The number of eggs per clutch is a function of when in the season it is laid. Larger clutches tend to be laid in the early part of the breeding season (Limpus, 1985).

2.2.8 HATCHLINGS

C. caretta hatchlings (Figure 1b) are dark brown dorsally and lighter brown ventrally. Mottled and/or spotted carapaces are rare.

Hatchlings orient to low elevation light horizons when moving from the nest to the sea (Limpus, 1971, 1985; Salmon and Wyneken, 1994). Hatchlings can be disoriented by bright lights that limit their ability to see distant horizons but they are not disoriented by the yellow wavelengths of low pressure sodium vapour lights (Witherington and Bjorndal, 1991). *C. caretta* hatchlings, like *Chelonia mydas* hatchlings, are not disoriented by intermittent flashing lights (C. Limpus, unpubl. data. Mrosovsky,1978). By orienting to swim perpendicular to wave fronts the hatchlings are directed to swim out to the open ocean (Lohmann, 1992; Salmon and Wyneken, 1994). See Lohmann and Lohmann (2003) for a review of orientation mechanisms.

The hatchling is imprinted to the inclination of the earth's magnetic field at the nesting beach (Lohmann, 1991; Lohmann and Lohmann, 2003; Light, Salmon and Lohmann, 1993). Imprinting to the smell of the sand or the water that the hatchling first contacts may also occur, as is the case with *Lepidochelys kempii* hatchlings (Grassman *et al.* 1984). This age class does not feed or sleep between leaving the nest and entering to deep offshore water.

Measurements of *C. caretta* hatchlings are summarised in Table 4.

Table 3. Summary of eastern Australian *Caretta caretta* egg and nest measurements.

	Measurement				**References**
	mean	**SD**	**Range**	**n**	
Clutches per season					
Mon Repos	3.41	1.214	1–6	1207	Limpus, 1985
Eggs per clutch					
Mon Repos	127.0	22.15	48–190	1056	Limpus, 1985
Heron Island	124.4	20.07	89–164	27	Limpus *et al.* 1984
Yolkless eggs per clutch					
Mon Repos	0.072	0.34	0–3	671	Limpus, 1985
Heron Island	0.15	0.46	0–2	27	Limpus *et al.* 1984
Egg diameter (cm)					
Mon Repos	4.04	0.132	3.47–4.57	3430	Limpus, 1985
Heron Island	4.12	0.119	3.91–4.34	170	Limpus *et al.* 1984
Egg weight (g)					
Mon Repos	36.54	2.95	26.2–43.1	240	Limpus, 1985
Heron Island	39.22	3.04	34.0–46.0	170	Limpus *et al.* 1984
Nest depth (cm)					
Mon Repos					Limpus, 1985
Top	33.05	10.10	0–59	277	
bottom	57.88	7.05	36–85	505	
Incubation period(d)					
Mon Repos					Limpus, 1985
1978/79	56.6	2.35	49–70	327	
1979/80	54.2	2.06	45–61	565	

2.2.9 EGG and HATCHLING SURVIVORSHIP

The duration of the hatchling phase is a few days, at most. The hatchling phase commences as the hatchling leaves the egg (embryonic stage 32, Miller 1985) and ceases when the hatchling commences to forage in offshore waters (Limpus 1985). Fecundity can be calculated using the pooled results that encompass the period from oviposition, during incubation and emergence to the time that the hatchlings enter deep water.

Clutches can have a zero hatchling emergence because of a wide range of natural factors including problems with the female (infertility, failure to break the embryonic diapause following oviposition), physical characteristics of the nest site (flooding, erosion, lethal temperatures), obstruction of hatchlings (roots and other debris blocking hatchling emergence, compacted sand above the nest) or external biological impacts on the eggs (predation, microbial invasion). No infertile eggs were detected among a large series of eggs examined at oviposition in eastern Australia, i.e. all eggs contained a gastrula (Miller *et al.* 2003).

Total clutch failure from natural causes can be variable between beaches and between breeding seasons (Table 5).

Table 4. Summary of measurements of eastern Australian *Caretta caretta* hatchlings.

	Measurement				References
	mean	**SD**	**Range**	**n**	
Straight carapace length (cm)					
Mon Repos	4.33	0.141	3.90–4.69	710	Limpus, 1985
Heron Island	4.37	0.154	4.00–4.69	127	Limpus *et al.* 1984
Weight (g)					
Mon Repos	20.90	1.680	14.6–26.4	690	Limpus, 1985
Heron Island	19.30	1.181	15.5–22.0	127	Limpus *et al.* 1984

Table 5. Summary of rate of failure of entire clutches from natural causes at eastern Australian *Caretta caretta* rookeries, in the absence of egg predation by vertebrates.

		Measurement		References
		Loss of entire clutch	**Range**	
Clutch failure from natural causes				
Mon Repos	1970s (average)	~13%	8.4–83.0%	Limpus, 1985
Other mainland beaches	1970s	Higher losses from erosion and flooding than at Mon Repos		Limpus, 1985
Heron Island	1986–1987	2% (41 clutches)		EPA Qld Turtle Conservation
	1987–1988	15% (13 clutches)		
	1988–1989	13% (46 clutches)		

The impact of vertebrate predators on *C. caretta* clutches in eastern Australia are summarised along with additional management related observations from the Queensland Turtle Conservation Project field studies in Table 6.

The introduced fox, *Vulpes vulpes*, has been the most significant predator of *C. caretta* eggs in eastern Australia in recent decades. This was one of the reasons that fox predation was listed nationally as a key threatening process. However, this fox predation of *C. caretta* eggs has been restricted to the mainland rookeries and there has been no equivalent predation loss on the GBR coral cay rookeries. In addition, fox predation of these eggs has increased from being non-existent or trivial in the mid 1900s through modest but significant predation levels in the 1960s–early 1970s to a major level by the late 1970s (Table 6). In the years that followed there were gradual management changes that resulted in significant reductions in this predation.

- The discovery of temperature dependent sex determination for marine turtles (Yntema and Mrosovsky, 1980; Miller and Limpus, 1981) led to a change in emphasis for the conservation of *C. caretta* in Queensland. During the 1960s – 1970s there was a perception that marine turtle conservation could be achieved via the protection of individual rookeries (Bustard, 1972), rather than through the management of groups of rookeries for the stock as a whole. As a consequence, prior to 1980 in Queensland, the emphasis had been to protect a few island rookeries, which supported about 60% of the *C. caretta* nesting, as National Parks. This was relatively easy because these island rookeries of the southern Great Barrier Reef had no major predation problems and the land was already owned by the Government.
- Because Mon Repos had been chosen as a long term study site for *C. caretta*, foxes were discouraged from being on the nesting habitat from 1970 onwards. The Mon Repos nesting habitat was at that time almost devoid of trees and shrubs, which made it easy for foxes to be regularly harassed by the research team and local residents. There was some shooting and baiting of the foxes. Fox predation of *C. caretta* eggs reached a peak intensity (~10% of clutches lost per season) at Mon Repos in the late 1960s. Predation levels declined during the early 1970s and have been relatively trivial since about 1975 (Table 6).
- At Wreck Rock, fox predation of *C. caretta* clutches continued to increase from the modest level when monitoring commenced in 1968–1969 to 90–95% predation levels in the mid 1970s. This very intense predation rate continued until the mid 1980s (Table 6).
- In the early 1980s it was realised that the warm beaches of the mainland *C. caretta* rookeries were the primary female hatchling producing beaches for eastern Australia (Limpus *et al.* 1983, 1985). In response, actions were initiated to increase protection to this nesting habitat and to reduce or eliminate predation of turtle eggs by foxes along the mainland beaches of south Queensland. Mon Repos was declared an Environmental Park in 1982 and was later gazetted as a Conservation Park.
- With the introduction of systematic fox baiting on the Wreck Rock and some adjacent beaches in 1987, fox predation of *C. caretta* eggs has been substantially reduced. It has been at an almost trivial level during most years since the mid-1990s for those years that the baiting project has been maintained (Table 6).

Fox control measures have yet to be applied systematically to the approximately 60 km of sand beaches that support low density *C. caretta* nesting between the Woongarra Coast and the Wreck Rock beach, viz: Moore Park, Littlabella, Winfield and Rules Beaches (Table 6) and the other low density rookeries to the north of Wreck Rock beach.

In summary, there have been high levels of fox predation of *C. caretta* clutches on the female hatchling producing rookeries of south Queensland since the late 1960s until the mid 1980s. Since that time there have been variable but generally low levels of continuing loss of clutches from fox predation. Additional losses of clutches from dingo/dog and varanid predation on these same beaches have been minor in comparison to the losses from fox predation.

Eggs killed by nesting turtles on the Bundaberg beaches are summarised in Table 7. Combining the results contained in Table 3 and Table 7, nesting turtles are estimated to destroy 0.437% of the seasonal *C. caretta* egg production.

Table 6. Summary of rate of loss of entire clutches from predation by vertebrate predators at eastern Australian *Caretta caretta* rookeries. Unless otherwise referenced, this table contains previously unpublished observations recorded by the EPA Queensland Turtle Conservation Project field teams led by C. Limpus at Wreck Rock (prior to 1976) and Mon Repos and by N. McLachlan at Wreck Rock (1976 onwards).

	Level of impact	**References**
Mainland beaches		
Mon Repos		
1940s	Local people have no recollection of fox predation of eggs on the beaches of the Woongarra Coast and foxes were rarely seen, if at all, at night on the roads in the surrounding farmland.	Allan Limpus, pers. comm.
1960s	First awareness of fox predation of clutches at Mon Repos.	Allan Limpus, pers. comm.
1963	A local game hunter shot his first foxes in the Bundaberg district near Bingera Weir and Bucca Weir after about seven years of hunting.	Wallace Cochrane, pers comm.
1967–68	"very large numbers of nests are destroyed by foxes." Probably only a hundred or so clutches (~10% of clutches) were destroyed by foxes.	Bustard, 1968
1968–69	Fox predation of eggs common; Up to 3 family groups of foxes visited beach at night & digging into up to 6 clutches/night; many clutches revisited over several nights until all eggs gone; probably of the order of 10% of clutches were being destroyed by foxes.	Limpus, 1985
1969–70	Fox predation common but the majority of clutches were not being predated.	
1970–71	Fox predation of eggs and hatchlings occurred but the majority of clutches were not being predated.	
1971–72	Only 3 clutches dug by fox up to 22 December; numerous clutches had been predated by late March but the majority of clutches were not being predated.	
1972–73	~99% emergence of clutches laid in early December; 89% emergence of clutches laid in late December with losses from erosion and foxes.	
1973–74	7% of clutches emerging in late February were being dug into by foxes.	
1974–75	Minor fox predation recorded.	
1975–76	No fox predation recorded. Most clutches eroded by Cyclone David in early January.	
1977–78	Only 15 clutches destroyed by foxes up to 26 February (1.1% of the seasons clutches).	Limpus, 1985
1980–81	No record of fox predation of clutches	
1981–82	No foxes recorded within nesting habitat but they were recorded in the district during the nesting season.	
1984–85	Less than 0.1% of clutches laid per year were lost to vertebrate predators.	Limpus, 1985
Woongarra Coast		
1990–03	<1% of clutches annually being dug into by foxes or dogs for all beaches along this coast.	
1969–70	Dingos and foxes plentiful on dunes; both are taking a heavy toll on eggs but foxes are the main predator; predation impact appears to be less than last year;	

Table 6 (continued).

	Level of impact	References
Mainland beaches (continued)		
Wreck Rock (22 km of beach)		
1968–69	1st survey of rookery; predation of large numbers of clutches by canids; numerous clutches of hatchlings emerging nightly in late January	
1969–70	Dingos and foxes plentiful on dunes; both are taking a heavy toll on eggs but foxes are the main predator; predation impact appears to be less than last year; varanids present but not preying on clutches	
1970–71	Fox predation common but most clutches not destroyed by foxes.	
1976–77	~90–95% of clutches destroyed by foxes	Limpus, 1985
1977–78	Extreme fox predation of clutches	
1978–79	~90%; mostly by foxes but about 10% by varanid	
1979–80	~90–95% of clutches destroyed by foxes	Limpus, 1985
1980–81	~90–95% of clutches destroyed by foxes	Limpus, 1985
1981–82	~90–95% of clutches destroyed by foxes	Limpus, 1985
1982–83	~90–95% of clutches destroyed by foxes	Limpus, 1985
1985–86	~50% clutch loss to foxes; 7 foxes shot in December	
1986–87	Spatially variable but high clutch loss to foxes	
1987–88	Almost nil fox predation; 1st year of 1080 baiting	
1988–89	Isolated clutches predated by foxes; 1080 baiting	
1989–90	Low level fox predation of clutches; 1080 baiting	
1992–93	Low level fox predation; 1080 baiting	
1994–95	No evidence of fox predation until 10 January; fox predation common after this date. There appears to have been no baiting for foxes immediately prior to the nesting season and first baits were laid on 17 January. Of 149 clutches for the season, 40 (27%) were dug by foxes, 19 (13%) by varanids, 8 (5%) by fox & varanid, 1 (1%) by dog.	McLachlan and McLachlan, 1995 Lemm, 1996
1995–96	No fox predation of clutches until hatchlings began to emerge on 11 January; From then on, clutches were destroyed by foxes every night. Baits laid by QPWS	McLachlan and McLachlan, 1996
1996–97	Foxes active on the beach each night but only 6 clutches dug by foxes up until 24 January; in addition to baiting, 3 foxes shot.	McLachlan and McLachlan, 1997
1998–99	No fox predation of clutches up until 22 January. Two standard baiting efforts for the season.	McLachlan and McLachlan, 1999
1999–00	Foxes active on the beach each night but only 4 clutches dug by foxes up until 24 January. Preseason baiting was implemented but the pre-hatchling-	McLachlan and McLachlan, 2000
2001–02	Foxes active on the beach each night but only 14 clutches dug by foxes up until 9 February.	McLachlan and McLachlan, 2002
2002–03	No fox predation of clutches up until 3 February. Two standard baiting efforts for the season.	McLachlan and McLachlan, 2003
2003–04	No fox predation in early season into late December but 2 clutches dug by varanids; following the failure to rebait for foxes in early January, fox predation increased with 3 clutches /night (range 2–4 clutches, 9 nights monitoring) being dug during January–early February.	McLachlan *et al*, 2004

Table 6 (continued).

		Level of impact	References
Mainland beaches (continued)			
Rules Beach			
	1994–95	Of 101 clutches for the season, 50 (50%) were dug by foxes, 4 (4%) by fox & varanid, 1 (1%) by dog	Lemm, 1996
Winfield Beach			
	1994–95	Of 36 clutches for the season, 7 (19%) were dug by foxes, nil by other vertebrates	Lemm, 1996
Littabella Beach			
	1994–95	Of 33 clutches for the season, 12 (36%) were dug by foxes, nil by other vertebrates	
GBR coral cays			
Capricornia Cays			
	All years	~nil to canids & felids. Trivial egg & hatchling loss to *Rattus rattus* on Wreck and Faifax Islands	Limpus, 1985
Swain Reef cays			
	1976-84	Nil	Limpus and Reed, unpubl. data

Table 7. Proportion of *Caretta caretta* eggs killed by nesting turtles on Mon Repos and adjacent beaches.

	Measurement				**References**
	mean	**SD**	**range**	**n**	
Proportion of clutches dug into by nesting turtles per season	2.6%	0.39	2.2–3.3%	5 seasons	Limpus, 1985
Eggs destroyed per clutch that is dug into by turtles	21.4* *(16.8% of a clutch)	22.24	–	79 clutches	Limpus, 1985

Success of incubation and hatchling emergence from nests onto the beach surface has been measured from undisturbed natural clutches that produced hatchlings:

- Mon Repos (Limpus, 1985)
  1978/79: 0.8189
  1979/80: 0.8041
- Heron Is. (Limpus, 1985; Unpublished data, EPA Queensland Turtle Conservation Project)
  1980/81: hatch success 20% lower than at Mon Repos.
  1986/87: 0.6668
  1987/88: 0.6
  1988/89: 0.6553

The principal predators of *C. caretta* hatchlings while they are crossing the beach from the nest to the sea are crabs and diurnal birds. Survivorship of hatchlings on the beach during the crossing from nest to sea was estimated at > 0.98 at Mon Repos (Limpus, 1973) and > 0.99 for the Capricorn-Bunker cays (Limpus, 1973).

Survivorship (S) of hatchlings while crossing from the beach to deep water off the mainland beaches is very high when quantified for 10 minute swim periods outside the surf zone (S = 0.992. Table 8). This is consistent with the observation that hatchlings have not been found in the gut content of any small sharks or other predatory fish caught from the beach at Mon Repos during the hatchling emergence season (Limpus, 1985).

As the hatchlings continue their swimming frenzy and swim further offshore from the mainland rookeries, they have been recorded as prey to small whaler sharks (*Carcharinus* sp. Limpus, 1985) but the predation rate has not been quantified.

Table 8. Fate of *Caretta caretta* hatchlings, each followed for 10 minutes while attached to a 10 metre monofilament tether, outside the surf zone of mainland nesting beaches, after the methods of Gyuris (1994).

Date	Time	Tide	No. in trial	No. lost	Sea, wind, moon condition
Hatchling releases off Agnes Water, a beach 12 km north of Wreck Rock beaches (n = 126; Lemm, 1996)					
5 Mar 1995	Day	High, rising	20	0	SE wind, new moon
7 Mar 1995	Day	Low, falling	20	0 (1 mauled)	NW wind, 1st Quarter
12 Mar 1995	Day	Low, rising	25	0	SE wind, 1st Quarter
19 Mar 1995	Day	High, falling	21	1	NE wind, Full moon
4 Apr 1995	Night	Low, rising	10	0	NE wind, 1st Quarter
5 Apr 1995	Night	Low, rising	10	0	NE wind, 1st Quarter
6 Apr 1995	Night	Low, rising	10	0	NW wind, 1st Quarter
7 Apr 1995	Night	Low, rising	10	0	NE wind, 1st Quarter
Hatchling releases off Mon Repos beach (n = 120; EPA Turtle conservation project, unpublished data)					
20 Jan 1988	Day, 09.30–10.00 hr	High	20	0	Slight SE wind, no white caps
20 Jan 1988	Day, 15.20–1615 hr	Low	20	0	Light wind, slight white caps
20 Jan 1988	Night, 21.00–22.00 hr	High	20	1	Light SE wind, white caps
21 Jan 1988	Day, 10.00–10.15 hr	High	20	0	Light SE wind, no white caps
21 Jan 1988	Day, 16.30–17.00 hr	Low	20	0	Slight E wind, some white caps
21 Jan 1988	Night, 22.00–23.00 hr	High	20	0	Light SE wind, white caps

Gyuris (1993, 1994), working at the Capricorn-Bunker rookeries that are surrounded by shallow coral reef habitat, measured substantial predation of *C. mydas* hatchlings as they swam from the beaches across the shallows to the deeper water beyond the reef. The mean predation rate during 10 minute trials of hatchlings swimming on 10 metre monofilament tethers was 31% (SE ± 2.5%, range = 0–85%). Fish were the major predators of hatchlings in these waters and predation rates were lowest during the combination of new moon and high tide and highest during low tide around the full moon. Smaller hatchlings had significantly lower survivorship than the larger hatchlings (Gyuris, 2000). Predation rates increased when the natural counter shading of white ventral and dark dorsal surfaces of the *C. mydas* hatchling was removed by painting the hatchling with black paint (Gyuris, 1993). *C. caretta* hatchlings with their brown ventral surface have less counter shading benefits than *C. mydas* hatchlings when swimming at the surface and they are smaller than *C. mydas* hatchlings (Limpus, 1985). Therefore it is expected that the predation rates by fish on *C. caretta* hatchlings swimming across these same shallow reef-flat waters should be higher than the predation rates measured on *C. mydas* hatchlings.

On the basis of the above, it is expected that there are marked differences in predation rates on hatchlings during their swimming frenzy as they disperse from their natal beaches, with very low predation rates occurring off the mainland rookeries and very high predation rates occurring off the coral cay rookeries.

2.2.10 HATCHLING SEX RATIO

The sex of *C. caretta* hatchlings is a function of the temperature of the nest during middle incubation (Yntema and Mrosovsky, 1980, 1982). The brown sand beaches of the mainland produce mostly female hatchlings and the white sand beaches of the coral cays and shaded habitats can produce mostly males (Limpus *et al.* 1983, 1985; Reed, 1980). The pivotal temperature, the temperature that theoretically produces a 1:1 hatchling sex ratio, varies between genetic stocks (Limpus *et al.* 1985; Yntema and Mrosovsky, 1980).

Pivotal temperature
Pivotal temperature = 28.6^{o}C for the eastern Australian stock (Limpus *et al.* 1985)

Hatchling sex ratio
There are differences in sex ratio for hatchlings born on the warm, brown sand, mainland beaches compared to those born on the cooler, white sand, coral cays of the southern Great Barrier Reef (GBR) (Limpus *et al.* 1983, 1985; Reed, 1980):

- Mon Repos: strongly biased to females;
- Heron Island: strongly biased to males.

Although not measured, hatchling sex ratio prior to the recent population decline may have been biased to male for the entire population given the larger number of nesting females on the coral cays, compared to the mainland beaches. However, this ratio would have been modulated by the higher emergence success of hatchlings on the mainland beaches and the higher survival rate of hatchlings swimming out to sea off the mainland beaches relative to the coral cays.

2.2.11 POST-HATCHLINGS

The distribution and biology of this age class is poorly understood. Turtles within this post-hatchling age class have been recorded rarely from GBR waters. It is believed that they follow an oceanic planktonic life in surface waters (Bolten, 2003a, b). Records of post-hatchling distribution suggest that they are swept south by the East Australian Current, past northern New South Wales and then east into the South Pacific Ocean (Limpus *et al.* 1994; Walker, 1994). Beach-washed *C. caretta* from New Zealand waters were in this post-hatchling size class (Gill, 1997). There is a progressive increase in size of *C. caretta* from hatchlings leaving the south Queensland nesting beaches (Table 9) along this hypothesised drift-path as they pass southeast Queensland, northern New south Wales and beyond New Zealand (Table 9).

An intermediate size range of post-hatchling *C. caretta* occurs in the eastern South Pacific Ocean off the coast of Peru (Alfaro-Shigueto *et al.* 2004; Kelez *et al.* 2004) and Chile (Donoso *et al.* 2000) where they are part of longline fishery bycatch (Table 9). Preliminary results from genetic analysis of these turtles have identified them as originating from the western South Pacific breeding populations (Alfaro-Shigueto *et al.* 2004).

While *C. caretta* have been recorded from the oceanic waters of the Coral Sea (Nishimura and Nakahigashi, 1990) their distribution and abundance has not been quantified.
5% of the post-hatchling *C. caretta* found in the eastern North Pacific Ocean off the Mexican coast have been identified as possibly originating from the eastern Australian stock by the use of genetic markers - the remainder were the Japanese genotypes (Bowen *et al.* 1995).

There is a paucity of data on the species within the oceanic South Pacific Ocean. Within the pelagic environment of the North Pacific Ocean, the post-hatchling size class feeds on macro zooplankton including violet snails - *Janthina sp.* (Gastropoda), *Carinaria cithara* (Heteropoda), chondropores - *Velella velella* (Hydrodia), gooseneck barnacles - *Lepas sp.* (Cirripedia), Columbus crabs - *Planes cyaneus* (Decapoda) and pyrosomas - *Pyrosoma sp.* (Tunicata) (Parkes *et al.* in press). These turtles appear to direct their movements along convergence fronts (Polovina *et al.* 2000) that can be assumed to be associated with elevated concentrations of plankton. These foraging *C. caretta* in deep oceanic waters tended to remain at depths shallower than 100 metres (Polovina *et al.* 2003).

Age duration of the post-hatchling life history phase in the South Pacific Ocean is unknown but it could be possibly 15 years or greater in duration (See Section 2.2.12).

2.2.12 AGE and GROWTH

Post-hatchling *C. caretta* from the pelagic environment of the North Pacific Ocean that were captured in drift-net fisheries have been aged by skeletochronology (Zugg *et al.* 1995) and ranged in age up to 9 years old for approximately CCL = 47 cm. Growth of these turtles is polyphasic and slow (Chaloupka, 1998). A small proportion of these turtles may originate from the eastern Australian rookeries (Bowen *et al.* 1995).

Large immature turtles recruit from the oceanic pelagic environment to residency in inshore waters of eastern Australia at a CCL of 78.6 cm (southern GBR to Moreton Bay feeding areas, Table 9). This size at recruitment from the oceanic pelagic environment is independent of the coastal habitat to which they recruit (Table 9) (Limpus and Limpus, 2003b). These immature turtles are slow growing and are resident for an average of 13 years (SD = 3.7, range = 9–23, n = 15) before they commence breeding (Limpus, 1994; Limpus and Limpus, 2003b).

A growth/aging experiment is in progress in which 129,921 hatchling *C. caretta* were "tagged" and released at Mon Repos and Heron Island during January 1974 to February 1980 (Limpus, 1985). The first recaptures of these turtles have now occurred in inshore coastal waters (Limpus *et al.* 1994: tag number T58404, captured 20 April 1992, Moreton Banks: immature female, carapace length = 75.6 cm; age = 15.2 yr; marked as a hatchling at Mon Repos in Jan/Feb 1977). The first adults that had been marked as hatchlings at the Mon Repos rookery have returned for their first breeding at 29 years of age in the 2003–2004 breeding season (C. Limpus, unpublished data).

Fraser *et al.* (1994) estimated an age of 35 years at first breeding for *C. caretta* growing up in the southern GBR. This analysis warrants re-evaluation with more appropriate mathematics.

C. caretta in the southwestern Pacific Ocean are slow growing, taking about three decades to grow from hatchlings to breeding adults.

The average female commences breeding when she is much larger than the size of the smallest breeding female (Limpus, 1991; Limpus *et al.* 1994; Limpus and Limpus, 2003b). Adult female *C. caretta* that are in their first nesting season (Table 9) are, on average, just slightly smaller than average size for the entire breeding population (Table 1).

Table 9. Size range distribution of post-hatchling (pelagic life history phase) and known age class *Caretta caretta* recorded from sites around the South Pacific Gyre.

	Curved carapace length (cm)				**References**
	Mean	**SD**	**Range**	**n**	
Post-hatchlings: Western South Pacific Ocean					
Beach washed on Sunshine Coast to Gold Coast beaches of SE Queensland	6.33	2.278	4.5–13.7	34	Limpus *et al.* (1994a); EPA Stranding and Mortality Database
Beach washed in northern and central New South Wales	8.05	2.513	5.1–13.0	11	Limpus *et al.* (1994a); EPA Stranding and Mortality Database
Beach washed in New Zealand	18.15	10.540	8.6–33.0	6	Gill, 1997; Limpus *et al.* (1994a); EPA Stranding and Mortality Database
Post-hatchlings: Eastern South Pacific Ocean					
Long-line fishery bycatch off Peru	54.3	11.1	27.0–64.5	15	Alfaro-Shigueto *et al.* 2004
Fishery bycatch off Chile	71	–	–	1	Donoso *et al.* 2000
Size at recruitment to residency in south Queensland coastal waters					Limpus and Limpus, 2003b
Capricornia reefs	79.05	4.336	68.0–93.9	53	
Hervey Bay	78.63	1.863	76.0–85.1	3	
Moreton Bay	78.18	3.746	66.7–85.1	52	
Combined sites	78.6	4.013	66.7–93.9	108	
Adult females at 1st breeding in south Queensland					
Nesting beach Mon Repos	93.65	4.25	84.5–103.5	69	Limpus, 1991
Feeding area Heron-Wistari Reefs	94.4	3.45	90.5–101.5	14	Limpus and Limpus, 2003b

2.2.13 IMMATURE and ADULT TURTLES

Feeding habitat

Large immature and adult-sized *C. caretta* from the eastern Australian management unit feed in a wide range of tidal and subtidal habitats including coral and rocky reefs, sea grass meadows, and soft-bottomed sand or mud areas. Their foraging range encompasses the eastern Arafura Sea, Gulf of Carpentaria, Torres Strait, Gulf of Papua, Coral Sea, and western Tasman Sea to southern New South Wales including the Great Barrier Reef, Hervey Bay, and Moreton Bay. The outer extent of their foraging range includes coastal waters in eastern Indonesia, north-eastern PNG (Trobriand Islands and Woodlark Islands), north-eastern Solomon Islands and New Caledonia (Limpus, 1985, 1994; Limpus *et al.* 1992, 1994b; Speirs, 2002; Bell, 2003).

Whether the *C. caretta* that have been recorded infrequently from Tasmania (Green, 1971), Victoria (EPA Marine Wildlife and Stranding database) and South Australia (Waite, 1929) are waifs from their normal foraging areas or are part of the broader oceanic dispersal of post-hatchling turtles cannot be answered at this time.

A substantial part of the coastal foraging habitat of *C. caretta* in eastern Australia is contained within Marine Parks:

- A portion of the *C. caretta* foraging habitat in northern New South Wales is also protected within State Marine Parks: Julian Rocks Aquatic Reserve; Solitary Island Marine Park.
- Moreton Bay Marine Park which includes large areas of shallow sea grass habitats that support a dense *C. caretta* feeding population is managed for habitat protection, exclusion of fisheries activities that are injurious to turtles and go-slow zones to reduce boat strike.
- Woongarra Marine Park since 1991.
- The Great Barrier Reef World Heritage Area since 1981 (Lucas *et al.* 1997) and the associated Great Barrier Reef Marine Park since 1975 and adjacent Queensland State Marine Parks since 1973 encompasses almost the entire coastal waters off eastern Queensland that span approximately 14° of latitude north from Baffle Creek to Cape York.

Diet

Adult and large immature *C. caretta* are carnivorous, specialised for feeding on hard-bodied, slow-moving invertebrate prey. In eastern Australian coastal waters, while the species has been recorded feeding on about 100 taxa, *C. caretta* feeds principally on gastropod and bivalve molluscs, portunid crabs and hermit crabs (Moodie, 1979; Limpus *et al.* 2001). It feeds less frequently on other invertebrates (including jellyfish, anemones, holothurians, sea urchins) and fish (Moody, 1979; Limpus *et al.* 1994; Limpus *et al.* 2001).

C. caretta forages using a range of strategies including digging within the substrate, picking prey items off the substrate and plucking them from within the water column or at the water surface (Preen, 1996; Limpus *et al.* 2001).

Basking

Low numbers of *C. caretta* bask along with the more abundant basking *Chelonia mydas* on beaches and exposed reefs of the southern Great Barrier Reef and Hervey Bay (Limpus and Limpus, 2003b). While basking is most frequently observed during the courtship period, both adult and immature turtles engage in the behaviour. “Basking” occurs at day and at night.

Population structure and function

The population structure for *C. caretta* in eastern Australian feeding areas has been described for Heron Reef (Limpus, 1985), Moreton Bay (Limpus *et al.* 1994) and Julian Rocks (Speirs, 2002):

- Immature *C. caretta* recruit from the pelagic environment to feeding residency in inshore waters of the southern GBR, Hervey Bay and Moreton Bay as large immature turtles (CCL > 67 cm; average carapace length = 78.6 cm (Table 9).
- Recruitment to coastal residency appears to be associated with an elevated risk of shark attack and death (Limpus and Limpus, 2003b).
- Once the young turtle chooses a feeding area, it remains associated with that area for years, possibly decades (Limpus, 1991, 1994, Limpus and Limpus, 2001, 2003b). Feeding home ranges have not been precisely measured but appear to be largely restricted to individual coral reefs (maximum spread of locations < 10 km for most) for turtles living in the southern GBR (Limpus, 1985). Within the less structured seagrass habitats of Moreton Bay, each turtle occupied a feeding area that was small (maximum spread of locations = 21 km for any one turtle) relative to the size of Moreton Bay (Limpus and Limpus, 2001).
- Many individual turtles have overlapping home ranges at the same site (Limpus, 1985, Limpus and Limpus, 2001).

- At maturity, the adult turtle makes breeding migrations to its traditional breeding site and, on the completion of each breeding season, returns to the same feeding-area home range (Limpus, 1994; Limpus and Reimer, 1992; Limpus and Limpus, 2001, 2003b).
- Adult female *C. caretta* resident in the same foraging area do not migrate together to breed at the same nesting beach. Those resident on coral reefs of the southern GBR travel from 8 to1600 km from the feeding area to breed (Limpus and Limpus, 2003b) and to at least 11 breeding sites (Figure 4c) while those resident in Moreton Bay travel from 30 to 1586 km (Limpus and Limpus, 2001, 2003b) and to at least nine breeding sites (Figure 4d). Turtles from different breeding assemblages, such as eastern Australia and New Caledonia, occur together in the same eastern Australian foraging areas.

Sex ratio

The sex ratio among large immature and adult *C. caretta* in feeding areas is strongly biased to males at both sites examined in eastern Australia (Table 10). There are approximately two males for each female. This sex ratio bias has been evident in the southern GBR foraging population since foraging area studies began in 1974 (Limpus, 1985).

Table 10. Sex ratio of *Caretta caretta* measured for large immature and adult turtles in feeding areas in eastern Australia.

Feeding area	**Sex ratio** male:female	**References**
Capricorn Reefs	1.0 : 0.41	Limpus, 1985
Moreton Bay	1.0 : 0.54	Limpus, Couper and Read, 1994

Survivorship

Based on tagging-recapture studies, the survivorship of various developmental size classes of adult female and immature *C. caretta* resident in very protected feeding habitat within the southern GBR have been previously estimated by Limpus (1985) and Heppell *et al.* (1996). New survivorship data has been recalculated for this same population using more appropriate statistical analysis (Table 11).

Table 11. Summary of annual survivorship estimates for *Caretta caretta* resident in coral reef habitats of the southern Great Barrier Reef (Chaloupka and Limpus, 2002) where there is very little anthropogenic impact on the turtles.

Life history stage	**Size range (CCL)**	**Annual survival rate**		
		Mean	**SE**	**95% confidence interval**
Adult	≥ ca.92 cm	0.875	0.0179	0.84–0.91
Immature (all)	< ~95 cm	0.859	0.0146	0.83–0.89
Immature (corrected for possible transients)		0.918	–	0.88–0.96
All sizes combined and not corrected for transients	> ~70 cm	0.861	0.0116	0.84–0.88

These values are presumed to approximate the survivorship that can be expected for these developmental classes in the absence of anthropogenic induced mortality (Heppell *et al.* 1996).

Based on tagging recapture studies along the Bundaberg coast, the annual survivorship of breeding females that remigrated for successive breeding seasons, 1982-1990, has been estimated at 0.782 (n = 557) (Heppel *et al.* 1996). Because these breeding females migrate from a diverse array of feeding areas, this survivorship value is presumed to represent the annual survivorship of adult female *C. caretta* in all feeding areas supporting turtles from the eastern Australian rookeries. There are no measured values that summarise the annual survivorship of immature turtles from the collective feeding areas supplying *C. caretta* to the eastern Australian rookeries.

Survivorship of adult female *C. caretta* while they are ashore for laying eggs at the nesting beaches = 0.9996 per breeding season (Limpus, 1985).

Chaloupka and Limpus (2001) identified that the *C. caretta* population resident on the coral reefs of the southern GBR declined at 3% per year during 1985 to the late 1990s. Because this decline occurred within a foraging population with very high, constant annual survivorship values (Table 11) and within a habitat with few anthropogenic impacts, they hypothesised that the decline was due to recruitment failure. The decline in numbers of recently recruited immature *C. caretta* captured on these coral reef feeding areas of the southern Great Barrier Reef during the late 1990s (Limpus and Limpus, 2003b) is consistent with this hypothesis.

Age duration

The time from when an immature *C. caretta* recruits from the open ocean and takes up residency in inshore habitat until it commences breeding is currently estimated at 13 years (Table 9). After reaching maturity, *C. caretta* remain at the same feeding area, except for brief breeding migrations, for the remainder of their adult life, which may encompass decades (Limpus 1994; Limpus *et al.* 1992, Limpus and Limpus, 2003b).

It has been hypothesised that a proportion of the immature and adult population for the Japanese stock remains associated with the oceanic pelagic environment in the western North Pacific Ocean (Hatase *et al.* 2004). There is no evidence to support this hypothesis with regard to the eastern Australian stock.

2.3 WESTERN AUSTRALIAN STOCK

In the absence of genetic studies to address the issue, the nesting populations of the various *C. caretta* rookeries in Western Australia, from Shark Bay to the southern Northwest Shelf, will be treated as a single interbreeding stock and independent of the other stocks that breed in eastern Australia and elsewhere in the Indian Ocean (Bowen, 2003; Dutton *et al.* 2002; FitzSimmons *et. al*. 1996). The Western Australian nesting distribution encompasses the Dirk Hartog Island to Muiron Island region. It probably supports the third largest loggerhead turtle population remaining in the world and is one of only four stocks in the Indian Ocean (Figure 2).

2.3.1 ROOKERIES

The principal Western Australian nesting sites that are documented to date include: Muiron Islands, Ningaloo Coast south to about Carnarvon and islands near Shark Bay, including Dirk Hartog Island (Prince, 1993, 1994; Baldwin *et al.* 2003) (Figure 2, Figure 7). Sporadic to low density nesting occurs over a much wider area, including the Ashmore Reef National Nature Reserve (Guinea, 1995).

The Western Australian government conservation agency under its various titles has examined the State on a biological system by system basis, starting in the 1960s and extending to the present to develop a comprehensive system of National Parks and Nature Reserves. As a result, some of the *C. caretta* nesting on islands occurs within these protected habitats.

The major *C. caretta* rookery on Dirk Hartog Island (Figure 7a) is not within protected habitat.

Marine turtle nesting on the mainland beaches is not well protected in the conservation reserve system. Almost the entire nesting habitat of the Ningaloo coast is contained within the 40 m wide strip of land above high tide that is contained within the Ningaloo Marine Park. However, outside of the Cape Range National Park, the management of the Ningaloo Coast nesting habitat is largely driven by the management of the adjacent pastoral leases. The other mainland *C. caretta* rookeries on the coast south of the Ningaloo Marine Park are mostly within pastoral leases.

7a. Western end of Turtle Beach, Dirk Hartog Island, Shark Bay, October 2002.

7b. Janes Bay, Ningaloo Coast, October 2002. 4x4 vehicle tracks on turtle nesting habitat.

Figure 7. Loggerhead turtle, *Caretta caretta*, nesting beaches in Western Australia.

7c. Muiron Island, southern North-west Shelf, October 2002.

7d. Bateman Bay, southern Ningaloo Coast, October 2002. 4x4 vehicle tracks on turtle nesting habitat.

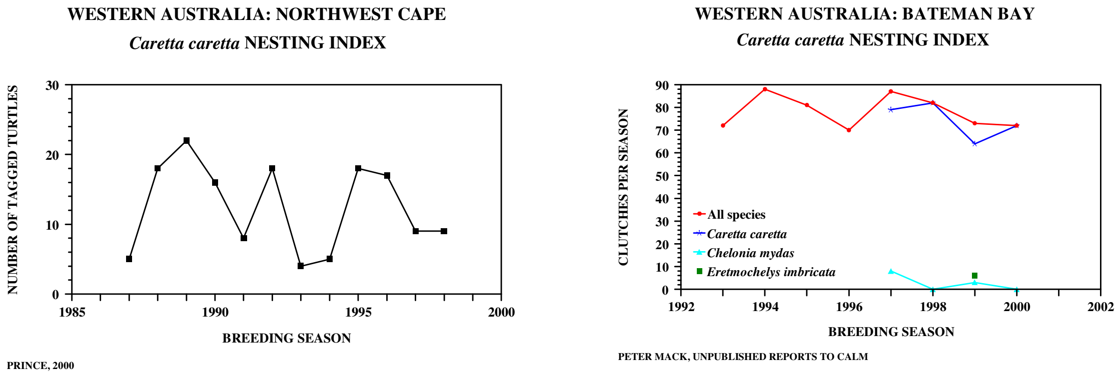
Figure 7. Continued.

To address problems in current management of the turtle populations, there are plans to enlarge the area of the Ningaloo Marine Park to include the coastal waters to the north and south of the existing park and to expand the landward boundary of the park to include a 2 km wide strip of coastal land (CALM, 2004). When completed, this extension will absorb the existing Muiron Islands Nature Reserve into the Ningaloo Marine Park.

Nesting census

While there are no long-term census data from the major rookeries in Western Australia, the annual nesting population for the entire stock is of the order of several thousand females (Baldwin *et al.* 2003). Nesting census data are available for two small rookeries: Northwest Cape based on tagging census data (Figure 8a. Prince, 2000) and Bateman Bay on the Ningaloo Coast based on clutch count data (Figure 8b). Peter Mack, unpublished reports to DCLM). These data display no significant trend away from a stable population within the census periods that encompass only a fraction of a generation for the species.

The choice of a index beach(s) for long term monitoring of the Western Australian *C. caretta* stock is under consideration by CALM (Keith Morris, pers. comm.)



8a. Northwest Cape

8b. Bateman Bay

	r^2			F		
Species	Value	Df	P	value	df	P
Caretta caretta	0.03	10	> 0.25 (NS)	0.29	1, 10	> 0.25 (NS)

8c. Regression analysis of the Northwest Cape *Caretta caretta* nesting data (NS = not significant)

Figure 8. Census data from index beaches for *Caretta caretta* breeding populations in Western Australia. Extrapolations from the census data from Northwest Cape loggerhead turtle nesting populations should be made with caution because uniform sampling effort was not applied in the census studies across the years (Prince, 2000).

Nesting beach impacts

Foxes have been active on the beaches of the Ningaloo Marine Park coast, including Cape Range National Park since the 1960s (K. Morris, pers comm. October 2002; Baldwin *et al.* 2003). In the absence of fox-control measures, foxes can destroy the vast majority of loggerhead turtle clutches laid on these beaches (Mack, 2000). The loggerhead turtle is the principal nesting species along much of the southern part of this coast.

On many of these same beaches, there is regular vehicle traffic over nesting habitat. Vehicle traffic in nesting habitat can compact nests with resulting death of eggs. Deep tyre ruts (Figure 7b, 7d) can trap hatchlings crossing the beach and expose them to increased predation by crabs and birds. In contrast, Western Australian *C. caretta* that are nesting on the islands such as Dirk Hartog and Muiron Islands are not exposed to egg or hatchling losses from fox predation and compaction of nest sites by beach traffic.

Although it remains unquantified, there is a high probability that the egg loss to foxes and vehicle traffic in recent years within this total complex of nesting beaches has exceeded the sustainable level of loss for the western Australian loggerhead turtle population.

During the 2003–2004 nesting season, CALM implemented (K. Morris, Pers. Comm.):

- A fox baiting program along the Ningaloo Coast with a resulting order of magnitude reduction in *C. caretta* egg loss from fox predation
- A summer closure of the turtle nesting beaches of the Ningaloo Coast to vehicle traffic.

However, there is another significant biological dimension to these differences in incubation success. *C. caretta* exhibit temperature dependent sex determination (Limpus *et al.* 1985).

While the pivotal temperature has not been measured for the Western Australian loggerhead turtles it can be expected to be close to the 28.6°C to 29.0°C values measured in Queensland (Limpus *et al.* 1985) and eastern USA (Mrosovsky, 1988), respectively. Nest temperatures below the pivotal temperature will produce mostly or all males. Nest temperatures above the pivotal temperature will produce mostly or all females.

In early October 2002 there was a 2.7°C–3.7°C temperature differential in sand temperatures at nest depth between Dirk Hartog Island (Turtle Beach: 24.2°C–24.3°C) and the Ningaloo Coast (Bateman Bay: 28.0°C. Surf Beach, Exmouth: 27.0°C) (C. Limpus, unpublished data). If this temperature differential is maintained during the summer there is a high probability that the cooler beaches of Dirk Hartog Island would produce predominantly male hatchlings and the warmer beaches of the Ningaloo coast produce predominantly female hatchlings. Therefore, there is a possibility that the principal areas for *C. caretta* egg mortality are the main female producing beaches for the regional population.

2.3.2 FIDELITY TO NESTING SITES

As for most *C. caretta* within the eastern Australian populations, all nesting recaptures of previously tagged nesting female *C. caretta* in Western Australia have occurred at the respective beaches where they were tagged (WACALM Marine Turtle Database, unpublished data).

2.3.3 MIGRATION

Based on the results of the tagging studies, *C. caretta* from the Western Australian rookeries inhabit widely dispersed feeding areas of western and northern Australia from Shark Bay, extending across Arnhem Land to as far west as Gove and into the Java Sea of Indonesia (Prince, 1998; Baldwin *et al.* 2003). The eastern and western Australian stocks are probably sharing feeding areas off Arnhem Land.

2.3.4 POST-HATCHLINGS

Appreciable numbers of post-hatchling *Caretta* with a CCL size range of 5–10 cm are beachwashed around the south and lower western coast of Western Australia after storms in the winter-spring period (Limpus, Walker and West, 1994; Prince, 1994; Walker, 1994). These small turtles are most likely to have originated from the Western Australian rookeries and been dispersed southwards by the Leeuwin Current, contrary to the hypothesis by South African researchers that they may have originated from the South African rookeries. The sex ratio of a sample of 41 beachwashed post-hatchling *C. caretta* from Perth beaches in 1991, based on endoscopic assessment of the gonads, was: female to male = 0.5 : 1 and was significantly different to 1 : 1 (Kuchling, 2004)

Based on long-line fisheries bycatch reports, Nishimura and Nakahigashi (1990) identified the occurrence of *C. caretta* in the oceanic waters off northern Western Australia in the late 1980's.

A headstarted, post-hatchling sized *C. caretta* that was released in Western Australia (R. Prince, pers. comm. 1998) was recovered in Brazil (Lum *et al.* 1998). Based on this recovery, we must allow for the possibility that some of the post-hatchling *C. caretta* from Western Australian rookeries may be dispersed within the Atlantic Ocean as well as the Indian Ocean.

2.3.5 IMMATURE and ADULT TURTLES

The best known area with concentrations of foraging *C. caretta* in Western Australia is Shark Bay (Lester *et al.* 1980; Heithaus *et al.* 2002). Here, as in eastern Australia, the *C. caretta* population is comprised of large immature and adult sized turtles of both sexes (Heithaus *et al.* 2002). The *C. caretta* captured in prawn trawls within the Northern Prawn fishery including those from eastern Arnhem Land to Bonepart Gulf on the Western Australian border during 1998–2001 were also all large immature to adult sized turtles (Robins *et al.* 2002). Heithaus *et al.* (2002) identified that the greatest incidence of injuries inflicted by predators in Shark Bay was with male *C. caretta* but they failed to discriminate between healed injuries inflicted on very young turtles by fish and other smaller predators and those inflicted by sharks on large turtles. The same study also failed to discriminate between injuries acquired in the home foraging area and those acquired while absent on a breeding migration. The results of this study with respect to risk of shark predation on *C. caretta* in Shark Bay should be used with caution.

The adult and near adult-sized *C. caretta* foraging in the subtidal waters off Fog Bay, Northern Territory (Guinea and Chatto, 1992) and in central and eastern Indonesia (Prince, 1998; Suarez, 2000) are presumed to be part of this Western Australian stock.

The Ningaloo Marine Park since 1983 and Shark Bay World Heritage Area and the associated Marine Park provide two large and significant areas of in-water habitat protection for marine turtles. These encompass a broad spectrum of foraging areas for adult and immature *C. caretta* and courtship and internesting habitat for adults. The Ningaloo Marine Park is being expanded (CALM, 2004).

Diet

In Shark Bay, Western Australia, *C. caretta* forages on a range of bivalve and gastropod molluscs and crabs (Lester *et al.* 1980). In Fog Bay, western Northern Territory, *C. caretta* selectively forage on a restricted range of gastropod molluscs (Conway, 1994).

Basking

Large aggregations of basking marine turtles are rare in present times on the global scale. Western Australia is an exception to this. Basking green turtles and to a lesser extent *C. caretta* can be encountered on islands between North West Cape and the Dampier Archipelago and on the Ningaloo Coast (Figure 9).

Figure 9. Basking adult sized *Caretta caretta* with a basking elephant seal, Ningaloo Coast, late 1990s. Photo courtesy of C. Williams, email 6 Oct 2000.

2.4 OTHER BREEDING UNITS

There are no reliable records of *C. caretta* breeding in northern Australia (Chatto, 1998) or in Indonesia or Papua New Guinea (Dodd, 1988; Limpus, 1985; Limpus and Limpus, 2003a).

2.4.1 NEW CALEDONIA

Of approximately a thousand (adult and immature; male and female) *C. caretta* that have been tagged in eastern Australian feeding areas, only two have been recorded migrating to breed outside of Australia:

- X9334 lives in Heron Reef lagoon in the southern GBR and nested on Isle des Pines, southern New Caledonia (Limpus and Limpus, 2003b).
- T92001 lives in Moreton Bay and was tracked by satellite telemetry to nesting in mid-eastern New Caledonia (Limpus and Limpus, 2001).

This New Caledonian/Vanuatu nesting population is thought to be small, perhaps a few hundred females annually at the most, and is the only other significant *C. caretta* breeding area within the South Pacific basin (Limpus and Limpus, 2003a).

Nesting census

Nesting census studies are lacking for *C. caretta* breeding sites in New Caledonia. Based on anecdotal information, *C. caretta* nesting on the beaches adjacent to Bourail on the west coast of Province Sud, New Caledonia may have declined by two orders of magnitude since the 1970s (C. Limpus, unpublished data).

2.4.2 NORTHERN INDIAN OCEAN

The small *C. caretta* foraging population on the reefs of Cocos (Keeling) Islands (Whiting, 2004) has not been genetically assessed for stock composition. Whether these *C. caretta* originate from the Western Australian rookeries or from the depleted Sri Lankan breeding population cannot be determined at present.

3. ANTHROPOGENIC IMPACTS, MORTALITY and DISEASE

C. caretta are being injured and killed through a wide range of anthropogenic activities throughout Australia (Figure 10). This mortality is not being quantified for the majority of the causes.

Loggerhead turtles were not significantly targeted, if at all, during past commercial harvests for turtle meat and skin in either Queensland or Western Australia during the late 1800s and up to the 1970s. In recent years, commercial harvest has not been permitted under any State or Federal legislation in Australia.

3.1 INDIGENOUS HARVEST FOR FOOD

Indigenous peoples with a recognised Native Title right can legitimately hunt marine turtles in Australia for communal, non-commercial purposes.

Most indigenous turtle hunters appear to preferentially hunt green turtles, *Chelonia mydas*. *C. caretta* has not been identified as significant in any report on traditional harvests of turtles in Western Australia (Kowarsky, 1982; Morris and Lapwood, 2002). *C. caretta* are taken occasionally for food in Torres Strait and the far northern Great Barrier Reef (Johannes and Macfarlane, 1991; Kwan, 1989; Smith, 1987) and Moreton Bay (Qunadamooka elders, pers. comm., May 2002). One long distance recapture of a tagged *C. caretta* by indigenous people within eastern Australia was reported (Limpus *et al.* 1992). The species has been recorded being eaten more frequently in the neighbouring countries of Papua New Guinea, Solomon Islands and New Caledonia (Bustard, 1974; Limpus *et al.* 1992).

C. caretta that had been tagged while nesting at Queensland rookeries and captured for food comprised 12.7% of tag recoveries and 28% of recorded mortalities of post nesting turtles recorded from all capture methods at all feeding areas (Limpus *et al.* 1992). A total of 29 tagged adult female *C. caretta* from Queensland rookeries from 25 yr of tagging studies at nesting beaches, 1968–1993, by Queensland Turtle Conservation Project and 9 yr of tagging studies by Dr H. R. Bustard have been reported captured and eaten by coastal indigenous people (Table 12). This reporting rate is much lower than for tags from *C. mydas* (Limpus *et al.* 1992). The *C. caretta* recapture rate represents approximately 1 reported hunted tagged turtle per year of the Queensland Turtle Conservation Project.

Tagged females recaptured from nesting studies represent approximately 3% of the resident turtles captured in feeding grounds in the southern GBR and Moreton Bay (Limpus, 1985; Limpus *et al.* 1994). Based on this rate of tag recoveries from Australian feeding areas and presuming most tags are returned, it is presumed that the harvest rate of *C. caretta* from indigenous hunting, both within Australia and in neighbouring countries, has been of the order of 40 per year.

Human consumption of *C. caretta* in the south Pacific basin appears to be uncommon except in the Trobriand-Woodlark Islands area of Papua New Guinea.

While low-level egg harvest at the Woongarra Coast rookeries occurred regularly until the 1970s (Limpus, 1985), egg and/or hatchling harvest for human consumption appear to have been approximately nil in recent decades at all Queensland rookeries.

Table 12. Distribution by country of international migration recaptures of adult female *Caretta caretta* originally tagged on Queensland nesting beaches. Data sources: A = Limpus *et. al.* (1992); B = Bustard (1974).

		No. of turtles	
Country		**Data source A**	**Data source B**
Indonesia	Irian Jaya	1	
Papua New Guinea:	Daru	2	
	Gulf of Papua	3	
	Trobriand Islands	17	1
	Woodlark Islands	1	
	Ferguson Islands	1	
Solomon Islands		1	
New Caledonia		1	1

3.2 ACCIDENTAL CAPTURE IN FISHERIES

3.2.1 SHARK CONTROL PROGRAMS

Queensland

C. caretta has been the most commonly captured turtle in the Queensland Shark Control Program (QSCP) which is managed by the Queensland Department of Primary Industries and Fisheries (Kidston *et al.* 1992).

- Prior to 1993 the species of turtle was not normally recorded by the contractors and hence the species composition of the catch and precise number of *C. caretta* drowned in these nets is not usually available.
- Since 1986, most captured turtles have been scored for their survival or otherwise. For the 7 yr period, 1986–1992, 586 turtles were recorded captured (unpublished data, Sunfish Shark Control Subsiduary Database for the years 1986–1992, QDPI): 410 were released alive; 81 were recorded as not released; survivorship was not recorded for the remaining 95. Therefore between 12 and 25 (probably close to 25) turtles have been killed annually by the Queensland Shark Control Program during that period. Not all of these would have been *C. caretta*. It is presumed that this species would not account for more than two thirds of these mortalities, ie < 14 *C. caretta* died annually in this program.
- The operations of the QSCP have been significantly modified since 1992, particularly with regard to reducing mortality of non-target species (Anon, 1997; Gribble *et al.* 1998). Average annual *C. caretta* mortality during 1992/3–1995 within the QSCP for all of Queensland was 3 adult or large immature turtles (90% of captures released alive. Gribble *et al.* 1998).
- During 1998–2002 there were 232 Loggerhead turtles captured with 195 taken on drum lines and 37 taken in nets. Of these 98% were released alive from drum lines and 92% were released alive from nets. Observed *C. caretta* mortality during 1998–2002 was 0.6 per year (Anon, 2003).

These data indicate that the modifications to the QSCP since 1992 have contributed to a reduction in loggerhead turtle mortality.

New South Wales

C. caretta was not recorded among those turtles identified to species from the New South Wales shark meshing programme (Krogh and Reid, 1996). However, most turtles were unidentified to species and mortality rates were not recorded. If *C. caretta* mortality occurs in this fishery, it does so at very low frequency given that the total capture for all species is 0–5 turtles per year.

3.2.2 COMMERCIAL FISHERIES

No precise figure can be placed on the total mortality of Australian *C. caretta* stocks in commercial fisheries bycatch. The highest mortalities recorded for the species are associated with the trawling industry. Until there is reliable reporting of threatened species bycatch in Australian commercial fisheries, the absence or infrequent reporting of associated turtle mortality should not be used as a measure of reality of the situation.

Shark gill nets

Approximately 15 *C. caretta* were estimated to have drowned in one shark net in a 2 week period: 2000 m of bottom set monofilament net (mesh size = 42.5 cm, drop = 12 m) approximately 4 km off shore in Fog Bay, Northern Territory, 15–30 November 1991 (Guinea and Chatto, 1992). These included large immature and adult sized *C. caretta*. These are assumed to have been turtles from the Western Australian rookeries. This type of fishing was banned in the Northern Territory following this event.

Trawling

The interaction between turtles and the Australian trawl fisheries, as they have increased the number of boats, the length of the shot-times and the number and size of nets towed since the 1960s, has been largely ignored until recent years. In 1989, the Queensland Parks and Wildlife Service (QPWS) implicated trawling as a significant contributing factor in the decline of the eastern Australian *C. caretta* stock (Limpus and Reimer, 1994).

The following summarises the more significant available data pertaining to the interaction of *C. caretta* and trawling in Australian waters:

- Following reports from fishers of numerous turtles being caught in prawn trawls operating off Burnett Heads in December 1983, a QPWS staff member accompanied one trawler for a day and recorded 1.2 *C. caretta* per shot (range = 0–2 turtles, 6 shots with 3 nets per shot). This equated to 0.88 *C. caretta* per hour of trawling (8hr of trawling, 1.0–1.5 hr per shot). All these turtles were immediately released, but it was noted that all were noticeably sluggish in comparison to turtles captured by the turtle rodeo method (Limpus, 1978). These trawlers were operating mostly by day for banana prawns and within three nautical miles of shore. Some fishers were recording tag numbers from multiple *C. caretta* per day. These tagged turtles had been previously tagged at the nearby Mon Repos and adjacent rookeries earlier in the breeding season. The highest catch reported was of 15 *C. caretta* for the day, including 5 in one shot on 23 December 1983. On 4 January 1984, five freshly dead, gravid female *C. caretta* were beach-washed in a 24 hour period at Oaks Beach area, downwind from 16 trawlers working within sight of the beach.
- The capture of *C. caretta* in prawn trawls has been recorded by trained on-board recorders prior to 1990 (Limpus and Reimer, 1994; EPA Queensland Turtle Conservation Project, unpublished data): 2% of 90 turtles captured by one fisher within the Northern Prawn Fishery operating in the Gulf of Carpentaria over seven years; 13% of 45 turtles captured in the northern GBR between Princess Charlotte Bay and Cape York; and 13% of 30 turtles captured in the Townsville area.
- A minimum of 61 adult female and 8 other *C. caretta* were beach-washed dead on the Bundaberg coast from the Kolan River to Elliot River adjacent to the Mon Repos rookery over six turtle breeding seasons 1983–1989 and this mortality of breeding females was attributed to drowning in the prawn trawls (Limpus and Reimer, 1994). The occurrence of beach-washed, dead, gravid female *C. caretta* along the Bundaberg District coast has been almost entirely eliminated since the declaration of the Woongarra Marine Park in 1991.
- The 22 resident foraging *C. caretta* that were beach-washed dead along the Bundaberg coast from Baffle Creek to Burrum River during 1992–93, including one non-breeding adult

female, were attributed mostly to increased trawling activity just to the east of the Woongarra Marine Park and other boating activities (Limpus *et al.* 1993).

- During 1 January – 19 March 1998, 20 beach-washed, dead, resident foraging *C. caretta* were reported from North Stradbroke Island to Gold Coast in SE Queensland for which there was direct or circumstantial evidence that these mortalities originated from drowning in an adjacent stout whiting trawl fishery (EPA Marine Wildlife and Mortality Stranding database).
- During a two year CSIRO study of turtle bycatch in the Northern Prawn Fishery, *C. caretta* made up 16 – 4% of the 165 and 161 turtles trawled in 1989 and 1990 respectively. The *C. caretta* impacted by this fishery encompassed the adult and large immature size ranges. Catch rate = 0.0078 ± 0.0016 turtles per trawl in 1989 and 0.0019 ± 0.0008 with a 19.2% probability of being landed dead in the sorting tray in 1989 and 33.3% probability in 1990. This study estimated that the Northern Prawn Fishery killed approximately 163 and 67 *C. caretta* in 1989 and 1990 respectively (Poiner and Harris, 1994, 1996).
- Based on a logbook recording program, turtle bycatch in the Queensland East Coast Trawl Fisheries (ECTF) and in the Torres Strait Prawn Fishery (TSPF) during 1991–1996 was investigated (Robins and Mayer, 1998). This study found that *C. caretta* was the most commonly reported turtle in the ECTF bycatch (40% of 1,527 turtles reported; range per year = 21% – 41%). *C. caretta* was relatively uncommon among the reported turtles in the TSPF bycatch (10% of the 151 turtles reported.). The *C. caretta* impacted by both fisheries encompassed the adult and large immature size ranges. The extrapolated mean annual catch of *C. caretta* within the entire fishery was estimated at 2,938 in ECTF and 85 in TSPF. The total annual direct mortality associated with these captures (assuming that some non-resuscitated comatose turtles could die on release) could be in the range of 1–5% (n = 29–147) in ECTF and 7–14% (n = 11–21) in TSPF. The majority of *C. caretta* were trawled in three areas: off Mackay, Bundaberg to Bustard Head and Moreton Bay.
- One *C. caretta* was among 15 dead beachwashed marine turtles in Fog Bay, western Arnhem Land over a few weeks prior to September 1995 (Guinea *et al.* 1997). *C. caretta* foraging in this area will have originated from the Western Australian stock.
- Based on reports from trained crew, turtle bycatch in the Northern Prawn Fisheries (NPF) was monitored during 1998–2001 (Robins *et al.* 2002). This study spanned two years before the compulsory introduction of Turtle Exclusion Devices (TEDs) into the NPF and two years after their introduction. About 15% of the turtles reported captured were *C. caretta*. The introduction of TEDs to the fishery resulted in a two orders of magnitude reduction in turtle captures in the NPF trawls.

There has been no study that has extrapolated back in time to estimate the size of the impact of the East Coast Trawling Fleet as it escalated from 699 trawlers in 1975 to 1154 in 1979 and peaked at 1410 vessels in 1981 (Beurteaux and Coles, 1988). At the same time the industry changed with the use of larger boats, towing larger nets and for longer shot times than was the case in the late 1960s when monitoring of the turtle population commenced (M. Helmuth, pers. comm. January 1982). This escalation in trawling occurred at a time when the eastern Australian *C. caretta* population was approximately two orders of magnitude larger than in the late 1990s. The fleet decreased to about 1200 vessels by 1986 and further decreased to 985 vessels in the early 1990s (Robins, 2002). This reduction in the number of vessels has been accompanied by changing regulations that limit the number of days a trawler is at sea and by Marine Park zoning that has reduced the total area of coastal waters available for trawling.

The trawl fisheries off the coast of New South Wales, Queensland, Northern Territory and Western Australia have had the potential to kill many hundreds or possibly thousands of *C. caretta* annually since the late 1970s. Fortunately, this situation has for the most part changed as we moved into the 21st Century. The compulsory use of TEDs has been regulated in the NPF since April 2000, ECTF since December 2000, TSPF since March 2002 and Western Australian prawn and scallop trawl fisheries since 2002. TEDs are currently used voluntarily in the T4 stout whiting trawl fishery in south Queensland and it is anticipated that their use will be mandatory from April 2005 (W. Norris, *in litt.*). TEDs are not compulsory within the trawl fishery in New South Wales in which *C. caretta* is a known part of the bycatch.

The process for regulating the compulsory use of TEDs in trawl fisheries was partly facilitated by Otter Trawling being listed under the EPBC Act as a key threatening process (KTP) in 2001 due to the level of bycatch of marine turtles.

Shark fisheries

The Western Australian demersal longline fishery for sharks has no recorded interaction with *C. caretta* (Victoria Slowik, pers. comm. August 2004).

Crabbing

Anecdotal information from fishermen has identified a conflict between fishermen and turtles, especially *C. caretta*, in the crab fisheries of southeast Queensland during the 1980s and early 1990s. Turtles that have been clubbed, shot or snared in nylon fishing line nooses have been circumstantially linked to these fisheries (EPA Marine Wildlife Stranding and Mortality Database). This deliberate killing or injuring of turtles appears to have ceased by the late 1990s.

In addition, there is a minimum mean mortality of 2.5 adult and large immature *C. caretta* per year (range = 0–6/yr) resulting from entanglement in the buoy lines of crab pot or dillies for stranded turtles that have been examined in Queensland during 1998–2002 (Table 13).

C. caretta mortality associated with crab fisheries throughout Australia is unquantified.

Cray pot fishery

Small numbers of *C. caretta* have been killed by entanglement in float line on crayfish pots in south Western Australia (R. Prince, pers. comm. August 2004).

Table 13. Frequency distribution of reported mortality of adult and near adult *Caretta caretta* from anthropogenic activities in near shore waters in Queensland. These are minimal mortality rates, given that some carcasses will be destroyed by predators or decay before they strand. EPA Marine Wildlife Stranding and Mortality database (Ludeke, 1993; Flakus and Limpus, 1999, Haines *et al.* 2000; Haines and Limpus, 2001; Greenland *et al.* 2004)

Year	Entangled in crab-pots or their floats	Boat strike & propeller damage fracture	Entangled in rope, fishing-line or bags	Ingested synthetic material	Dredging
1992	0	2	4	0	–
–					
1998	1	13	11	–	–
1999	6	4	1	3	–
2000	4	10	1	1	1
2001	0	8	0	2	1
2002	1	5	2	0	3

10a. Trawl bycatch, Northern Prawn Fishery, before TEDs

10b. Entangled in in crabpot float line (K7196), Moreton Bay, 2000.

10c. Strangled with nylon noose, Moreton Bay. Photo by A. Preen.

10d. Shot, beachwashed, Moreton Island

10e. Propeller cuts (K36628), Moreton Bay, 2000.

10f. Tangled in fishing line which has restricted blood flow to flipper (K40373), Moreton Bay 2002

10g. Presumed killed by dredging, Burnett River, 9 July 2001. Photo by C. Gatley.

10h. Snagged on Queensland Shark Control drum-line hook (K74490).

Figure 10. Illustrations of a range of anthropogenic impacts on *Caretta caretta* in Queensland. Records from EPA Marine Wildlife Stranding and Mortality database.

Oceanic fisheries

Because the post-hatchling phase for *C. caretta* disperses through entire ocean gyres, there is the potential for all the oceanic longline and gill-net fisheries within an ocean basin to contribute to the mortality for the species. The combined mortality rates of pelagic *C. caretta* in oceanic net and longline fisheries for the numerous fleets within the South Pacific and Indian Ocean basins cannot be quantified at this time.

Indian Ocean

- Large immature *C. caretta* (CCL = 70–80 cm) are killed in the Japanese tuna longline fishery off the Western Australian coast and further north in Indonesian waters (W. Nishimura, *in litt.*).
- No suitable longline bycatch data are available to estimate the *C. caretta* bycatch for the Indian Ocean (Lewison *et al.* 2004).

South Pacific Ocean

- *C. caretta* is part of the bycatch within the pelagic longline fisheries of the Eastern Tuna and Billfish Fishery and the Southern and Western Tuna and Billfish Fishery (Robins *et al.* 2002). These fisheries may catch around 400 turtles (all species) per year. The species composition of the catch is poorly reported and observer coverage of the effort is low (5%).
- *C. caretta* is part of the longline bycatch of the Western and Central Pacific Ocean Tuna Fisheries of the Pacific Island countries and monitored by the Secretariat of the Pacific Community (Oceanic Fisheries Program, 2001). The impact of these fisheries on turtles could not be quantified because the turtle bycatch was not normally identified and the observer coverage of the effort was < 1%.
- Immature *C. caretta* comprised about 30% of the turtle bycatch by longline vessels off Peru in the eastern Pacific (Kelez *et al.* 2004). The catch per unit effort (CPUE) combined for all species of turtles caught was 0.296 turtles per 1000 hooks but the total size of the fleet and its total fishing effort was not described. Most *C. caretta* were hooked in the mouth or deeper in the throat. All turtles were released alive but some are released with hooks in the oesophagus. Some turtles are killed onboard for food.

North Pacific Ocean

- The 1990 mortality of small pelagic *C. caretta* incidentally captured in the large-mesh high-seas driftnet fisheries of Japan and Taiwan that operated in the north Pacific was estimated at 1380 (Weatherall *et al.*1993). A small proportion of these North Pacific *C. caretta* may have originated from the eastern Australian stock (Bowen *et al.* 1995).
- During 1994–2000, the Hawaiian Longline Fishery was killing an estimated 64–106 *C. caretta* annually (from a catch of hundreds of *C. caretta* annually). With restrictions to the Swordfish component of this longline fishery, the estimated kill dropped to about eight annually (from a catch of tens of *C. caretta* annually) (Table 14) (Pelagics Plan Team & council staff, 2004).

North and South Pacific Oceans

- The diverse longline fleet of the Western Central Pacific Ocean contained approximately 5,000 vessels in 2002: over 500 vessels were domestically based in the Pacific Island countries; 3,000 vessels domestically based in non-Pacific Island countries; 1,000 large distant-water freezer vessels based in non-Pacific Island countries; and 500 offshore vessels based in Pacific Island countries with approximately equal numbers from China, Japan and Taiwan (Pelagics Plan Team & council staff, 2004).
- An estimated 30,000–75,000 *C. caretta* may have been captured by longline fisheries in the North and South Pacific Oceans in 2000 (Lewison *et al.* 2004). No mortality estimate was provided in this study.

Table 14. Estimated catch and kill of *Caretta caretta* in Pacific Ocean pelagic longline fisheries with a summary of their fishing effort. CI denotes confidence limits.

Longline fishery	**Year**	**Effort**	**Observer Coverage**	**Estimated *C. caretta* catch (95% CI)**	**Estimated *C. caretta* kill (95% CI)**	**Reference**
Hawaii	1994			501 (315–669)	88 (36–141)	Pelagics Plan Team & council staff, 2004
	1995			412 (244–543)	72 (31–115)	
	1996			445 (290–594)	78 (34–127)	
	1997			371 (236–482)	65 (28–102)	
	1998			407 (259–527)	71 (32–112)	
	1999			369 (234–466)	64 (28–102)	
	2000			246 (NA)	106 (NA)	
	2001			18 (NA)	8 (NA)	
	2002	6,786,303, 3,523 sets	24.6%	19 (NA)	8 (NA)	
American Samoa	1988	3 boats, 1st longlining records				Pelagics Plan Team & council staff, 2004
	1993	4 boats, beginning of escalation of fleet				
	1996	12 boats, 528 sets				
	1997	21 boats, 1,528 sets				
	1998	25 boats, 1,754 sets				
	1999	29 boats, 2,011 sets				
	2000	37 boats, 2,708 sets				
	2001	62 boats, 4,800 sets				
	2002	58 boats, 6,861 sets		No reference to turtle bycatch		

3.2.3 BREATH-HOLDING ABILITY

In a USA study (Magnuson *et al.* 1990), small increases in trawl tow time between 45 and 125 minutes resulted in large, steep increases in the number of dead and comatose turtles landed on the deck (the subsequent survival of the comatose turtles following their release was not investigated); for most tow times there were more comatose turtles than dead turtles. A tow time limit in warm waters of 40 minutes was identified as possibly necessary to ensure negligible mortality of captured marine turtles in contrast to a 90 min tow time in cooler waters. This USA study also concluded that a significant number of comatose turtles would die following their release as a result of the capture.

In the Northern Prawn Fisheries studies (Poiner and Harris, 1996), there were large interspecific differences in probability of drowning when a turtle is captured in a trawl (Table 15). *C. caretta* appears to be very susceptible to drowning when compared to other marine turtle species in Australia.

Table 15. Probability of marine turtle mortality with trawling capture in the Northern Prawn Fisheries, 1989–1990 (Poiner and Harris, 1994).

Species	Mortality probability
Caretta caretta	21.9%
Chelonia mydas	12.0%
Eretmochelys imbricata	26.4%
Lepidochelys olivacea	12.5%
Natator depressus	10.9%

Mortality data from trawling studies that does not address post-release mortality of trawled turtles must be viewed as an underestimate of mortality. There is a need for more data to better assess the impact of forced submergence in nets on *C. caretta* mortality.

3.2.4 OTHER FISHERIES INTERACTIONS

C. caretta, through its diet, has additional unquantified negative interactions with a number of coastal fisheries. Commercially fished species such as sand crabs *Portunus pelagicus* and *P. sanguinolentus*, spanner crab *Ranina ranina*, and scallop *Amusium balloti*, are targeted as food by some *C. caretta*. Potentially more significant to scallop fisheries is the role of *C. caretta* in the life cycle of the ascaridoid nematode *Sulcascaris sulcata*, a parasite of commercial scallops. *C. caretta* is the definitive host of *S. sulcata* (Sprent, 1977) with the adult worms inhabiting the stomach and intestine while eggs are shed to sea with faecal material. Molluscs are the secondary host to the larval worms and immature *S. sulcata* are frequently found in the adductor muscles of large bivalves, especially *A. balloti* (Cannon, 1978). The parasite completes its life cycle when the mollusc is eaten by *C. caretta*. This parasite can cause loss of fisheries production in areas where there is coincidence of large numbers of *C. caretta* and the scallops (Lester, 1980). The occurrence of *C. caretta* off the Bundaberg coast and in Exmouth Gulf where scallops are abundant enough to form a significant part of their diet, has the potential for maintaining locally elevated levels of infection of scallops by *S. sulcata*.

3.3 BOAT STRIKES

Collision between boats and turtles has been reduced in Moreton Bay since late 1990s when extensive areas of shallow sea grass habitat that support a high density of foraging *C. caretta* started to be managed as go-slow area within the Moreton Bay Marine Park.

On average, a minimum of 8.0 adult and near adult *C. caretta* were killed by collision with a boat or by propeller cuts in Queensland during 1998–2002 (Table 13). The majority of this form of human related mortality in Queensland occurs in Hervey Bay and Moreton Bay. The actual annual mortality is expected to be higher than this reported value.

Interaction between boats and turtles can be high in areas of shallow water and high frequency boat usage.

- Nine (13%) of 72 *C. caretta* captured on the eastern banks of Moreton Bay in May 2002 had healing/healed fractures from collision with a boat or from propeller cuts. In some confined gutters within the Moreton Banks, more than 50% of the resident *C. caretta* had fractures (EPA Queensland Turtle Conservation Project).
- Two (18%) of 11 *C. caretta* captured in the Julian Rocks Aquatic Reserve in northern New South Wales had old healing fractures from interactions with boats (Speirs, 2002).

The indications are that while these types of injuries are healing, the turtles will grow slower if they are immature or they can be prevented from completing preparation for breeding if they are adults.

3.4 PORT DREDGING

C. caretta mortality resulting from dredging of channels associated with Queensland port in recent years are summarised in Table 13. During the four years, 1999–2002, the average annual reported mortality was 1.7 turtles per year (range = 1–3) from port dredging operations.

3.5 MARINE DEBRIS

The less frequently encountered examples of *C. caretta* mortality resulting from a range of anthropogenic sources in recent years from Queensland are summarised in Table 13. During the four years, 1999–2002, the average annual reported mortality was:

- 5.0/yr (range = 0–11) from entanglement in rope, fishing-line or bags.
- 1.5/yr (range = 0–3) from ingestion of synthetic material, usually fishing line.

Of hundreds of necropsied, beach-washed dead *C. caretta* from south Queensland since 1990, none contained ingested plastic bags or similar material that caused gut blockage and death.

3.5.1 GHOSTNET ENTANGLEMENT

C. caretta has not been reported among the species identified entangled in ghostnets that are beachwashed or floating offshore in the Northern Territory (Roeger, 2004; White, 2004). However, there is a photograph of an adult sized *C. caretta* in a beachwashed ghostnet in northeast Arnhem Land in Roeger's report (Roeger, 2004). The extent of mortality from this source is unquantified but expected to be low.

3.6 DISEASES

There are no reports of diseases causing significant mortality among *C. caretta* in Australia.

Some diseases carried by these turtles may cause health problems for humans. In the extreme, a US researcher contracted a life threatening vibrio infection (probably *V. vulnificus*) during a *C. caretta* necropsy (Keinath, 1996).

Virus

Herpes virus has been implicated with green turtle fibropapilloma disease (GTFD) tumours in *C. caretta* (Quackenbush *et al.* 2001). This study identified that it is the same virus associated with GTFD in all species of marine turtles. The increased incidence of this disease in areas adjacent to altered catchments raises concerns that there are anthropogenic factors associated with this disease. GTFD occurs at low frequency among *C. caretta* in Moreton Bay and the southern Great Barrier Reef (Figure 11a. Limpus and Miller, 1994). An undetermined number of the turtles are recovering from this infection (EPA Queensland Turtle Conservation Project). There are no data to indicate that this disease is having a significant impact on the population.

11a. Fibropapilloma tumours on *C. caretta* (T78610), Moreton Bay, June 2002.

11b. Adult nematodes, *Sulcascaris sulcata* and associated ulcer on stomach wall of *C. caretta* from Woongarra Coast.

Figure 11. Disease and parasites in *Caretta caretta* in Australia.

Parasitic worms

There have been numerous species of parasitic worms described from *C. caretta* (Table 16, Figure 11b). However, there is a paucity of studies that evaluate the health impact of these parasites on the turtles. No studies have addressed whether there are anthropogenic factors linked to parasitic worm infections.

Fungus

Fungi have been isolated from the cloaca of female *C. ca*retta in foraging and courtship areas and on nesting beaches (Table 17. Phillott *et al.* 2002). These fungi have the potential for infection of eggs as they are being laid. Soil fungi can also infect incubating eggs (Table 17. Phillott *et al.* 2001).

Table 16. Summary of parasitic worms identified from *Caretta caretta* in Australia.

Species	Biology	Reference
Nematoda		
Cucullamus carettae	Attach to the anterior wall of the intestine.	Lester *et al.* 1980
Echinocephalus sp.	Attach to the wall of the stomach and intestine. Larval phases in bivalves and *C. caretta* and adults in spiral valve of elasmobranchs.	Lester *et al.* 1980
Kathlania leptura	Swim freely in lower intestine	Lester *et al.* 1980
Sulcascaris sulcata	Attach to the wall of the stomach and intestine. Adult in *C. caretta* and juveniles in adductor muscles of bivalve molluscs.	Lester *et al.* 1980 See Figure 11b.
Platyhelminthes, Digenea		
Cymatocarpus solearis	In stomach and intestine	Blair and Limpus, 1982
Elytrophallus carettae	In stomach	Blair, 1984
Enodiotrema carettae	In liver and gall bladder	Blair and Limpus, 1982
Orchidasma amphiorchis	In stomach and intestine	Blair and Limpus, 1982
Pachypsolus irroratus	In stomach	Blair and Limpus, 1982
Plesiochorus cymbiformis	In urinary bladder and cloaca	Blair and Limpus, 1982
Rhytidodes gelatinosus	Intestine	Blair and Limpus, 1982

Table 17. Recorded fungal infection of *Caretta caretta* turtles and eggs in Australia. A = adult; I = immature.

Species	In cloaca of turtles	On eggs in nests	Reference
Aceremonium sp.	Foraging on Heron Rf (A)		Phillott *et al.* 2002
Aspergillus sp.	Nesting on Mon Repos (A)		Phillott *et al.* 2002
Fusarium solani	Nesting on Wreck Is (A)	Heron Is	Phillott *et al.* 2001, 2002
Penicillium sp.	Nesting on Mon Repos (A)		Phillott *et al.* 2002
Pseudallescheria boydii		Heron Is	Phillott *et al.* 2001
Stachybotrys sp.	Nesting on Mon Repos (A)		Phillott *et al.* 2002

3.7 LIGHT HORIZON DISORIENTATION

Disorientation of *C. caretta* hatchlings by street and house lights as the hatchlings are crossing the beach and swimming in inshore waters results in increased hatchling mortality from being lost in vegetation, from heat exhaustion, from being run over by cars and from increased bird, crab and fish predation.

A more difficult issue to address, but one that may have far greater consequences in the long term, is the potential for nesting turtles to respond negatively to the increased illumination over their nesting beaches. There is accumulating evidence that when the skyline of turtle nesting beaches become brightly illuminated, the associated adult nesting population will decline (Salmon *et al.* 2000), not because of mortality of the turtles but because the adult turtles choose not to use that beach. About two decades ago a large gas processing plant and its associated flares were constructed immediately behind the frontal dunes at Paka, Terengganu, Malaysia. This was then the most significant of green turtle rookeries on mainland Peninsula Malaysia. Since then, the green turtle nesting population breeding at Paka beach has declined to almost zero (Ibrahim and Limpus, unpubl. data). At the same time green turtle nesting numbers have been increasing at other less optimal nesting habitats to the south of Paka. If turtles shift from preferred nesting areas with their presumably good conditions for egg incubation, hatchling emergence success, hatchling imprinting and hatchling dispersal, then movement of nesting adults to breed on alternate beaches leaves them vulnerable to laying eggs in areas where the population may function sub-optimally.

Queensland
Disoriented hatchlings regularly have been found inland from the small nesting beaches adjacent to Mon Repos (Burnett Heads, Neilson Park, Bargara) and at Heron Island (Limpus, 1985; EPA Queensland Turtle Conservation Project unpubl. data). In an attempt to reduce hatchling disorientation, low pressure sodium vapour lights have been installed in street lights adjacent to the Burnett Heads beach. At the other beaches where lighting has not been controlled (Neilson Park, Bargara, Kellys Beach), eggs are relocated to artificial nests on nearby dark beaches. To minimise movement- induced egg mortality during these relocations, the eggs are moved within two hours of oviposition and with the minimum of rotation of the eggs (Limpus *et al.* 1979). For the past decade, hatchling mortality due to altered light horizons on the Woongarra Coast has been reduced to a few clutches annually.

Western Australia
Coastal Western Australia, from Shark Bay, through the Ningaloo Coast and northward to the Pilbara Coast with the associated islands from Northwest Cape to Dampier Archipelago, is a region that can be expected to have continued extensive industrial and tourism development in the decades to come. This same region supports extremely significant marine turtle breeding and foraging populations. These changes are likely to be accompanied by changes to the light horizons over the nesting beaches. For *C. caretta*, the most significant sources of altered light horizons will be associated with coastal real estate and tourist facilities within line of sight of the nesting beaches along the Ningaloo Coast. There are no studies that quantify the magnitude of this problem with respect to hatchling disorientation for the region.

No studies are addressing the impact of changed light horizons on adult female selection of nesting beaches at Australian rookeries.

3.8 SEISMIC SURVEY

Based on extrapolations from a small sample of caged *C. caretta* and *C. mydas* exposed to air-gun signals, it has been estimated that a seismic vessel operating 3D air-gun arrays in 100–120 m water depth should impact marine turtles by producing behavioural changes at about 2 km range and avoidance at around 1 km range (McCauley *et al.* 2000). Seismic surveys are not likely to cause direct mortality with marine turtles. However, this study provides a basis for recommending that a buffer zone of at least 2 km radius should be maintained between seismic surveys and significant aggregations of marine turtles such as internesting, courtship or dense foraging aggregations. The highest priority would be to avoid causing disruptive behaviour for the turtles during the time-limited reproductive period.

3.9 BASKING

Basking turtles are of interest to tourists when encountered. At Heron Island in the southern Great Barrier Reef where this type of behaviour was once common (Barrett, 1919), it has now all but ceased since the establishment of the tourist resort on the island. Presumably this change has been in response to regular human approach to turtles in the shallows and on the beach. Small numbers of basking *C. caretta* can still be encountered on Fraser Island in Queensland among the more plentiful basking *C. mydas*. Here it has been necessary to introduce education material to discourage tourists from “rescuing” the basking turtles back into the water.

4. POPULATION STATUS

4.1 POPULATION DEMOGRAPHY

Eastern Australian stock

Population modelling research is progressively improving for the eastern Australian stock (Crouse *et al.* 1987; Somers, 1994; Heppell *et al.* 1996; Chaloupka and Limpus, 1997; Chaloupka, 2003). It is now apparent that because of the protracted delay in maturity and the long intervals between breeding seasons, *C. caretta* populations will be at risk from even modest increases in mortality at any stage in their life history that have an extended impact.

Chaloupka (2003) demonstrated that the greatest potential threats to the eastern Australian *C. caretta* stock are uncontrolled fox predation of eggs on the mainland rookeries; trawl bycatch mortality of the large immature and adult turtles in the coastal foraging areas of eastern and northern Australia and oceanic long-line bycatch mortality of the pelagic post-hatchling.

Understanding the impact of threats to the stock and the benefits that will flow from improved stock management requires an integration of the time scale of the life history of the species with the timing of the mortality and intervention events. The following is a summary to provide some insights in this regard.

Age structure and observed population decline

- The best estimate of age from birth to first breeding for the eastern Australian *C. caretta* is 29 years or more (Section 2.2.12).
- The time from recruitment from the pelagic post-hatchling phase to coastal benthic feeding phase is 13 years (Section 2.2.13).
- There has been a general decline in the size of the annual *C. caretta* nesting population at all monitored rookeries in eastern Australia since the mid 1970s (Section 2.2.1).

Trawling

- Trawling impacts the adult and large immature *C. caretta* that forage over the coastal waters (Section 2.2.13). Excessive mortality via trawl bycatch should be detectible in the breeding population as a reduction in annual breeding numbers within a single breeding cycle (for a young adult = about 5 years), i.e. it should be almost immediately evident within the total life history of the species.
- The trawl industry of eastern Australia escalated in the late 1970s.
- The trawl fisheries off the coast of New South Wales, Queensland, Northern Territory and Western Australia fisheries have had the potential to kill many hundreds if not thousands of *C. caretta* annually since the late 1970s (See Section 3.2.2).
- An escalation in trawling bycatch in association with the increasing fleet sizes of the late 1970 would be consistent with the observed beginning of the decline in nesting female *C. caretta* at the east coast rookeries by the late 1970s.
- Similarly, the benefits of a greatly reduced trawl bycatch mortality resulting from the use of TEDs in the NPF, ECTF and TSPF in the early 2000s should be detectible as a slowing in the rate of decline of the population at the east coast nesting beaches within a single breeding cycle of about 5 years for a young adult, i.e. by about 2005.

Fox predation

- In eastern Australia fox predation of *C. caretta* eggs on the female-hatchling-producing mainland rookeries increased from non-existent or trivial in the mid 1900s through modest but significant predation levels in the 1960s–early 1970s to a major level by the late 1970s (Section 2.2.9)

- At Mon Repos and the other minor rookeries of the Woongarra Coast, the predation level reached about 10% by the late 1960s and was effectively reduced to a very minor level by the early 1970s.
- At Wreck Rock, the predation level reached about 90–95% of clutches laid by the mid 1970s and was not brought under control until the late 1980s. Loss of eggs to foxes has been mostly at a minor level at Wreck Rock since the mid 1990s.
- At the other minor rookeries on approximately 55 km of coast between the Burnett River and Deepwater Creek, fox predation has not been controlled with baiting and remains at a presumed high level.
- Excessive loss of eggs will not be detectable in the adult nesting population until young from that cohort reach maturity, i.e. in about 30 years after the excessive predation commences. Therefore, the excessive loss of "female" eggs from the mainland beaches that was evident by about 1970, should impact on the number of the breeding females at the nesting beaches in about 2000. This time scale does not fit with an hypothesis that the eastern Australian population decline that began in the 1970s was initiated by fox predation. The observed declining recruitment of immature *C. caretta* from the pelagic life history phase to coastal habitats in the 1990s (Section 2.2.13) is generally consistent with the timing of the increased fox predation of eggs. If this hypothesis is correct then there should be about 15–20 years of reduced recruitment to the nesting adult population during the period of 2000–2020. The benefits of the predator control of the 1990s have yet to flow through the population to the next generation of breeding adults and should not be obvious at the rookeries until about 2020.

Oceanic fisheries

- Oceanic long-line fishing in the South Pacific escalated in the 1980s in response to the phasing out of oceanic gill-net fisheries. These long-line fisheries commenced after the beginning of the decline of the of the eastern South Pacific (Australian and New Caledonian rookeries) *C. caretta* stock.
- While long-line fisheries may not have initiated the decline, Chaloupka (2003) has clearly demonstrated their potential for significant negative impact on the stock. Long-line fishery bycatch in the South Pacific has the potential to negate the benefits that should flow from the significant reduction in egg loss through fox baiting and the reduced *C. caretta* mortality following the introduction of TEDs to our trawl fisheries. However, there is still a lack of fisheries bycatch data that unambiguously demonstrates the extent of the threat of the collective long-line fisheries of the South Pacific to our *C. caretta* stock.
- An additional fishery that impacted our *C. caretta* and that appears to have been poorly assessed in the past is the oceanic gill-net fisheries in the Pacific and Indian Oceans. That they had the potential for killing large numbers of post-hatchling *C. caretta* has been demonstrated (Weatherall *et al.* 1993).
- These oceanic gill-net fisheries operated during the 1960s–1970s and may have contributed to the late 1970s decline in eastern Australian adult female *C. caretta*. The data are lacking to conclusively demonstrate this.

These gill-net fisheries have been replaced mostly by the long-line fisheries.

In addition to the above, there is also the combined impacts of an array of other mortalities from anthropogenic activities that cause the death of *C. caretta,* including harvest by coastal communities in the South West Pacific region, boat strike, entanglement in fishing line and ropes, entanglement in crab-pot float lines, ingestion of synthetic debris and shark control bycatch in eastern Australia, that collectively may cause the loss of 60 or more adult and near adult turtles annually. Even if the population losses from trawling, fox predation and long-line fishery bycatch could be completely eliminated right now, these combined mortalities from other sources have the potential to compromise or delay the recovery of this severely depleted stock.

Mathematical modelling of the life history and population dynamics of *C. caretta* is well advanced (Chaloupka, 2003) and it can be assumed that it will continue to improve as better biological data becomes available. Models such as that developed by Chaloupka (2003), provide powerful tools for investigating the potential outcomes from the competing human impacts and the consequences of decisions that we may make with regard to the management of the species. These modelling exercises need to continue so that the models can improve and take into account the emerging new information as it comes to hand for the stocks.

It is apparent from the above that the South Pacific *C. caretta* stock has been exposed to a complex array of threats of changing intensity, each with a different temporal impact (date of initiation and duration) on the stock and impacting different life history phases. It should also be apparent that for effective assessment of the impact of threats they need to be quantified, not just by listing the number of individuals lost but by identifying when the losses occurred and the life history phases (age class, size, sex, and maturity) impacted with each threat. This is a significant challenge for conservation management of *C. caretta* in the South Pacific. Unless the mortalities from anthropogenic actions that affect the stock are much better quantified, the mathematical modelling of management outcomes will continue to be theoretical.

If the cumulative impact of the remaining mortalities from anthropogenic sources on the total population continues, strong concern must be held for the capacity of the depleted and endangered eastern Australian stock to recovery to a secure population level.

Western Australian stock

The conservation status of the Western Australian stock cannot be determined because the size of the annual breeding population is incompletely quantified and mortality from anthropogenic sources within the migratory range of this stock has not been monitored adequately.

There is however, circumstantial evidence indicating a need for concern for the security of the Western Australian stock. There is a high probability that the egg loss to foxes and vehicle traffic within this total complex of nesting beaches has exceeded the sustainable level of loss for the Western Australian loggerhead turtle population. In addition, the principal areas for egg mortality for these turtles are the beaches that are almost likely to be the main female producing beaches. Therefore the impact of fox predation and vehicle traffic could be expected to be even more negative with respect to population dynamics than one would expect. To this, there must also be added, the additional unquantified mortality from bycatch in trawling, longline fisheries and entanglement in floatlines within the lobster fishery, boat strike, even within Marine Parks and increases in hatchling mortality associated with lighting disorientation near coastal development. Even though Western Australia supports one of the largest nesting populations of loggerhead turtles in the world, this stock is exposed to substantial unquantified losses from a broad range of anthropogenic activities, compounded by the possible impact of temperature dependent sex bias associated with the reduced hatchling production.

Strong concern should be held for the capacity to maintain the Western Australian stock at its current high population level.

5. CONSERVATION STATUS WITHIN AUSTRALIA

Conservation management of loggerhead turtles, *C. caretta,* within Australia had its beginnings in 1968 with the 18 July 1968 Order in Council under the Queensland Fisheries Act that declared an all year round closed season for the harvest of all species of marine turtles and their eggs for all of Queensland.

C. caretta is recognised and protected as a threatened species by all Commonwealth, Northern Territory and State conservation agencies in Australia except Victoria (Table 18). The eastern Australian stock clearly warrants continued listing as an Endangered species. Given the lack of detailed information on the size and trend of the Western Australian stock and the existing multiple threats to its population stability, this stock also warrants retention of its Endangered species status.

Table 18. Summary of the legally defined conservation status of *Caretta caretta* within Australia.

	Status	**Legal basis**
International obligations		
Convention for the Conservation of Migratory Species of Wild Animals (CMS)	Appendix I & II	Australia is a signatory state.
Convention for International Trade in Endangered Species (CITES)	Appendix 1	Australia is a signatory state.
Legislation		
Australia including Australian Territories	Endangered Migratory species Marine species	*Commonwealth Environment Protection and Biodiversity Conservation Act 1999*
Great Barrier Reef Marine Park	Protected	*Great Barrier Reef Marine Park Act 1975; Great Barrier Reef Marine Park Regulations 1983*
Tasmania	Endangered	*Threatened species Protection Act 1995*
Victoria	(not listed)	*Advisory list of Threatened Vertebrate Fauna in Victoria 2003*
New South Wales	Endangered	*Threatened Species Conservation Act 1995*
Queensland	Endangered	*Nature Conservation Act 1992. A protected species under the Fisheries Act since 1968.*
Northern Territory	Endangered	*Territory Parks and Wildlife Conservation Act 2000*
Western Australia	Rare or likely to become extinct	*Wildlife Conservation Act 1950*
South Australia	Vulnerable	*National Parks and Wildlife Act 1972*

The Australian Government has jurisdiction over waters three nautical miles offshore to the end of the Exclusive Economic Zone (EEZ). In these waters marine turtles are protected under the Environment Protection and Biodiversity Conservation (EPBC) Act. The Australian States and Northern Territory have jurisdiction over intertidal waters and coastal waters out to three nautical miles offshore from their State/Territory lands. The respective State legislation's are applicable to the management of marine turtles in these State and Territorial waters. Under the EPBC Act, actions in all Australian waters that have, will have, or are likely to have a significant impact on marine turtles are subject to a rigorous referral, assessment, and approval process.

6. REFERENCES

Ackerman, R. A. (1980). Physiological and ecological aspects of gas exchange by sea turtle eggs. *American Zoologist* 20, 575–583.

Alfaro-Shigueto, J., Dutton, P. H., Mangel, J. and Vega, D. (2004). First confirmed occurrence of loggerhead turtles in Peru. *Marine Turtle Newsletter* 103, 7–11.

Anon (1997). The Queensland Shark Control Program: Report of the Committee of Review. (Department of Primary Industries: Brisbane.)

Anon. (1999). Management Plan Capricornia Cays National Park and Capricornia Cays National Park (Scientific). (Queensland Government Queensland Parks and Wildlife Service: Brisbane)

Anon (2003). Queensland Government Submission in response to the Nomination under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act): "Death or injury to marine species following capture in beach meshing (nets) and drum lines used in Shark Control Programs" as a *Key Threatening Process*.

Baldwin, R., Hughes, G. R., and Prince, R. I. T. (2003). Loggerhead turtles in the Indian Ocean. In "Loggerhead Sea Turtles". A. B. Bolten, and B. E. Witherington, ed. Pp. 218 – 232. (Smithsonian Institution: Washington, D.C.)

Barrett, C. (1919). In Australian Wilds. The Gleanings of a Naturalist. (Melbourne Publishing Company: Melbourne.)

Bell, I. (2003). Turtle population dynamics in the Hay Point, Abbot Point, and Lucinda Port areas. Unpublished Report to Queensland Parks and Wildlife Service, Townsville. Pp. 1–37.

Beurteaux, Y. and Coles, R. (1988). Effort trends in the north-east coast prawn trawl fishery. *Queensland Department of Primary Industries* Q188006, 1–24.

Blair, D. (1984). *Elytrophallus carettae* sp. n. (digenea: Heliuridae) from the stomach of loggerhead turtles (*C. caretta* (L.)) from Australia. *Proceedings Helminological Society* 51(1), 135–139.

Blair, D. (1986). A revision of the subfamily Microscarphidiinae (Platyhelminthes: Digenea: Microoscaphidiidae) parasitic in marine turtles (Reptilia: Chelonia) *Australian Journal of Zoology* 34, 241–277.

Blair, D. (1987). A revision of the subfamily Octangiinae (Platyhelminthes: Digenea: Microoscaphidiidae) parasitic in marine turtles (Reptilia: Chelonia) *Australian Journal of Zoology* 35, 75–92.

Bolten, A. B. (2003a). Variation in sea turtle life history patterns: Neritic vs. oceanic developmental stages. In "The Biology of Sea Turtles". Vol II. (Eds. P. L. Lutz, J. A. Musick, J. A. and J. Wyneken). Pp. 243–257. (CRC Press: Boca Raton.)

Bolten, A. B. (2003b). Active swimmers – passive drifters: the oceanic juvenile stage of loggerheads in the Atlantic System. In "Loggerhead Sea Turtles". (eds Bolten, A. B. and Witherington, B. E.) Pp. 63–78. (Smithsonian Institution: Washington, D.C.)

Bolten, A. B. and Witherington, B. E. (2003). “Loggerhead Sea Turtles.” (Smithsonian Institution: Washington, D.C.)

Bowen, B. W. (2003). What is a loggerhead turtle? The genetic perspective. In “Loggerhead Sea Turtles". A. B. Bolten, and B. E. Witherington, ed. Pp. 7–27. (Smithsonian Institution: Washington, D.C.)

Bowen, B. W., Abreu-Grobois, F. A., Balazs, G. H., Kamezaki, N., Limpus, C. J. and Ferl, R. J. (1995). Trans-Pacific migrations of the loggerhead turtle (*Caretta caretta*) demonstrated with genetic markers. *Proceedings National Acadamy of Science, USA* 92, 3731–3734.

Bowen, B. W., Kamezaki, N., Limpus, C. J., Hughes, G. H., Meylan, A. B. and Avise, J. C. (1994). Global phylogeography of the loggerhead turtle (*Caretta caretta*) as indicated by mitochondrial DNA haplotypes. *Evolution* 48(6), 1820–1828.

Bowen, B. W., Richardson, J. I., Meylan, A. B., Margaritoulis, D., Hopkins-Murphy, S. R. and Avise, J. (1993). Population structure of loggerhead turtles (*Caretta caretta*) in the west Atlantic Ocean and Mediterranean Sea. *Conservation Biology* 7, 834–844.

Bustard, H. R. (1968). Protection for a rookery. Bundaberg Sea turtles. *Wildlife in Australia* 5(2) 43–44, 63.

Bustard, R. (1972). "Sea Turtles: Their Natural History and Conservation." (Collins: London.)

Bustard, H. R., Greenham, P. and Limpus, C. J. (1975). Nesting behaviour of loggerhead and flatback turtles in Queensland. *Proc. Koninkl. Nederl. Akademie van Wetenschappen* Sereies C 78(2), 111–122.

CALM (2004). “Ningaloo Marine Park Draft Management Plan and indicative management plans for the extension of the existing Park and Muiron Islands Marine Management Area.” (Department of Conservation and Land Management: Perth.)

Cannon, L. R. G. (1978). A larval acsaridoid nematode from Queensland scallops. *International Journal of Parasitology* 8, 75–80.

Chaloupka, M. (1998). Polyphasic growth apparent in pelagic loggerhead sea turtles. *Copeia* 1998, 516–518.

Chaloupka, M. (2003). Stochastic simulation modelling of loggerhead population dynamics given exposure to competing mortality risks in the western South Pacific. In Biology and Conservation of Loggerhead Turtles. (Eds. Witherington, B. and Bolten, A.) Pp. 274–294. (Smithsonian Institution Press: Washington, D. C.)

Chaloupka, M. and Limpus, C. (1997). Heuristic simulation modelling of trawl fishery impacts on sGBR loggerhead population dynamics. Proceedings 17th International Symposium on Sea Turtle Biology and Conservation (in press).

Chaloupka, M. and Limpus, C. J. (2002). Survival probability estimates for the endangered loggerhead sea turtle resident in southern Great Barrier Reef waters. *Marine Biology* 140, 267–277.

Chatto, R. (1998). A preliminary overview of the locations of marine turtle nesting in the Northern Territory. In “Marine Turtle Conservation and Management in Northern Australia". (Eds. Kennett, R.; Webb, A.; Duff, G.; Guinea, M., and Hill, G.) Pp. 33–40. (Northern Territory University: Darwin.)

Cogger, H. G. (1992). "Reptiles and Amphibians of Australia". (Reed Books: Sydney.)

Conway, S. P. (1994). Diets and feeding biology of adult olive ridley (*Lepidochelys olivacea*) and loggerhead *(Caretta caretta*) sea turtles in Fog Bay (Northern Territory). Unpublished dissertation, Northern Territory University.

Crouse, D. T., Crowder, L. B. and Caswell, H. (1987). A stage-based model for loggerhead sea turtles and implications for conservation. *Ecology* 68, 1412–1423.

Dodd, C. K. (1988). Synopsis of the biological data on the loggerhead turtle *Caretta caretta* (Linnaeus 1758). *U.S. Fish and Wildlife Service Biological Report* 88(14), 1–110.

Donoso, M., Dutton, P., Serra, R. and Britomontero, J. L. (2000). Sea turtles found in the waters off Chile. *NOAA Technical Memorandum NMFS–SEFSC* 443, 218–219.

Dutton, P., Broderick, D., and FitzSimmons, N. (2002). Defining management units: molecular genetics. In: Proceedings of the Western Pacific Sea Turtle Cooperative Research & Management Workshop. Pp. 93–101. I. Kinan, Ed. (Western Pacific Regional Fishery Management Council: Honolulu.)

Flakus, S. and Limpus, C. J. (1999). “Environmental Protection Agency Marine Wildlife Stranding Data. Sea turtle strandings 1 January – 31 December 1999.” (Environmental Protection Agency: Brisbane.)

Fraser, N. B., Limpus, C. J. and Green, J. L. (1994). Growth and estimated age at maturity of Queensland loggerheads. *NOAA Technical Memorandum NMFS–SEFC* 351, 42–46.

Gill, B. J. (1997). Records of turtles and sea snakes in New Zealand, 1837–1996. *New Zealand Journal of Marine and Freshwater Research* 31, 477–486.

Grassman, M. A., Owens, D. W., McVey, J. P. and Marquez, M. R. (1984). Olfactory-based orientation in artificially imprinted sea turtles. *Science* 224, 383–384.

Green, R. H. (1971). Sea turtles around Tasmania. *Records Queen Victoria Museum* 38, 1–4.

Greenland, J. A., Limpus, C. J. and Currie, K. J. (2004). Queensland marine wildlife stranding and mortality database annual report 2001–2002 III. Marine Turtles. (Environmental Protection Agency; Brisbane.)

Gribble, N. A., McPherson, G. and Lane, B. (1998). Review of the impact of Queensland Shark Control Program on non-target species: whale, dugong, turtle and dolphin, a review *Marine and Freshwater Fisheries* 49, 645–651.

Guinea, M. L. (1995). Report to Australian Nature Conservation Agency: the sea turtles and sea snakes of Ashmore Reef National Nature Reserve. (School of Biological Sciences, Northern Territory University: Darwin. Unpublished report to Australian Nature Conservation Agency.)

Guinea, M. L. and Chatto, R. (1992). Sea turtles killed in Australian shark fin fishery. *Marine Turtle Newsletter* 57, 5–6.

Guinea, M. L., Whiting, S. and Chatto, R. (1997). Sea turtle deaths coincide with trawling activities in northern Australia. *Marine Turtle Newsletter* 77, 11–14.

Gyuris, E. (1993). Insights into the ecology of hatchlings of the green turtle, *Chelonia mydas*: implications for the life histories of marine turtles. Unpublished Ph.D. thesis, James Cook University of North Queensland: Townsville.)

Gyuris, E. (1994). The rate of predation by fish on hatchlings of the green turtle (*Chelonia mydas*). *Coral Reefs* 13, 137–144.

Gyuris, E. (2000). The relationship between body size and predation rates on hatchlings of the green turtle (*Chelonia mydas*): is bigger better? In Sea Turtles of the Indo-Pacific: Research Management and Conservation. (Eds. Pilcher, N. and Ismail G.) Pp. 143–147. (ASEAN Academic Press:London.)

Gyuris, E. and Limpus, C. J. (1988). The loggerhead turtle, *Caretta caretta*, in Queensland; population breeding structure. *Australian Wildlife Research* 15, 197–209.

Haines, J. A., Limpus, C. J. and Flakus, S. (2000). Marine wildlife stranding and mortality database annual report, 1999. III. Marine turtles. (Queensland Parks and Wildlife Service: Brisbane.)

Haines, J. A. and Limpus, C. J. (2001). Marine wildlife stranding and mortality database annual report, 2000. III. Marine turtles. (Queensland Parks and Wildlife Service: Brisbane.)

Greenland, J. A., Limpus, C. J., Currie, K. J. (2004). Marine wildlife stranding and mortality database annual report, 2001–2002. III. Marine turtles. (Queensland Environmental Protection Agency: Brisbane.)

Heithaus, M. R., Frid, A. and Dill, L. M. (2002). Shark-inflicted injury frequencies, escape ability, and habitat use of green and loggerhead turtles. *Marine Biology* 140, 229–236.

Hamann, M., Limpus, C. J. and Owens, D. W. (2003). Reproductive cycles of males and females. In “The Biology of Sea Turtles". Volume II. (Eds. Lutz, P. L., Muzick, J. A. and Wyneken, J.) Pp. 135–161. (CRC Press: Boca Raton.)

Hatase, H., Matsuzawa, Y., Sato, K., Bando, T. and Goto, K. (2004). Remigration and growth of loggerhead turtles (*Caretta caretta*) nesting on Senri Beach in Minabe, Japan: life-history polymorphism in a sea turtle population. *Marine Biology* 144, 807–811.

Heppell, S., Limpus, C. J., Crouse, D., Frazer, N. and Crowder, L. (1996). Population model analysis for loggerhead sea turtle, *Caretta caretta*, in Queensland. *Wildlife Research* 23, 143–159.

Johannes, R. E. and MacFarlane, J. W. (1991). "Traditional Fishing in the Torres Strait Islands." (CSIRO Division of Fisheries: Hobart.)

Jessop, T., Summer, J., Lance, V. and Limpus, C. (2003). Reproduction in shark-attacked sea turtles is supported by stress reduction mechanisms. Proceedings Royal Society London B (Supplement) online publication 30 Oct 2003: 1–4.

Kelez, S., Velez-Zuazo, X, Manrique, C. (2004). Conservation of sea turtles along the coast of Peru. Partial project report. Unpublished report to UNEP Convention for Migratory Species.

Keinath, J. A. (1996). Use protection! Or a case of vibro infection from sea turtle. *National Oceanic and Atmospheric Administration Technical Memorandum National Marine Fisheries Service Southeast Fisheries Center* 387, 144.

Kidston, W., Dwyer, K., Buhk, A., Waldock, J. and Anderson, G. (1992). "Review of the Operation and Maintenance of Shark Meshing Equipment in Queensland Waters: Report of the Committee of Inquiry." (Queensland Department of Primary Industries: Brisbane.)

Kowarsky, J. (1982). Subsistence hunting of sea turtles in Australia. In 'Biology and Conservation of Sea Turtles.' (Ed. K. A. Bjorndal) Pp. 305–313. (Smithsonian Institution Press: Washington, D.C.)

Krogh, M. and Reid, D. (1996). Bycatch in the protective beach meshing program off southeastern NSW. *Biological Conservation* 77, 219–226.

Kuchling, G. (2004). Male biased sex ratio and occurrence of intersexes in pelagic juvenile *Caretta caretta* washed up at Perth beaches (Western Australia) during winter storms *Amphibia-Reptilia* (in press).

Kwan, D. (1989). The Status of the Daru turtle fishery from October 1984 to December 1987: with implications and recommendations for management and conservation. Unpublished report to the Raine Island Corporation: Brisbane.

Lemm, S. (1996). Nest success and hatchling sex ratio of loggerhead sea turtles, *Caretta caretta* at mainland rookeries in Eastern Australia. Unpublished M.Sc. Thesis, University of Queensland: Brisbane.

Lester, R. J. G. (1980). Marine parasitology research aiding industry. *Australian Fisheries* 1980 (October), Pp. 13–14.

Lewison, R. L., Freeman, S. A. and Crowder, L. B. (2004). Quantifying the effects of fisheries on threatened species: the impact of pelagic longlines on loggerhead and leatherback sea turtles. *Ecology Letters* 7, 221–231.

Light, P., Salmon, M. and Lohman, K. J. (1993). Geomagnetic orientation of loggerhead sea turtles: evidence for an inclination compass. *Journal of Experimental Biology* 182, 1–10.

Limpus, C. J. (1971). Sea turtle ocean finding behaviour. *Search* 2:385–387.

Limpus, C. J. (1973). Avian predators of sea turtles in southeast Queensland rookeries. *The Sunbird* 4(3), 45–51.

Limpus, C. J. (1978). The Reef. In “Exploration North." Ed. H. J. Lavery. (Richmond Hill Press: Victoria.)

Limpus, C. J. (1985). A Study of the loggerhead turtle, *Caretta caretta*, in Queensland. Ph.D. thesis, University of Queensland, Brisbane.

Limpus, C. J. (1989). Forage area fidelity following breeding migrations in *Caretta caretta*. *National Oceanic and Atmospheric Administration Technical Memorandum National Marine Fisheries Service Southeast Fisheries Center* 232, 135–137.

Limpus, C. J. (1991). Puberty and first breeding in *Caretta caretta*. *National Oceanic and Atmospheric Administration Technical Memorandum National Marine Fisheries Service Southeast Fisheries Center* 278, 81–83.

Limpus, C. J. (1992). "Indo-Pacific Marine Turtle Identification Key." (Queensland Department of Environment and Heritage: Brisbane.)

Limpus, C. J. (1994). The loggerhead turtle, *Caretta caretta*, in Queensland: feeding ground selection following her first breeding season. *NOAA Technical Memorandum NMFS-SEFC* 351, 78–81.

Limpus, C. J., Baker, V. and Miller, J. D. (1979). Movement induced mortality of loggerhead eggs. *Herpetologica* 35, 335–338.

Limpus, C. J., Couper, P. J. and Read, M. (1994b). The loggerhead turtle, *Caretta caretta*, in Queensland: population structure in a warm temperate feeding area. *Memoirs of the Queensland Museum* 37, 195–204.

Limpus, C. J., Deacon, M. and Meech, M. (1993). Dead turtles on the Woongarra Marine Park and adjacent coast. Unpublished internal report, QDEH: Brisbane.

Limpus, C. J., de Villiers, D. L., de Villiers, M. A., Limpus, D. J., and Read, M. A. (2001). The loggerhead turtle, *Caretta caretta*, in Queensland: observations on feeding ecology in warm temperate *waters. Memoirs Queensland Museum* 46(2): 631–645.

Limpus, C. J., Fleay, A. and Guinea, M. (1984). Sea turtles of the Capricornia Section, Great Barrier Reef. In 'The Capricornia Section of the Great Barrier Reef: Past, Present and Future.' (Eds. W.T. Ward and P.Saenger) Pp. 61–78. (Royal Society of Queensland and Australian Coral Reef Society: Brisbane.)

Limpus, C. J. and Limpus, D. J. (2001). The loggerhead turtle, *Caretta caretta*, in Queensland: breeding migrations and fidelity to a warm temperate feeding area. *Chelonian Conservation and Biology* 4(1): 142–153.

Limpus, C. J. and Limpus, D. J. (2003a). Loggerhead turtles in the Equatorial and Southern Pacific Ocean: a species in decline. In “Loggerhead Sea Turtles.” A.B. Bolten and B.E. Witherington ed. Pp. 199–209. (Smithsonian Institution: Washington, D.C.)

Limpus, C. J. and Limpus, D. J. (2003b). Biology of the loggerhead turtle in western South Pacific Ocean foraging areas. In “Loggerhead Sea Turtles.” A.B. Bolten and B.E. Witherington ed. Pp. 93–113. (Smithsonian Institution: Washington, D.C.)

Limpus, C. J. and Miller, J. D. (1994). The occurrence of cutaneous fibropapillomas in marine turtles in Queensland. In 'Proceedings of the Marine Turtle Conservation Workshop' (Compiled by Russell James) Pp. 186–188. (Australian National Parks and Wildlife Service: Canberra.)

Limpus, C. J., Miller, J. D., Parmenter, C. J., Reimer, D., McLachlan, N. and Webb, R. (1992). Migration of green (*Chelonia mydas*) and loggerhead (*Caretta caretta*) turtles to and from eastern Australian rookeries. *Wildlife Research* 19, 347–358.

Limpus, C. J. and Reed, P. C. (1985). The loggerhead turtle, *Caretta caretta*, in Queensland: observations on internesting behaviour. *Australian Wildlife Research* 12, 535–540.

Limpus, C. J., Reed, P. and Miller, J. D. (1983). Islands and turtles. The influence of choice of nesting beach on sex ratio. In 'Proceedings of Inaugural Great Barrier Reef Conference, Townsville, 28 August – 2 September 1983.' (Eds. J. T. Baker, R. M. Carter, P. W. Sammarco and K. P. Stark) Pp. 397–402. (JCU Press: Townsville.)

Limpus, C. J., Reed, P. C. and Miller, J. D. (1985). Temperature dependent sex determination in Queensland sea turtles: intraspecific variation in *Caretta caretta*. In 'Biology of Australasian Frogs and Reptiles.' (Eds. G. Grigg, R. Shine and H. Ehmann) Pp. 343–351. (Royal Zoological Society: New South Wales.)

Limpus, C. J. and Reimer, D. (1992). Observations on first breeding by a loggerhead turtle. *Marine Turtle Newsletter* 56, 1–2.

Limpus, C. J. and Reimer, D. (1994). The loggerhead turtle, *Caretta caretta*, in Queensland: a population in decline. In “Proceedings of the Marine Turtle Conservation Workshop” (Compiled by R. James) Pp. 34–48. (Australian National Parks and Wildlife Service: Canberra.)

Limpus, C. J., Walker, T. A. and West, J. (1994a). Post-hatchling sea turtle specimens and records from the Australian region. In “Proceedings of the Marine Turtle Conservation Workshop.” (Compiled by Russel James.) Pp. 95–100. (Australian Nature Conservation Agency: Canberra.)

Lohmann, K. J. (1991). Magnetic orientation by hatchling Loggerhead Sea turtles (*Caretta caretta*). *Journal of Experimental Biology* 155, 37–49.

Lohmann, K. J. (1992). How sea turtles navigate. *Scientific American* 1992 (January), 100–106.

Lohmann, K. J and Lohmann, C. M. F. (2003). Orientation mechanisms of hatchling loggerheads. In “Loggerhead Sea Turtles.” A.B. Bolten and B.E. Witherington ed. Pp. 44–62. (Smithsonian Institution: Washington, D.C.)

Lucas, P. H. C., Webb, T., Valentine, P. S. and Marsh, H. (1997). The outstanding universal value of the Great Barrier Reef World Heritage Area. (Great Barrier Reef Marine Park Authority and James Cook university of North Queensland: Townsville.)

Ludeke, J. (1993). Survey of stranded marine turtles in south Queensland. Unpublished report to Queensland Department of Environment and Heritage: Brisbane.

Lum, L. L., Lima, E. M. and Santos, A. (1998). Green turtle tagged in Brazil recovered in Trinidad. *Marine Turtle Newsletter* 82, 9.

Mack, P. (2000). Turtles at Coral Bay. Summer 1999–2000. Unpublished Annual Report to C.A.L.M. Pp. 1–30.

McCauley, R. D., Fewtrell, J., Duncan, A. J., Jenner, C., Jenner; M. N., Penrose, J. D., Prince, R. I. T., Adhitya, A., Murdoch, J. and McCabe, K. (2000). Marine seismic surveys: Analysis and propogation of air-gun signals; and effect of air-gun exposure on humpback whales, sea turtles, fishes, and squid. In “Environmental implications of offshore oil and gas development in Australia: further research.” (APPEA Secretriat.) Pp. 364–521. (Australian Petroleum production and exploration Association Limited: Canberra.)

McLachlan, N. (1995). Report on Wreck Rock turtle rookery December 94 – January 95. Unpublished Report to Queensland National Parks and Wildlife Service. Pp. 1–4.

McLachlan, N. and McLachlan, B. (1996). Report on Wreck Rock turtle rookery December 95 – January 96. Unpublished Report to Queensland National Parks and Wildlife Service. Pp. 1–3.

McLachlan, N. and McLachlan, B. (1997). Report on Wreck Rock turtle rookery December 96 – January 97. Unpublished Report to Department of Environment. Pp. 1–3.

McLachlan, N. and McLachlan, B. (1999). Report on Wreck Rock turtle rookery December 98 – January 99. Unpublished Report to Queensland Parks and Wildlife Service. Pp. 1–3.

McLachlan, N. and McLachlan, B. (2000). McLachlan, N. Wreck Rock turtle monitoring report 1999/2000 season. Unpublished Report to Queensland Parks and Wildlife Service. Pp. 1–4.

McLachlan, N. and McLachlan, B. (2002). McLachlan, N. Report on Wreck Rock turtle rookery December 01 – February 02. Unpublished Report to Queensland Parks and Wildlife Service. Pp. 1–4.

McLachlan, N., McLachlan, B. and McLachlan, J. (2003). Report on Wreck Rock turtle rookery November 02 – February 03. Unpublished Report to Queensland Parks and Wildlife Service. Pp. 1–13.

McLachlan, N., McLachlan, B., McLachlan, J. and McLachlan, B. (2004). Report on Wreck Rock turtle rookery November 03 – February 04 (2003–2004). Unpublished Report to Queensland Parks and Wildlife Service. Pp. 1–13.

Magnuson, J. J., Bjorndal, K. A., DuPaul, W. D., Graham, G. L., Owens, D. W., Peterson, C. H., Pritchard, P. C. H., Richardson, J. I., Saul, G. E. and West, C. W. (1990). 'Decline of the Sea Turtles Causes and Prevention.' (National Academy Press: Washington, D.C.)

Miller, J. D. (1985). Embryology of marine turtles. In "Biology of the Reptilia." vol.14. (Eds. C. Gans, F. Billett and P. F. A. Maderson) Pp. 271–328. (Wiley Interscience; New York.)

Miller, J. D. and Limpus, C. J. (1981). Incubation period and sexual differentiation in the Green turtle. In “Proceedings of the Melbourne Herpetological Symposium. Melbourne.” (Eds. Banks, C. B. and Martin, A. A.) Pp. 66–73. (Zoological Board of Victoria: Melbourne.)

Miller, J. D. and Limpus, C. J. (2003). Ontogeny of marine turtle gonads. In The Biology of Sea Turtles. Volume II. Pp. 199–224. (Eds. Lutz, P. L., Muzick, J. A. and Wyneken, J.) (CRC Press: Boca Raton.)

Miller, J. D., Limpus, C. J. and Godfrey, M. H. (2003). Nest site selection, oviposition, eggs, development, hatching, and emergence of loggerhead turtles. In “Loggerhead Sea Turtles.”

A. B. Bolten, and B. E. Witherington, Eds. Pp. 125–143. (Smithsonian Institution: Washington, D.C.)

Moody, E. G. (1979). Aspects of the feeding biology of the loggerhead turtle (*Caretta caretta*). B.Sc.Hon. Thesis, James Cook University of North Queensland, Townsville.

Morris, K. and Lapwood, M. (2001). Development of a joint management strategy between Aboriginal communities and WA Department of Conservation and Land Management for the conservation of marine turtles in the Dampier Peninsula region of Western Australia: progress report, November 2001. Department of Conservation and Land Management, Western Australia, Pp. 1–7.

Mrosovsky, N. (1978). Effects of flashing lights on sea-finding behaviour of green turtles. *Behavioral Biology* 22, 85–91.

Mrosovsky, N. (1988). Pivotal temperatures for loggerhead turtles (*Caretta caretta*) from northern and southern nesting beaches. *Canadian Journal of Zoology* 66, 661–669.

Oceanic Fisheries Program (2001). A review of turtle bycatch in the western and central Pacific Ocean tuna fisheries. (South Pacific Regional Environment Programme: Apia.)

Office of the Queensland Parliamentary Council (2003). Nature Conservation (Protected Areas) Regulation 1994. (Queensland Government: Brisbane.)
Parker, D. M., Cooke, W. J. and Balazs, G. H. (in press). Dietary components of oceanic loggerhead turtles, *Caretta caretta*, in the North Pacific. Fishery Bulletin.

Pelagics Plan Team and Council Staff (2004). “Pelagic fisheries of the Western Pacific Region 2002 Annual Report.” (Western Pacific Regional Fisheries Management Council: Honolulu.)

Phillott, A. D., Parmenter, C. J. and Limpus, C. J. (2001). Mycoflora identified from failed green (*Chelonia mydas*) and loggerhead (*Caretta caretta*) sea turtle eggs at Heron Island, Australia. *Chelonian Conservation and Biology* 4(1), 170–172.

Phillott, A. D., Parmenter, C. J., Limpus, C. J. and Harrower, K. M. (2002). Mycobiota as acute and chronic cloacal contaminants of female sea turtles. *Australian Journal of Zoology* 50, 687–695.

Poiner, I. R. and Harris, A. N. M. (1994). The incidental capture and mortality of sea turtles in Australia's northern prawn fishery. In "Proceedings of the Marine Turtle Conservation Workshop." (Compiled by Russel James.) Pp. 115–123. (Australian Nature Conservation Agency: Canberra.)

Poiner, I. R. and Harris, A. N. M. (1996). Incidental capture, direct mortality and delayed mortality of sea turtles in Australia’s Northern Prawn Fishery. *Marine Biology* 125, 813–825.

Polovina, J. J., Kobayashi, D. R., Parker, D. M., Seki, M. P. and Balazs, G. H. (2000). Turtles on the edge: movement of loggerhead turtles (*Caretta caretta*) along oceanic fronts, spanning longline fishing grounds in the central North Pacific, 1997–1998. *Fisheries Oceanography* 9, 71–82.

Polovina, J. J., Howell, E., Parker, D. M., and Balazs, G. H. (2003). Dive-depth distribution of loggerhead (*Caretta caretta*) and olive ridley (*Lepidochelys olivacea*) sea turtles in the central

North Pacific: might deep longline sets catch fewer turtles? *Fisheries Bulletin* 101(1), 189–193.

Preen, A. R. (1996). Infaunal mining: a novel foraging method of loggerhead turtles. *Journal of Herpetology* 30, 94–96.

Prince, R. I. T. (1993). Western Australian marine turtle conservation project: an outline of scope and an invitation to participate. *Marine Turtle Newsletter* 60, 8–14.

Prince, R. I. T. (1994). Status of the Western Australian marine turtle populations: the Western Australian Marine Turtle Project 1986–1990. In "Proceedings of the Marine Turtle Conservation Workshop." (Compiled by Russell James) Pp. 1–14. (Australian National Parks and Wildlife Service: Canberra.)

Pritchard, P. C. H. and Trebbau, P. (1984). 'The Turtles of Venezuela.' (Society for the Study of Amphibians and Reptiles: Oxford, Ohio.)

Quackenbush, S. L., Casey, R. N., Murcek, R., Paul, T. A., Work, T. M., Limpus, C. J., Chaves, A., duTroit, L., Perez, J. V., Aguirre, A. A., Spraker, T. R., Horricks, J. A., Vermeer, L. A., Balazs, G. H. and Casey, J. W. (2001). Quantitative analysis of herpesvirus sequences from normal tissue and fibropapillomas of marine turtles with real-time PCR. *Virology* 287, 105–111.

Reed, P. C. (1980). The sex ratio of hatchling loggerhead turtles - progeny of two nesting adult females. B.Sc.Hon. Thesis, Zoology Department, James Cook University of North Queensland.

Robins, C. M., Bache, S. J., and Kalish, S. R. (2002). Bycatch of sea turtles in pelagic longline fisheries - Australia. (Fisheries Research and Development Corporation: Canberra.)

Robins, T. B. (1995). Estimated catch and mortality of sea turtles from the east coast otter trawl fishery of Queensland, Australia. *Biological Conservation* 74, 157–167.

Robins, J. B. and Mayer, D. G. (1998). Monitoring the impact of trawling on sea turtle populations of the Queensland East Coast. *DPI Project Report Series* Q098012, 1–59.

Robins, C. M., Goodspeed, A. M., Poiner, I. R. and Harch, B. D. (2002). Monitoring the catch of turtles in the Northern Prawn Fishery. (Fisheries Research and Development Corporation: Canberra.)

Roeger, S. (2004). Entanglement of marine turtles in netting: northeast Arnhem Land, Northern Territory, Australia. (Dhimurru Land Management Aboriginal Corporation: Nhulubuy.)

Salmon, M., Witherington, B. E. and Elvidge, C. D. (2000). Artificial lighting and the recovery of sea turtles. In "Sea Turtles of the Indo-Pacific: Research Management and Conservation." (Pilcher, N. and Ismail G., Eds.) Pp. 25–34. (ASEAN Acedemic Press: London.)

Salmon, M. and Wyneken, J. (1994). Orientation by hatchling sea turtles: mechanisms and implications. *Herpetological Natural History* 2, 13–24.

Smith, A. (1987). 'Usage of Marine Resources by Aboriginal Communities on the East Coast of Cape York Peninsula.' (Great Barrier Reef Marine Park Authority: Townsville.)

Smith, A. (1989). "Usage of Marine Resources by Aboriginal Communities on the East Coast of Cape York Peninsula." (Great Barrier Reef Marine Park Authority: Townsville.)

Somers, I. (1994). Modelling loggerhead turtle populations. In 'Proceedings of the Marine Turtle Conservation Workshop' (Compiled by R. James) Pp. 142–145. (Australian National Parks and Wildlife Service: Canberra.)

Speirs, M. (2002). A study of marine turtle populations at the Julian Rocks Aquatic Reserve, northern New South Wales. Unpublished B.Sc.Hon. thesis, Southern Cross University: Lismore.)

Sprent, J. F. A. (1977). Ascaroid nematodes of amphibians and reptiles: *Sulcascaris*. *Journal of Helminthology* 51, 379–387.

Suarez, A. (2000). The sea turtle harvest in the Kai Islands, Indonesia. In: Sea Turtles of the Indo-Pacific: Research Management and Conservation. Eds N. Pilcher, and G. Ismail Eds. Pp. 3–12. (ASEAN Acedemic Press, London.)

Tucker, A., FitzSimmons, N. and Limpus, C. J. (1996). Conservation implications of internesting habitat use by loggerhead turtles *Caretta caretta* in Woongarra Marine Park, Queensland, Australia*. Pacific Conservation Biology* 2, 157–166.

Waite, E. R. (1929). “The reptiles and amphibians of South Australia.” (South Australian Museum: Adelaide.).

Wallner, B. and Sashse, M. (1998). Marine turtle bycatch in the Northern Prawn Fishery: scale of the problem and developing solutions. In “Marine Turtle Conservation and Management in Northern Australia.” (Eds. Kennett, R.; Webb, A.; Duff, G.; Guinea, M., and Hill, G.) Pp. 101–105. (Northern Territory University: Darwin.)

Walker, T. (1994). Post-hatchling dispersal of sea turtles. In "Proceedings of the Marine Turtle Conservation Workshop." (Compiled by Russel James.) Pp. 159–160. (Australian Nature Conservation Agency: Canberra.)
Wetherall, J. A., Balazs, G. H., Tokunaga, R. A. and Yong, Y. Y. (1993). Bycatch of marine turtles in the North Pacific high-seas driftnet fisheries and impacts on the stocks. *North Pacific Commission Bulletin* 53(III), 519–538.

White, D. (2004). Marine debris in Northern Territory waters, 2003. (WWF Australia: Darwin.)

Whiting, S. (2004). The sea turtle resources of Cocos (Keeling) Islands, Indian Ocean. (Biomarine International: Darwin.)

Whittier, J. M., Corrie, F. and Limpus, C. (1997). Plasma steroid in nesting loggerhead turtles (*Caretta caretta*) in Queensland, Australia: relationship to nesting episode and season. *General and Comparative Endocrinology* 106, 30–47.

Wibbels, T., Owens, D. W., Limpus, C. J., Reed, P. C. and Amoss, M. S. (1990). Seasonal changes in serum gonadal steroids associated with migration, mating and nesting in loggerhead sea turtle (*Caretta caretta*). *General and Comparative Endocrinology* 79, 154–164.

Witherington, B. E. and Bjorndal, K. A. (1991). Influences of artificial lighting on the seaward orientation of hatchling loggerhead turtles (*Caretta caretta*). *Biological Conservation* 55, 139–149.

Wyneken, J. (2001). The Anatomy of Sea Turtles. *NOAA Technical Memorandum NMFS-SEFSC* 470, 1–172.

Yntema, C. and Mrosovsky, N. (1980). Sexual differentiation in hatchling loggerheads (*Caretta caretta*) incubated at different controlled temperatures. *Herpetologica* 36, 33–36.

Yntema, C. and Mrosovsky, N. (1982). Critical periods and pivotal temperatures for sexual differentiation in loggerhead sea turtles. *Canadian Journal of Zoology* 60, 1012–1016.

Zug, G. R., Balazs, G. H. and Wetherall, J. A. (1995). Growth of juvenile loggerhead seaturtles (*Caretta caretta*) in the north Pacific Pelagic habitat. *Copeia* 1995, 484–487.