A BIOLOGICAL REVIEW OF AUSTRALIAN MARINE TURTLES.

2. GREEN TURTLE *Chelonia mydas* (Linnaeus)

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Cover photographs: Clockwise from top left: Nesting female *Chelonia mydas*, Raine Island; Lady Musgrave Island, a forested coral cay in the Capricorn-Bunker Group; Post-hatchling from pelagic Coral Sea. Photograph by D. Limpus; Basking *Chelonia mydas* on a southern beach, Barrow Island. Photograph by K. Morris.

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PREFACE

This review of the green 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 In particular, I have drawn together data contained in many unpublished reports on file in various government and non-government agencies.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To provide a more comprehensive summary of available information, previously unpublished data drawn from the Queensland Environmental Protection Agency (EPA) Turtle Conservation Project database have been summarised and included.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, Scott Whiting, Ray Chatto and Dr Rod Kennett assisted with information regarding turtles in the Northern Territory.

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GREEN TURTLE *Chelonia mydas* (Linnaeus)

1. THE SPECIES

1.1 TAXONOMY

Green turtle, *Chelonia mydas.*

CLASS: REPTILIA
ORDER: TESTUDINES
FAMILY: CHELONIIDAE
SPECIES: *Chelonia mydas* (Linnaeus, 1758)

Although Pritchard and Trebbau (1984) and Marquez (1990) recognise several species within this genus, Hirth (1997) concludes that "the green turtle (*Chelonia mydas*) is a circumglobal, morpho-species .... made up of several distinct populations and metapopulations". This is consistent with the results of skeletal morphology studies (Kamezaki and Matsui, 1995) and global population genetics (Bowen, 1997).

1.2 GLOBAL DISTRIBUTION

The genus *Chelonia* has a worldwide tropical and subtropical distribution (Hirth, 1997).

Population genetic structure in *Chelonia* has distinctive biparental (nuclear DNA) and maternal (mtDNA) components. This probably arises at least in part from the mating system coupled with characteristic natural histories for males *vs* females with different population genetic structures co-existing within a single organismal line (Bowen, *et al*. 1989, 1992; Karl *et al*. 1992; FitzSimmons *et al*. 1997). Recent genetic studies have demonstrated that there is little or no female-mediated interbreeding between the major breeding aggregations (Bowen *et al*. 1989, 1992; Norman *et al*. 1994a,b). In management terms it means that should there be a significant population decline at one of the major breeding units (stocks), there is little probability of it being repopulated from other stocks in the time frame of human management.

The taxonomy of the genus needs to be re-evaluated in the light of the recognition of independent stocks on the global scale. The current use of subspecific nomenclature for the western Pacific populations is considered appropriate at this time. However, these taxonomic considerations will probably have little impact on the conservation status of the taxon in Australia.

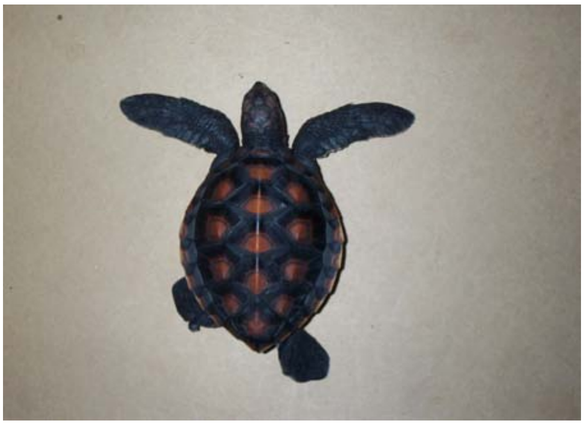
1.3 IDENTIFICATION

In *C. mydas* the carapace is high domed, smooth with non-imbricate (= non-overlapping) scutes and usually has four pairs of costal scutes; the head has one pair of prefrontal scutes and no preoccular scutes (Figure 2) while there are no inframarginal pores in the bridge (Cogger, 1992; Limpus, 1992a).

Chelonia mydas eggs are distinct in size (average egg diameter = 4.4 cm) and the clutches rarely contain yolkless eggs (Limpus *et al.*1984).

1a. Nesting females, Raine Island, December 1984.

1b. Hatchlings, Wreck Island, December 2000



1c. Post-hatchling, CCL = 10 cm, beach-washed North Stradbroke Island, May 2002.

1d. Post-hatchling from pelagic Coral Sea, December 2003. Photograph by D. Limpus.

1e. Assorted colour patterns of adult and large immature *Chelonia mydas* foraging in Shoalwater Bay.

1f. Head of adult female, Raine Island.

Figure 1. Green turtle, *Chelonia mydas*, from eastern Australia.

Figure 2. Diagnostic features for identifying *Chelonia mydas*. Refer to the description of the flatback turtle, Natator depressus, for an example of a preoccular scale. (Limpus, 2007).

When ashore, adults of this species move with a breast-stroke gait, pushing with all four flippers together and leaving a distinctive track ~ 1.0–1.2m wide with wide marks from the front flippers, except for hatchlings which move with a wide alternating gait (Limpus, 1985).

Wyneken (2001) has described the morphology of *C. mydas* while Kesteven (1911) described the anatomy of the skull. Thompson (1980) describes the anatomy and histology of the digestive tract for the species.

2. BIOLOGY OF THE GREEN TURTLE *Chelonia mydas* (Linnaeus), IN AUSTRALIA

Where possible, data will be derived from studies of *C. mydas* within the Australian stocks. Where relevant data are not available from these stocks, data can be derived from studies on *Chelonia* stocks elsewhere (Hirth, 1997) 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 stocks, these stocks have been described in greatest detail. Where the general biological characteristics have not been described for other stocks in the region, readers are recommended to refer to the description of the eastern Australian stocks.

Much has been learned of the biology of *C. mydas* since the pioneering study by Moorehouse (1933) at Heron Island in the 1929–1930 breeding season. He proved, via the world's first tagging project with nesting females, that the female lays many clutches in a single breeding season and that the same female does not return to lay eggs in successive breeding seasons.

Seven widely separated breeding aggregations that are separate stocks and require independent management have been identified for Australia (Bowen *et al*. 1992; Norman *et al*. 1994b; Moritz *et al*. 2002; Dutton *et al*. 2002). These are: southern Great Barrier Reef (GBR), Coral Sea, northern GBR, Gulf of Carpentaria, Ashmore Reefs, Scott Reef and the Northwest Shelf (Figure 3). The turtles nesting in western Northern Territory have not been identified to a stock. Although they have different breeding distributions, the turtles from the different Australian stocks occupy sympatric feeding areas which they also share with turtles from other breeding units with nesting beaches in neighbouring countries (Limpus *et al*. 1992).

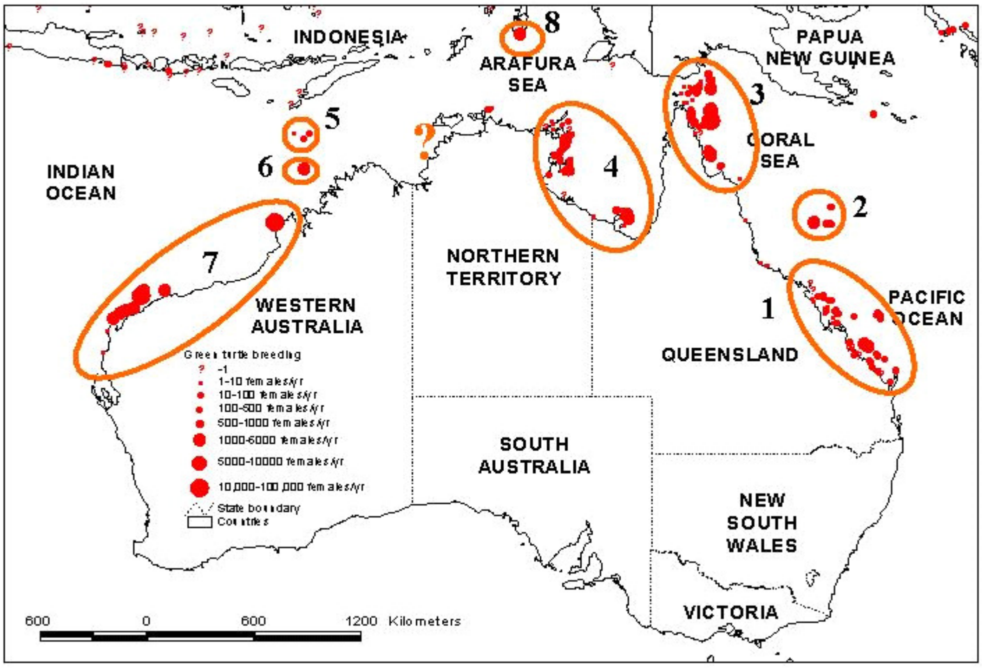


Figure 3. Genetically identifiable Australian breeding *Chelonia mydas* stocks. 1=southern GBR; 2=Coral Sea; 3=northern GBR; 4=Gulf of Carpentaria; 5=Ashmore Reefs; 6=Scott Reef; 7=Northwest Shelf. The Indonesian breeding stock at Aru Islands (8) is another stock in the region (Dutton et al. 2002). ? denotes where nesting populations have yet to be assessed for genetic stock.

2.1 GENETIC STATUS OF STOCKS

There is no identified genetic interchange between the breeding units of the GBR and Gulf of Carpentaria (Norman *et al*. 1994a, b). The southern GBR, northern GBR and Coral Sea breeding units have the closest links with South Pacific stocks, including those breeding in New Caledonia and French Polynesia (Bowen *et al*. 1992; Moritz, *et al*. 2002; Dutton *et al*. 2002). Only a small amount of genetic exchange occurs between the southern GBR breeding unit and the northern GBR breeding unit (FitzSimmons *et al*. 1997a; Dutton *et al*. 2002). The Western Australian and Gulf of Carpentaria stocks appear to have been derived from an Indian Ocean source (Norman *et al*. 1994a; Bowen, 1997; Moritz *et al*. 2002; Dutton *et al*. 2002).

2.2 SOUTHERN GREAT BARRIER REEF BREEDING UNIT (STOCK)

2.2.1 ROOKERIES

Within the southern GBR breeding unit, major breeding concentrations occur on the islands of the Capricorn Bunker Groups of the southern GBR (Bustard, 1972; Limpus *et al*. 1984; Limpus, 1985): Northwest, Wreck, Hoskyn, Tryon, Heron, Lady Musgrave (Figure 4a), Masthead, Erskine, Fairfax, North Reef, and Wilson Islands. Minor breeding aggregations occur at Bushy Island, the Percy Islands (Figure 4b), Bell Cay, Lady Elliott Island, the mainland coast from Bustard Head to Bundaberg and the northern part of Fraser Island. Very low-density nesting can occur on almost any other beach within this area.

Protected habitat

Greater than 90% of all southern GBR *C. mydas* nesting occurs within the protected habitat of National Parks and Conservation parks (Nature Conservation Act 1992, Regulations 1994), including:

- Capricornia Cays National Park and Capricornia Cays National Park Scientific (Northwest, Tryon, Wilson, Wreck, Heron, Erskine, Masthead, Hoskyn, Fairfax, Lady Musgrave Island) (Anon, 1999; Limpus *et al*. 1984);
- Great Sandy National Park (Fraser Island);
- Swain Reefs National Park (Bell Cay);
- Percy Island National Park (South Percy and Pine Peak Islands);
- Bushy Island National Park.

At Heron Island, approximately 25% of the beach length is outside of the National Park. North Reef Island is a Commonwealth Lighthouse Reserve.

Nesting census

The size of the annual breeding population (females only) has been monitored at several rookeries for the southern GBR stock for varying periods since 1964 (Bustard, 1972; Limpus *et al*. 1984; Limpus, 1985; Limpus and Nicholls, 1988, 2000). Those data (Figure 5) provide the primary measure of the changing size of the annual nesting population within this *C. mydas* stock.

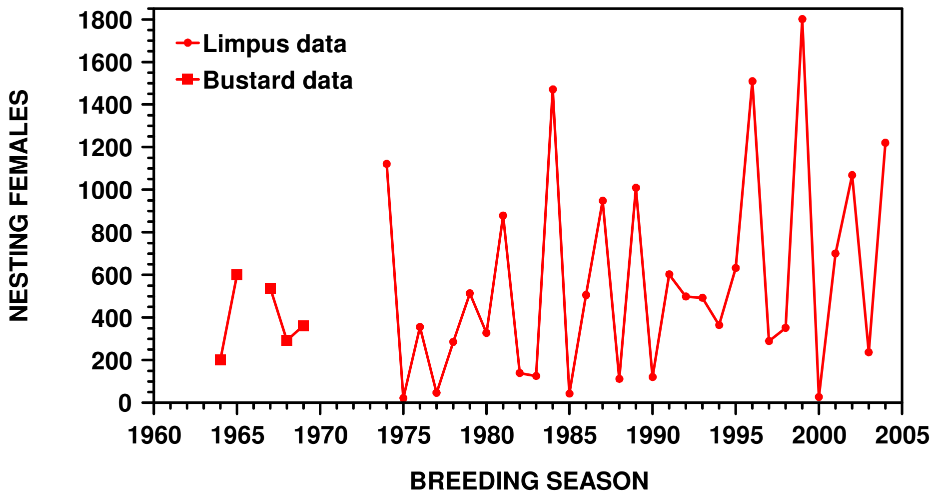
No attempt has been made to conduct a total tagging census (count of the number of nesting females) of the southern GBR *C. mydas* rookeries apart from at Heron Island (Figure 5a). Based on mid-season nightly track counts, the total nesting population for the southern GBR *C. mydas* stock is expected to be approximately 8,000 females in an average breeding season (Limpus *et al*. 1984; Limpus, 1985).


4a. Lady Musgrave Island, a forested coral cay in the Capricorn-Bunker Group.

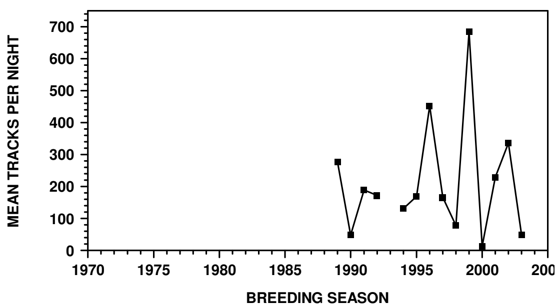

4b. Northern beach, Pine Islet, a continental island in the Percy Group.

Figure 4. *Chelonia mydas* nesting beaches in the southern Great Barrier Reef region.

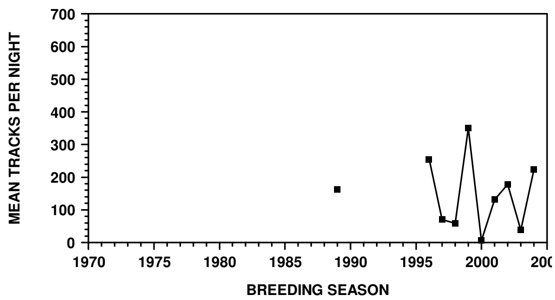
Heron Island has been monitored annually using an extended season total tagging census for approximately four decades (Figure 5a). There has been no significant upward or downward trend in the size of the annual nesting population at this representative index beach for this southern GBR stock during 1967-2004 (linear correlation: $F_{1,32} = 2.69$; $0.1 > p > 0.25$. $R^2 = 0.078$, df = 32). The annual breeding population has fluctuated about an approximately stable level over the past four decades. During this same period there has been a significant decline in the mean size of the nesting females (Figure 5d) (linear correlation; $F_{1,32} = 25.76$, $p < 0.0005$. $R^2 = 0.446$, df = 32). In each breeding season, the mean size of remigrant females is larger than the mean size of the first time breeding females. In addition, in years with increased breeding numbers, the females are on average smaller than the females breeding in the years with low breeding numbers.



5a. Heron Island. Total tagging census for the breeding season. Dr. H. R. Bustard led the turtle monitoring at Heron Island during 1964 –1973; Dr C. Limpus led the research team during 1974 – present.

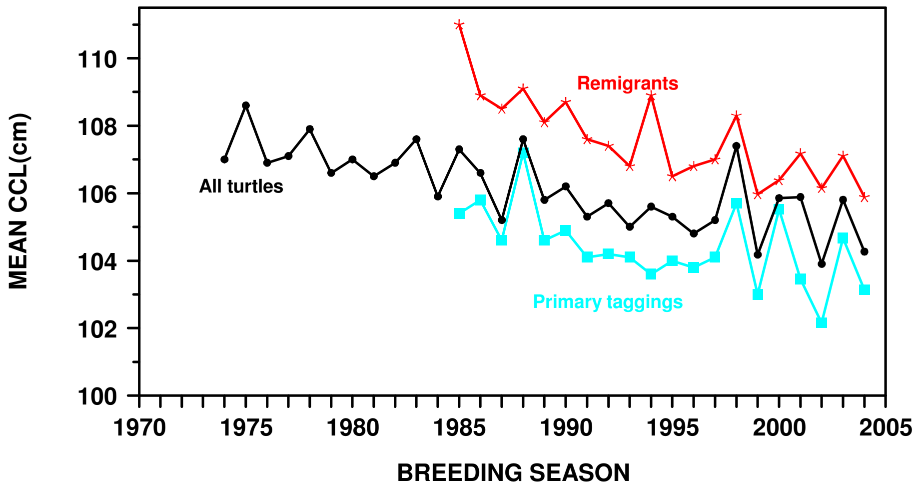


5b. Northwest Island. Mean daily track count during a two-week census from mid December to late January.



5c. Wreck Island. Mean daily track count during a two-week census from mid December to late January.

Figure 5. Census data from representative index nesting beaches for the southern Great Barrier Reef *Chelonia mydas* stock.



5d. Size of nesting females recorded during the tagging census at Heron Island. CCL = curved carapace length. Dots denote all measured turtles; stars denote remigrant turtles; squares denote turtles tagged for the first time (primary taggings) (After Limpus, 2000).

Figure 5. Continued.

Internesting habitat

The nesting female occupies 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 used by an individual turtle may be very restricted whereas in habitat with less structure, the female may range up to tens of kilometres from the nesting beach. 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). During this first 3 day period, the internesting female is less active (slower swimming, shorter displacement distances) than during the remainder of the internesting period (Tucker *et al*. 1996). There is little or no feeding by the breeding females while in the internesting habitat (Tucker and Read, 2001; Limpus *et al*. 2001; Hamann *et al*. 2003).

The internesting habitat adjacent to all major and most minor *C. mydas* rookeries of southern GBR region is contained within the Great Barrier Reef Coastal Marine Park and the adjacent Great Barrier Reef Marine Park.

Basking

Basking by adult male and female *C. mydas* at courtship and nesting areas has been recognised in the southern GBR since the early 1900's (Barrett, 1919, 1930). However, the phenomenon has been little studied in eastern Queensland. The large basking aggregation at courtship time described for Heron Island by Barrett (1919) has been non-functional since at least the mid 1900s. This change may have been in response to the turtle harvest on Heron Island during 1925–1930 or to the presence of tourists wandering the beach by day during each summer since 1930.

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 *et al*. 1984, 1994, 1992).

The genetics studies provide convincing evidence that the breeding adult is returning to the region of her birth (Bowen *et al*. 1992; Norman *et al*. 1994a,b). 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 imprinted to the region of her birth and is imprinted to the specific rookery as an adult during her first breeding season.

The adult male displays a similar level of philopatry (fidelity involving the return to the area of its birth) to the courtship region and across breeding seasons as the female does to the nesting areas (FitzSimmons *et al*. 1997b).

2.2.3 MIGRATION

Adult females migrate from their dispersed foraging areas to traditional breeding areas. Recaptures of females tagged at southern GBR rookeries have been recorded from foraging sites in Papua New Guinea, New Caledonia, Fiji, Northern Territory, Queensland, and New South Wales (Limpus *et al*. 1992; Limpus, 1993; Limpus *et al*. 2003) (Figure 6a).

Some generalities can be applied to the behaviour of adult *C. mydas* during breeding migrations (Limpus *et al*. 1992):

- There is no one path followed by all turtles during breeding migrations;
- Adults living in the same feeding area can be expected to migrate to breed at widely separated rookeries (Figure 7);
- Nesting females at any one rookery will have migrated from widely distributed feeding areas;
- Each adult migrates with a high degree of faithfulness between its particular feeding area and its rookery.
- While some individuals migrate in excess of 2600 km, most migrate less than 1000 km to their rookeries.

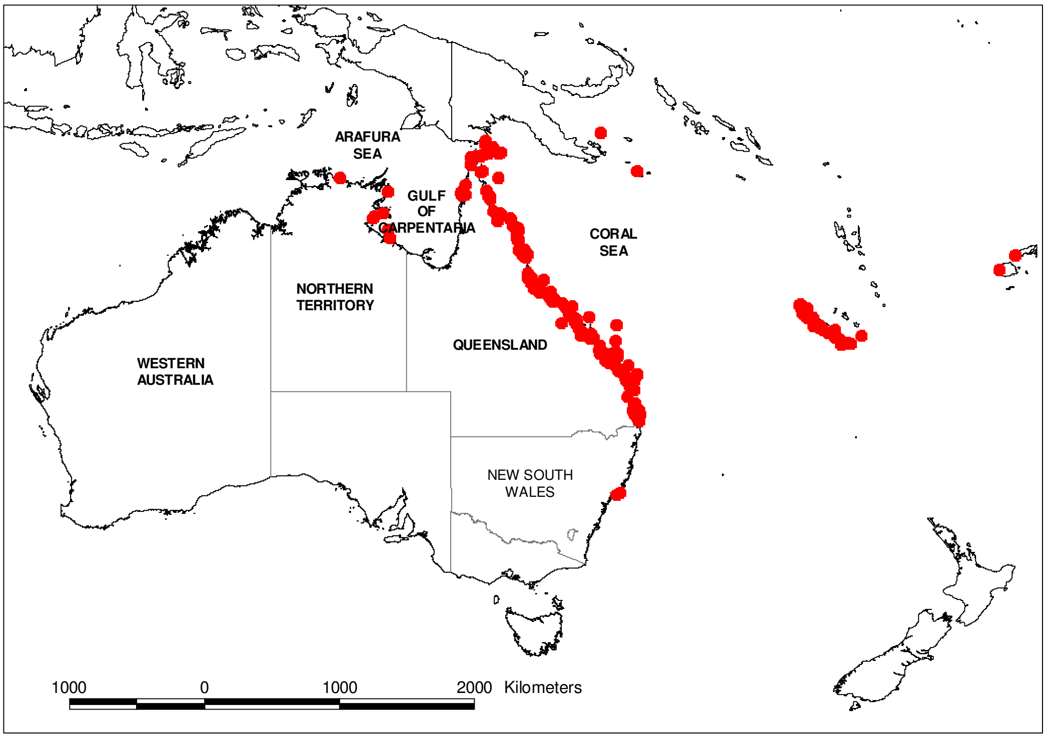
It has been proposed that adult turtles migrate with the aid of a large-scale, bi-coordinate magnetic map sense (Lohmann and Lohmann 1996).

Based on tag recoveries, the adult females that breed within the southern GBR are not uniformly distributed among their available foraging areas (Limpus *et al*. 2003):

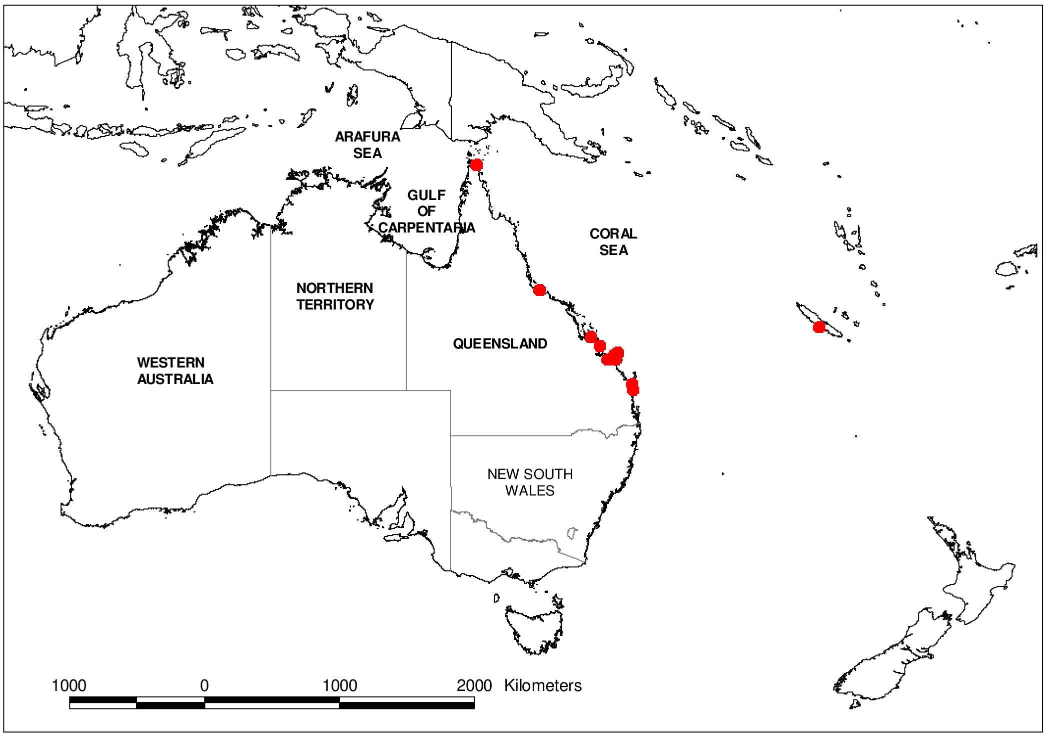
- The majority of the tag recoveries from this stock have occurred along eastern Australia south of 14^{o}S to central New South Wales and from New Caledonia (Figure 8).
- North of 14^{o}S recaptures from the SGBR stock represent only a small proportion of the recaptured turtles from known rookeries (Figure 8).

Breeding migrations are physiologically demanding for the breeding females (Kwan, 1994; Hamann *et al*. 2002, 2004a) because of greatly reduced or absence of foraging during migration and egg production.

Breeding males make comparable migrations to those undertaken by the breeding females (Limpus, 1993) (Figure 6b, 7b). Breeding migrations are physiologically demanding on the males also (Jessop *et al*. 2004a).

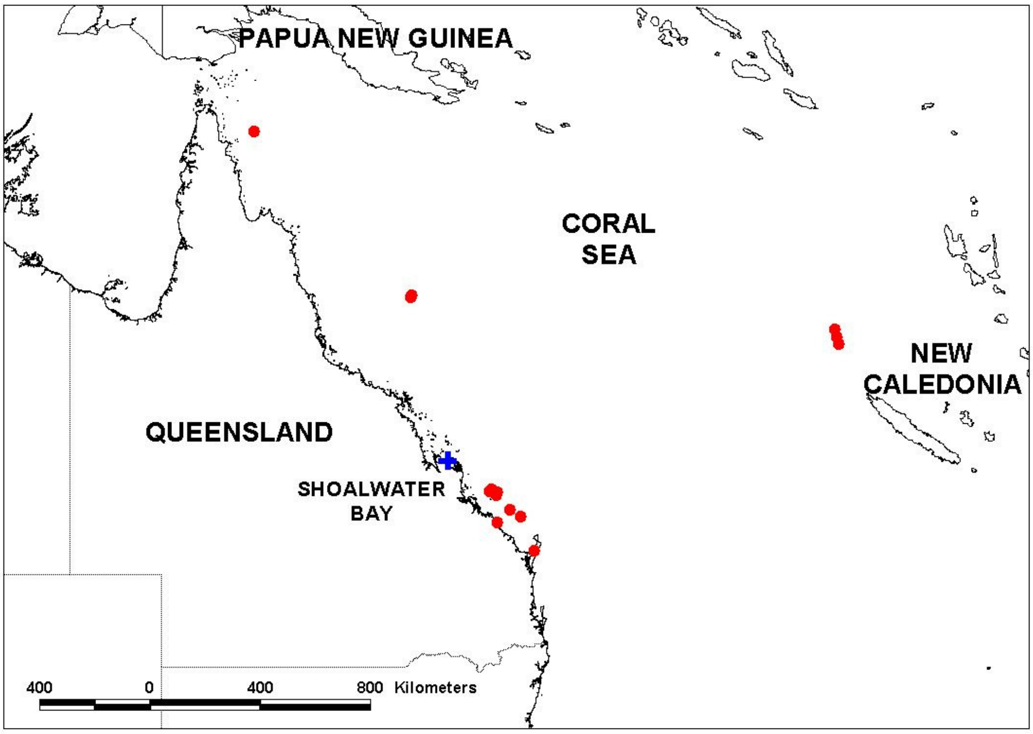


6a. Distribution of migration tag recoveries for foraging adult female *Chelonia mydas* that also have been recorded breeding within southern Great Barrier Reef area. See Figure 3 for the distribution of nesting for the southern GBR stock.

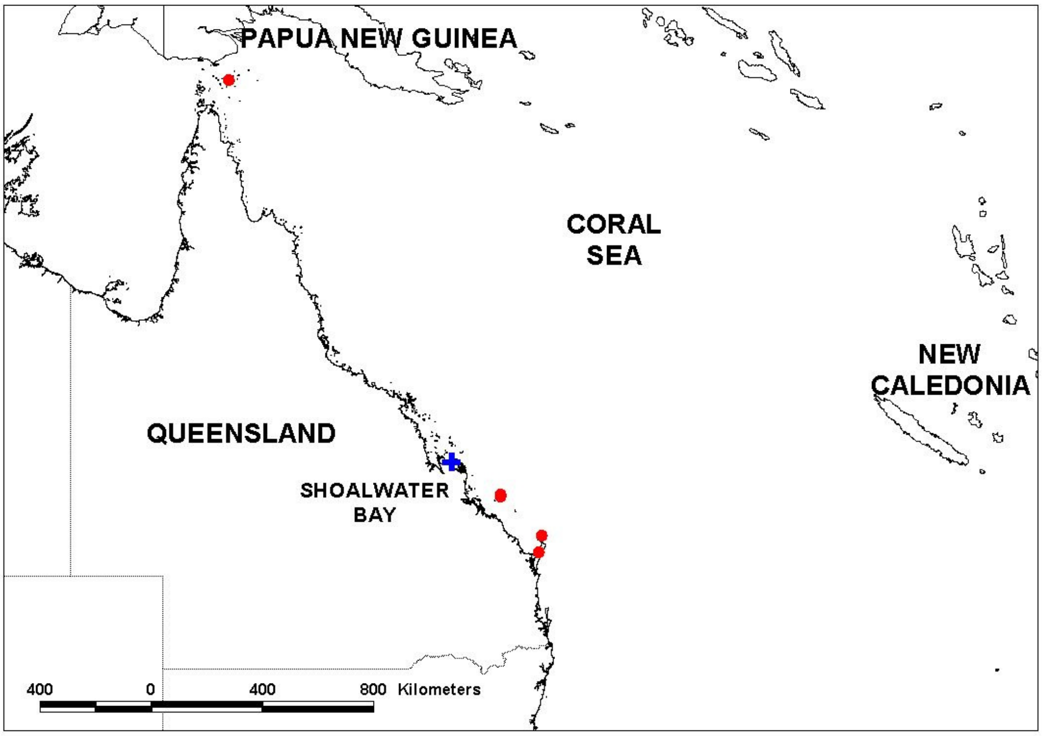


6b. Distribution of migration tag recoveries for foraging adult male *Chelonia mydas* that also have been recorded breeding within southern Great Barrier Reef area.

Figure 6. Distribution of migration tag recoveries for foraging adult male and adult female *Chelonia mydas* within southern Great Barrier Reef.



7a. Distribution of breeding sites (dots) recorded from tag recoveries of nesting adult female *Chelonia mydas* that migrated from foraging in Shoalwater Bay (cross), central Queensland.



7b. Distribution of breeding sites (dots) recorded from tag recoveries of courting adult male *Chelonia mydas* that migrated from foraging in Shoalwater Bay (cross), central Queensland.

Figure 7. Distribution of breeding sites recorded from tag recoveries of courting males and nesting females that migrated from foraging in Shoalwater Bay.

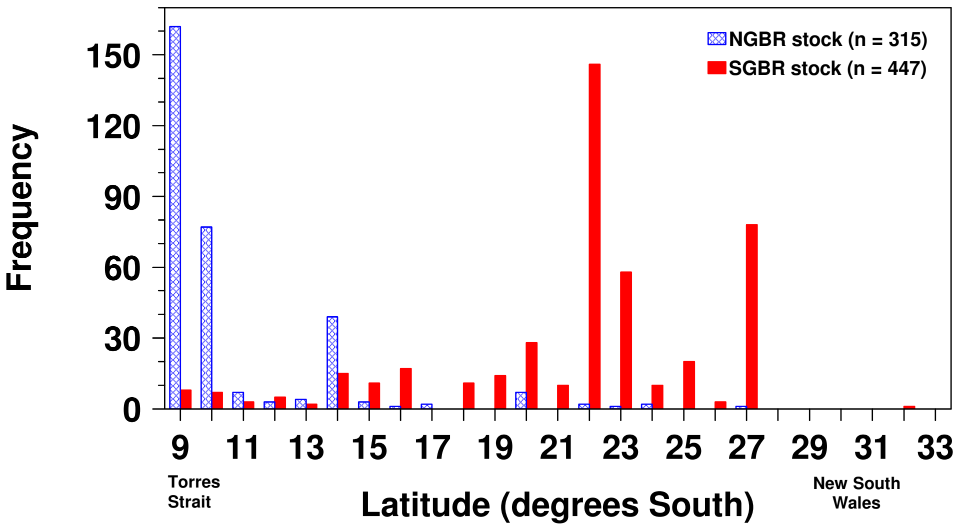


Figure 8. Distribution of foraging area tag recoveries (n = 762) of adult females from known breeding areas within the southern and northern Great Barrier Reef *Chelonia mydas* stocks. Distribution data are displayed in 1° latitudinal blocks for turtles captured in southern PNG, Torres Strait and eastern Australia (After Limpus et al. 2002).

2.2.4 BREEDING SEASON

In south Queensland the breeding is distinctly seasonal:

- Mating commences in about mid September, reaches a peak in October and ceases by about mid November (Limpus, 1993);
- Nesting commences in mid to late October, reaches a peak in late December to early January and ends in about late March–early April (Bustard, 1972); and
- Hatchlings emerge from nests from late December until about May with a peak of hatching in February and March (EPA Queensland Turtle Conservation Project unpubl. data).

Nesting behaviour was described and defined by Bustard and Greenham (1969).

2.2.5 BREEDING ADULTS

There are no external characters by which turtles from the various stocks can be reliably distinguished at present. Adult *C. mydas* have distinct horny scales on a smooth domed carapace. Adult females are olive green dorsally and variably variegated with brown, reddish-brown and black; whitish or cream ventrally and shields on sides of face with distinctive pale-edged sutures (Figure 1). Breeding males, identified by their much longer tails and longer recurved claws, tend to be darker and lower domed than females (Frazier, 1971; Bustard, 1972). During courtship, breeding males may have a concave plastron. Table 1 summarises the size of breeding adults.

There has been a significant reduction in the mean size of the breeding females within this stock over the 26 breeding seasons, 1974–1999, measured at the Heron Island index rookery (Limpus, 2000) (Figure 5d). Short-term fluctuations in the size of these nesting females have been superimposed on this long-term downward trend in adult female size. Smaller females are nesting in high density nesting seasons and larger females are nesting in the low density nesting seasons (Limpus, 2000).

Table 1. Summary of the size of breeding adult *Chelonia mydas* from the southern Great Barrier Reef, eastern Australia.

		Measurement				References
		mean	SD	Range	n	
Curved carapace length (cm)						
Female	Heron Island	107.0	5.52	91.0–124.0	1942	Limpus, Fleay & Guinea, 1984
Male	Heron-Wistari Reefs	100.6	4.61	89.5–114.5	361	Limpus, 1993a
Weight (kg)						
Female	Heron Island	130.0	–	98–184	–	Limpus, Fleay & Guinea, 1984

Recruitment rate

Based on gonad examinations of nesting *C. mydas*, first-time-breeding females recruited into the nesting population at Heron Island at a rate of 24% and 32% of the total annual nesting population during the 1992–1993 and 1994–1994 breeding seasons respectively (Limpus, 2000). These high values may be indicative of either a population in which the adults are being over-harvested or of a population that is increasing, or both.

2.2.6 BREEDING CYCLES

Marine turtles require approximately two weeks after ovulation to fertilise and prepare an egg for oviposition (Limpus *et al*. 1984; Miller, 1985. Table 2). Reproduction is energetically costly for *C. mydas* especially for the female (Kwan, 1994). Biological constraints restrict females to reproduce at breeding intervals of three years or greater. (Limpus *et al*. 1994b. Table 2).

Table 2. Summary of southern Great Barrier Reef *Chelonia mydas* breeding cycles.

		Measurement				References
		mean	SD	Range	n	
Renesting interval (d)						
Female	Heron Island	14.1	1.65	9–21	264	Limpus *et al*. 1984
Remigration interval (yr)						
Female	Heron Island	5.78	1.48	1–9	518	Limpus *et al*. 1994b
Male	Heron-Wistari Reefs	2.08	1.14	1–5	24	Limpus, 1993a

The duration of the breeding season and nesting periodicity is a function of how many mature ovarian follicles the female prepares prior to commencing her breeding migration, modified by body condition, lipid storage and endocrine cycles (Hamann *et al*. 2002, 2003a,b; Jessop and Hamann, 2004; Jessop *et al*. 2004a,b). The breeding female depresses hormonal responses to stress to maximise its capacity for breeding success (Jessop *et al*. 2000; Jessop and Hamann, 2004).

2.2.7 EGGS

The eggs are amniotic, cleidoic, white and spherical with flexible shells. They contain embryos at middle gastrulation when ovulated (Miller, 1985). For successful incubation, the eggs must be laid in 25–33 ^{o}C, well ventilated, low salinity, high humidity nest substrate not subjected to flooding (Ackerman, 1980, 1997; Miller, 1985, 1997). There is no parental care for the eggs or hatchlings. Rotation of eggs during incubation can cause death of the embryos (Parmenter, 1980). Egg and nest parameters are summarised in Table 3.

Multiple paternity within a clutch was identified at a low frequency (9%) for *C. mydas* nesting at Heron Island (FitzSimmons, 1998).

Table 3. Summary of egg and nest parameters for *Chelonia mydas* nesting at Heron Island within the southern Great Barrier Reef population. * 10 eggs per clutch.

		Measurement				References
		Mean	SD	Range	n	
Clutches per season per female						
Heron Island		5.06	1.99	1–9	878	Unpubl. data, EPA Queensland Turtle Conservation Project
Eggs per clutch						
Heron Island	1974–1975	112.0	21.56	62–153	35	Limpus, 1980
	1980–1981	115.2	27.88	42–195	50	Limpus *et al*. 1984
Yolkless eggs per clutch						
Heron Island	1980–1981	0.078	0.337	0–2	51	Limpus *et al*. 1984
Egg diameter (cm)						
Heron Island	1974–1975	4.46	0.18	3.89–4.69	220*	Limpus, 1980
	1980–1981	4.41	0.14	4.07–4.68	160*	Limpus *et al*. 1984
Egg weight (g)						
Heron Island	1974–1975	50.02	7.31	33.5–58.3	110*	Limpus, 1980
	1980–1981	46.93	5.251	35.0–56.0	160*	Limpus *et al*. 1984
Nest depth (cm)						
Heron Island						
Top	1980–1981	40.2	11.1	18–61	17	Limpus *et al*. 1984
Bottom	1980–1981	69.2	12.0	50–92	17	Limpus *et al*. 1984
Incubation period (d)						
Heron Island	1988–1989	64.5	6.14	54–87	178	Limpus, 1989a

2.2.8 HATCHLINGS

Chelonia mydas hatchlings are black to dark brown dorsally, white ventrally and have a white margin to the carapace and trailing edges of flippers. Hatchlings usually emerge from the nests at night (Bustard, 1967), the timing being largely a function of the surface sand temperature gradient (Gyuris, 1993). Hatchlings orient to low elevation light horizons when moving from the nest to the sea (Limpus, 1971; Salmon and Wyneken, 1994). Hatchlings can be disoriented by bright lights that limit their ability to see distant horizons and they are disoriented by the yellow wavelengths of low pressure sodium vapour lights (Witherington and Bjorndal, 1991), with increased potential for hatchling mortality. *C. mydas* hatchlings are not disoriented by intermittent flashing lights (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). Hatchlings may be imprinted to the smell of the sand or the water that they first contact as they leave the beach, as is the case with *Lepidochelys kempii* hatchlings (Grassman *et al*. 1984). This age class does not feed or sleep but lives off its internalised yolk-sac between leaving the nest and entering to deep offshore water. Hatchling size is summarised in Table 4.

Table 4. Summary of measurements of southern Great Barrier Reef *Chelonia mydas* hatchlings (10 hatchlings per clutch) at Heron Island.

		Measurement				References
		Mean	SD	Range	n	
Straight carapace length (cm)						
Heron Island	1974–1975	4.97	0.19	4.02–5.19	110	Limpus, 1980
	1980–1981	4.89	0.19	4.55–5.35	220	Limpus *et al.* 1984
Weight (g)						
Heron Island	1974–1975	24.83	1.84	19.8–28.4	110	Limpus, 1980
	1980–1981	24.93	2.36	19.0–30.5	220	Limpus *et al.* 1984

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 it 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. These include: 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, 1985; Miller and Limpus, 2003; Miller *et al.* 2003).

Proportion of clutches that produce no hatchlings (total failure) because of natural causes:

- Heron Island
  1988/89: 0.048 (Limpus, 1989a)

Proportion of clutches that produce no hatchlings (total failure) because of feral predators:

- All beaches
  Recent decades: approaching zero (Limpus, 1988a, 1989a)

Natural incubation and emergence success (including mortality by nesting turtles and excluding total failures.)

- Heron Island
  1988/89: 0.879 (Limpus, 1988a, 1989a)

Table 5 summarises annual *C. mydas* hatchling emergence success corrected for all the above sources of egg mortality at Heron Island.

Table 5. Mean annual *Chelonia mydas* hatchling emergence success corrected for all sources of egg mortality at Heron Island for two (n) nesting seasons 1987/88 and 1988/89.

		Measurement				References
		Mean	SD	Range	n	
		Straight carapace length (cm)				
Heron Island	1987–1988 & 1988–1989	0.841%	–	0.836–0.846	2	Limpus, 1988a, 1989a

Survivorship of hatchlings on the beach during the crossing from nest to sea, accounting for crab and bird predation.

- Heron Island
  "estimate" = ~ 0.98 (Limpus, 1971)

Survivorship of hatchlings in the water while crossing the reef flat between the beach and deep water outside of the coral reef.

- Heron Island, across coral reef habitat
  Survivorship estimate = 0.4 (Gyuris, 1994)

Larger hatchlings have a higher survivorship than smaller hatchlings while crossing the reef flats (Gyuris, 2000).

2.2.10 HATCHLING SEX RATIO

The sex of hatchlings is a function of the temperature of the nest during middle incubation (Miller and Limpus, 1981; Yntema and Mrosovsky, 1980,1982). The pivotal temperature, (the temperature that produces a 1:1 hatchling sex ratio) varies between breeding units (EPA Queensland Turtle Conservation Project unpubl. data).

The pivotal temperature for hatchling sex ratio from the Heron Island rookery is 27.6 °C (EPA Queensland Turtle Conservation Project unpubl. data). The northern aspect beaches of the Capricorn Group cays produce mostly female hatchlings and the southern aspect beaches and shaded habitats can produce mostly males (Limpus *et al.* 1983,1984 *et al*). Hatchling sex ratio has not been measured for the entire population. However, it is anticipated that it will be strongly biased to female in most seasons, based on sand temperatures at nest depth (Bustard, 1972; Bustard and Greenham, 1968; Limpus *et al.* 1983, 1984; Booth and Astill, 2001a).

Hatchlings produced from male producing, constant-temperature incubation of 26 °C were of greater mass and had smaller residual yolks than hatchlings from female producing, constant-temperature incubation of 30 °C (Booth and Astill, 2001b).

2.2.11 AGE and GROWTH

Absolute age has been poorly quantified with this species in the wild.

A growth/aging experiment is in progress in which 107840 hatchling *C. mydas* were "tagged" and released at Heron Island during 1978–1983 (Limpus, 1985). The first recaptures of these turtles have now occurred when they recruited to inshore feeding areas after the pelagic post-hatchling phase (Limpus et al. 1994. Table 6).

Table 6. Size of known-age immature *Chelonia mydas* marked as hatchlings and recaptured in Moreton Bay (Limpus *et al.* 1994). CCL = curved carapace length.

Tag	Sex	Hatchling data		Recapture data		
Number		Rookery	Date	Date	CCL	Age
T51184	F	Heron Is.	Jan–Feb 1982	13 Oct 1990	54.4 cm	8.7 yr
T47413	M	Heron Is.	Jan–Feb 1981	09 May 1992	68.0 cm	11.3 yr

The growth rates of wild turtles have been measured at several sites along the Queensland coast. Partial analyses of these data are summarised in Table 7. Growth rate is a function of the size/maturity and sex of the turtle, the study year (Limpus and Walter, 1980; Limpus and Chaloupka, 1997) and the feeding ground (Table 7). Growth rate is at a maximum among medium sized turtles and slows as the turtle approaches maturity.

Immature *C. mydas* from the southern GBR stock are slow growing (Limpus and Chaloupka, 1997; Chaloupka *et al.* 2004), taking decades to grow from hatchlings to breeding adults. Age to maturity should be in the order of 30 to 40 years.

Table 7. Mean growth rates (cm/yr) of immature *Chelonia mydas* from Queensland feeding grounds (sample size). EPA Queensland Turtle Conservation Project unpublished data.

CCL size class (cm)	Locality					
	Clack Rf	Green Is. Rf	Repulse Bay	Shoalwater Bay	Heron & Wistari Rfs	Moreton Bay
40–45	2.113 (8)	–	–	0.500 (35)	1.056 (20)	1.349 (5)
45–50	2.649 (26)	1.045 (4)	–	1.227 (42)	1.204 (64)	2.035 (16)
50–55	3.562 (17)	2.422 (3)	–	1.921 (17)	1.981 (56)	3.471 (18)
55–60	3.345 (10)	2.067 (1)	–	2.014 (17)	1.942 (77)	3.040 (4)
60–65	3.500 (8)	2.523 (1)	2.577 (2)	2.049 (10)	2.083 (85)	3.040 (10)
65–70	2.639 (8)	–	–	1.722 (7)	1.791 (108)	4.573 (1)
70–75	4.121 (4)	2.190 (1)	2.136 (1)	1.929 (6)	1.760 (136)	0.531 (2)
75–80	3.704 (2)	–	–	0.338 (7)	1.336 (149)	0.270 (9)
80–85	2.644 (4)	–	2.356 (1)	0.780 (6)	1.237 (185)	0.751 (18)
85–90	1.734 (5)	–	–	1.151 (3)	1.088 (191)	1.024 (11)
90–95	1.231 (2)	–	–	0.542 (7)	0.863 (107)	0.575 (4)
95–100	–	–	–	–0.065 (3)	0.643 (42)	0.574 (1)
100–105	–	–	–	0.154 (2)	0.570 (8)	1.137 (1)

Adult turtles are very slow growing, with growth effectively ceasing in some cases, as illustrated by the data in Table 8.

Table 8. Mean growth rates (cm/yr) of adult *Chelonia mydas* from Queensland feeding grounds (sample size). EPA Queensland Turtle Conservation Project unpublished data.

Sex	Locality					
	Clack Rf	Green Is. Rf	Repulse Bay	Shoalwater Bay	Heron & Wistari Rfs	Moreton Bay
Female	0.158 (8)	–	–0.265 (15)	–0.007 (44)	–0.404 (60)	–
Male	0.054 (7)	–	0.277 (1)	–0.125 (38)	–1.001 (186)	–

2.2.12 POST-HATCHLING

The distribution and biology of this age class is poorly understood. In the Coral Sea–Tasman Sea region, this age class has been recorded rarely from GBR waters but is regularly recorded in south Queensland from Fraser Island southward to the mid New South Wales coast (Figure 9).

The stranding records suggest that post-hatchling *C. mydas* are swept southward from southern GBR waters by the East Australian Current, past northern New South Wales and then east into the Pacific Ocean (Limpus *et al.*1994a; Walker, 1994). This age class is believed to follow an oceanic surface-water dwelling, planktonic life, feeding on macro zooplankton. (Walker, 1994; Bolten, 2003).

Age at completion of this life history phase is undetermined but should be in the range of 5–10 yr (Table 6) (Zug and Glor, 1999; Zug *et al.* 2002).

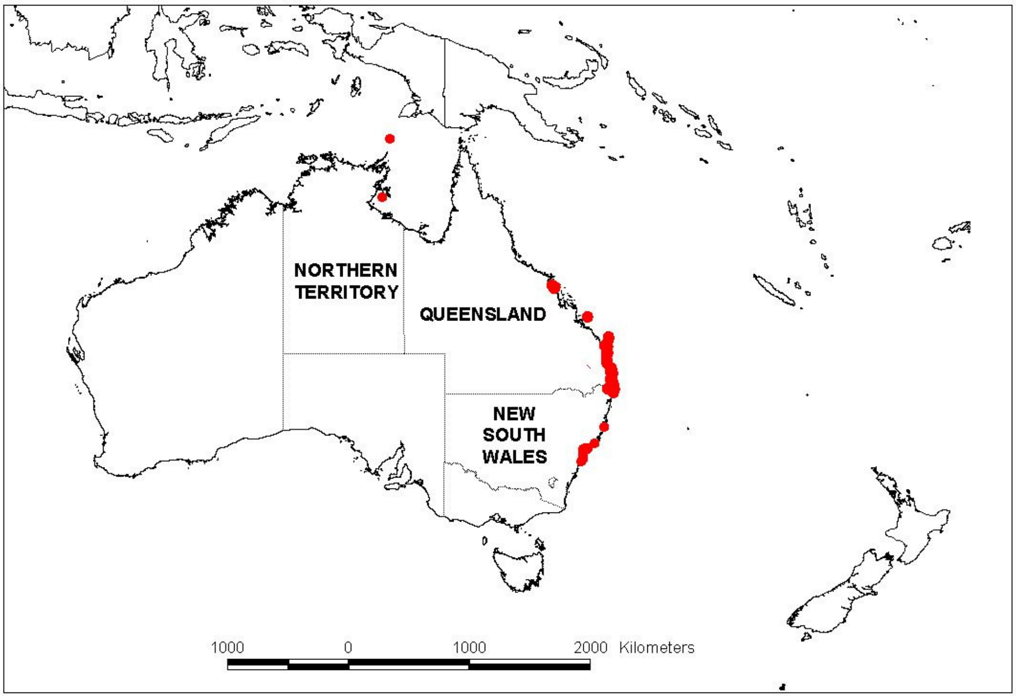


Figure 9. Distribution of post-hatchling *Chelonia mydas* records (dots) in Australian waters. Data from Limpus et al. (1994b) and EPA Queensland Turtle Conservation Project database.

2.2.13 ADULT and IMMATURE TURTLES

Feeding habitat

Immature *C. mydas* recruit from the pelagic post-hatchling phase to benthic foraging over the eastern Australian continental shelf at sizes of approximately 40–50 cm CCL (Limpus and Limpus, 2003). Immature and adult *C. mydas* feed in tidal and subtidal habitats including coral and rocky reefs, sea grass meadows and algal turfs on sand and mud flats throughout an area bounded by the eastern Arafura Sea, Gulf of Carpentaria, Torres Strait, Gulf of Papua, Coral Sea, Great Barrier Reef, Hervey Bay, Moreton Bay and NSW coastal waters (Limpus and Reed, 1985a; Limpus *et al*. 1994a; Speirs, 2002; EPA Queensland Turtle Conservation Project unpublished data,). Based on tag recoveries of adults, the major part of the southern GBR stock can be assumed to occupy feeding areas to the south of Princess Charlotte Bay to northern New South Wales and in New Caledonia (Figures 6, 8).

Chelonia mydas are year-round foraging residents to at least as far south as northern New South Wales (Speirs, 2002). Specific site related data are included in the following sections on the basis that a major proportion of the turtles present at the site belongs to this stock (Figure 6).

Diet

Chelonia mydas in coastal waters is almost totally herbivorous, feeding principally on sea grass, a wide range of algae and mangrove fruits (Forbes 1994; Lanyon *et al*. 1989; Read, 1991, Read *et al*. 1996; Whiting and Miller, 1998; Brand, 1999; Brand–Gardner, 1999; Limpus and Limpus, 2000; Read and Limpus, 2002; Speirs, 2002). It occasionally feeds on macroplankton including jellyfish (*Catostylus mosaicus*), and bluebottles (*Physalia*), dead fish and small crustaceans.

In Moreton Bay, small immature *C. mydas* forage selectively on plants with higher nitrogen levels and lower levels of fibre (Brand-Gardner *et al*. 1999). Gut passage time for normal food within immature *C. mydas* ranged from 6.5 to 13.5 days (Brand *et al*. 1999). Feeding continues in waters as cool as 15 °C during winter in Moreton Bay (Read *et al*.1996).

Population structure and dynamics

The population structure in feeding areas has been studied at Julian Rocks in northern NSW (Speirs, 2002), and in Queensland at Moreton Bay (Limpus *et al*. 1994a), Heron Reef (Limpus and Reed, 1985a) and Shoalwater Bay and Repulse Bay (Limpus, 1989a).

- Young turtles recruit to take up residence in the habitats of the continental shelf at sizes between 40 to 50 cm CCL. (Limpus and Limpus, 2003). Once the young turtle chooses a feeding area, it appears to remain associated with that area for extended periods of time, possibly decades (Limpus and Chaloupka, 1997).
- Feeding home ranges have not been quantified in most studies:
    - Based on radio tracking and tagging-capture results, adult *C. mydas* foraging in Repulse Bay seagrass pastures occupied foraging ranges of 84–850 ha during study periods of 4–29 days (Whiting and Miller, 1998). During the same periods these turtles made short term movements of 4–25 km.
    - Foraging home ranges may be variable between habitats.
    - Many individual turtles can have overlapping home ranges.
- 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 *et al*. 1992). As a consequence of this, local depletion of a population can occur on a feeding site as a result of over harvest while there may still be relatively unchanged populations at other feeding sites for the duration of that generation.

Size classes / size at first breeding

The population in each of the above feeding areas (in Table 9) usually consists mostly of immature turtles (Limpus, 1988a; Limpus and Reed, 1985a; Limpus *et al*. 1994a; Speirs, 2002). There is considerable variability in the proportion of adults in the population feeding at the various sites (Table 9).

Table 9. Maturity ratio expressed as the proportion of adult turtles in the sample for each sex from various feeding areas for *Chelonia mydas* from the southern Great Barrier Reef Stock. (Limpus, 1988a; Limpus and Reed, 1985a; Limpus et al. 1994a; EPA Queensland Turtle Conservation Project unpublished data,). n denotes total sample examined at each site.

Feeding area	Proportion of adult turtles		
	Female (n)	**Male (n)**	**Reference**
Port Denison	0.14 (7)	0.24 (4)	Limpus, 1989a
Repulse Bay	0.52 (108)	0.44 (18)	Limpus, 1989a
Shoalwater Bay	0.36 (158)	0.56 (64)	Limpus, 1989a
Capricornia	0.17 (94)	0.28 (93)	Limpus and Reed, 1985a
Moreton Bay	0.11 (393)	0.04 (206)	Limpus *et al*. 1994

The average turtle does not commence breeding at the minimum breeding size (Limpus and Reed, 1985a; Limpus *et al*. 1994a). The average size of the new recruit to the nesting population is consistently smaller than the average size of turtles with a past breeding history (Table 10) and little growth occurs following maturation.

Table 10. The size (CCL, cm) of new recruits to the females breeding population compared with that of turtles with a past breeding history, Heron Island nesting population, 1992/93. (Unpublished data, EPA Queensland Turtle Conservation Project).

Age class	Curved carapace length (cm)			
	mean	**SD**	**Range**	**N**
New recruits	104.2	5.2	91.5–122.5	212
Remigrants	107.6	5.5	95.5–122.0	122

Sex ratio

In most feeding areas the population sex ratio is biased to female (Table 11).

Table 11. Sex ratio expressed as the proportion of females in the sample (sample size) from various feeding area dominated by *Chelonia mydas* from the southern Great Barrier Reef stock (south of latitude 14°S).

Feeding area	Sex ratio		References
	Immature turtles	Adults	
Port Denison	0.67 (9)	–	Limpus, 1989a
Repulse Bay	0.84 (62)	0.88 (64)	Limpus, 1989a
Shoalwater Bay	0.77 (129)	0.61 (93)	Limpus, 1989a
Capricornia	0.54 (145)	0.38 (42)	Limpus and Reed, 1985a
Moreton Bay	0.63 (536)	0.84 (51)	Limpus *et al*. 1994

Survivorship

This parameter is rarely measured with wild marine turtle populations. It has been quantified for the turtles resident on Heron Island Reef (Table 12). There were no sex-specific differences in survival or recapture probabilities for any of the stages (Chaloupka and Limpus, 1997).

Table 12. Stage-specific survivorship values for *Chelonia mydas* resident on Heron Island Reef derived by multinomial Cormack-Jolly-Seber modelling. (Chaloupka and Limpus, 1997).

Life history stage	Approx. size range	Survival rate	
		Mean	95% confident interval
Adults	CCL ≥ ca. 85 cm	0.9482	0.92–0.98
Subadults	CCL 65–90 cm	0.8474	0.79–0.91
Juveniles	CCL <65 cm	0.8804	0.84–0.93

Age duration

For *C. mydas* growing up in the southern GBR, it is expected that they will take several decades to grow from CCL = ~ 40 cm to sexual maturity (Limpus and Walter, 1980; Limpus and Chaloupka, 1997; Chaloupka, 2001b; Chaloupka *et al*. 2004).

The breeding life expectancy for *C. mydas* has not been determined but, based unpublished results from mark-recapture studies with nesting females at Heron Island, the average may be of the order of two decades with unexploited populations. This parameter warrants quantification.

2.2.14 ENSO REGULATION OF ANNUAL BREEDING RATE

Within any one feeding area, the proportion of adult females that undergoes vitellogenesis in any one year is variable (Figure 10) and is a function of the Southern Oscillation Index two years before the breeding season (Limpus, 1989b; Limpus and Nicholls, 1988, 1994, 2000). Breeding males appear to be regulated in a parallel manner (Figure 10. Limpus, 1993a; Limpus and Nicholls, 2000). This regional climatic event regulates, by presumably impacting on the quantity or quality of the forage, the proportion of adult *C. mydas* that will prepare for and hence migrate to breeding in any one year.

Consequences of this phenomenon include:

- There are wide fluctuations in annual nesting numbers of green turtles at any one rookery (Figure 5).
- All green turtle rookeries within the region will fluctuate in unison with respect to annual number of nesting females (Figure 11).

- Decades of monitoring will be required to provide the necessary data for assessing the status and trends of a nesting population.

The remigration interval provides an estimate of the frequency with which individual turtles will breed, i.e. adult females from the southern GBR *Chelonia mydas* stock should breed about once every six years (Limpus *et al*. 1994).

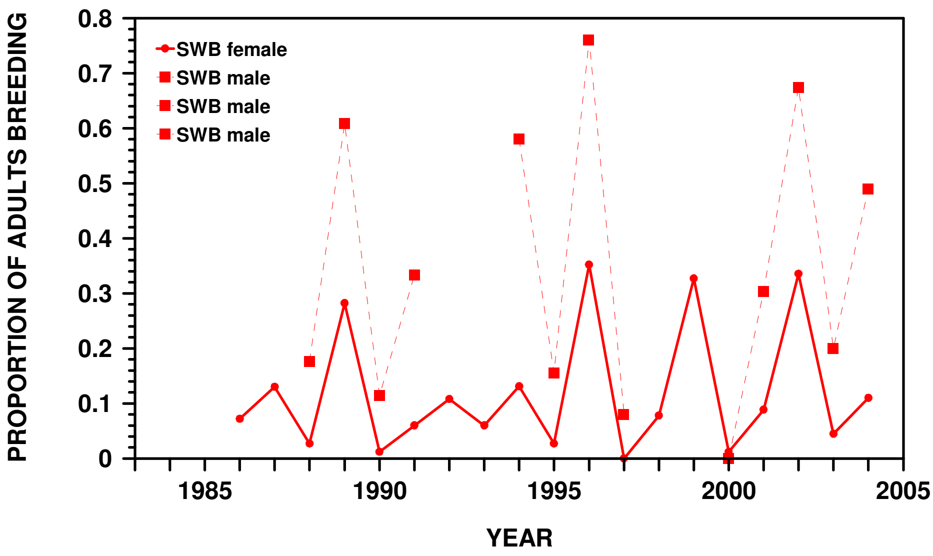


Figure 10. Annual fluctuations in the proportion of the resident adult *Chelonia mydas* foraging in western Shoalwater Bay (SWB) that prepared for breeding in any one year. (After Limpus and Nicholls (2000); unpublished data, EPA Queensland Turtle Conservation Project).

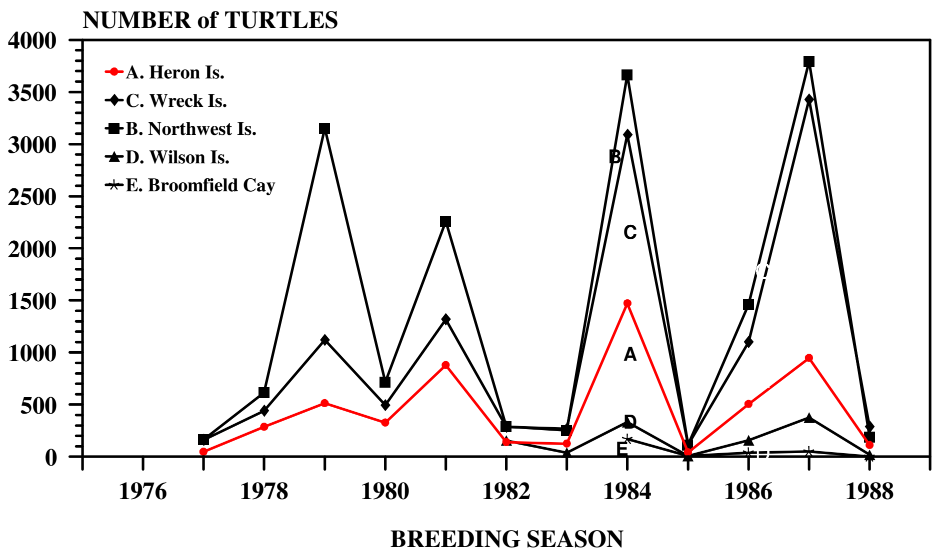


Figure 11. El Nino Southern Oscillation driven, synchronous, fluctuations in the size of the total annual nesting population of *Chelonia mydas* at five islands within the Capricorn Group, southern Great Barrier Reef.

2.3 NORTHERN GREAT BARRIER REEF BREEDING UNIT

2.3.1 ROOKERIES

Major breeding concentration occurs on the islands of the outer edge of the northern Great Barrier Reef: Raine Island (Figure 12), Moulter Cay, No.7 and No.8 Sandbanks (Limpus *et al*. 2003; Norman *et al*. 1994a).

Minor breeding aggregations occur on the Murray Islands, Bramble Cay (Figure 12. Miller and Limpus, 1991; Limpus *et al*. 2003) and other islands of the outer barrier of the NGBR, most inner shelf cays and the mainland coast north of Cape Grenville and Torres Strait (Limpus *et al*. 1983a; Miller *et al*. 1995; Loop *et al*. 1995).

Most of the *C. mydas* nesting of the northern GBR occurs within protected habitat under the Queensland *Nature Conservation Act* 1992.

- Raine Island, Moulter Cay and MacLellan Cay form the Raine Island Nature Refuge. Raine Island is under the trusteeship of Department of Aboriginal and Torres Strait Islander policy and the remaining two islands are under the trusteeship of the Raine Island Corporation.
- No.7 and No.8 Sandbanks form the Sandbanks National Park.
- Most of the other minor *C. mydas* rookeries of the northern GBR are part of the Queensland National Park (NP) estate within Denham Group NP, Saunders Islands NP, Sir Charles Hardy Group NP, Clairmont Isles NP and Howick Group NP.

The internesting habitat surrounding these rookeries is managed within the Great Barrier Reef Coastal Marine Park and the adjacent Great Barrier Reef Marine Park.

None of the *C. mydas* nesting habitat of Torres Strait is within protected habitat.

12a. Raine Island and surrounding reef.

Figure 12. Representative breeding sites for the northern Great Barrier Reef *Chelonia mydas* stock

12b. Raine Island: south beach, December 1978.

12c. Mer, Murray Islands: southwestern beach, February 1997.

12d. Bramble Cay, February 1997.

Figure 12. continued.

Nesting census

The present day rookeries that support this population have been in existence for no more than a few thousand years at the most, since the last sea level rise (Limpus, 1987). Raine Island has been a significant *C. mydas* rookery for more than 1,100 years.

There has been limited monitoring of the size of the annual nesting population at northern GBR – Torres Strait *C. mydas* rookeries. Bramble Cay is the only northern GBR rookery monitored annually with a total tagging census. During 1976–1977 to 1979–1980 breeding seasons, Bramble Cay supported 338*, 35, 181 and 687 nesting female *C. mydas* in the four seasons respectively (Parmenter, 1977*, 1978, 1979 [* data from partial season 22 Dec 1976–11 Feb 1977]; Limpus *et al*. 2001)

Raine Island has been the primary index beach for monitoring the long term functioning of the northern GBR stock since 1974–1975 breeding season (Limpus *et al*. 2003). However, because of the size of the nightly nesting numbers and the remoteness of the site, a total tagging census has not been attempted. The index metric has been the mean nightly tally count (average number of females ashore for nesting that are counted during one complete search of the nesting habitat at night commenced an hour after the tide levels enable turtles to swim across the reef to access the entire island).

- There have significant inter-annual fluctuations in the size of the annual nesting population (Figure 13). In high density nesting seasons, in excess of 10,000 female *C. mydas* may be ashore on the 1.8 km nesting beach at one time. In contrast, in low density nesting seasons as few as tens of females may come ashore for the entire night.
- These fluctuations in the nesting population are driven primarily by El Niño southern Oscillation climate impacts on the foraging populations.
- High density nesting seasons with densities exceeding recent breeding seasons when in excess of 10,000 nesting female *C. mydas* were counted ashore at once have been reported in the past in the mid 1950s (probably 1955–1956 breeding season) and in the 1965–1966 breeding season (Limpus *et al*. 2003).
- By themselves, short term census of *C. mydas* nesting populations are not a reliable indicator of the size and stability of the adult female population in the total foraging areas.
- In the very dense 1999–2000 nesting season, 78,672 ± 10,586 adult female *C. mydas* were present in the internesting habitat adjacent to Raine Island during early December, based on mark-recapture estimates. In a medium density nesting season, about 25,000 breeding females can be expected to be present off the island in early December.
- There has been a significant decline over the last three decades in the proportion females that are successfully laying eggs when they come ashore to nest at Raine Island. This reduction in nesting success is associated with changes in the nesting habitat at Raine Island. Even though large numbers of turtles migrate to breed at Raine Island, concern should be held for the breeding success of these turtles.

Moulter Cay has similar nightly nesting density as occurs on Raine Island but has a smaller beach length. The nightly number of *C. mydas* ashore for nesting at Moulter Cay is well correlated with the corresponding nightly tally count at Raine Island (Limpus *et al*. 2003). The combined early December population estimate for Raine Island + Moulter Cay = 1.6386 x Raine Island December Estimate + 112. Based on this approach it is estimated that about 131,000 females were present in the very high-density nesting seasons and in the order of 41,000 females breeding annually in a typical dense nesting season. In dense nesting seasons, a few thousand extra females would be nesting at No.7 and No.8 Sandbanks, Murray Islands, Bramble Cay and the other smaller nesting populations of the northern GBR and Torres Strait.

There has been significant downward trend in the mean carapace length (CCL) of the nesting female *C. mydas* at Raine Island and Moulter Cay during mid summer over 26 breeding seasons, 1976–2001 (Limpus *et al*. 2003). This was clearly apparent in “older” turtles with a past breeding history. This decrease in the size of the females has occurred in conjunction with a progressive increase in remigration interval. While the long term census of the size of the annual nesting population has not provided a clear indication of the stability of this *C. mydas* stock, the changes in CCL and remigration interval are consistent with a population that could be in the early stages of population decline as a result of excessive loss of adult females (Limpus *et al.* 2003).

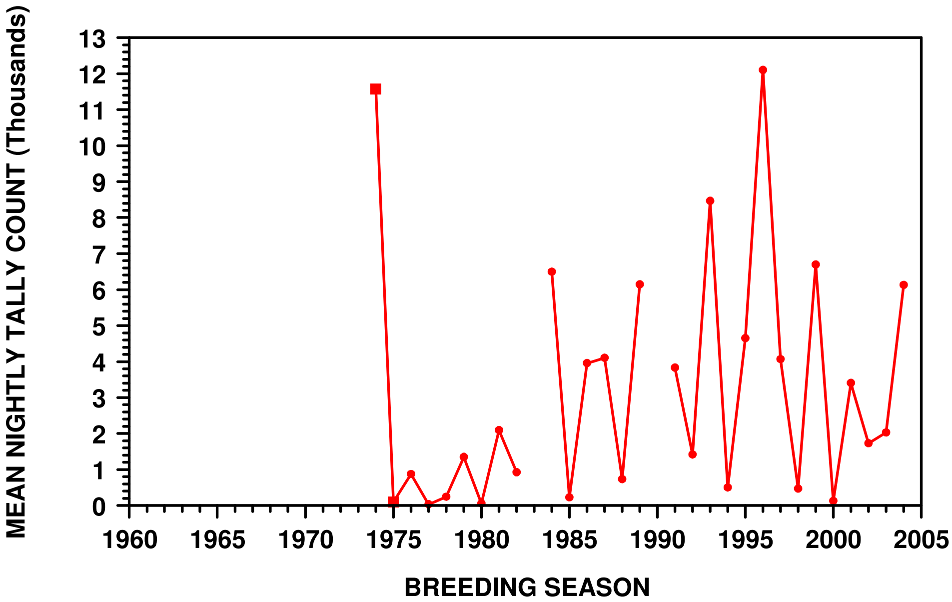


Figure 13. Annual nesting index (mean nightly tally count) of female *Chelonia mydas* at Raine Island (after Limpus *et al.* 2003 and unpublished data, EPA Queensland Turtle Conservation Project). Dots denote standard mean nightly tally counts. Squares denote approximate values based on incomplete census.

2.3.2 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 (98%) (Limpus *et al.* 2001, 2003; Limpus and Reed, 1985b). While occasional turtles interchange between nesting beaches within this breeding unit, there have been only rare recaptures of nesting females moving between nesting beaches across the boundaries of the recognised genetic stocks. Only one female out of some 40,000 nesting females originally tagged while nesting in the southern GBR has been recorded in a later breeding season nesting in the northern GBR. Similarly, only one female originally tagged while nesting on the Coral Sea Platform was recorded nesting in the northern GBR in a later season (Limpus *et al.* 2003). None have been recorded making the reverse interchanges. This rare interchange of breeding females across stock boundaries is consistent with the genetic assessment of these stocks (FitzSimmons *et al.* 1997a. See also Section 2.2.2.

2.3.3 MIGRATION

See section 2.2.3 for general comments.

Tag recoveries from females tagged at northern GBR rookeries have been recorded internationally within a radius of 2773 km of the rookeries from eastern Indonesia (Aru, Ambon, Kei, Irian Jaya), southern and eastern Papua New Guinea, Vanuatu, New Caledonia. Within

Australia, tag recoveries have been reported from across northern Australia from as far west as Melville Island, NT, throughout the Gulf of Carpentaria and on the east coast to as far south as Moreton Bay (Figure 14. Limpus *et al.* 1992, 1994, 2001, 2003; Miller and Limpus, 1991). The foraging area spans a region of 25° in latitude from southern West Papua, Indonesia, to Moreton Bay in south Queensland and 37° in longitude from Melville Island in western Northern Territory to southeast New Caledonia (Limpus *et al.* 2003).

The majority of the feeding area tag recoveries from this stock have occurred from Torres Strait, Gulf of Carpentaria and Arafura Sea. In addition, the northern GBR stock accounts for the majority of *C. mydas* foraging in the GBR north of 13°S (Limpus *et al.* 2003. Figure 7). Further south in the GBR, the southern GBR stock forms the majority of the foraging *C. mydas*.

2.3.4 BREEDING SEASON

The breeding season has been described by Limpus *et al.* (2001, 2003):

- Mating activity is usually obvious in southern Torres Strait in August and increases in occurrence until late October/early November. Little mating activity is seen after mid December.
- Although nesting can occur year round, most nesting occurs during October – March and is at a peak in late December – early January (Figure 15). Approximately 80% of the total nesting population could be encountered during a sampling period of one renesting interval duration at this peak of the nesting season.
- Most hatchlings emerge from nests from December to May.

The date of commencement of laying is a function of the females size and how many clutches she will lay for the season (Limpus *et al.* 2001).

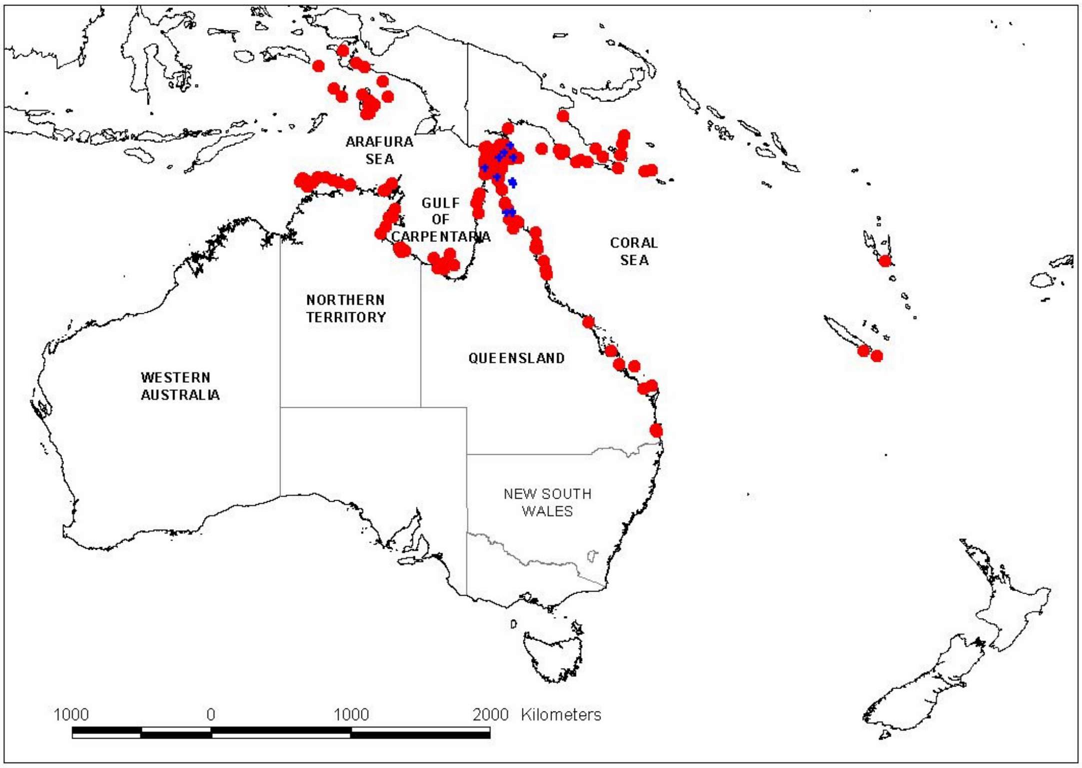


Figure 14. Distribution of migration tag recoveries of adult female *Chelonia mydas* (dots) originally tagged while nesting at a northern Great Barrier Reef or Torres Strait rookery (crosses).

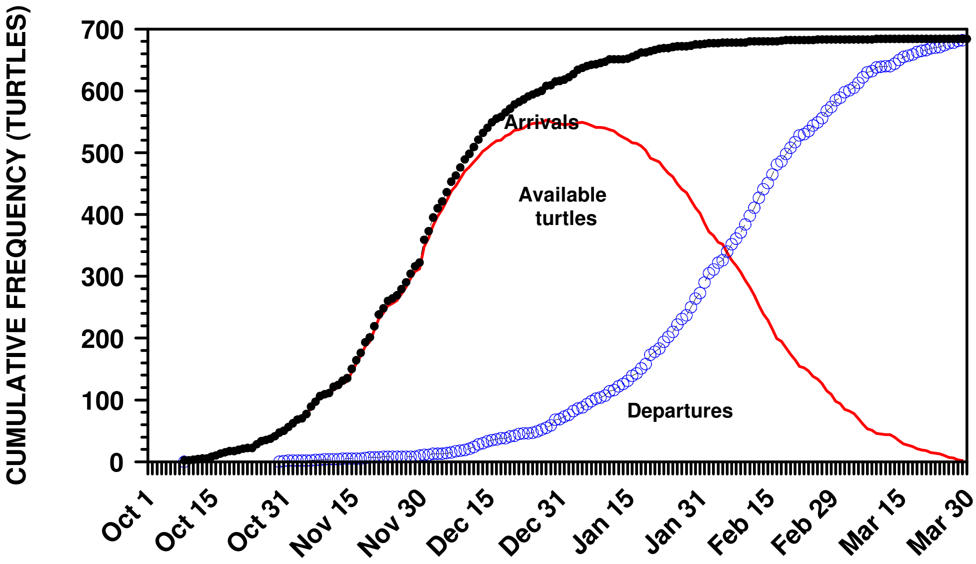


Figure 15. Availability of the adult females nesting at Bramble Cay, 1979–1980 breeding season. The solid symbols plot the cumulative arrivals of breeding females to the rookery for the commencement of nesting; open symbols plot the cumulative cessation of nesting. The difference between the cumulative arrivals and departures provide an instantaneous measure of the annual population that is available for nesting at that time of the season (solid line).

2.3.5 BREEDING ADULTS

See Section 2.2.5 for a general description of adult turtles and Table 13 for a summary of adult measurements. There have been significant reductions in the size of the nesting females in recent decades (Limpus *et al*. 2003).
Breeding males are significantly smaller than females.

Recruitment rate

Over the past decade, first-time-breeding females have recruited into the annual nesting population at Raine Island at the rate of 7.17% of the total nesting population per year (SD = 6.41, range = 0–18.5%, n = 11 annual samples. Limpus *et al*. 2003).

Table 13. Size of breeding adult *Chelonia mydas* from the northern Great Barrier Reef, eastern Australia.

		Measurement				References
		mean	SD	Range	n	
Curved carapace length (cm)						
Female	Raine Island	106.0	5.14	86.0–130.1	20,947	Limpus *et al*. 2003
	Bramble Cay	105.0	4.80	94.0–119.0	687	Limpus *et al*. 2001
Male	Raine Island reef	99.4	4.89	90.5–114.5	37	Limpus *et al*. 2003
Weight (kg)						
Female	Raine Island	126.2	13.9	101–154	24	Limpus *et al*. 2003
	Bramble Cay	121.0	16.3	85–183	375	Limpus *et al*. 2001
Male	Raine Island	97.6	9.50	83–123	24	Limpus *et al*. 2003

2.3.6 BREEDING CYCLES

Breeding cycles are summarised in Table 14. See Section 2.26 for general description.

Table 14. Breeding cycles for *Chelonia mydas* nesting at rookeries within the northern Great Barrier Reef.

		Measurement				References
		mean	SD	Range	n	
Renesting interval (d)						
Bramble Cay	1978–1979	12.0	–	9–21	979	Parmenter, 1979
	1979–1980	12.4	1.67	9–19	2781	Limpus *et al.* 2001
Raine Island	April 1984	12.4	1.02	10–14	16	Limpus *et al.* 2003
Remigration Interval (yr)						
Female	Raine Island	5.35	1.519	1–8	2094	Limpus *et al.* 2003
Male		Not recorded for this population				

Renesting interval is variable throughout a breeding season with the shortest intervals being recorded in mid nesting season (Limpus *et al.* 2001). The shorter renesting interval in the northern GBR relative to the southern GBR is more likely to be a function of water temperature rather than genetic differences between the stocks (Limpus *et al.* 2003).

Short remigration intervals are rare with this population. No remigrant turtles were recorded in four consecutive years of total tagging census at Bramble Cay using double tagging with monel tags (Limpus *et al.* 2001). At Raine Island, 1 yr and 2 yr remigration intervals were extremely rare (0.33% from a sample of 2094 remigration turtles), 3 yr remigration turtles accounted for only 10.7% of captures and the majority of turtles returned to breed after 4 to 7 years (Limpus *et al.* 2003).

Mean remigration interval has increased over the 11 breeding seasons, 1991 to 2001 (Limpus *et al.* 2003).

2.3.7 EGGS

See Section 2.2.7 for general description. Measurements of eggs and nests are summarised in Table 15. The number of eggs in a clutch is a function of the size of the female (Limpus *et al.* 2001).

At Raine Island and Moulter Cay, with widely variable but often high density of nesting turtles, there are several egg and hatchling production issues that require consideration that are not significant at low density nesting beaches (Limpus *et al.* 2003):

- The probability of a turtle nesting successfully when she beaches on a nesting crawl is an inverse function of the density of nesting turtles.
- The probability of digging into an existing clutch(es) when the female is ashore for nesting increases with increasing density of nesting turtles. The mean egg mortality per disturbed clutch, pooled across nesting seasons, was 18.3 eggs and was not density dependent.
- The rate of egg destruction by nesting turtles per clutch laid varied from low values approaching zero in very low density nesting seasons to 0.23 in a high density nesting season.
- With increased turtle-turtle interaction and disturbance, there will be an increase in the number of turtles disturbed during oviposition. A turtle that is disturbed having laid less than half a clutch can be expected to return to lay the remainder of the clutch on the same night or following nights. A turtle that is disturbed having laid more than half a clutch is expected to drop the remainder of her clutch at sea and return to lay her next complete clutch after a

normal renesting interval. Although not quantified, the mean clutch size in high density nesting seasons will be decreased below the actual potential clutch size for the population.

- With reduction in nesting success and the consequent increase in the number and duration of nesting crawls that a turtle makes before she successfully lays her eggs, there will be a more rapid depletion of stored fat reserves (Hamann *et al*. 2002). When this is excessive, the female changes to also resorb stored nutrient and energy from the yolks of mature oviducal follicles. This will result in a reduction in the number of clutches she will lay for the season.

2.3.8 HATCHLINGS

See Section 2.2.8 for general description. Measurements of hatchlings are summarised in Table 16.

Table 15. Measurements of *Chelonia mydas* eggs and nests at rookeries within the northern Great Barrier Reef. SE denotes standard error measured in place of standard deviation (SD). * denotes that 10 eggs per clutch were sampled.

		Measurement				References
		mean	**SD**	**Range**	**n**	
Clutches per season per female						
Bramble Cay	1979–1980	6.2	2.1	1.10	684	Limpus *et al*. 2001
Eggs per clutch						
Bramble cay	1977–1978	111.1	1.4SE	53–165	185	Parmenter, 1978
	1979–1980	102.1 18.4 60–182 615	18.4	60–182	615	Limpus *et al*. 2001
Raine Island	Multiple seasons	103.9	19.83	47–175	501	Limpus *et al*. 2003
No.7 & No.8 Sandbanks	Multiple seasons	104.84	25.52	68–147	10	Limpus *et al*. 2003
Yolkless eggs per clutch						
Bramble Cay	1979–1980	0.04	0.29	0–4	662	Limpus *et al*. 2001
Raine Island	Multiple seasons	0.12	0.40	0–2	349	Limpus *et al*. 2003
Multi-yolked eggs per clutch						
Raine Island	Multiple seasons	0.03	0.290	0–4	224	Limpus *et al*. 2003
Egg diameter (cm)						
Bramble Cay	19771978	4.45	0.01SE	3.88–4.97	1538*	Parmenter, 1978
Raine Island	Multiple seasons	4.34	0.86	3.66–5.38	4594*	Limpus *et al*. 2003
Egg weight (g)						
		Not measured for this population				
Nest depth (cm)						
Raine Island	Top of eggs	52.3	12.61	33–88	45	Limpus *et al*. 2003
	Bottom of eggs	81.63	14.73	55–152	138	Limpus *et al*. 2003
Incubation period (d)						
Bramble Cay	1977–1978	53.4	0.4SE	48–58	38	Parmenter, 1978
	1979–1980	56.6	–	49–63	32	Limpus *et al*. 2001

Table 16. Measurements of hatchling *Chelonia mydas* at rookeries within the northern Great Barrier Reef. SE denotes standard error measured in place of standard deviation (SD).

		Measurement				References
		mean	SD	Range	n	
Straight carapace length (cm)						
Bramble Cay	1977–1978	4.85	0.05 SE	3.93–5.35	2249	Parmenter, 1978
Raine Island	Multiple seasons	4.86	0.59	3.84–5.43	694	Limpus *et al.* 2003
Weight (g)						
Bramble Cay	1977–1978	23.2	0.05 SE	14.5–29.0	2248	Parmenter, 1978
Raine Island	Multiple seasons	23.8	1.92	17.5–29.5	694	Limpus *et al.* 2003

2.3.9 EGG and HATCHLING SURVIVORSHIP

See Section 2.2.9 for general comments.

Proportion of clutches that produce no hatchlings (total failure) because of natural causes.

Raine Island: The proportion of clutches that produce no hatchlings (total failure) was not quantified during the early years of the Raine Island studies because it was not perceived to be significant. However, during the 1996–1997 breeding season, there was a near total kill of eggs resulting from flooding within an elevated water table beneath the beach. In this season with the greatest number of nesting turtles recorded ashore for nesting on a nightly basis, there was a trivial hatchling production (Limpus *et al.* 2003). Since at least the 1996–1997 breeding season, flooding from beneath much of the nesting habitat during the mid-nesting season has been a regular event. Hatchling production from this major rookery, although not well quantified, appears to be severely reduced (Limpus *et al.* 2003).

Bramble Cay: Total clutch loss occurs through flooding and erosion:

1977–1978: 42.7% (Parmenter, 1978)
1978–1979: 44.1% (Parmenter, 1979)
1979–1980: ~ 33.5% (Limpus *et al.* 1996)

Proportion of clutches that produce no hatchlings (total failure) because of native or feral predators

All beaches: Approximately nil in recent decades (Parmenter, 1978; Limpus *et al.* 1983a, 2001, 2003).

Incubation and emergence success for clutches producing hatchlings to the beach surface.

Hatchling emergence success is summarised in Table 17.

Table 17. Success of incubation and emergence of hatchling *Chelonia mydas* from the nest and onto the beach surface from natural clutches which produce hatchlings at rookeries within the northern Great Barrier Reef. SE denotes standard error measured in place of standard deviation (SD).

		Measurement				References
		mean	SD	Range	n	
Incubation to emergence success						
Bramble Cay	1977–1978	41.0%	5.0 SE	0–84	34	Parmenter, 1978
Raine Island	June 1979	73.9%	23.18	1.2–99.0	37	Limpus *et al.* 2003
	April 1983	83.9%	13.35	44.8–100	16	Limpus *et al.* 2003
	April 1984	78.6%	15.21	19.4–100	162	Limpus *et al.* 2003

Survivorship of hatchlings on the beach during the crossing from nest to sea (includes crab and bird predation) has not been measured within the northern GBR stock.

- At all locations except Raine Island, this parameter is expected to be low (< 2%).
- At Raine Island, this parameter is expected to be variable between the breeding seasons, being highest in the low density nesting seasons or seasons with low numbers of clutches producing hatchlings and during the period when the rufous night herons are feeding their young (Limpus *et al*. 2003).

Survivorship of hatchlings in the water while crossing from the beach to deep water has not been measured for this stock.

2.3.10 HATCHLING SEX RATIO

See Section 2.2.10 for general description.

For the northern GBR stock, pivotal temperature is ~ 29.3 ^{o}C (EPA Turtle Conservation Project unpublished data)

Hatchling sex ratio has not been recorded from any rookery for this stock.

2.3.11 AGE and GROWTH

See Section 2.2.11 for general description.

Growth data from wild turtles of the northern GBR stock are available from Clack Reef only (see Section 2.2.11). As for the southern GBR stock, age when first reaching maturity is expected to be of the order of 30 + years for the northern GBR stock (Chaloupka *et al*. 2004).

2.3.12 POST-HATCHLING

See Section 2.2.12 for general description.

No data are available on post-hatchling dispersal from this population. In a desktop study of oceanography of the Coral Sea region, it was concluded that if post-hatchlings commence their passively-drifting life history phase from offshore and east from Raine Island, then they should be transported northward by the Hiri Current into the Gulf of Papua gyre (Bode and Dight, 1995). They also suggest that, if the post-hatchlings remain passive within the currents, they could be transported out of the Coral Sea into the Solomon Sea and hence westwards towards Indonesia.

2.3.13 IMMATURE and ADULT TURTLES

See Section 2.2.13 for general description.

Sex ratio

The population sex ratio in foraging areas is biased to females at all recorded sites (Table 18).

Diet

In Torres Strait, *C. mydas* forage on a wide range of algae and seagrass (Garnett *et al*. 1985a) with the plant species being dependent on the food available at the site rather than the plants determining the residency site.

Table 18. Sex ratio of *Chelonia mydas* from feeding areas for the northern Great Barrier Reef stock, expressed as the proportion of females in the sample (sample size).

Feeding area	Sex ratio immature turtles	adults	References
off MacArthur R., GoC	0.93 (15)	0.93 (15)	Limpus and Reed, 1985b
Daru Market, southern PNG in Torres Strait	0.82 (158)	–	Unpublished data from collaborative study, PNG Fisheries Division and QPWS
Clack Reef, northern GBR	0.74 (741)	0.69 (329)	Unpublished data, EPA Queensland Turtle Conservation Project

2.3.14 ENSO REGULATION OF ANNUAL BREEDING RATE

See Section 2.2.14 for general description of the influence of ENSO climate change on *C. mydas* breeding rates.

A significant proportion of the inter-annual variability in annual nesting numbers at northern GBR rookeries continues to be explained by the impact of ENSO climate variation on the turtles as they prepare for a breeding season (Limpus and Nicholls, 1994, 2000; Limpus *et al*. 2003). Allowing for a less precise census of nesting turtles at Raine Island (average number of turtles counted ashore in one walk of the island on successive nights during the first two week of December = tally count) than at Heron Island (total tagging census), there has been a similar response of the northern GBR *C. mydas* stock to regional climate variability 1.5 years after the climate event as has been observed with the southern GBR stock.

2.4 GULF of CARPENTARIA BREEDING UNIT

2.4.1 ROOKERIES

During the last interglacial period, the "Gulf of Carpentaria" contained a large freshwater-brackish lake that was completely separated from the marine environment (Torgersen *et al*. 1988). With rising sea levels, the seas commenced flooding into the Gulf at about 12 thousand years ago and a fully marine environment was established about 8 thousand years ago (Torgersen *et al*. 1988). The *C. mydas* genetic stock of the Gulf of Carpentaria represents a geologically very recent colonisation with breeding having been established in only the last few thousand years. The population aggregates for breeding at rookeries across the southern and western Gulf (Figure 3).

Wellesley Group

Within Queensland, the majority of *C. mydas* breeding occurs on Bountiful (Figure 16a), Pisonia and Rocky Islands near Mornington Island (Bustard, 1972; Limpus and Preece, 1992; Limpus *et al*. 2000). There are no extended census data available for these rookeries. An order of magnitude estimate of the annual nesting population is 5000 females. (EPA Queensland Turtle Conservation Project unpublished data,).

Eastern Arnhem Land, Groote Eylandt and Sir Edward Pellew Islands

Nesting distribution and abundance in the western Gulf of Carpentaria has been surveyed (Chatto, 1998; Limpus *et al*. 2000). A preliminary estimate of the size of the annual *C. mydas* nesting population for eastern Arnhem Land is thousands of females annually. A more precise estimate will require a quantified survey to be conducted at the peak of the nesting season. The principal nesting sites include: mainland beaches from Binanangoi Point (Port Bradshaw) south to Cape Shield, especially between Binanangoi Point and Wanyanmera Point (Figure 16b); northern beaches of Woodah Island; eastern Groote Eylandt area, especially North East Island and south-eastern Groote Eylandt (south from Ilyungmadja Pt.; south from Ungwanba Point; Marangala Bay); and Sandy Islet. For each site with high-density nesting, except for Sandy Islet, there was a series of lower density nesting sites in the vicinity. The significant *C. mydas* nesting population of the Sir Edward Pellew Islands has yet to be quantified.

The vast majority of the Gulf of Carpentaria *C. mydas* nesting occurs outside National Park or other habitat managed primarily for conservation purposes. The low-density *C. mydas* on the mainland and adjacent islands of northeast Arnhem Land that lie south from Cape Arnhem are within the Dhimurru Indigenous Protected Area (IPA). Page: 40
Declaration of Indigenous Protected Areas over Lhanapuy and Groote Eylandt means that the majority of the *C. mydas* nesting habitat in western Gulf of Carpentaria is now on indigenous protected and managed lands. (See www.environment.gov.au/indigenous/ipa/index.html). It can be noted that the Dhimurru, Yanyuwah Sir Edward Pellew and the Wellesly Islands have completed Sea Coubtry Plans (see www.deh.gov.au/indigenous/scp.html) and the latter two communities are exploring the possibility of IPAs.

16a. Bountiful Island, Wellesley Group, July 1999**.**

16b. Port Bradshaw area, eastern Arnhem Land, October 1997.

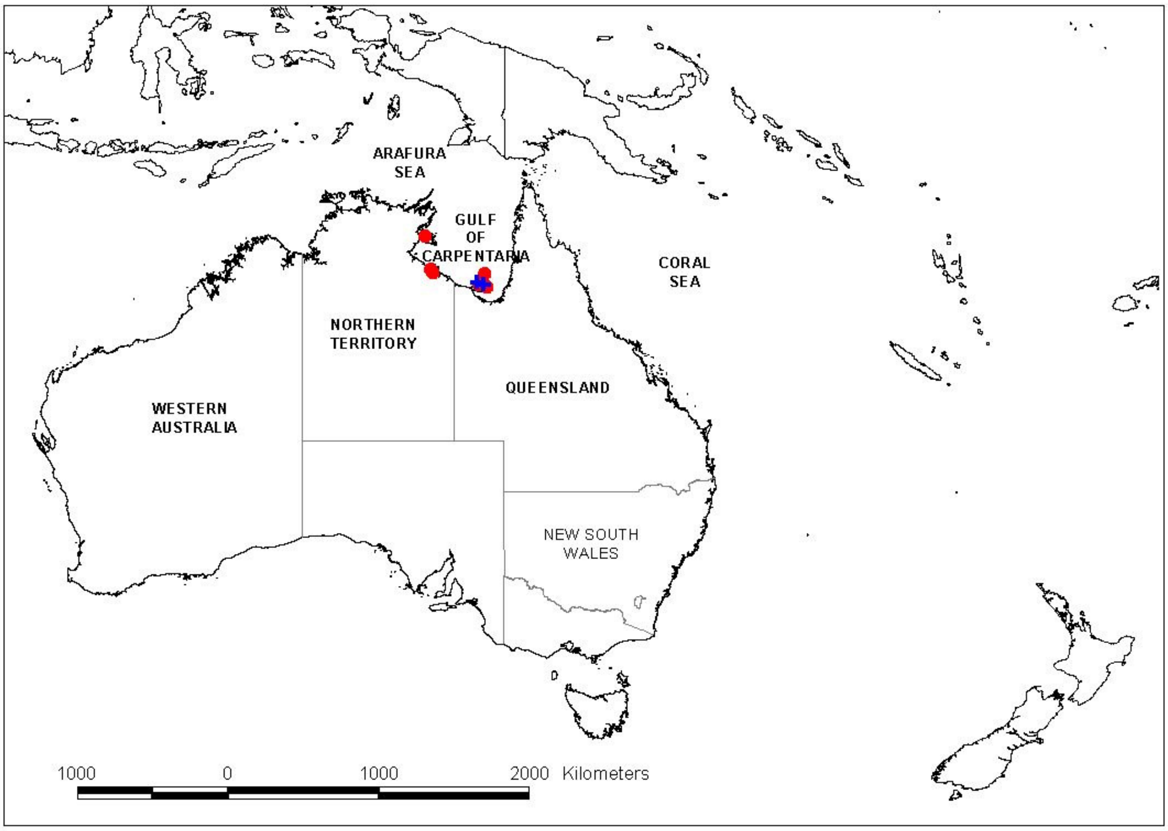
Figure 16. *Chelonia mydas* nesting habitat within the Gulf of Carpentaria.

2.4.2 MIGRATION

Post-breeding migration of foraging areas has been derived from flipper tag recoveries from the Wellesley Group Rookeries (Figure 17a) and from satellite telemetry of females from eastern Arnhem Land Rookeries (Figure 17b. Kennett *et al*. 2004). All foraging areas linked to this breeding assemblage by tag recovery and satellite tracking lie within the Gulf of Carpentaria. This appears to be the most restricted foraging distribution recorded for a *C. mydas* stock.

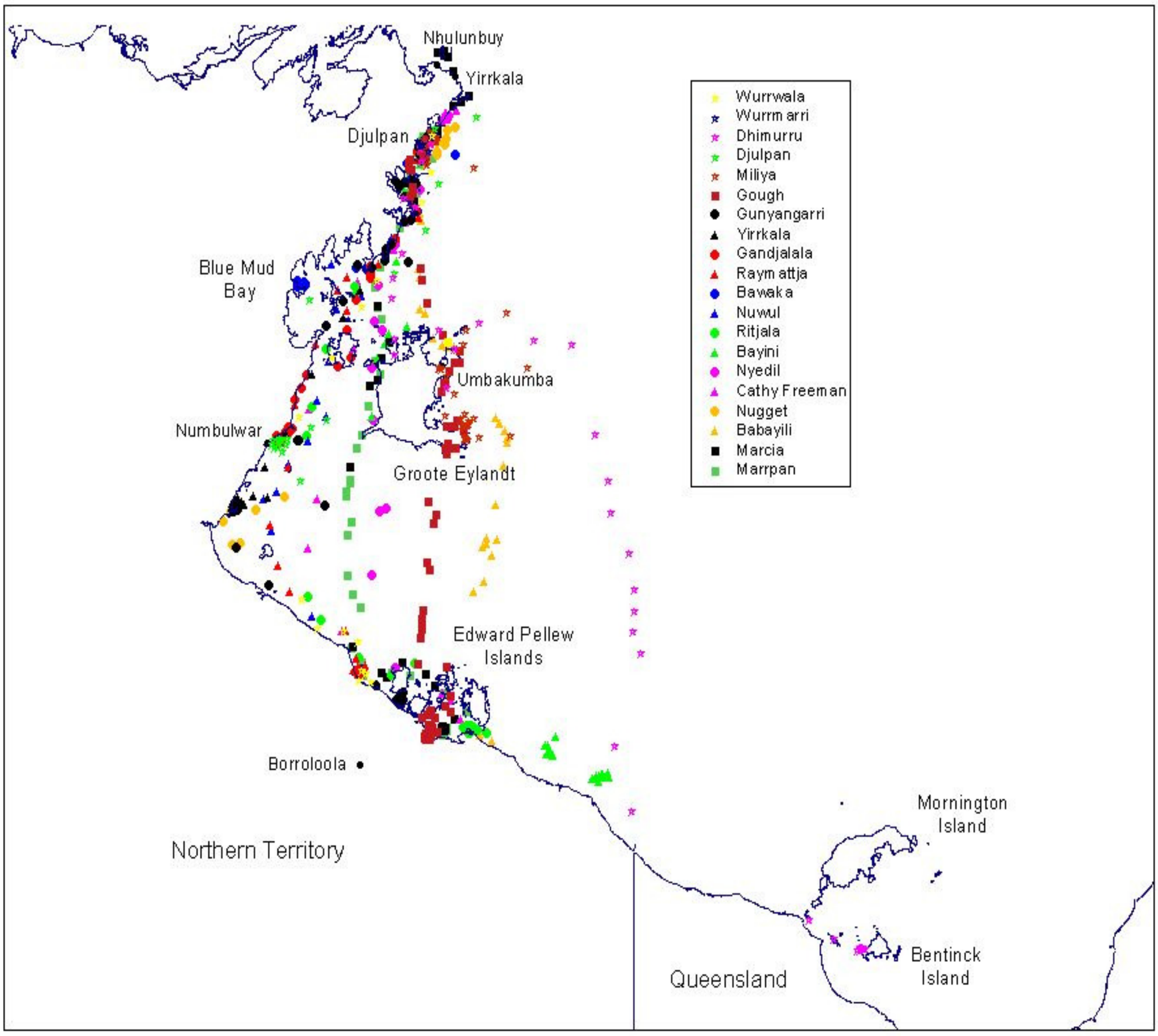
2.4.3 BREEDING SEASON

Nesting occurs year round but with a mid year peak of nesting activity (Bustard, 1972; Limpus and Preece, 1992)



17a. Post nesting dispersal of tagged adult female *Chelonia mydas* (dots) from the Wellesley Island Group rookeries (crosses) to their respective foraging areas.

Figure 17. Foraging area distribution and recorded post reproductive migrations for adult female *Chelonia mydas* from the Gulf of Carpentaria stock.



17b. Post-nesting migratory tracks of adult females from north-eastern Arnhem Land nesting beaches identified by satellite telemetry. Image supplied by Dr R. Kennett

Figure 17. continued.

2.4.4 BREEDING ADULTS

See Section 2.2.5 for a general description of adult turtles. The sizes of breeding adults are summarised in Table 19. These *C. mydas* are smaller than those that breed in eastern Australia. This is one of the few sites globally where large aggregations of marine turtles still can be seen ashore for basking (Bustard, 1972; Garnett *et al.* 1985b; Limpus *et al.* 1994c). These basking turtles are mostly breeding females within their internesting phase during which they are making eggs. Limpus *et al.* (1994c) proposed that the internesting habitat for this breeding area was within the intertidal habitats surrounding the rookeries. Basking turtles are easily disturbed by the close approach of humans.

2.4.5 IMMATURE AND ADULT TURTLES IN FORAGING AREAS

There have been no studies of the foraging populations associated with this stock. That large populations of *C. mydas* forage over the seagrass pastures along the Gulf coast was evident from the many hundreds of individuals stranded by the storm surge of Cyclone *Kathy* in 1984 on the MacArthur River Delta coast (Limpus and Reed, 1985b). This sample was strongly biased to female.

Table 19. Size of breeding adult *Chelonia mydas* from the rookeries within the Wellesley Group, Gulf of Carpentaria.

		Measurement				References
		mean	SD	Range	n	
Curved carapace length (cm)						
Female	Bountiful and Rocky Islands, 1992	102.7	4.67	91.4–114.1	219	Limpus and Preece, 1992
Male	Bountiful and Rocky Islands, 1992	94.9	4.30	88.6–106.1	27	Limpus and Preece, 1992

2.4.6 NESTING IN NORTHERN AND WESTERN ARNHEM LAND

Low density *C. mydas* nesting occurs in norhtern and western Arnhem Land and the adjacent islands (Limpus and Preece, 1992; Chatto, 1998; Hope and Smit, 1998). These *C.mydas* have not been investigated to identify their genetic stock.

There is limited data for *C. mydas* breeding in this area, see table 20.

Table 20. Measurements for *Chelonia mydas* from the M^{c}Cluer group of islands off north western Arnhem land.* from one clutch.

	Measurement				References
	mean	SD	Range	n	
Eggs per clutch	109	-	69-149	2	Limpus and Preece, 1992
Nest depth (cm)	89	-	71-87	2	Limpus and Preece, 1992
Hatchling straight carapace length (cm)	4.88	0.07	4.72-4.97	8*	Limpus and Preece, 1992
Emergence Success (%)	40.8	-	-	2	Limpus and Preece, 1992
Hatch Success (%)	44.5	-	-	2	Limpus and Preece, 1992

2.5 WESTERN AUSTRALIAN BREEDING UNIT (STOCK)

2.5.1 ROOKERIES

Western Australia supports one genetic stock of green turtles nesting from the Ningaloo Coast to the Lacepede Islands (Figure 3. FitzSimmons *et. Al*. 1997, Moritz *et. Al*. 2002). This is one of the largest green turtle populations remaining in the world and appears to be the largest for the Indian Ocean. The principal rookeries include Lacepede Islands, Monte Bello Islands (Figure 29b), Barrow Island (Figure 18a), North West Cape (Figure 18d) and Browse Island (Prince, 1994). Numerous small rookeries also occur in Western Australia.

The Dampier Archipelago, Thevenard Island and Barrow Island are Nature Reserves and together with the Ningaloo Marine Park and Montebello Conservation Park, provide protected nesting habitat for a significant part of the Western Australian stock.

18a. Barrow Island, southern Beach, October 2002.

18b. Basking *Chelonia mydas* on a southern beach, Barrow Island. Photograph by K. Morris.

18c. Thevenard Island, Northwest Shelf, October 2002

Figure 18. *Chelonia mydas* nesting habitat in Western Australia.

18d. Jurabi Point, Ningaloo Marine Park, October 2002.

Figure 18. Continued.

Nesting census

There has been limited long-term census of the Western Australian *C. mydas* nesting populations. Northwest Cape nesting beaches have the potential for establishment of a low cost index beach for monitoring *C. mydas* nesting trends (Figure 19).

Although there are no accurate census data, the anecdotal information from Dr Andrew Burbidge, Dr. Keith Morris and Dr Robert Prince indicates that in an average nesting season, tens of thousands of *C. mydas* breed on western Australian beaches.

The size of the annual female *C. mydas* nesting population at North West Cape, based on available census data (Figure 19), has fluctuated but remained relatively stable during the period 1987 to 1988 (Linear regression analysis: $F_{1,9} = 0.50$, $p > 0.25$ (ns). $R^2 = 0.05$, df = 9, $p > 0.25$ (ns).

Basking

Basking is a common behaviour for adult male and female *C. mydas* at the nesting beaches in Western Australia (Figure 18b). This phenomenon has not been researched in Western Australia and its significance with respect to conservation management needs is not being evaluated.

2.5.2 FIDELITY TO NESTING SITES

All nesting recaptures of previously tagged nesting female *C. mydas* in Western Australia have occurred at the respective beaches where they were tagged (Prince, 1994; R. Prince, pers. comm. August 2004).

2.5.3 MIGRATION

Numerous adult female *C. mydas* that were tagged while nesting at the Western Australian rookeries have been captured for food by indigenous hunters in Western Australia, Arnhem Land, Queensland and eastern Indonesia (Prince, 1994, 1998). Some tagged females from this breeding unit have been captured as far east as Mornington Island and western Cape York Peninsula in Queensland and as far south as Shark Bay in Western Australia.

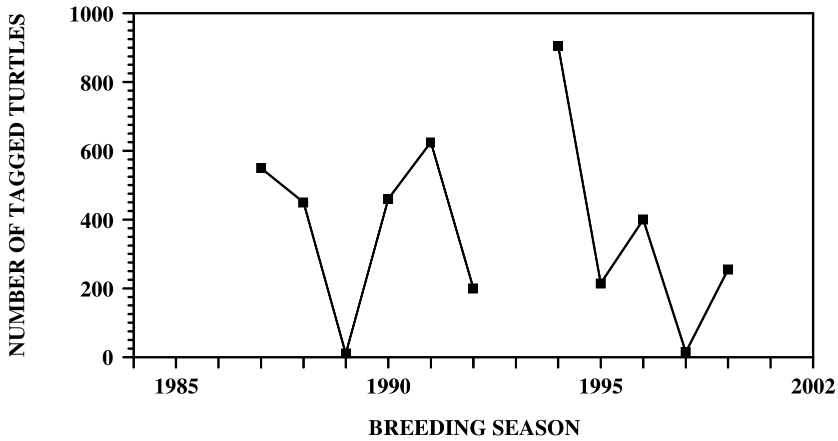


Figure 19. Available long-term census data from an index beach for *Chelonia mydas* breeding population at Northwest Cape, Western Australia. Extrapolations from these census data should be made with caution. Uniform sampling effort was not applied in the census studies across the years (Prince, 2000).

2.5.4 HATCHLING SURVIVORSHIP

Incubation success and hatchling survivorship remains unquantified for the Western Australian rookeries.

On the Northwest shelf there are gas burn-off flares associated with oil and gas production that are in close proximity to turtle rookeries (Pendoley, 1991). These flares have the potential to impact on hatchling dispersal and associated hatchling survivorship. At Thevenard Island (Figure 18c), *C. mydas* hatchlings crossing the beach in close proximity to the flares have a high probability of being disoriented when no moon is visible because of the moon phase or because of heavy overcast conditions (Pendoley, 2000). Hatchlings crossing the beach more than 400m from the flares on Thevenard Island were far enough away not to be disoriented (Pendoley, 2000).

The extent to which there is a dispersal of pollution into the same gyres that are dispersing hatchling turtles from the oil field areas of the Northwest Shelf from oil-gas production and from shipping is unquantified. Given the potential for post-hatchling turtles to ingest floating tar and to be fouled by oil, concern must be raised for the health and survival of the hatchling turtles dispersing from the Northwest Shelf out into the Indian Ocean (Unpublished observations, EPA Queensland Turtle Conservation Project).

Introduced foxes, *Vulpes vulpes*, have been predators of turtle eggs and hatchlings in the North West Cape area for some decades. Predation levels appear to have been reduced since the introduction of a fox baiting program in 1980 (Anon, 1980).

2.5.5 IMMATURE AND ADULT TURTLES

Chelonia mydas that occur within the migratory range of this stock forage over a range of habitats. In Shark Bay, adult and immature *C. mydas* of both sexes were more frequently encountered over seagrass pasture than over open sand substrates (Heithaus *et al*. 2002). *C. mydas* is reported to be abundant in Shark Bay where a fishery for them ceased in 1971 (Lester *et al*. 1980). Shark Bay is probably the most southern major foraging area for turtles from this stock.

The reefs of the Ningaloo coast and Northwest Shelf have long had a reputation for an abundance of immature and adult foraging *C. mydas* that supported a turtle fishery over decades until it was closed in 1973 (Caldwell, 1951; Cassidy 1998).

The *C. mydas* that forage in western Northern Territory are presumed to include turtles from this stock. Adult and immature *C. mydas* forage in large numbers over rocky reefs within Darwin Harbour (Whiting, 2001). Large numbers of small immature *C. mydas* (Mean CCL = 47.7 cm, SD = 8.13) forage on algae on the rocky reefs of Fog Bay (Whiting & Guinea, 1998). However, their tagging studies indicate that the residency time of these turtles is of short duration and large immatures and adults are rare on these reefs. Whiting and Guinea (1998) have invoked the theory of "developmental migration" to explain this apparent short-term residency of individual *C. mydas* on these reefs.

2.6 CORAL SEA BREEDING UNIT (STOCK)

Chelonia mydas dominates the marine turtle nesting on the Coral Sea cays (Figure 3), with a nesting population of many hundreds of females annually (Unpublished data, Queensland Turtle Research Project, DoE). mtDNA genetics analysis of these turtles has demonstrated that they are not part of the SGBR stock (Moritz *et al*. 2002).

The coral cays of the western Coral Sea are Australian Territory, administered as National Nature Reserves.

Post-breeding migration records of females tagged at these rookeries have been recorded in foraging areas from northern New South Wales, throughout the GBR and from southern Papua New Guinea (Figure 20).

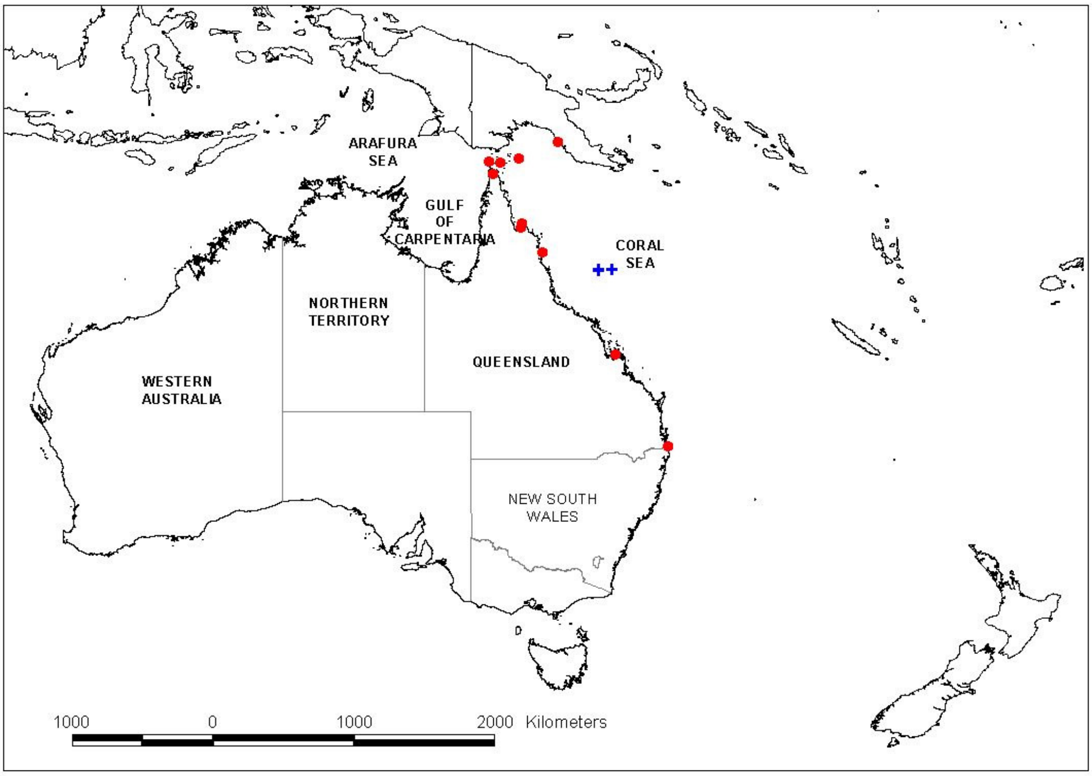


Figure 20. Post nesting dispersal of tagged adult female *Chelonia mydas* (dots) from the Coral Sea Nature Reserve rookeries (crosses) to their respective forging areas.

Size of nesting females is summarised in Table 21.

Table 21. Size of breeding adult *Chelonia mydas* from the Coral Sea rookeries.

		Measurement				References
		mean	SD	Range	n	
Curved carapace length (cm)						
Female	Multiple rookeries	105.7	5.08	92.6–116.6	100	Koloi, 1992

2.7 AUSTRALIAN TERRITORY OF ASHMORE AND CARTIER ISLANDS STOCK

2.7.1 ROOKERIES

The National Nature Reserve (NNR) in the Indian Ocean encompasses three vegetated cays (West Island, Middle Islet, and East Islet) which support marine turtle nesting (Whiting *et al*. 2000). Also in this Territory is the unvegetated Cartier Reef, which also is a *C. mydas* rookery (Russell & Hanley, 1993).

There has been no standard mid season census of the nesting population. However, early season nesting counts suggest that the total *C. mydas* nesting population, in an average density nesting season, is of the order of hundreds of females annually (Guinea, 1995; Whiting *et al*. 2000). Most nesting occurs on West Island (Whiting *et al*. 2000).

This population is an independent *C. mydas* stock to those in adjacent Western Australia and Indonesia (Moritz *et al*. 2002).

2.7.2 MIGRATION

There is one tag recovery/satellite telemetry of a nesting female which made a post-breeding migration from the Ashmore Reefs to Coburg Peninsula in north-western Northern Territory (Spring, 1994; Spring & Pike, 1998).

2.7.3 BREEDING SEASON

Nesting probably occurs all year round with a mid summer peak (Guinea, 1995). The increasing frequency of sightings of mating pairs of *C. mydas* during September through to November and small numbers of nesting turtles in September–October recorded by Guinea (1995) and the hatchling emergence and low density nesting in May (Russell & Hadley, 1993) is consistent with a high density nesting period in December–January. However, small numbers of emerging clutches in September–October indicate that low-density nesting had also occurred in July–August.

2.7.4 BREEDING ADULTS

See section 2.2.5 for general description. On average, these nesting females (Table 22) appear to be smaller than the nesting females from the eastern Australian stocks (Sections 2.2.5, 2.3.5 and 2.6) and of similar size to those that breed in the Gulf of Carpentaria (Section 2.4.4).

2.7.5 EGGS

See section 2.2.7 for general description. Egg and nest measurements are summarised in Table 23.

The mean number of eggs per clutch may be reduced below the natural potential of these turtles as a result of repeated disturbance of the nesting turtles by the loose/dry sand conditions. Nesting success is very low, 0.152 clutches/beaching, and some eggs are dropped at sea (Guinea, 1995; Whiting *et al*. 2000).

Table 22. Size of breeding adult *Chelonia mydas* from the Ashmore Banks rookeries.

	Measurement				References
	mean	SD	Range	n	
Curved carapace length (cm)					
Female	102.2	5.30	93.5–113.0	17	Guinea, 1995
	101.1	4.48	92.0–113.0	44	Whiting *et al*. 2000
Curved carapace width (cm)					
Female	91.5	4.36	81.50101.5	44	Whiting *et al*. 2000

Table 23. Measurements of *Chelonia mydas* eggs and nests at rookeries within the Ashmore Banks, north-eastern Indian Ocean.

	Measurement				References
	mean	SD	Range	n	
Eggs per clutch					
	97.8	27.2	71–132	5	Guinea, 1995
Egg diameter (cm)					
	4.24	0.08	4.07–4.35	20	Guinea, 1995
Egg weight (g)					
	42.5	1.5	40.0–46.0	20	Guinea, 1995
Nest depth (cm)					
Bottom of eggs	68.3	7.6	60–70	3	Guinea, 1995

2.7.6 HATCHLINGS

See section 2.2.8 for general description. Hatchling measurements are summarised in Table 24.

Table 24. Measurements of hatchling *Chelonia mydas* from rookeries within the Ashmore Banks, north-eastern Indian Ocean.

	Measurement				References
	mean	SD	Range	n	
Straight carapace length (cm)					
	4.68	0.13	4.41–4.91	21	Guinea, 1995
Weight (g)					
	20.40	1.40	17–22.5	21	Guinea, 1995

2.7.7 EGG and HATCHLING SURVIVORSHIP

See section 2.2.9 for general description. There were no feral predators to impact on the eggs on these beaches (Guinea, 1995). Incubation and emergence success is summarised in Table 25.

Table 25. Success of incubation and emergence of hatchling *Chelonia mydas* from the nest and onto the beach surface from natural undisturbed clutches which produce hatchlings at rookeries within the Ashmore Reefs.

	Measurement				References
	mean	SD	Range	n	
Incubation to emergence success					
	52.3%	19.5	36.4–74.0	3	Guinea, 1995

Survivorship of hatchlings on the beach during the crossing from nest to sea (includes crab and bird predation) has not been measured but it should be high.

2.7.8 ADULT and IMMATURE TURTLES

The numerous immature and adult-sized *Chelonia* (Curved carapace length = 58.0–102.5 cm, n = 10) that are feeding residents on the Ashmore Reefs are not necessarily part of the same genetic stock as those that breed on the islands of the Ashmore Reefs (Guinea, 1995).

2.8 SCOTT REEF STOCK

The small *C. mydas* population that nests at Scott Reef is an independent *C. mydas* stock to those elsewhere in the eastern Indian Ocean, Australia and Indonesia (Moritz *et al*. 2002).

2.9 INTERNATIONAL STOCKS

The *C. mydas* populations that forage within eastern Australia are of mixed genetic stocks (Norman *et al*. 1995). Tag recoveries have demonstrated clearly that turtles from multiple stocks forage at the same locality (Figure 3, 14, 17, 20). Foraging along-side the *C. mydas* from Australian rookeries within Australian foraging areas have been numerous individuals that have been also recorded breeding within neighbouring Nations (Figure 21).

New Caledonia
The *C. mydas* that breed in northern New Caledonia (Isle de Surprise, Isle de Fabre, Huon Island) are characterised by a mixture of genotypes from the NGBR and SGBR stocks as well as a genotype unique to northern New Caledonia (Moritz, *et al*. 2002). The nesting population is under ongoing monitoring by Association pour la Sauvegarde de la Nature Neo-Caledonienne (Serre *et al*. 2000, Huruguen *et al*. 2000). The annual nesting population numbers in the order of many hundreds of nesting females annually.

Numerous tagged adult female turtles from this New Caledonian stock have been recaptured within eastern Australian foraging areas from Princess Charlotte Bay south to Moreton Bay (Figure 21). In addition, one adult male, tagged while foraging on Heron Island Reef, has been recorded at courtship in southern New Caledonia.

Vanuatu
One reproductive migration was identified when an adult female, tagged in Moreton Bay in South Queensland, was recorded nesting in southern Vanuatu. The genetic distinctness of the turtles that breed in southern Vanuatu has not been investigated.

Solomon Islands
One reproductive migration was identified when a *C. mydas,* tagged while feeding in the GBR off Cairns, was captured on a nesting beach in the extreme eastern Solomon Islands. The genetic distinctness of the turtles that breed in southern Solomon Islands has not been investigated.

Papua New Guinea
There have been three tag recoveries of adult female *C. mydas* that linked eastern Australian foraging areas within the GBR and nesting beaches in Papua New Guinea: Long Island (x1) and Louisiade Archipelago (x2). The Long Island nesting population has been identified as separate genetic stock to all other *C. mydas* populations tested (Norman, 1995; Dutton *et al*. 2002).

Indonesia
The principal *C. mydas* nesting areas in southern Indonesia occur in Java and the Aru Islands (Schulz, 1984).

The main Javanese *C. mydas* nesting aggregation occurs at Pangunbahan, Southwest Java (Schulz, 1984). This *C. mydas* population is reproductively isolated from the nesting populations in Malaysia, Indonesia and in western and northern Australia that have been genetically evaluated (Norman *et al*. 1994a,b; Moritz *et al*. 2002; Dutton *et al*. 2002). This Javanese population is in decline, primarily because of long term excessive harvest of the eggs (Limpus, 1997). There have been captures of two female *C. mydas* tagged at rookeries in eastern and western Java by Australian aboriginal turtle hunters at Coburg, Northern Territory, and One Arm Point, Western Australia, (Limpus *et al*.1992; R. Prince, pers. comm.).

There have been no tag recoveries from Australia from the *C. mydas* nesting population that breeds in southern Aru in eastern Indonesia in the northern Arafura Sea. This is the closest significant nesting population to Australia (Moritz *et al.* 2002; Dutton *et al*. 2002). Given the occurrence of *C. mydas* from more distant rookeries occurring in Australian foraging areas, it is expected that this stock will be represented in foraging areas across northern Arnhem Land.

New Zealand

There has been no confirmed marine turtle breeding in New Zealand. Small numbers of immature *C. mydas* (CCL = 41.4 – 90.0 cm) are stranded in New Zealand annually (Gill, 1997). The origin of these turtles has not been identified.

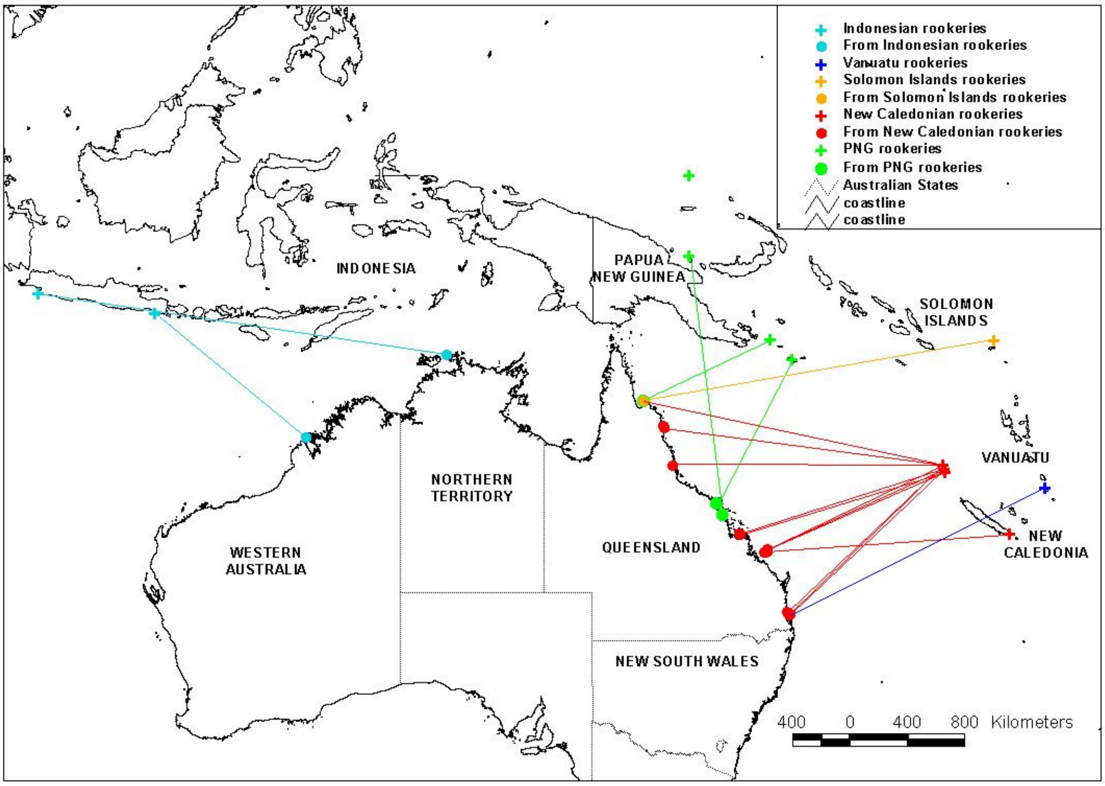


Figure 21. Tag recoveries (dots) of foraging foreign adult *Chelonia mydas* in Australia that have been recorded at breeding areas (crosses) in neighbouring countries.

3. ANTHROPOGENIC MORTALITY and DISEASES

The eggs and flesh of *C. mydas* are eaten while its skin is used for making leather, its oils for making cosmetics, its scutes for jewellery and ornaments and its offal for fertiliser. The species is famous for making turtle soup. In recent years, commercial harvest has not been permitted under any State or Federal legislation in Australia.

3.1 PAST COMMERCIAL HARVESTS IN AUSTRALIA

3.1.1 QUEENSLAND

Unless otherwise indicated, the following account is based on information derived by interview and correspondence by C. Limpus with persons associated with or who witnessed the past commercial harvest and transport of turtles in Queensland: Pam Land and Bob Poulson 1974–1978; Betty Tate 1975–1977; W. R. Golding 27 March 1977; A. Echart 23 January 1978; B. Faithful 23 January 1978; W. J. Limpus 23 January 1978; W. R. Mackay 23 January 1978; J. Cameron 24 January 1978; E. Dwyer 26 January 1978; Dr. Fison 9 September 1978; Dr. O. A. Jones 9 September 1978; Alec Stuart 27 April 1979; W. Unie mid 1980.

There is no current commercial harvest of *C. mydas* in Queensland. However, there was appreciable commercial harvesting of the species until approximately one turtle generation in the past when the harvest ceased in 1959 (Anon, 1894–1928; Anon, 1929–1951; Wood, 1940; Limpus *et al*. 2003).

Turtles were harvested for local commercial consumption in Queensland at least as early as 1863. A turtle fishery at Masthead Island, a southern GBR rookery, was reported in 1873 in the *Mackay Mercury*. A turtle soup cannery (B. Skinner, Turtle Preserver and Exporter) operated in Brisbane from approximately 1877 to at least 1902 and this turtle soup was sold widely throughout the colonies and in England (Addison *&* McKay, 1985).

Many thousands of nesting female *C. mydas* were harvested from the southern GBR rookeries during 1902–1950 for turtle soup production and meat export (Anon, 1894–1928; Musgrave *&* Whitley, 1926; Anon, 1929–1951; Moorhouse, 1933; Wood, 1940). This harvest must have depleted the breeding population, especially with an estimated > 18% of the southern GBR nesting females having been harvested in 1924–1930. However, the population was not monitored and subsequent changes in the population were not recorded. Similarly, following total protection for this species in Queensland south of 15oS since 1950, there was effectively no monitoring of any recovery of this population prior to the commencement of the monitoring program at Heron Island in 1964 by Dr H. R. Bustard (Bustard, 1972). Monitoring was continued from 1974 by Dr C. J. Limpus (Limpus, 1980). There is the distinct possibility that there was also local depletion of *C. mydas* numbers in some feeding areas such as Moreton Bay as a result of turtle fisheries prior to 1950 (Limpus *et al.* 1994).

- Turtle soup factories operated intermittently on North West Island (Capricornia) from 1902 to 1923 and for four breeding seasons during 1924–1928.
- Jones operated a turtle soup factory on Heron Island (Capricornia) in the 1925–26 breeding season. In 1928, the North West Island factory closed and its operation was moved to Heron Island where it operated during two breeding seasons, 1928–1930 (Moorhouse, 1933). Only female *C. mydas* were taken from the beaches for this industry. While earlier harvests were not quantified, at least 8472 nesting females were killed from SGBR breeding unit rookeries to supply these factories in the six summers of 1924–1930.
- Prior to commencing the soup factory on Heron Island and following its closure in 1927, Jones produced turtle soup at his meat processing factory in Brisbane from nesting female *C. mydas* which had been captured on the southern GBR rookeries and sent to Brisbane. The size of this continuing harvest is not well documented but at least 870 were sent in the two summers, 1931–1933. The first attempt to manage the harvest of *C. mydas* in Queenland was the declaration of a “closed season for turtle and egg harvest during months

October and November" south of 17°S (Order in Council, 15 December 1932, Queensland Fisheries Act). "Jones" became "Foggitt–Jones" and they contracted fishermen to harvest turtles for them, including fishermen from Bundaberg who collected from Lady Elliot and Lady Musgrave Islands in the early 1930s and transferred the turtles live to holding pens in the Burnett River. The turtles were subsequently shipped as deck cargo to Brisbane on *Baralaba* and other boats (estimated 30–40 turtles per load). Turtles were shipped direct to this Brisbane factory via coastal shipping, including *Bingera*, *Babinda* and *Baralaba*, from Heron Island following World War II (up to 60 turtles as deck cargo per load, loads approximately 1 month apart). This harvest ceased in 1950, with the declaration of a "year round closed season for turtle and egg harvest" for *C. mydas* through out Queensland. (Order in Council, 7 September 1950, Queensland Fisheries Act).

- Small numbers of nesting *C. mydas* were also captured from Heron Island and adjacent islands and exported whole to England "for many years" up to 1925 (anon, 1925). Fishermen took whole turtles as deck cargo from Heron Island to unrecorded locations even during the years the factory was in operation and from North West Island to Lakes Creek Meat Works, Rockhampton, while the North West island soup factory was in operation (Musgrave *&* Whitley, 1926). An estimated 100^{+} *C. mydas* were taken off North West Island in one summer in the early 1930s and shipped as chilled carcasses to England by the Gladstone Fisheries and Cold Stores Ltd. Barge loads of turtles were shipped off Heron Island to Gladstone in the period 1943–1947. Several loads of ~ 25 turtles each were taken off North West Island in the 1949–1950 breeding season and sent to Brisbane from Gladstone.

In response to lobbying from north Queensland fishermen, Queensland Fisheries Regulations were changed to permit a turtle harvest from north of 15°S (approximately Cooktown) in 1958 (Order in Council, 4 September 1958, Queensland Fisheries Act). In January and February 1959 there was a harvest of approximately 1200 nesting *C. mydas* from northern GBR rookeries (Raine Island and Moulter Cay) by the Cairns based Whittaker brothers (Limpus *et al*. 2003):

- The primary sales outlet for these turtles was to have been to the food processing company, Master Foods, in Sydney for turtle soup manufacture. This turtle harvesting venture ceased after one season because no satisfactory price could be agreed on by Master Foods and the Whittaker brothers and because of the lack of a large enough local market for consumption of turtle meat in Cairns.

Commercial harvest of *C. mydas* ceased in Queensland in 1968 following 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.

A turtle farming project was initiated in Torres Strait in 1970 by Dr H. R. Bustard of Applied Ecology Limited within the Australian National University. The project was funded by the Australian Government. After a reorganisation of leadership, the farming venture continued as a quasi-government agency, Applied Ecology Pty Ltd in 1973. Carr and Main (1973) describe the operations and scale of the farms at this time. Onions (1980) summarised the status of this experimental farming project in 1979 as consisting of "five experimental farms, some two thousand turtles (1-5 years old) and seven thousand hatchlings located on four of the thirteen island reserves of the group (Torres Strait) and employs some sixty Islanders as turtle farmers or to service the project". Doomed eggs that had been laid in erosion prone areas, at least in the later years of the project, were collected from Bramble Cay in north-eastern Torres Srtait and distributed to the turtle farms for incubation (Parmenter, 1980a; Kowarsky and Capelle, 1979). Carr and Main (1973) indicated that in the earlier years, clutches (possibly the *Eretmochelys imbricata* eggs) were collected from the beaches adjacent to the respective farms. This egg collection was permitted under Queensland Fisheries Regulations. While the farms did not succeed in providing a food supply for the islander communities, limited numbers of headstarted, immature turtles were released from these farms (Kowarski and Capelle, 1979). This turtle farming project was closed down in 1980.

The numbers of turtles and eggs collected to stock the Applied Ecology Turtle Farms in Torres Strait during the 1970s are not available (Kowarsky, 1977; Parmenter, 1980c). Similarly the numbers and fate of the thousands of turtles released to the wild from their farms has only been partly quantified (Kowarsky & Capelle, 1979).

3.1.2 NORTHERN TERRITORY

There appear to be no records of a commercial harvest of *C. mydas* in the Northern Territory. Missionaries in several coastal locations encouraged local Aboriginal people to collect eggs and adults to feed people at the missions. Some records of the quantities were kept by missionaries but there has been no systematic attempt to search for and collate these records (Rod Kennett, pers. comm.).

3.1.3 WESTERN AUSTRALIA

The following does not encompass a comprehensive literature review of the Western Australian turtle harvests. However, it indicates that a protracted and extensive harvesting, especially of green turtles, has occurred in that State.

Early European explorers and navigators sought marine turtles wherever they could be encountered. Live turtles were a significant source of fresh meat because they could be carried beyond the capture point without the need to provide food and freshwater for the turtles to survive for extended periods. For example:

- Dampier, during his visits to Western Australia in 1688 and 1689, regularly recorded and harvested marine turtles (Masefield, 1906).
- Stokes (1846) took 30 large turtles, presumably greens, and 1 small hawksbill turtle from the reef flat at South Turtle Isle near Port Hedland in July 1840. Later that year in August he recorded taking 7 tons of turtle from Barrow Island. If these were breeding green turtles, this would equate to approximate 70 adult turtles. Stokes can also be credited with the first "trading" of turtles within Western Australia: p.211 - "Many of them (turtles) we gave to our friends at Swan River on our arrival."

Commercial exploitation of Western Australian turtles was operational by at least the 1930s onward:

- A turtle soup factory was established at Cossack in about 1931 by Monte Bello Sea Products Ltd (Douglas, 2000) and supposedly processed turtles caught in the Monte Bello Islands. Caldwell (1936) describes this turtle soup cannery and the processing *C. mydas* captured at reefs around Flying Foam Islands.
- Caldwell (1951) describes some of the operations of this cannery. His photographs show numerous large immature to adult-sized *C. mydas* being hand-captured on reefs adjacent to Flying Foam Islands and transported to and held in an inter-tidal pen. Approximately 50 turtles per week were reported being processed at that time. While the longevity of the cannery operation is not identified, these data are indicative of a harvest of some 2500 large *C. mydas* annually. The Exclusive License for taking turtle by the "Australian Canning Co. Ltd" at Cossack was cancelled on November 18, 1936 for non-payment of license fees (Department of Forestry & Fisheries file248/50).
- Wood (1940) reported that "a turtle soup cannery is in operation in Perth, working on turtles brought from the north-west coast".
- In the 1950s a turtle harvest to supply to a turtle cannery at Cossack was recommenced (Department of Forestry & Fisheries file248/50: 18 April 1950). R. V. Randal advocated more controlled turtle harvesting to avoid mistakes of over harvests in other countries (Department of Forestry & Fisheries file248/50: 17 Jan 1951).

- During the 1960s the last two turtle harvesting licenses (Tropical traders Ltd and West Coast Traders Pty Ltd) operated at Maud point and North West Cape and out to 3 miles offshore. They were issued for the capture of turtles in the sea. See Table 26 for a summary of available harvest statistics. Some reports indicate that some of the turtles were taken from the nesting beaches at that time.
- In 1962, the Western Australian Meat Export Works was holding 5 tons of turtle eggs for sale (Department of Forestry & Fisheries file248/50: 18 April 1962; Daily News 24 April 1962). This weight was estimated to contain ~128,000 eggs. Based on this number of eggs in 5 tons, they would have been mostly green turtle eggs. This many eggs would have been equivalent to about 1200 clutches, which would have been equivalent to the annual egg production of some 240 females. There was also "4 tons of red and green turtle meat" in storage along with the eggs. "Red" turtle could indicate that loggerhead (= Indian Ocean red-brown) turtles as well as green turtles were being harvested at this time. This meat was dumped to make room for a consignment of salted turtle skins.
- In 1968, the export of wet-salted turtle flipper skins to presumably Japan and probably Europe is implied to be an established export from Western Australia (Department of Forestry & Fisheries file248/50: 9 Oct 1968).
- In 1968, turtles and turtle eggs were also being harvested for sale in unspecified amounts from the beaches near Port Headland (Department of Forestry & Fisheries file248/50: p.100). However, this may not have been a harvest of *C. mydas*.
- During 1970–1972, Cassidy (1998) was contracted to capture turtles by Tropical Traders who were licensed by Western Australian Fisheries. He was of the opinion that a second license operated out of Onslow at the same time. Cassidy reported that his fishing accounted for some 10,000 large green turtles (>120lb dressed weight) harvested during 3 years, 1970–1972, from the Ningaloo Coast (40 mile lease running northward from Maud Point). Cassidy was specific that he did not catch small turtles. A minimum dressed weight of about 120lb would translate to turtles of about 90kg and above (= large immature and adult turtles) being taken. He was harvesting these large green turtles in the waters adjacent to nesting beaches during July–October. Cassidy reported convincingly that few green turtles were harvested from on the nesting beach. However, it is inevitable that they would have been harvesting not only the locally resident foraging green turtles but also breeding migrants aggregated for courtship along the Maud Point area coast as well as internesting adult females while they were preparing eggs for laying in their respective seasons.
- It appears that the only organised sales outlet for a large portion of these turtles was for turtle soup manufacture by the food processing company, Master Foods, following an unsuccessful attempt by that company to use turtles from Raine Island in the summer of 1958–1959 (Limpus *et al*. 2003).
- As of 30 June 1973 there was no renewal of turtle harvesting licenses in Western Australia. This marks the end of commercial harvests of turtles in Western Australia.

The turtle skin trade that operated during the 1960s and early 1970s would have been in response to the demand within European and Japanese markets for high quality reptile skin for the luxury leather trade. Marine turtle skin was found to be a suitable substitute from the then scarce, high quality crocodilian skins. It is presumed that skins exported from Western Australia were a by-product from the turtles harvested for meat.

Based on the incomplete data available from the commercial turtle harvest during 1960–1972, it is evident that many thousands of adult and near adult *C. mydas* were harvested annually during these years.

Turtle farming

- The Bardi Community at One Arm Point participated in the turtle farming venture initiated by Dr H. R. Bustard of Applied Ecology Limited in the early 1970s and continued by

Applied Ecology Pty Ltd (Carr *&* Main, 1973). An undetermined number of eggs were gathered from Lacepede Island and incubated to provide turtles for captive rearing. This farming venture ceased, presumably on economic grounds, in the early to mid 1970s.

Table 26. Turtle harvest data from Western Australia. DF&F refers to Western Australian Department of Forestry & Fisheries.

Year	West Coast Traders Block 2113		Tropical Traders Block 2213		Whole of WA			Reference
	Turtles	Live weight (lb)	Turtles	Live weight (lb)	Turtles	Live weight (lb)	Dressed wt Export wt (lb)	
1962						90,628		DF&F file P71
1963						214,523		DF&F file P71
1964	2001	400200	2430	349390	4431	749,590 or 869,632		DF&F file P54,P71
1965						800,600 or 427,000		DF&F file P71,P151
1966						357,454		DF&F file P151
1967						509,510	299,030	DF&F file P151 Anon, 1969
1968						744,483	362,027	DF&F file.P151 Anon, 1969
1969						633,445	356,241	DF&F file P151
1970			Estimated 3000–4000 turtles/yr				398,139	Cassidy, 1998
1971							264,096	Cassidy, 1998
1972								Cassidy, 1998

3.1.4 OTHER STATES

There appears to have been no organised harvest of turtles from or to the remaining states during the 19th and 20th Century.

3.2 INDIGENOUS HARVESTS IN AUSTRALIA

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

3.2.1 QUEENSLAND EAST COAST HARVEST SOUTH OF CAPE MELVILLE

Hopevale

Indigenous inhabitants of this area have hunted *C. mydas* since long before European colonisation (Cook, 1770 in Reed, 1969). During 1984–86, approximately 95 *C. mydas* per year were captured by this community (Smith, 1989):

- Of 26 turtles examined for sex and maturity, there were 12 adult females, 10 immature females, 1 adult male, 3 immature males; in contrast to dugong hunting, selection does occur, based primarily on the tail length and fatness of the turtle. By selecting for large short-tailed turtles, hunters tend to take mostly adult females (Figure 22).

- The majority of tagged *C. mydas* captured by this community have been adult females tagged while nesting at southern GBR rookeries.

Wujal Wujal

- This north Queensland community around Mossman hunts some tens of *C. mydas* annually (Grey & Zann, 1988; Pers. comm. J. D. Miller, 1995). The take is mostly of large immature and adult-sized turtles (Figure 22).

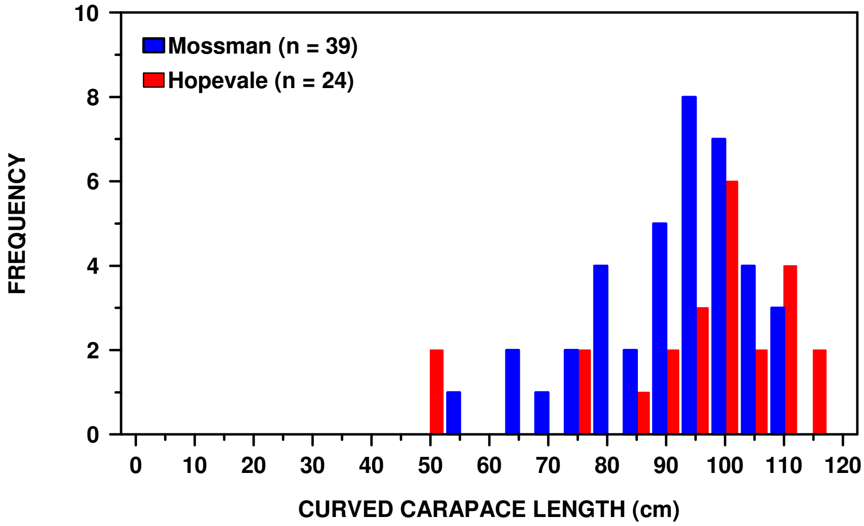


Figure 22. Size range of Cheloina mydas harvested in the Great Barrier Reef south from Cooktown. Mossman sample recorded by J. Miller (pers. comm.). Hopevale Community data from Smith (1989).

Yarrabah

The size of the annual turtle harvest by this community has been poorly documented (Unpublished data from GBRMPA files; EPA Queensland Turtle Conservation Project, unpublished data):

- It has been estimated that this community may take approximately 260 turtles annually.
- The tagged adult female *C. mydas* captured within the hunting area of this community have been mostly from the SGBR rookeries (Figure 8).

Palm Island

In 1976, the author spoke with elders on the island who described the difficulty in finding turtles on the reefs adjacent to the island where in past decades they had been readily available. They claimed they were now travelling further afield to capture turtles. The size of the annual turtle harvest by this community has not been documented, although there is the qualitative opinion that "turtles have decreased significantly" and the community believes that "pleasure boating is disturbing the turtle populations" (Gray & Zann, 1988).

- Depending on who has been interviewed, the Palm Island community catch has been estimated at 100 – >500 per year. However, these data have not been validated.
- All except one of the tagged *C. mydas* captured by this community have been adult females tagged while nesting at southern GBR rookeries, the remaining one had been tagged when nesting in northern New Caledonia.

Other east coast communities

There are no quantified catch statistics from the other coastal Aboriginal communities in eastern Australia. In addition there is now regular hunting of turtles by urban dwelling indigenous people along the east coast (EPA Marine Wildlife Stranding and Mortality Database).

- While the number of turtles taken by urban hunters is not quantified, permits were issued by GBRMPA to capture 140 *C. mydas* between June 1991– March 1993 from Mackay to Cairns (Unpublished data from GBRMPA files).
- There is no indication of the size of the harvest at localities further south such as Port Curtis, Hervey Bay and Moreton Bay.

Because most nesting occurs on uninhabited islands, the annual egg and/or hatchling harvest for human consumption from within the southern GBR *C. mydas* stock, although not measured, probably approaches zero (Unpublished data, EPA Queensland Turtle Conservation Project:).

An order of magnitude estimate of the size of the combined annual catch for all east-coast Aboriginal communities south of 14^{o} latitude (Hopevale, Mossman, Yarrabah, Palm Island, Bowen, Mackay, Rockhampton, Port Curtis, Hervey Bay and Moreton Bay) and urban hunters from Mossman to the Gold Coast is 500–1000 per year. This harvest targets mostly large females and, based on tag recoveries, consists primarily of turtles from the southern GBR *C. mydas* stock.

3.2.2 QUEENSLAND TORRES STRAIT AND FAR NORTHERN GBR

Lockhart River

In former times, *C. mydas* was the favoured species for harvest and, when harvesting from mating pairs, the female with immature "eggs" was preferred (Smith, 1989; Thomson, 1934). These authors identified that *C. caretta* and *E. imbricata* were also taken. In 3 months (late September–late December 1985), at least 30 *C. mydas* were captured (at least 27 *C. mydas* captured in a comparable period at Hopevale) and of 12 turtles examined for sex and maturity, there were 3 adult females, 8 immature females, 1 adult male (Smith, 1989).

- Tagged *C. mydas* captured within the hunting area of this community (11–13^{o}S latitude in the northern GBR) have been mostly adult females from the northern GBR rookeries (Figure 8).
- It is presumed that the annual harvest by the Lockhardt River community is similar in size to that of the Hopevale community, ie. approximately 100 *C. mydas* per year.

Torres Strait

Chelonia mydas has been harvested by Indigenous inhabitants of Torres Strait (Figure 24b) since pre-European times (Allen & Corris, 1977; Moore, 1979). An estimated 2410 (2050–2760) turtles (approximately 98% *C. mydas*) were captured annually from the 14 inhabited islands of the Torres Strait Protected Zone, and the catch appears to be biased to females with the majority being adult and near adult turtles (Harris *et al*. 1992a,b). An estimated 4000 could be killed annually by Islanders who live in the whole Queensland Torres Strait north from Bamaga (Harris *et al*. 1992a,b; Johannes & MacFarlane, 1991; Limpus & Parmenter, 1986; Limpus *et al*. 2001; EPA Queensland Turtle Conservation Project, unpublished data).

- This harvest was not quantified in the distant past but appears to have been of this order of magnitude over the past decade.
- Most of these turtles are caught in the water but some nesting turtles are taken from beaches, especially at the Murray Islands, Darnley Island and Bramble Cay (Limpus *et al*. 2001).
- There is active selection for large female turtles in this harvest (Figure 23, 24). Of 28 *C. mydas* recorded from the Badu Island harvest during April–November 1979 and sexed on gonad examination, only 3 were males (S. Garnett, pers. comm.). Of 41 large *C. mydas* harvested at Yorke Island during October 1976–June 1977, only 11 were males (Parmenter, 1980b).

The harvest includes:

- Resident turtles that feed in Torres Strait.
- Turtles migrating through the straits to nest at rookeries in the GBR and Coral Sea (Figure 6, 14, 19).
- Courting turtles (this is a mixed subset of the migrating and resident turtles).
- Migrant turtles that nest on the islands of Torres Strait.

Egg harvest occurs at the Torres Strait rookeries but it has not been quantified.

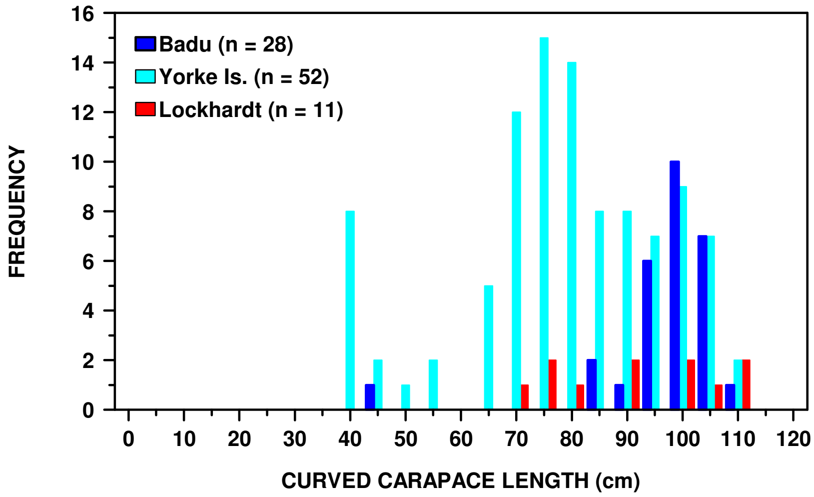


Figure 23. Size range of *Chelonia mydas* harvested in Torres Strait and far northern Great Barrier Reef. Badu Island sample recorded by S. Garnett (pers. comm.), York Island data from Parmenter (1980b) & Lockhardt River Community from Smith (1989).

24a. Live slaughter of an adult *Chelonia mydas* in a street-side butcher shop, Denpasar, Bali, 1986.

24b. Butchering an adult male *Chelonia mydas*, Torres Strait, 1978.

Figure 24. *Chelonia mydas* is a commonly harvested turtle in northern Australia and in neighbouring countries.

24c. *Chelonia mydas* captured on the Warrior Reefs, Torres Strait and being brought to market at Daru, PNG, 1992.

24d. *Chelonia mydas* awaiting slaughter, Tandang Benoa, Bali, 1995.

Figure 24. continued.

An unquantified annual egg harvest occurs at the rookeries of the northern GBR stock. Most of this harvest occurs in eastern and central Torres Strait, particularly from Bramble Cay and the Murray Islands, and the small rookeries of the inner shelf of the northern Great Barrier Reef (Johannes *&* MacFarlane, 1991; EPA Queensland Turtle Conservation Project, unpubl. data).

The majority of the turtles tagged at rookeries and recaptured in Torres Strait have been from the northern GBR breeding unit (Figure 6, 14). Small numbers have come from the southern GBR and Coral Sea stocks (Figure 6, 8, 20). Genetic analysis of hunted turtles from Queensland Torres Strait showed that they were predominantly from the northern GBR stock (Norman, 1995).

Western Cape York and Gulf of Carpentaria

The turtle harvest within the Queensland Gulf of Carpentaria by indigenous communities is unquantified. Bradley (1991, 1997, 1998) provides insights into the significance of turtles and turtle hunting within indigenous culture in this region Individual clans and out-stations may be taking in the low tens of turtles annually. Tag recoveries from hunted turtles have originated mostly from females tagged in the northern GBR rookeries with smaller numbers from the southern GBR and Western Australian rookeries. Within the Wellesley Group the harvest targets both the foraging turtles from mixed stock origins and nesting females from the local Wellesley Group courtship and nesting population.

3.2.3 NORTHERN TERRITORY and WESTERN AUSTRALIA

There are few data on the numbers, size range, sex and breeding status of *C. mydas* that are harvested at the many coastal communities and out-stations of Northern Territory and Western Australia.

Kennett *et al.* (1998) estimated that the eight out-stations on the north east Arnhem coast from near Nhulunbuy to the northern end of Blur Mud Bay harvested predominantly *C. mydas* (97% of the harvested turtles by species) and that these communities harvested a total of approximately 480 *C. mydas* annually. This harvest:

- A significant proportion of this was boat based harvesting in Blue Mud Bay some distance south of Nhulunbuy (Rod Kennett, pers. Comm.).
- Targets mostly adult and large immature turtles (Figure 25) from both the local foraging areas and the nesting beaches.

- Is biased to females with about 3:1 female to male ratio. This reflected to community preference for consumption of female turtle.

During the 1995 Nanydjaka beach survey (northeast Arnhem Land), *C. mydas* accounted for 11% of clutches of eggs harvested from this 11km beach (Kennett *et al*. 1998). The Yolngu egg collectors took 87% and 95% of all clutches laid on the beach during two monthly surveys and they showed no bias to species during egg collection. It can be noted that access to much of the nesting areas on Nanydjaka is now restricted by a locked gate (Rod Kennett, pers. Comm.).

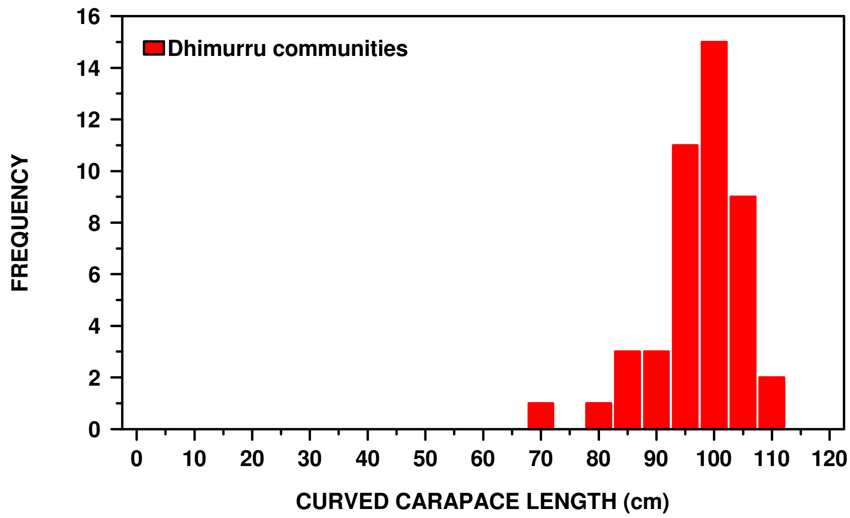


Figure 25. Size range of *Chelonia mydas* harvested in northeastern Arnhem Land (Kennett et al. 1998).

On the Dampier Peninsula of northern Western Australia, Morris and Lapwood (2001) recorded a harvest of 96 *C. mydas*, with the harvest biased to adult-sized females, during 4 months in October 2001– January 2002. Morris (Pers. comm., October 2002) expressed the opinion that the annual harvest for the Dampier Peninsula area could be about 500 *C. mydas* annually. Three partial clutches of *C. mydas* eggs were harvested during this study period. The level of hunting reported in this study is an order of magnitude higher than that reported from the late 1970s (Kowarsky, 1982). In 1990, Dr Prince also expressed the opinion that the indigenous harvest in the Dampier Peninsula area was considerably larger than that reported by Kowarsky (Prince, 1994). Given the differences in methodogies and the vagueness of extrapolations, these opinions/studies highlight the need for rigorous methodologies to be applied in studies of directed take of turtles and the need for repeated assessment of current take levels.

The size of the annual harvest by indigenous people across northern and Western Australia needs better quantification. The total harvest probably is of the order of several thousand *C. mydas* annually (Kowarsky, 1982; Henry & Lyle, 2003).

While Stock composition within this harvest has not been quantified:

- *C. mydas* harvested in this indigenous fishery have included adult females tagged while nesting at rookeries for the southern and northern GBR, Gulf of Carpentaria, North West Shelf of Western Australia and southern Java stocks (Limpus *et al*. 1992; Prince, 1998; Kennett *et al*. 2004).
- The harvest is expected to be strongly biased to taking large immature and adult-sized turtles that are mostly female (Kennett *et al*. 1998; Morris & Lapwood, 2001).
- The Aru Islands (Indonesia) Stock (Figure 3) is expected to be represented in this harvest also.

For a number of years there has been a non-permitted harvest of *C. mydas* and/or their eggs from the more remote rookeries in the Timor Sea off northwestern Western Australia and Northern Territory by Indonesian fishermen. In the extreme, nesting turtles ashore for egg laying at Browse Island were turned and their oviducal eggs removed via an incision in the inguinal pocket (Figure 26. Saunders, 1999). Although this results in the death of the turtle, these turtles were not utilised for food. In October 1999, there were 39 recently dead turtles on the beach, presumably mostly killed by this activity.

There has also been non-permitted harvest of *C. mydas* by Indonesian fishermen within the Ashmore Reefs and Cartier Island (Whiting *et al*. 2000). This harvest has been poorly quantified.

Figure 26. Adult female *Chelonia mydas* that were killed at Browse Island in October 1999 by the removal of oviducal eggs via an incision in front of the hind limb while the turtle was still alive. The turtles were subsequently left to die. Photographs by K. Saunders.

3.3 HARVESTS IN NEIGHBOURING COUNTRIES

3.3.1 NEW CALEDONIA, FIJI, VANUATU

Chelonia mydas tagged while nesting in the GBR have been harvested in the countries bordering the eastern Coral Sea and south western Pacific basin in New Caledonia, Fiji, Vanuatu (Limpus *et al*. 1992).

- Almost all tag recoveries are of turtles hunted for food.
- There have been more tag recoveries of southern GBR *C. mydas* stock reported from these countries (Figure 6) than from aboriginal hunting in Queensland south of Cape Grenville (EPA Queensland Turtle Conservation Project, unpublished data). Assuming that there is approximately equal probability of reporting of tag recoveries from both sources, then it is presumed that the 500–1000 or more southern GBR *Chelonia mydas* stock are harvested annually from these countries.
- The harvest of northern GBR *C. mydas* stock in these countries appears to be minimal (Figure 14).

3.3.2 PAPUA NEW GUINEA

Torres Strait

Within the north eastern area of the Torres Strait Protected Zone, there was a minimum harvest by the Kiwai people estimated at 953 – 1363 turtles annually during 1985–1987, of which 94–98% were *C. mydas* (Kwan, 1989, 1991. Figure 24c). An independent study based in Tureture village during 1986 provides a larger estimate (by a factor of 2 or more) of the harvest by the Kiwai (Eley, 1989).

- This harvest centres on Daru and villages along the adjacent coast.
- There is additional hunting, probably taking smaller numbers, by PNG villagers in northwestern Torres Strait (Limpus *et al*. 1989).
- The hunting in Torres Strait by the Kiwai people has been characterised by (Kwan, 1989, 1991):
    - Increasing number of fishermen, especially those with no traditional experience in turtle fishing.
    - Modernisation of traditional hunting methods, particularly the use of the motorised canoe.
    - Apparent breakdown of traditional practices such as the reef ownership system.
- These people show a preference for large female turtles, especially breeding females because of their perceived better taste and higher fat content.

Stock composition of this PNG harvest is similar to that described for Queensland Torres Strait with ~90% of the harvested *C. mydas* originate from Australian (Queensland) rookeries (Norman, 1995).

The remainder of PNG

The *C. mydas* harvest in the remainder of PNG remains to be quantified. Turtles are sold in most coastal markets (Spring, 1982, Hirth & Rohovit, 1992). A substantial proportion of nesting turtles and their eggs have been harvested in past years at Long Island on the northern coast (Spring, 1983).

Turtles from both northern and southern GBR *C. mydas* stocks are represented in this harvest (Figure 6, 14).

3.3.3 INDONESIA

The most significant harvest of *C. mydas* in the Australian region occurs in Indonesia (Groombridge & Luxmoore, 1989).

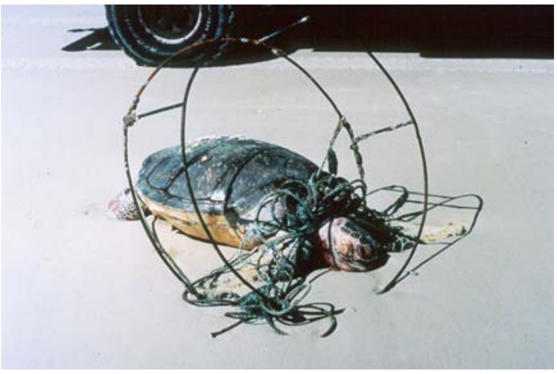
- Tag returns to the EPA, WACALM and SPREP turtle research projects indicate that substantial numbers of turtles from the eastern and western Australian rookeries and the PNG Long Island rookery are being captured in eastern Indonesia.
- These turtles are eaten locally (Kitchener, 1996; Saurez, 2000) or were shipped to Bali and other centres of turtle trade within Indonesia (Schulz, 1984,1989; Sahertian & Noija, 1994).

The total size of this *C. mydas* harvest in Indonesia has been partially documented.

- At Bali alone, there was an annual kill of some 20 000$^+$ *C. mydas* during the 1980's and 1990's (Limpus, 1994, 1997). Allowing for mortality during the capture and transport of the turtles to Bali, it is estimated that approaching 30 000 green turtles annually were harvested to supply the Bali markets (Figure 24a, 24d).
- WWF Indonesia staff have indicated that 50 000$^+$ green turtles annually could have been killed in the whole of Indonesia in the 1980s (H. Reichart, pers. comm.).
- The large trade in turtle to Bali has been reduced since about 2001 following the declaration of *C. mydas* as a protected species in Indonesia. In 2003, it was reported that the trade in turtles in Bali had been reduced by at least 50% and with "whole turtles now not always being brought into Bali but brought in as meat" (W. Adnyana, *in litt*.).
- Given that the major nesting concentrations for the species within the region occur in Australia, it is presumed that a large proportion of the *C. mydas* harvested in southern and eastern Indonesia were from Australian nesting stocks.

Eating of turtles is a long-standing tradition among the Balinese and some other ethnic groups in Indonesia (Putra, 1987). However, the Bali harvest appears to have escalated with increased human population levels during the late 20th Century. The large harvest numbers appear to be a feature since about 1980 and are probably coincident with an escalation of intense harvests of *C. mydas* from eastern Indonesia. It is considered that the current level of harvest in Indonesia is not sustainable and is threatening the regional *C. mydas* stocks.

3.4 ACCIDENTAL MORTALITY FROM HUMAN RELATED ACTIVITIES



27a. Entangled in the floatline to a lost or discarded crab-pot, Fraser Island.

27b. Trawl bycatch, Northern prawn Fishery. Photograph by C. Robins.

27c. Large immature *C. mydas* with propeller cuts, Moreton Bay

27d. Immature *C. mydas* with ingested fishing line, Moreton Bay.

27e. Juvenile *C. mydas* in beach-washed ghost nets, Weipa.

27f. Post-hatchling *C. mydas* (CCL = 10cm). The plastic debris had formed a gut blockage, resulting in its stranding on North Stradbroke Island.

Figure 27. Illustrations of a range of anthropogenic impacts on *Chelonia mydas* in northern Australia.

3.4.1 SHARK CONTROL PROGRAMS

Queensland

Chelonia mydas has been to be a 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 contractors did not normally record the species of turtle and hence the species composition of the catch and precise number of *C. mydas* drowned in these nets is not usually available.
- Since 1986, most captured turtles were scored for their survival or condition at release. For the 7yr period, 1986–1992, 586 turtles were recorded captured (Sunfish Shark Control Subsidiary 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. mydas*. It is presumed that this species would not account for more than a third of these mortalities, i.e. <7 *C. mydas* 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. mydas* mortality during 1992/3–1995 within the QSCP for all of Queensland was low, <8 individuals, because ~87% of captured turtles were released alive (Gribble *et al*. 1998).
- During 1998–2003 there have been 53 *C. mydas* captured with 33 taken on drum lines and 23 taken in nets. Of these, 91% are released alive from drum lines and 52% are released alive from nets. Observed *C. mydas* mortality during 1998–2003 was 2.7 per year (Anon, 2003; EPA Queensland Turtle Conservation Project).

These data suggest that the modifications to the QSCP since 1992 have contributed to a reduction in *C. mydas* mortality.

New South Wales

Chelonia mydas has been recorded among those turtles identified to species from the New South Wales shark-meshing program (Krogh *&* Reid, 1996). However, most turtles were unidentified to species and mortality rates were not recorded. If *C. mydas* 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.

3.4.2 COMMERCIAL FISHERIES

No precise figure can be placed on the total mortality of Australian *C. mydas* stocks in commercial fisheries bycatch. 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.

Trawling

The interaction between turtle 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 *&* Reimer, 1994).

In contrast to the regular capture of tagged *C. caretta* and *N. depressus* being reported in prawn trawls in Queensland, tagged *C. mydas* have been less frequently reported. The following summarises the more significant available data pertaining to the interaction of *C. mydas* and trawling in Australian waters:

- The capture of *C. mydas* in prawn trawls has been recorded by trained on-board recorders prior to 1990 (Limpus & Reimer, 1994; EPA Queensland Turtle Conservation Project, unpublished data); 6.7% of 90 turtles captured by one fisher within the Northern Prawn Fishery operating in the Gulf of Carpentaria over seven years; 8.9% of 45 turtles captured in the northern GBR between Princess Charlotte Bay and Cape York; and 3.3% of 30 turtles captured in the Townsville area.
- During a two-year CSIRO study of turtle bycatch in the northern prawn fishery, *C. mydas* made up 8.5%–6.8% of the 165 and 161 turtles trawled in 1989 and 1990 respectively. The *C. mydas* impacted by this fishery encompassed all size ranges from small immature to adults. Catch rate were 0.0042±0.0011 turtles per trawl in 1989 and 0.0036±0.0011 in 1990, with a 14.3% probability of being landed dead in the sorting tray in 1989 and 9.1% probability in 1990. This study estimated that the northern prawn fishery killed approximately 51 and 48 *C. mydas* in 1989 and 1990 respectively (Poiner & 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, 1995; Robins & Mayer, 1998). This study found that *C. mydas* was the second most commonly reported turtle in the ECTF bycatch (28.4% of 1,527 turtles reported; range per year = 23%–42%). *C. mydas* was the second most common among the reported turtles in the TSPF bycatch (21% of the 151 turtles reported.). The *C. mydas* impacted by both fisheries encompassed mostly the adult and large immature size ranges. The extrapolated mean annual catch of *C. mydas* within the entire fishery was estimated at 1562 in ECTF and 145 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 1–6% (n = 4–26) in ECTF and 9% (n = 13) in TSPF. *C. mydas* were trawled across the entire length of the east coast from Moreton Bay to Torres Strait.
- One small immature *C. mydas* was among 15 dead beach-washed marine turtles in Fog Bay, western Arnhem Land over a few weeks prior to September 1995 (Guinea *et al*. 1997). These deaths were attributed to trawl bycatch. *C. mydas* foraging in this area will have originated primarily 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 3% of the turtles reported captured were *C. mydas* (Figure 27b). The introduction of TEDs to the fishery resulted in a two order of magnitude reduction in turtle captures in the NPF trawls.

The trawl fisheries off the coast of New South Wales, Queensland, Northern Territory and Western Australia have had the potential to kill many tens or possibly low hundreds of *C. mydas* annually since the late 1970s. Since the late 1980's, the best guess estimate of *C. mydas* mortality in trawl fisheries in eastern and northern Australia is 50–100 turtles per year (Poiner & Harris, 1996; Robins & Mayer, 1998). The comparable data from Western Australian trawl fisheries is not available. Collectively across Australia, 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 the Northern Prawn Fisheries studies (Poiner & Harris, 1996), there were large interspecific differences in probability of drowning when a turtle is captured in a trawl (Table 27). *C. mydas* appears to have a low susceptibility to drowning when compared to *C. caretta* and *E. imbricata* in Australia.

Table 27. Probability of marine turtle mortality with trawling captures in the Northern Prawn Fisheries, 1989–1990 (Poiner & Harris, 1994).

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

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 because of the level of bycatch of marine turtles.

Tunnel nets

Tunnel-nets, which capture many thousands of *C. mydas* annually in Moreton Bay and Hervey Bay appear to cause no mortality to these turtles (EPA Queensland Turtle Conservation Project, unpublished data).

Gill nets

Chelonia mydas are caught and occasionally drown in barramundi, salmon, mackerel and shark gill-net fisheries (N3 and N9 fisheries) in Queensland and the Northern Territory.

- Immature *C. mydas* have been regularly captured in N3 fishery gillnets set along the coast of the southeastern Gulf of Carpentaria (21% of 47 turtles tagged by G. Ward during two years in the early 1990's. Unpublished data, EPA Queensland Turtle Conservation Project).
- N3 fishery, Gulf of Carpentaria: On board observers recorded 3 turtles, including *C. mydas*, that interacted with N3 fishing gear during 4446 fishing hours in 1999–2002 (Roelofs, 2003). All were released alive.
- N9 fishery, Gulf of Carpentaria: On board observers recorded 3 *C. mydas* that interacted with N9 fishing gear during 195 shots (0.0016 turtles/500m of net/hour) in 1999–2002 (Roelofs, 2003). Two of the three were released alive.
- *C. mydas* mortality has been recorded in gill nets at Hervey Bay, Gladstone, Repulse Bay, Cairns and Torres Strait (EPA Queensland Turtle Conservation Project, unpublished data).

The annual kill of turtles in the inshore gill net fisheries of eastern Queensland, the Gulf of Carpentaria and Arnhem Land remains unquantified.

Crab fisheries

C. mydas is increasingly being found tangled in float lines to crab pots in Queensland (Table 28. Figure 27a). In recent years, small immature *C. mydas* are drowning inside the collapsible crab pots increasingly being used by amateur crabbers. The extent of size of this crab fishery mortality remains incompletely quantified. Mortality is presumed to be in the tens per year.

3.4.3 BOAT STRIKES

With increasing high-speed boating traffic in coastal waters, many tens of *C. mydas* annually are recorded killed by boat strike and propeller cuts in Queensland (Table 28. Figure 27c). The majority (60%) of *C. mydas* killed by boats are adult-sized (Figure 28). Given that strandings provide an incomplete census of the actual number of turtles being killed by boating interactions, it is expected that the high tens or low hundreds of *C. mydas* die from this source annually in Queensland.

3.4.4 PORT DREDGING

In response to concerns from the conservation community regarding turtle mortality, a code of practice that addressed reduction in turtle captures was developed for port dredging operations in Queensland during the late 1990s. *C. mydas* mortality from port dredging in Queensland is expected to be of the order of ten turtles or less annually (Table 28).

Table 28. Frequency distribution of reported mortality of adult and near adult *Chelonia mydas* from anthropogenic activities in near shore waters in Queensland. These are minimal mortality rates, given that predators or decay will destroy some carcasses before they can strand. EPA Marine Wildlife Stranding and Mortality Database (Ludeke, 1993; Flakus & Limpus, 1999, Haines et al. 2000; Haines & 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	1	13	3	0	–
–					
1998	4	38	11	2	–
1999	7	69	4	8	–
2000	7	57	3	11	1
2001	14	66	4	3	3
2002	18	55	4	7	0

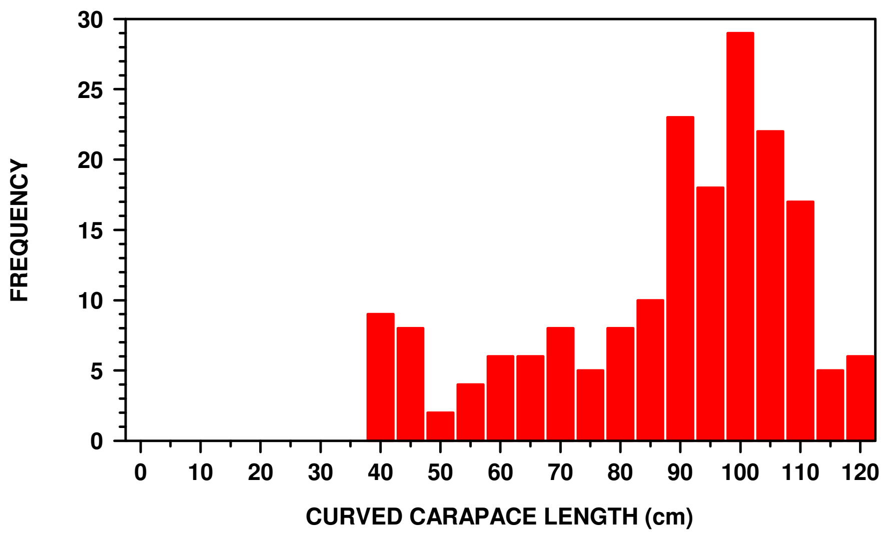


Figure 28. Size class distribution of *Chelonia mydas* killed by boat-strike and propeller cuts in Queensland. Data derived from the EPA Marine Wildlife Stranding and Mortality Database.

3.4.5 MARINE DEBRIS

Chelonia mydas mortality in Queensland from ingestion of fishing line and other synthetic debris and from entanglement in fishing line and ropes is expected to account for at least tens of turtles annually (Table 28. Figure 27d, 27f). Without necropsies of a large proportion of the dead beach washed turtles, mortality from ingested synthetic debris remains poorly quantified.

There are isolated records of immature *C. mydas* that died from ingestion of synthetic debris in northern New South Wales (EPA Marine Wildlife Stranding and Mortality Database).

Glazebrook and Campbell (1990) identified that *C. mydas* could not digest the introduced aquatic fern, *Salvinia molestra*, and gut blockage could result from its ingestion.

Ghost net entanglement

Large amounts of fishing net are discarded or lost from the fisheries of the Gulf of Carpentaria and Arafura Sea and end up beach-washed on the Queensland and Northern Territory beaches of the Gulf of Carpentaria (Chatto *et al*. 1995; Leitch, 1997; Limpus & Miller, 2002; White, 2003, 2004). In addition, when cyclones pass from the Coral Sea across Cape York Peninsula into the Gulf of Carpentaria each summer, they cause erosion of the beaches of western Cape York Peninsula and the southern Gulf coast. With this erosion, thousands of nets can be returned to the sea only to drift and re-strand in the weeks that follow (Figure 27e). For example, in the six weeks following Cyclone *Abigail* in February 2001, it is estimated that over 4000 nets washed ashore containing in excess of 400 turtles along the eastern Gulf of Carpentaria Coast (C. Limpus, unpublished data). Similar stranding of nets and entangled turtles has been recorded following cyclones in the three years since 2001 (V. Wallen, pers. comm. August 2004; EPA Marine Wildlife Stranding and Mortality Database). There are thus two separate issues with regard to the entrapment of turtles in these "ghost nets": entanglement in floating nets which drift onto beaches each year and the recycling of nets from the beaches back to the sea where they have the potential for entangling turtles before subsequent re-stranding.

Turtle entanglement in beach-washed ghostnet has been monitored in the vicinity of Cape Arnhem and Port Bradshore from 1996 to 2003 (Leitch, 1997, 2001; Roeger, 2004). Turtles entangled in ghost nets appear to strand here mainly in the early dry season, April–August (Roeger, 2004).

An unquantified proportion of the turtles stranding in these nets along the Queensland Gulf of Carpentaria coast are small immature *C. mydas* (Figure 27e) (EPA Marine Wildlife Stranding and Mortality Database). In northeastern Arnhem Land, there have been 34 (17.5%) immature *C. mydas* among a sample of 194 marine turtles recorded entangled in discarded or lost fishing net which drifted ashore during 1996–2003 with 62% of *C. mydas* released alive (Leitch, 1997, 2001; Roeger, 2004). The extent to which this type of mortality extends further across northern Arnhem Land (Chatto *et al*. 1995) is undetermined. However, White (2004) reports that *C. mydas* account for 17% of turtles in ghostnets floating in the Arafura Sea north of Tiwi Islands.

The *C. mydas* mortality throughout the Gulf of Carpentaria and Arnhem Land within this "ghost net" fishery is unquantified but appears to be many hundreds of turtles annually.

3.5 DISEASES

Diseases in wild *C. mydas* have received limited study in Australia. The following are health problems described for Australian populations.

3.5.1 COCCIDIOSIS

During late 1991, at least 70 *Chelonia mydas*, mostly large immatures, died in southeastern Queensland from coccidiosis infection (Gordon *et al*. 1993). There is the distinct possibility that this disease was the result of environmental contamination. Mortality from this disease was not detected during comparable studies in 1992 and 1993 in the same area but it has been detected more recently (EPA Queensland Marine Wildlife Stranding and Mortality Database).

3.5.2 FIBROPAPILLOMA-ASSOCIATED TURTLE HERPESVIRUS

Green turtle fibropapilloma disease is an infective disease that is currently believed to be caused by a "herpes" virus (Balazs & Pooley, 1991). Genetically the fibropapilloma-associated turtle herpesvirus (FATHV) from Queensland and Hawaii are very similar, irrespective of the infected turtle species (Quackenbush *et al*. 2001). Mortality from this disease is unquantified but beach-washed, dead or moribund, infected turtles are regularly encountered in south Queensland (EPA Queensland Turtle Conservation Project, unpublished data).

Davidson (2001) has reviewed the history of this disease with an emphasis on Hawaii. The mode of transmission of the disease has been ambiguous (Aguirre *et al*.1994a). Attempts to correlate the incidence of the disease with pesticide residue and heavy metal pollution levels in US waters have, to date, been unsuccessful (Aguirre *et al*.1994b). However, all areas reported with high rates of infection occur adjacent to agricultural and/or industrial lands. Ecto-parasitic, annilid leeches, *Ozobranchus* spp., with external gills are common on *C. mydas*, especially in seagrass habitats throughout eastern and northern Australia (Limpus *et al*. 1994a). These leeches have been implicated as the vector for fibropapilloma associated turtle herpes virus from one turtle to another (Greenblatt *et al*. 2004).

The occurrence of FATHV disease in turtles is variable between habitats. In Queensland, it is rarely encountered in off shore coral reef habitats but is prevalent with *C. mydas* in semi-enclosed waters such as Moreton Bay and Repulse Bay (Limpus *et al*. 1994a; Limpus & Miller, 1994). However, 14.3% of *C. mydas* foraging in the near-shore, open waters of Julia Rock Aquatic Reserve in New South Wales had externally visible tumours (Speirs, 2002). The disease has been reported by local turtle hunters with *C. mydas* foraging among the Wellesley Islands, Gulf of Carpentaria (EPA Queensland Turtle Conservation Project, unpublished data) and from Western Australia (Raidal & Prince, 1996).

There is increasing evidence that the development of tumours in infected turtles may be influenced by the presence of naturally occurring tumour promoting toxins ingested by the turtles (Landsberg *et al*. 1999). The most likely candidates for the sources of these toxins are dinoflagelates (*Procentrum*) and cyanobacteria (*Lyngbya*) (Landsberg *et al*. 1999; Davidson, 2001).

3.5.3 PARASITIC WORMS

Chelonia mydas is host to a wide array of parasitic worms (Table 29). However, the most frequently encountered and those that are probably the cause of some mortality with *C. mydas* are the blood flukes, spirorchiid trematodes (Gordon *et al*. 1998; Raidal *et al*. 1998) that inhabit the turtle's circulatory systtem.

The mode of transmission of these parasites to the turtle is unidentified. The turtle is the primary host and the blood fluke eggs distribute widely in the turtle's soft tissues, sometimes causing blockages to blood vessels. These eggs presumably hatch when a suitable predator consumes the turtle. Because the eggs fail to hatch in the human digestive tract and are voided with the faeces (Blair & Miller, 1992), it is unlikely that mammals are part of the life history of these blood flukes. Mortality from parasitic worms is mostly unquantified in Australia but beach-washed, dead or moribund turtles that are heavily infected with blood flukes are regularly encountered in south and north Queensland (Gordon *et al*. 1998). These may not be related to anthropogenic factors.

Table 29. Summary of endo-parasitic worms identified from *Chelonia mydas* in Australia.

Species	Biology	Reference
Nematoda		
Anisakis type I	In gut and pleuroperitoneal cavity of farmed turtles. Derived from feeding infected fish to the captive turtles. This is probably not a natural parasite of *C. mydas*	Carr and Main, 1973 Glazebrook & Campbell, 1990a
Platyhelminthes, Digenea		
Angiodictyum postervitellatum	Large intestine	Blair, 1986
Angiodictum longum	Pseudocaecum and large intestine	Blair, 1986
Cricoephalus sp.	In stomach and small intestine	Glazebrook & Campbell, 1990a
Desmogonius sp.	In stomach and small intestine	Glazebrook & Campbell, 1990a
Microscaphidium reticulare	In oesophagus, intestine, pseudocaecum, large intestine	Blair, 1986
Microscaphidium warui	In oesophagus, intestine, pseudocaecum, large intestine	Blair, 1986
Octangium sp.	In large intestine	Glazebrook & Campbell, 1990a
Polyangium Linguatula	In intestine	Blair, 1986
Polygorgyra cholados	In intestine	Blair, 1986
Rhytidodes sp.	In gall bladder	Glazebrook & Campbell, 1990a
Schizamphistomum sp.	In large intestine	Glazebrook & Campbell, 1990a
Spirorchiidae		
Hapalotrema mehrai	In circulatory system, eggs in body organs	Gordon *et al*. 1998
Hapalotrema postorchis	In circulatory system, eggs in body organs	Gordon *et al*. 1998
Learedius sp.	In circulatory system, eggs in body organs	Glazebrook & Campbell, 1990a
Neospirorchis schistosomatoides	In circulatory system, eggs in body organs	Gordon *et al*. 1998

3.5.4 FUNGI

Fungi (Table 30) have been identified from the cloaca of *C. mydas* and from nesting substrate and in some cases, causing the death of eggs within the nest.

3.5.5 PARASITIC ARTHROPODS

Cloacaridae mites, *Chelonacarus* sp. have been found in the cloaca of nesting female *C. mydas* at Raine Island (Shaw, 2002; Pence & Wright, 1998). These parasites have not been linked to any health issues for the turtles.

Table 30. Recorded fungal infection of *Chelonia mydas* turtles and eggs in Australia. A = adult; I = immature

Species	In cloaca of adults (A), immature (I)	On eggs in nests	Reference
Aceremonium sp.	Foraging on Heron Reef (A) Foraging at Shoalwater Bay (A,I) Nesting on Heron Island (A)		Phillott *et al*. 2002
Aspergillus sp.	Nesting on Heron Island (A)		Phillott *et al*. 2002
Cladosporium sp.	Foraging on Heron Reef (A,I)		Phillott *et al*. 2002
Fusarium solani	Nesting on Heron Island (A)	Heron Island	Phillott *et al*. 2001, 2002
Fusarium oxysporum	Nesting on Heron Island (A)		Phillott *et al*. 2001, 2002
Mucor sp.	Nesting on Heron Island (A)		Phillott *et al*. 2002
Penicillium sp.	Foraging on Heron Reef (A) Nesting on Heron Island (A)		Phillott *et al*. 2002
Pseudallescheria boydii		Heron Island	Phillott *et al*. 2001

3.5.6 SOUTHERN GULF OF CARPENTARIA POOR HEALTH TURTLES

During 2002–2003, local residents in the Wellesley Islands were concerned about the unusual numbers of poor condition *C. mydas* with "black fat" (Kwan *&* Bell, 2003). Dugongs in the same area were reported to be in poor health also. During 2003–2004, local residents in the Sir Edward Pellew Islands area have reported exceptionally large numbers of debilitated/floating *C. mydas* (Chapman, 2003). This same report indicated that a number of these poor health turtles had "black fat and jelly meat". Unusually large numbers of recently dead *C. mydas* beach-washed on Vanderlin Island were observed in late 2004 by local fishers (G. Newman, pers. comm. September 2004). Local indigenous hunters are reportedly no longer hunting turtles in the area because of the large numbers of diseased turtles (S. Whiting, pers. comm. September 2004).

While this issue is under investigation (Chapman, 2003), several issues have been hypothesised as the cause of this health change with these turtles (Kwan *&* Bell, 2003; S. Whiting pers. comm.; C. Limpus personal opinion):

- Possible negative impacts on seagrass pastures in response to local flooding and
- Possible negative impacts from the zinc-lead export infrastructure in the Karumba–Wellesley Islands and MacArthur River Delta areas.

However, there is insufficient information to refute or support these hypotheses (Kwan *&* Bell, 2003).

3.6 TOXIC COMPOUNDS

Farm reared *C. mydas* died from ingestion of fish that had been contaminated with spilt diesel fuel (Glazebrook *&* Campbell, 1990a).

Chlorinated hydrocarbon compounds

In a study to investigate the potential effects of the DDT metabolite DDE on sexual differentiation of *C. mydas*, Podreka *et al*. (1998) failed to demonstrate any change in sex ratio in response to incubation temperature, while incubation time, hatching success, incidence of body deformities, hatchling size and weight were within the limits of healthy hatchlings. This same study reported less than 2.5ng/g DDE concentration in natural eggs at Heron Island.

Polychlorinated dibenzo-p-dioxins and dienzofurans (PCDD/Fs) have been identified at significant concentrations in eastern Australian *C. mydas* with evidence of bioaccumulation via coastal sediments and seagrass (Gaus *et al*. 2001; Hermanussen *et al*. in press). The former study found that the lowest levels were from offshore turtles compared to highest concentrations from inshore turtles. The impact of these potentially damaging contaminants on marine turtle population dynamics remains to be determined.

Heavy metals

Heavy metal concentrations in *C. mydas* have been reported from few studies in Australia (Dight & Gladstone, 1994; Reiner, 1994; Gordon *et al*. 1998). The implications of heavy metal concentrations measured in the turtles with respect to their health have not been evaluated. Heavy metal values from samples collected from nesting females (Reiner, 1994) have little relevance to the local environmental impacts within the internesting habitat, given the brief time the turtles spend in the area and their reduced foraging that occurs at this time of their life history. Similarly, the heavy metal values measured in a few turtles during the Torres Strait base line study (Dight & Gladstone, 1994) cannot be broadly applied to the turtles in Torres Strait because the study failed to identify whether resident foraging turtles were sampled or if they were breeding migrants from some distant foraging areas.

3.7 HABITAT DAMAGE

Nuclear testing on nesting habitat

The British Government in collaboration with the Australian Government conducted the 1st test of nuclear weapons in Australia during *Operation Hurricane* on 3 October 1952 near Trimouille Island, Montebello Group, Western Australia (Figure 29). The Montebello Group is a significant breeding site for *C. mydas* and *N. depressus* (Pendoley, 1999) and this nuclear test would have coincided with courtship time for these populations. It can be assumed that the October 1952 nuclear test would have killed an appreciable number of the turtles that were aggregated in the shallow waters for the 1952–1953 breeding season. There is a brief account of a landing on beaches south of Pitt Point, Trimouille Island (1–1.5km north of the blast site) in June 1953 that describes the stench and devastation of the turtles (Kendrick, 2003): "….for the entire length of the beach (two beaches, each about 500 metres long). Dead turtles were 'piled three or four deep, in a layer from six to ten feet (two to three metres) wide'. Turtles of all sizes were represented: some were too large for one man to lift, while others were clearly hatchlings being small enough to fit in one's hand'." A medium sized carapace; "about 0.5m long" was removed from the beach but discarded because it was "radioactive". While the number of turtles killed will never be known, one of the sailors who made the above observations claimed that he saw "tens of thousands" of dead turtles. Kendrick (2003) estimated from gross approximations without measurements of the turtles involved that perhaps 5000 turtles were piled ashore on the two beaches. Based on the observations, turtles of all size ranges were killed, including large adults, intermediate-sized immature and hatchlings. A high proportion of these turtles would have been *C. mydas*.

There were two additional nuclear tests among these islands on 16 May 1956 and 19 June 1956. All three tests would have killed resident turtles in the vicinity. Radiation poisoning should have debilitated or killed turtles that arrived to breed or feed for years to come. While no monitoring data are available from which to determine the impact of these nuclear tests on these turtle populations, the local foraging and breeding populations of *C. mydas*, *Natator depressus*, and *Eretmochelys imbricata* would have suffered large losses over some years. Eggs laid on the beaches during the following years would have been bombarded with radiation from the sand. These nuclear tests probably caused the largest localised kill of marine turtles from human activities in Australia's history.

29a. Detonation of the 1st atomic bomb in the Montebello Islands, Western Australia, 3 October 1952. Photograph courtesy of Courier Mail.

29b. Trimouille Island, Montebello Group, October 2002. Two of the three atomic bombs were detonated on or adjacent to this island.

Figure 29. British and Australian Government collaborated to detonate three atomic bombs in the Montebello Islands during 1952–1956.

RAAF Bombing ranges on nesting and foraging habitat

The small *C. mydas* rookery of Cartier Island and the surrounding reef with its associated internesting and foraging population in the Timor Sea has been used in the past as a Military Exercise Area for bombing practice (Russell & Hanley, 1993).

Fairfax Island in the southern Great Barrier Reef and the surrounding reef with its associated internesting and foraging population in the southern GBR has been used in the past as a Military Exercise Area for bombing practice. The damage to the nesting population, eggs, internesting population and the resident foraging population from the bombing over many years has not been quantified. Fairfax Island is now part of the Capricornia Cays National Park Scientific and is closed to public access because of the presence of unexploded ordinance and nesting seabirds.

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 100–120m water depth should impact marine turtles by producing behavioural changes at about 2km range and avoidance at around 1km 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 2km 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 LIGHT HORIZON DISORIENTATION

Disorientation of *C. mydas* hatchlings by housing and industrial lighting 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 and from increased bird and fish predation. Disoriented hatchlings are regularly found inland from the nesting beach at Heron Island and the camping areas of the Capricorn-Bunker islands (EPA Queensland Turtle Conservation Project, unpubl. data). *C. mydas* hatchlings are attracted to low pressure sodium vapour lights that are not attractive to *C. caretta* hatchlings (See Section 2.2.8).

At rookeries such as Raine Island, deck lighting from anchored boats can trap large numbers of hatchlings in inshore waters with resulting increases in predation (Limpus *et al*. 2003).

The greatest potential within Australia for altered lighting horizons to cause the disorientation of hatchlings or to cause the alteration in nesting distribution of adult turtles occurs with the oil and gas fields of the Northwest Shelf of Western Australia. These oil-gas production areas are coincident with one of the world's largest *C. mydas* nesting populations (Section 2.5.4). Studies such as Pendoley (2000) are needed to guide sound turtle conservation management as the infrastructure associated with this industry continues to expand.

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 *C. mydas* rookeries on mainland Peninsula Malaysia. Since then the *C. mydas* nesting population breeding at Paka beach has declined to almost zero (K. Ibrahim *&* C. Limpus, unpubl. data). At the same time *C. mydas* nesting numbers have been increasing at other less optimal nesting habitats to the south of Paka. Shifting from preferred nesting areas with their presumably good conditions for egg incubation, hatchling emergence success, hatchling imprinting and hatchling dispersal leaves them vulnerable to laying eggs in areas where the population may function sub-optimally.

4. POPULATION STATUS

Australia supports the largest remaining *C. mydas* breeding populations of the world. The major breeding populations in the neighbouring countries within this region have been dramatically reduced during the 20th Century (Limpus, 1997).

4.1 POPULATION DEMOGRAPHY

Population modelling research is progressively improving for the southern GBR stock (Chaloupka & Limpus, 1996; Chaloupka, 2001, 2002; Dobbs & Limpus 2006). It is now apparent that because of the protracted delay in maturity and the long intervals between breeding seasons, *C. mydas* populations are at risk from even modest increases in mortality that have an extended impact at any stage in their life history.

Southern GBR stock

Although this is the most comprehensively studied *C. mydas* stock within the Indo-Pacific region, there are still problems in providing a definitive answer on the conservation status of the population based on the field census data alone. This population should have commenced recovery following declaration of a Queensland wide, all year round, closed season in 1950 which brought to an end the extended and extensive commercial harvest of *C. mydas* in Queensland (Section 3.1.1).

The annual nesting population is large by global standards and:

- The annual nesting population has fluctuated around an approximately stable level during 1967 to the present (Figure 5a) . However, much of the variability in size of the annual nesting population is due to the impact of climate variability which determines what proportion of the available adult population in the foraging areas prepares to breed in any one year (Limpus & Nicholls, 2000; Limpus *et al*. 2003).
- There has been an obvious and significant decrease in the mean size (CCL) of nesting female *Chelonia mydas* at the southern GBR index rookery (Heron Island) during 31 years (1974 to 2004) of annual approximately total tagging census of the nesting population (Section 2.2.5).
- Recruitment rate of first time breeding females into the annual breeding population at Heron Island has increased (~24–32%) (Section 2.2.5). A 30% adult female, relative recruitment rate is considered to be too high to be indicative of a stable population.
- In the absence of a pronounced increase in the size of the annual nesting population, these last two dot points are consistent with a decrease in the proportion of older (remigrant) females returning to breed.
- Chaloupka and Limpus (2001) measured an increase in the size of the *C. mydas* population foraging in the protected habitats of the coral reefs in the vicinity of Heron Island. However, the author has, in the course of interviews with local residents, been advised that *C. mydas* populations were depleted locally during the middle to latter part of the 20th Century at locations including western Moreton Bay, Palm Island reefs off Townsville, Missionary Bay and nearby reefs off Cairns.

Overall, this population is not showing signs of decreasing numbers of breeding females at the nesting beaches over the past four decades. However, there are warning signs within the breeding population that indicate the possible excessive loss of adult turtles from the population.

Chaloupka (2002) concluded from his modelling of the population dynamics that even limited turtle harvesting would result in the southern GBR stock being categorised as vulnerable under the IUCN criteria for listing of threatened species. Extensive harvesting of either eggs or turtles is not a prudent management policy if the long-term viability of the southern GBR stock is the primary conservation objective. Dobbs and Limpus (2006) concluded from their modelling that current estimates of mortality from all sources of anthropogenic mortality impacting on this stock is unsustainable. Indigenous hunting accounts for the greatest proportion of the current mortality for this stock with the loss of hundreds of *C. mydas* annually and with a bias to adult-sized turtles (Section 3.2). The next most significant impact on this stock is the increasing mortality from boat strike and propeller cuts, which also impacts mostly adult-sized turtles (Section 3.4.3). Based on the results of the above population modelling, the loss of only a few hundred adult females per year from this stock would not be sustainable. The combined loss from all anthropogenic sources exceeds this (Section 3).

Both Chaloupka (2002) and Dobbs and Limpus (2006) conclude that the impact of harvest/loss can be minimised by shifting the mortality from adults to immature turtles if the total number of killed turtles is not increased.

Northern GBR stock

This is the largest remaining *C. mydas* population in the world.

- There has been an upward trend in the size of the annual nesting population during 1976 to 1996 followed by a downward trend since 1996 (Figure 13). However, a major part of the variability in size of the annual nesting population is due to the impact of climate variability in determining what proportion of the available adult population in the foraging areas prepares to breed in any one year (Limpus & Nicholls, 2000; Limpus *et al*. 2003).
- High density nesting seasons with densities consistent with or exceeding those of recent breeding seasons when in excess of 10,000 nesting female *C. mydas* were counted ashore at once, have been reported in the past in the mid 1950s (probably 1955–1956 breeding season), in the 1965–1966 breeding season and in the 1974–1975 breeding season (Limpus *et al*. 2003).
- There has been an obvious and significant decrease in the mean size (CCL) of nesting female *C. mydas* at the northern GBR index rookery (Raine Island) during 26 years (1974 to 2001) of annual tagging census of the nesting population (Limpus *et al*. 2003).
- Mean remigration interval has increased over the11 breeding seasons, 1991 to 2001 (Limpus *et al*. 2003)
- During the 1990s, first-time-breeding females have recruited into the annual nesting population at Raine Island at the low rate of 7.17% of the total nesting population for the season (Section 2.3.5. Limpus *et al*. 2003).
- In the absence of a pronounced increase in the size of the annual nesting population, a reduction in mean CCL and an increase in mean remigration interval are consistent with a decrease in the proportion of older (remigrant) females returning to breed. This, however, is not consistent with the low relative recruitment rate for first time breeding females.

In the absence of comprehensive demographic data to develop a comparable model for the northern GBR stock to that available for the southern GBR stock; an option could be to scale the input parameters to the southern GBR model to mirror the known parameters for the northern GBR stock. Under these conditions, the model population will display a significant population decline in response to the scaled mortalities from anthropogenic sources. Although imprecisely quantified, turtle harvest by coastal communities of the far northern GBR, Torres Strait, southern Papua New Guinea, Gulf of Carpentaria, Arnhem land and eastern Indonesia is the largest source of loss to the population (Section 3.2.2, 3.2.3, 3.3.2, 3.3.3). This harvest is biased to take adult-sized females and appears to have escalated since the 1970s. In the absence of precise data and comprehensive modelling of the population, it is presumed that the northern GBR stock is more threatened by harvest than the southern GBR stock.

In addition to the above consideration, there has been an unquantified but severe reduction in hatchling production from the Raine Island rookery since at least the 1996–1997 breeding season caused by a net loss of sand and a rising water table (Section 2.3.9). Bramble Cay has been losing a large proportion of its eggs since at least the 1970s (Section 2.3.9). If this death of eggs because of flooding of the nests continues, then this major nesting population will crash within about 30 years, irrespective of whether or not the harvest is managed for sustainability. There is no indication that the ecological processes causing this egg mortality will cease in the foreseeable future.

The northern GBR *C. mydas* stock is impacted by two independent threatening processes:
- The excessive harvest of adults and near-adult turtles throughout much of the foraging range for the stock and
- Climate and habitat related loss of hatchling production.

Taken together, these impacts represent a very serious threat to the survival for this population within the life of the current generation of northern GBR *C. mydas*.

Gulf of Carpentaria stock
This is a large stock of *C. mydas* by global standards. However, there are no data on population trends or stock specific mortality data from which the status of this stock can be quantitatively assessed. The largest direct source of mortality from anthropogenic sources is probably indigenous harvest. Because of the regular harvest of *C. mydas* and their eggs by all coastal aboriginal communities bordering the Gulf of Carpentaria and because the harvest will be biased to take either nesting females or adult-sized turtles, concern should be held for the stability of this population. The additional loss of smaller numbers of *C. mydas* through fisheries bycatch and ghost net entanglement within the Gulf waters should add to this concern.

Western Australian stock
The Western Australian stock could be expected to be in a recovery mode since the extensive mortality inflicted on these *C. mydas* with the Montebello nuclear tests that ceased in the 1950s (Section 3.7) and the long running substantial commercial harvesting that ceased in the 1970s (Section 3.1.3).

This is another very large population by global standards but the population size is poorly quantified. There are no long-term census data to provide a measure of population trend and stock specific mortality has not been quantified. However, the foraging areas for this stock encompass coastal waters where extensive ongoing harvesting of *C. mydas* is a regular practice by coastal communities in northwestern Western Australia, Northern Territory, Gulf of Carpentaria and eastern Indonesia (Section 3.2.3). Fisheries bycatch mortality, fox predation of clutches laid on mainland rookeries along the Ningaloo Coast, impact of the oil and gas industry infrastructure and associated altered light horizons on nesting adults and hatchlings are also impacting this stock.

Because modelling of the southern GBR stock indicates that only modest levels of increased loss at any phase in the live history of this species can threaten population stability (Chaloupka, 2001, 2002), concern should be held for the conservation status of this stock.

Coral Sea stock
There are no data on population trends or stock specific mortality data from which the status of the modest sized Coral Sea stock can be quantitatively assessed. However, because the principal foraging areas for this stock appear to be coincident with the same foraging areas in which the northern GBR stock is being extensively harvested, concern should be held for the stability of this population.

Ashmore Reefs stock
There are no data on population trends or stock specific mortality data from which the status of the small Ashmore Reefs stock can be judged.

Scott Reef stock
There are no data on population trends or stock specific mortality data from which the status of the small Scott Reef stock can be judged.

4.2 CONSERVATION STATUS WITHIN AUSTRALIA

Conservation management of green turtles, *Chelonia mydas* within Australia had its beginnings in 1932 with the 15 Dec 1932 Order in Council under the Queensland Fisheries Act that declared an October–November closed season for the harvest of green turtles and their eggs south of 17°S. This was followed with the 7 September 1950 Order in Council declaring an all-year closed season in Queensland, only to be altered with the 4 September 1958 Order in Council to restrict the closed season for turtle harvest to south of 15°S. The 18 July 1968 Order in Council declared an all-year closed season for the whole of Queensland.

Chelonia mydas is protected as a threatened species by all Federal and State conservation agencies in Australia except Northern Territory and Victoria (Table 31). The eastern Australian stocks clearly warrant continued listing as a vulnerable species. Given the uncertainty of the status of the Western Australian stock and the existing multiple threats to its population stability, this stock warrants retention of its vulnerable status. In the absence of population stability and mortality data for the small Ashmore Reef and Scott Reef stocks and given the poor conservation outlook for *C. mydas* populations in the Australasian region, the precautionary principle could be invoked for listing these as threatened populations also.

Table 31. Summary of the legally defined conservation status of *Chelonia mydas* 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	Vulnerable 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	Vulnerable	*Threatened species Protection Act 1995*
Victoria	Not listed	*Advisory list of Threatened Vertebrate Fauna in Victoria 2003*
New South Wales	Vulnerable	*Threatened Species Conservation Act 1995*
Queensland	Vulnerable	*Nature Conservation Act 1992. A protected species under the Fisheries Act since 1968.*
Northern Territory	Not listed	*Territory Parks and Wildlife Conservation Act 2000*
Western Australia	Fauna that is rare or is 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 Exclusive Economic Zone (EEZ). In these waters marine turtles are protected under the EPBC Act. The respective Australian States and Territories have jurisdiction over intertidal waters and coastal waters out to three nautical miles offshore from their State lands. The respective State legislations are applicable to the management of marine turtles in these State and Territories 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.

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