# A BIOLOGICAL REVIEW OF AUSTRALIAN MARINE TURTLES.

## 3. HAWKSBILL TURTLE, *Eretmochelys imbricata* (Linnaeus)


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Queensland Government
Environmental Protection Agency

**Cover photographs:** Clockwise from top left: immature to adult-sized *Eretmochelys imbricata* inhabiting coral reef habitats of eastern Queensland; *Eretmochelys imbricata*, nesting habitat in north Queensland at Long Island (Sassie) in Central Torres Strait; Juvenile *E. imbricata* dead in a beach-washed trawl net, Hawk Island, Northern Territory, August 1992; *Eretmochelys imbricata*, nesting habitat at Rosemary Island in Dampier Archipelago.

**A biological review of Australian marine turtle species. 3. Hawksbill turtle, *Eretmochelys imbricata* (Linnaeus)**

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# PREFACE

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 In particular, I have drawn together data contained in many unpublished reports on file in various government and non-government agencies.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

To provide a more comprehensive summary of available information, previously unpublished data drawn from the Queensland Environmental Protection Agency (EPA) Turtle Conservation Project database have been summarised and included.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

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

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

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This assistance is gratefully acknowledged.

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# HAWKSBILL TURTLE, *Eretmochelys imbricata* (Linnaeus)

## 1 THE SPECIES

### *1.1 TAXONOMY*

Hawksbill turtle, *Eretmochelys imbricate*.

| | |
|---|---|
| CLASS: | REPTILIA |
| ORDER: | TESTUDINES |
| FAMILY: | CHELONIIDAE |
| SPECIES: | *Eretmochelys imbricata* (Linnaeus, 1758) |

There is one extant species for the genus and there are no valid subspecies currently recognised (Pritchard and Trebbau, 1984) (Figure 1).

**1a**. Size range of immature to adult-sized *E. imbricata* inhabiting coral reef habitats of eastern Queensland.

**1b**. Hatchling *E. imbricata*.

**1c.** *E. imbricata* head, immature, Sunshine Coast, May 2002. Photograph by D. Limpus.

**1d**. An immature *E. imbricata* recently recruited to residency on Heron Island Reef, 1999.

**Figure 1.** *Eretmochelys imbricata* from eastern Australia of varying age-classes and depicting key identification characteristics.

## 1.2 GLOBAL DISTRIBUTION

The genus *Eretmochelys* has a worldwide circumtropical and subtropical distribution (Witzell, 1983, Chelonian Conservation and Biology vol.3 (2)).
Recent mitochondrial DNA (mtDNA) analysis has demonstrated that there are discrete stocks of *Eretmochelys imbricata* on a global scale (for example, between the Pacific and Atlantic oceans) and that there is little interbreeding between the *E. imbricata* populations that breed in northeastern and western Australia (Broderick *et al*. 1994; Bass, 1999; Dutton *et al*. 2002). The Australian nesting populations represent separate management units from those in the Solomon Islands, Malaysia and probably Indonesia. Given the similarity of results from comparable research with other cheloniid turtles (Moritz *et al*. 2002), it is presumed that each widely separated major grouping of rookeries supports an independent stock of *E. imbricata* with respect to their conservation management.

## 1.3 IDENTIFICATION

In *E. imbricata* the carapace is high domed, approximately smooth and covered with imbricate (overlapping) scutes (Cogger, 1992). The species typically has 4 pairs of costal scutes, 2 pairs of prefrontal scutes and no preoccular scutes (Limpus, 1992a) (Figure 2). It has no inframarginal pores. *E. imbricata* eggs are small (average egg diameter = 3.6 cm) and the clutches in Australia rarely contain yolkless eggs (Limpus *et al*. 1983, Dobbs *et al*. 1999). Nesting females move with an alternating gait when ashore.

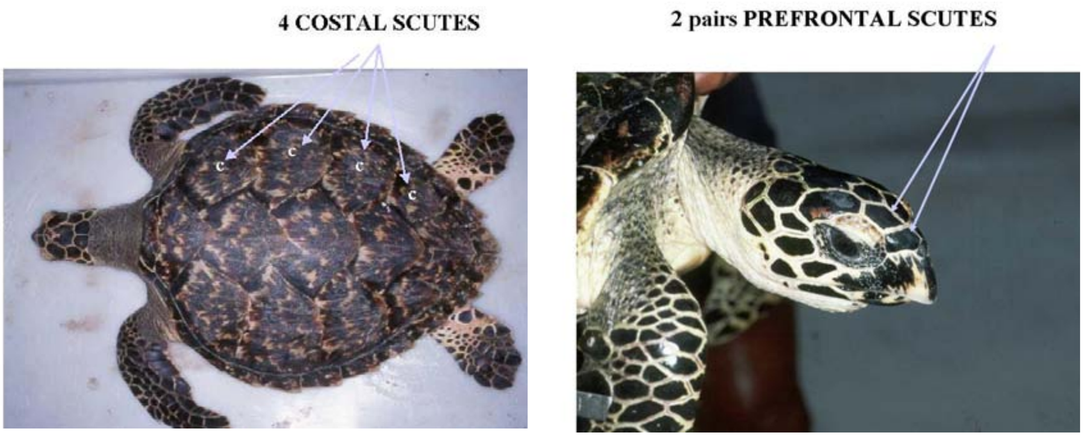



**Figure 2.** Diagnostic feature for identifying *Eretmochelys imbricata*.

The morphology of *E. imbricata* has been described by Wyneken (2001). Limpus and Miller (1990) provide a method for identifying the size of *E. imbricata* from measured scutes. Munroe and Limpus (1979), Limpus *et al.* (1983a) and Dobbs *et al*. (2004) describe commensals found on *E. Imbricata* in Australia.

# 2. BIOLOGY OF THE HAWKSBILL TURTLE, *Eretmochelys imbricata* (Linnaeus), IN AUSTRALIA.

Data are drawn primarily from studies of the species in Australia. Where data are not available from Australian populations, data from overseas populations are used. However, this species is one that has been poorly studied globally and it may be necessary to extrapolate from the other cheloniid turtles to estimate some parameters. In these latter instances, data are used primarily from Australian stocks. Because the most comprehensive data for the species in Australia are available from the Torres Strait–Northern Great Barrier Reef and Arnhem Land stock(s), this stock is 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 Torres Strait–Northern Great Barrier Reef and Arnhem Land stock(s).

## *2.1 GENETIC STATUS OF STOCKS*

Within the Indian Ocean–Western Pacific Ocean region, Australia supports the largest remaining stocks of breeding *E. imbricata* (Figure 3a). Within Australia, genetic analysis indicates that there is one stock that incorporates the *E. imbricata* rookeries of the northern Great Barrier Reef (GBR), Torres Strait and Arnhem Land that is independent of a second stock that breeds at rookeries on the northwestern shelf of Western Australia (Broderick *et al*. 1994) (Figure 3b). However, while the breeding population of the northern GBR and Torres Strait has a peak density of nesting in summer (January–February) (Dobbs *et al*. 1999), the Arnhem Land population has a winter–spring peak in nesting density (Limpus *et al*. 2000). Given the differences in the timing of the physiological cycles (Hamann *et al*. 2003) required to maintain this difference in timing of the breeding seasons, these two sub-populations are unlikely to be interbreeding. Therefore in the following summary, the Arnhem Land sub-population will be treated as if it is a separate stock to the Torres Strait–northern GBR sub-population.

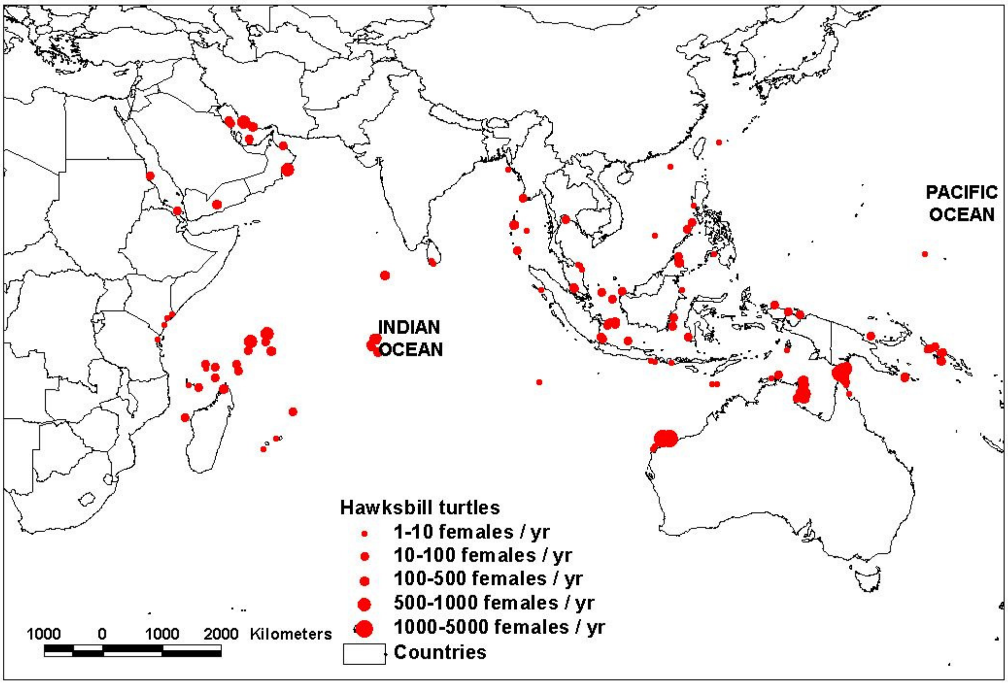



**Figure 3a**. Distribution of *Eretmochelys imbricata* nesting beaches in the Indian Ocean and Western Pacific Ocean.

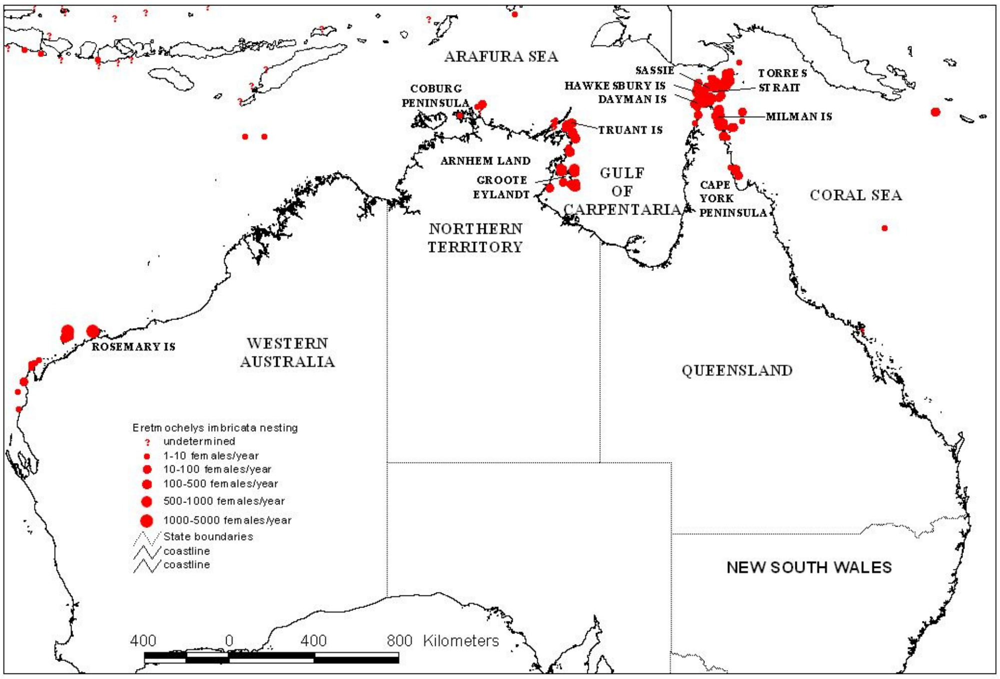



**Figure 3b.** Distribution of *Eretmochelys imbricata* nesting beaches in Australia.
The data are incomplete for the western Northern Territory and Western Australia.

**Figure 3.** Distribution of *Eretmochelys imbricata* nesting beaches.

## *2.2 TORRES STRAIT–NORTHERN GREAT BARRIER REEF AND ARNHEM LAND STOCK(S)*

### 2.2.1 ROOKERIES

**Torres Strait–Northern Great Barrier Reef sub–population**

The distribution of marine turtle breeding in eastern Australia, Torres Strait and Queensland Gulf of Carpentaria has been extensively surveyed (Limpus *et al* 2000; Dobbs *et al*. 1999; Limpus, 1980; Limpus *et al*. 1983a, 1993a, 2001, 2003; Loop *et al*. 1995; Miller *et al*. 1995; Miller and Limpus, 1991 Limpus and Preece 1992, Loop *et al*. 1993). At least 72 *E. imbricata* rookeries are currently identified within northeastern Queensland (Limpus *et al* 2000):

- estimated > 500 nesting females per year: 3 islands:
  Torres Strait: Long (Sassie) Island (Figure 4), Hawkesbury Island, Dayman Island.
- estimated 100–500 nesting females per year: ~13 islands:
  Great Barrier Reef: Milman Island, Boydong Island, Mt Adolphus Island, Albany Island.
  Torres Strait: Zuizin Island, Mimi Island, Bourke Island, Aukane Island, Layoak Island, Bet Island, Saddle Island, Dadalai Island, Albany Island, and Mt Adolphus Island.
- estimated 10–100 nesting females per year: ~28 islands:
  throughout the Great Barrier Reef and Torres Strait and the mainland coast of Western Cape York Peninsula north of Cotterell River.
- estimated 1–10 nesting females per year: ~27 islands

Only one *E. imbricata* nesting has been recorded in the last 70 years in the Great Barrier Reef to the south of Princess Charlotte Bay: an emerging clutch of hatchlings on Rocky Island (14°14'S, 144°21'E) in January 1997 (E. Gyuris, pers. comm.). No *E. imbricata* have been recorded nesting on the islands of the Coral Sea Platform in recent decades.

**Figure 4.** *Eretmochelys imbricata*, nesting habitat in north Queensland at Long Island (Sassie) in Central Torres Strait. *E. imbricata* nest on a series of crescentic beaches backed by closed forest on the shingle ridge on the western margin of this large mangrove island.

Most rookeries of the inner-shelf area of the northern GBR, including Milman, Boydong, Bird, Hannabul, Piper and Wallace Islands are within National Parks.
Almost all rookeries throughout Torres Strait and along western Cape York Peninsula are Aboriginal or Torres Strait Islander owned land. As a result, the vast majority of *E. imbricata* nesting in northeastern Australia lies outside of protected habitat, including the three largest nesting aggregations of Long (Sassie) Island, Hawkesbury Island, Dayman Island.

**Nesting census**

There has been limited monitoring of the size of the annual breeding population at *E. imbricata* rookeries in Queensland:

- Milman Island has been selected as the primary index beach for monitoring the long term variability in the size of the Torres Strait–Northern GBR *E. imbricata* subpopulation. The nesting population has been monitored using a one month, mid breeding season (mid January to mid February), nightly tagging census since the 1990–1991 breeding season. (Loop *et a*l. 1995, Dobbs *et al.* 1999, Miller *et al.* 2000a) This index nesting population has been declining at 3–4% per year for at least a decade (Miller *et al*. 2000a).
- Campbell Island was monitored using a three month (December to February) total tagging census of the nesting population for one nesting season only (1978–1979) (Limpus *et al*. 1983a).

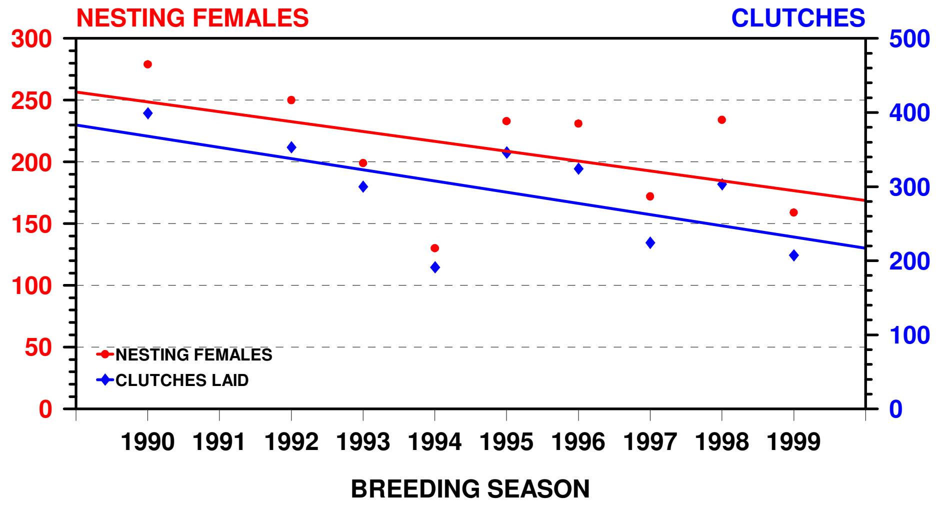



**Figure 5.** Milman Island *Eretmochelys imbricata* index beach census: annual, mid season, one month (15 January to 15 February) tagging census of nesting females and count of clutches laid. Based on data from Miller *et al.* (2000a).

The current total *E. imbricata* nesting population for Queensland is expected to be of an order of magnitude of 4000 females annually (Miller *et al.* 1995) when the census counts are adjusted for the proportion of the population that interchanges between nesting beaches within a breeding season (Limpus *et al*. 2000). This is one of the largest nesting populations for the species in the world (Meylan and Donnelly, 1999). If the current rate of decline measured at the Milman Island index beach continues, (Figure 5) then the Torres Strait–northern GBR *E. imbricata* stock can be expected to decline by > 90% by 2020, i.e. in less than one generation for the species.

**Northeastern Arnhem Land sub-population**
The distribution of marine turtle nesting in Arnhem Land has been broadly surveyed (Chatto, 1998). However, the size of the nesting population at each of the numerous *E. imbricata* rookeries have been incompletely surveyed (Limpus *et al*. 2000; Gow, 1981; Limpus and Preece, 1992). Approximately 40 nesting sites were recorded for *E. imbricata* in northeastern Arnhem Land during a spring aerial survey (Limpus *et al*. 2000). Additional low density nesting beaches probably occur in the region; however, their identification may be obscured by concurrent *L. olivacea* nesting for those sites where positive distinction between these species could not be made for all tracks observed. It is considered that approximately all higher density nesting sites (hundreds of nesting females annually) for *E. imbricata* within the sampled area will have been detected in this survey; however, additional low density nesting sites will be identified with more intense surveys. This survey found that the 12 sites identified with an estimated more than 100 nesting female *E. imbricata* annually were clustered into four focal areas of abundant nesting:

- Outer islands of the English Company Islands area: Truant Island and Bromby Island.
- Northeastern Groote Eylandt area: North East Island, Hawk Island, Lane Island, extreme northeastern beaches of Groote Eylandt. This area appears to be the most significant area for *E. imbricata* nesting in the Northern Territory.
- Northwestern Groote Eylandt area: Hawknest Island, Bustard Island, the small island southwest of Bustard Island.
- Southeastern Groote Eylandt area: Two small islands of Cape Beatrice and the southeast coast of Groote Eylandt.

For each site with high density nesting there was a series of lower density nesting sites in the vicinity.
Most of the *E. imbricata* rookeries of Arnhem Land lie outside National Park or other habitat managed for conservation purposes. The exceptions are:

- The low density *E. imbricata* on the mainland and adjacent islands of northeast Arnhem Land that lie south from Cape Arnhem are within the Dhimurru Indigenous Protected Area.
- Some low density nesting also occurs within the Gurig National Park on Coburg Peninsula.

**Nesting census**
There has been no detailed monitoring of the size of the annual breeding population at any of the Arnhem Land *E. imbricata* rookeries. Based on the 1997 survey results, a preliminary estimate of the current size of the annual *E. imbricata* nesting population for eastern Arnhem Land was > 2500 females annually (Limpus *et al*. 2000).

### 2.2.2 FIDELITY TO NESTING SITES

The genetic studies are providing convincing evidence that the species returns to breed at the region of its birth (Broderick *et al*. 1994).

Tagging studies have demonstrated that the adult female displays a high degree of fidelity to her chosen nesting beach, with most females returning to the same small beach for oviposition of their successive clutches within a nesting season and in successive nesting seasons (Limpus *et al*. 1983a; Loop *et al*. 1995; Dobbs *et al*. 1999; Hoyle and Richardson, 1993). However, a small proportion of the nesting population interchange among adjacent rookeries up to 38 km apart between and within breeding seasons (Miller *et al*. 2000, Bell *et al*. 2000).

## 2.2.3 MIGRATION

Tag recoveries resulting from over a decade of tagging studies at both nesting and foraging sites throughout eastern Queensland and the Solomon Islands have demonstrated that *E. imbricata* is a highly migratory species (Miller *et al*. 1998; Parmenter, 1983; Vaughan and Spring, 1980). Adult females tagged while nesting at Milman Island in the northern GBR have been recaptured at foraging areas in the southern Gulf of Carpentaria, southeastern Indonesia, southern Papua New Guinea and the northern GBR (Figure 6).

*E. imbricata* is as migratory as the other species of marine turtles in the Coral Sea region: *Chelonia mydas* and *Caretta caretta* (Limpus *et al* 1992) and *Natator depressus* (Limpus *et al*. 1983b).

It is presumed that *E. imbricata* that breed in Arnhem Land will be similarly migratory and originate from widely scattered foraging areas in northern Australia and Indonesia. If so, this stock contributes to the vast number of *E. imbricata* harvested in Indonesia.

## 2.2.4 BREEDING SEASON

In the Coral Sea region, including the GBR and central to eastern Torres Strait, *E. imbricata* has an all year round nesting season with a peak of nesting in approximately January–February (Limpus *et al*. 1983a; Limpus *et al*. 1993; McKeown, 1977; Loop *et al*. 1995; Dobbs *et al*. 1999).

In northeastern Arnhem Land there appears to be all year round nesting but with a peak of nesting activity in winter and early spring in approximately July to October (Gow, 1981; Limpus and Preece, 1992; Limpus *et al*. 2000)

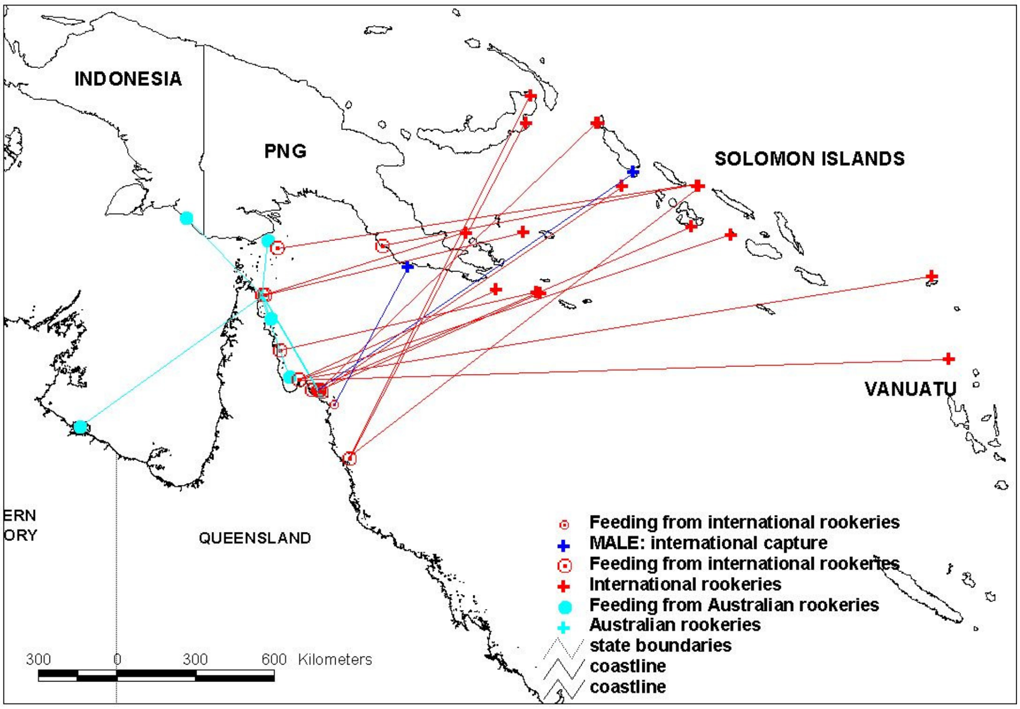



**Figure 6.** Migration distribution of adult female and male *Eretmochelys imbricata* relative to their respective foraging areas. Circles denote foraging areas and crosses denote breeding areas. Adult female E. imbricata migrating from feeding sites to international breeding sites outside of Australia are denoted in red. Those migrating between breeding sites within Australia to foraging areas are denoted in light blue. Adult males are depicted in dark blue.

### 2.2.5 BREEDING ADULTS

Adults are usually brown dorsally, variegated with dark brown to black; cream to yellowish ventrally; and have pale edged scutes temporally (Figure 1a). Carapace scutes are imbricate, although this may not be obvious with some freshly captured individuals.

The size of nesting females are summarised in Table 1. The mean size of nesting females in their first breeding season is slightly smaller, but not statistically significant, than the mean size of the total nesting population (Miller *et al.* 2000a).

**Table 1.** Size of adult Eretmochelys imbricata in northeastern Australia.

| | Measurement | | | | References |
|---|---|---|---|---|---|
| | **Mean** | **SD** | **Range** | **n** | |
| **Curved carapace length (cm)** | | | | | |
| **QUEENSLAND** | | | | | |
| **FEMALE** | | | | | |
| Pooled samples of nesting females of all ages | | | | | |
| Milman Island | 81.55 | 3.65 | 63.5–95.0 | 2681 | Miller *et al.* 2000a; Dobbs *et al.* 1999; Loop *et al.* 1995 |
| Campbell Island | 83.2 | 3.9 | 75.5–92.5 | 22 | Limpus *et al.* 1983a |
| Crab Island | 84.3 | 2.6 | 81.5–89.3 | 14 | Limpus *et al.* 1993 |
| Adult females in their 1st breeding season | | | | | |
| Milman Island (nesting) | 80.2 | 3.10 | 74.0–88.2 | 59 | Miller *et al.* 2000a |
| GBR (foraging) | 82.7 | 4.19 | 79.3–90.4 | 6 | Limpus *et al.* 2000a |
| Size at which 50% of females are adult (AS50) | | | | | |
| GBR (foraging) | 83.89 | – | CI95=76.8–91.6 | – | Limpus *et al.* 2000a |
| **MALE** | | | | | |
| Pooled samples of breeding males of all ages | | | | | |
| GBR | 80.1 | 2.65 | 74.6–85.0 | 33 | Limpus *et al.* 2000a |
| Torres Strait | 82.0 | – | – | 1 | Limpus *et al.* 1983a |
| Size at which 50% of males are adult (AS50) | | | | | |
| GBR (foraging) | 80.55 | – | CI95=74.0–87.6 | – | Limpus *et al.* 2000a |
| **ARNHEM LAND** | | | | | |
| **FEMALE** | | | | | |
| Pooled samples of nesting females of all ages | | | | | |
| Truant Island | 85.2 | 0.65 | 84.4–86.0 | 4 | Limpus and Preece, 1992 |
| McCluer Group | 81.8 | – | 81.8 | 1 | Limpus and Preece, 1992 |
| **Weight (kg)** | | | | | |
| **QUEENSLAND** | | | | | |
| **FEMALE** | | | | | |
| Pooled samples of nesting females of all ages | | | | | |
| Milman Island | 50.2 | 6.32 | 32.0–72.0 | 753 | Miller *et al.* 2000a; Dobbs *et al.* 1999 |
| Campbell Island | 51.55 | 8.22 | 38.5–68.0 | 38 | Limpus *et al.* 1983a |

During the course of a breeding season the female looses 1.36% of her body weight while laying 6.54% of her body weight in eggs for each successive clutch laid (Limpus *et al.* 1983a).

Breeding cycles have only been measured for females in northern Queensland (Table 2).

While females lay clutches at two weekly intervals, there are small but significant differences in the renesting interval between breeding seasons at Milman Island between 1990 to 2000 (Miller *et al*. 2000a).

*E. imbricata* in northeastern Australia have an unusually long remigration period for the species: five years between breeding seasons (Table 2). Less than 2% of females return to breed at less than three years (Miller *et al*. 2000a).

**Table 2.** Breeding cycles for adult *Eretmochelys imbricata* in northeastern Australia.

| | | Measurement | | | | References |
|---|---|---|---|---|---|---|
| | | **Mean** | **SD** | **Range** | **n** | |
| Renesting interval (d) | | | | | | |
| | Campbell Island | 14.7 | 1.02 | 13–17 | 27 | Limpus *et al*. 1983a |
| | Milman Island | 14.28 | 2.02 | 8–25 | 3237 | Miller *et al*. 2000a; Dobbs *et al*. 1999; Loop *et al*. 1995 |
| Remigration interval (yr) | | | | | | |
| Female: | Milman Island | 5.00 | 1.54 | 2–9 | 435 | Miller *et al*. 2000a, Dobbs *et al*. 1999 |
| Male: | | Not recorded | | | | |

## 2.2.7 EGGS

The eggs are cleidoic, white and spherical; for successful incubation, they must be laid in 25℃–33℃, well ventilated, low salinity, high humidity nest substrate not subjected to flooding (Miller, 1985). There is no parental care of the hatchlings. As for other species of marine turtles, embryos can be killed by rotation of eggs during incubation (Limpus *et al*. 1979; Parmenter, 1980; Chan, 1989).

Measurements of *E. imbricata* eggs and nests are summarised in Table 3. There was no significant difference in the number of eggs per clutch among successive clutches laid by a female within the same breeding season (Limpus *et al*. 1983a, Dobbs *et al*. 1999). However, there was no significant difference in the number of eggs per clutch between breeding seasons at Milman Island through 1990 to 1999 (Miller *et al*. 2000a). There were significant differences in the number of clutches laid by a female within a breeding season at Milman Island during 1990 to 1999 (Miller *et al*. 2000a).

## 2.2.8 HATCHLINGS

*Eretmochelys imbricata* hatchlings are dark brown dorsally, occasionally with darker spotting, and light brown ventrally (Figure 1b) (Limpus *et al*. 1983a). This age class does not feed or sleep between leaving the nest and entering to deep offshore water. The duration of this life history phase is a few days and ends when they commence ingestion of external food.

There has been limited research on the processes underlying *E. imbricata* hatchling orientation and ocean finding behaviour (Lohmann *et al*. 1997). It is presumed that *E. imbricata* hatchlings respond in a manner similar to hatchlings of the other species of marine turtles. Marine turtle hatchlings orient to low elevation light horizons when moving from the nest to the sea (Limpus, 1971, 1985; Salmon and Wyneken, 1994). Hatchlings are disoriented by bright lights that limit their ability to see distant horizons. However, it has not been determined whether or not *E. imbricata* hatchlings are disoriented by the yellow wavelengths of low pressure sodium vapour lights (Witherington and Bjorndal, 1991). *C. caretta*, *N. depressus* and *E. imbricata* hatchlings, like *C. mydas* hatchlings, are not disoriented by intermittent flashing lights (C. Limpus, unpubl. data. Mrosovsky, 1978). By orienting to swim perpendicular to wave fronts, the hatchlings are directed to swim out to the open ocean (Lohmann, 1992; Salmon and Wyneken, 1994). See Lohmann and Lohmann (2003) for a review of orientation mechanisms for *C. caretta*.

**Table 3.** Summary of northern and eastern Australian *Eretmochelys imbricata* egg and nest measurements.

| | Measurement | | | | References |
|---|---|---|---|---|---|
| | **Mean** | **SD** | **Range** | **n** | |
| **QUEENSLAND** | | | | | |
| **Clutches per season** | | | | | |
| Milman Island | > 2.4 | 1.37 | 1–6 | 2731 | Miller *et al*. 2000a; Dobbs *et al*. 1999; Loop *et al*. 1995 |
| Campbell Island | ~3 | | | | Limpus *et al*. 1983a |
| **Eggs per clutch** | | | | | |
| Milman Island | 121.7 | 23.4 | 18–215 | 1852 | Miller *et al*. 2000a, Dobbs *et al*. 1999 |
| Campbell Island | 131.8 | 22.87 | 89–192 | 47 | Limpus *et al*. 1983a |
| Crab Island: 1978 | 142.2 | 12.2 | 123–154 | 5 | Limpus *et al*. 1983c |
| Crab Island: 1991 | 139.3 | 10.3 | 123–151 | 4 | Limpus *et al*. 1993 |
| **Yolkless eggs per clutch** | | | | | |
| Milman Island | 0.11 | 0.43 | 0–5 | 1296 | Dobbs *et al*. 1999 |
| **Multiyolked eggs per clutch** | | | | | |
| Milman Island | 0.12 | 0.34 | 0–5 | 1296 | Dobbs *et al*. 1999 |
| **Egg diameter (cm)** | | | | | |
| Milman Island | 3.51 | 0.167 | 2.27–3.92 | 5520 | Miller *et al*. 2000a, Dobbs *et al*. 1999 |
| Campbell Island | 3.60 | 0.11 | 3.23–4.07 | 470 | Limpus *et al*. 1983a |
| Crab Island: 1978 | 3.60 | 0.08 | 3.35–3.37 | 50 | Limpus *et al*. 1983c |
| Crab Island: 1991 | 3.60 | 0.07 | 3.49–3.77 | 30 | Limpus *et al*. 1993 |
| **Egg weight (g)** | | | | | |
| Milman Island | 26.69 | 2.09 | 20.4–31.8 | 349 | Miller *et al*. 2000a, Dobbs *et al*. 1999 |
| Campbell Island | 25.99 | 2.08 | 19.5–32.5 | 470 | Limpus *et al*. 1983a |
| Crab Island: 1978 | 27.6 | 2.78 | 24.0–33.5 | 40 | Limpus *et al*. 1983c |
| Crab Island: 1991 | 26.08 | 1.08 | 24.0–28.0 | 30 | Limpus *et al*. 1993 |
| **Nest depth (cm)** | | | | | |
| **Top** | | | | | |
| Milman Island | 18.0 | 8.99 | 1–53 | 1690 | Miller *et al*. 2000a, Dobbs *et al*. 1999 |
| Campbell Island | 25.7 | 6.70 | 11–46 | 45 | Limpus *et al*. 1983a |
| **Bottom** | | | | | |
| Milman Island | 36.7 | 7.27 | 17.9 | 1666 | Miller *et al*. 2000, Dobbs *et al*. 1999a |
| Campbell Island | 43.2 | 4.73 | 35.0–59.5 | 45 | Limpus *et al*. 1983a |
| **Incubation period(d)** | | | | | |
| Milman Island | 58.9 | 6.26 | 47–90 | 90 | Miller *et al*. 2000a, Dobbs *et al*. 1999 |
| Campbell Island | 55 | 1.87 | 52–57 | 5 | Limpus *et al*. 1983a |

**Table 3.** Continued

| | Measurement | | | | References |
|---|---|---|---|---|---|
| | Mean | SD | Range | n | |
| **ARNHEM LAND** | | | | | |
| **Clutches per season** | | | | | |
| | | | Not recorded | | |
| **Eggs per clutch** | | | | | |
| | 130.4 | 29.7 | 91–172 | 7 | Limpus and Preece, 1992 |
| **Egg diameter (cm)** | | | | | |
| | 3.53 | 0.13 | 3.19–3.73 | 49 | Limpus and Preece, 1992 |
| **Nest depth (cm)** | | | | | |
| **Top** | | | | | |
| | 29.4 | 14.33 | 1–45.0 | 7 | Limpus and Preece, 1992 |
| **Bottom** | | | | | |
| | 46.7 | 5.67 | 38.0–55.0 | 7 | Limpus and Preece, 1992 |

Marine turtle hatchlings are imprinted to the inclination of the earth's magnetic field at the nesting beach (Lohmann, 1991; Lohmann and Lohmann, 2003; Light *et al*. 1993). Imprinting to the smell of the sand or the water that the hatchling first contacts may also occur, as is the case with *Lepidochelys kempii* hatchlings (Grassman *et al*. 1984).

Measurements of *E. imbricata* hatchlings are summarised in Table 4. *E. imbricata* hatchlings are among the smallest of the marine turtle hatchlings in Australia.

**Table 4.** Summary of measurements of northern and eastern Australian *Eretmochelys imbricata* hatchlings.

| | | Measurement | | | | References |
|---|---|---|---|---|---|---|
| | | mean | SD | range | n | |
| **QUEENSLAND** | | | | | | |
| **Straight carapace length (cm)** | | | | | | |
| | Milman Island | 3.95 | 0.166 | 3.2–4.4 | 453 | Miller *et al*. 2000a; Dobbs *et al*. 1999; Loop *et al*. 1995 |
| | Campbell Island | 4.11 | 0.14 | 3.82–4.38 | 70 | Limpus *et al*. 1983a |
| **Weight (g)** | | | | | | |
| | Milman Island | 13.80 | 1.50 | 8.0–17.5 | 339 | Dobbs *et al*. 1999; Loop *et al*. 1995 |
| | Campbell Island | 14.3 | 1.09 | 12.7–16.8 | 70 | Limpus *et al*. 1983a |
| **ARNHEM LAND** | | | | | | |
| **Straight carapace length (cm)** | | | | | | |
| | | 3.69 | 0.14 | 3.50–3.81 | 3 | Limpus and Preece, 1992 |

## 2.2.9 EGG and HATCHLING SURVIVORSHIP

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

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

Mortality involving total failure of clutches as a result of flooding, infertility or microbial invasion has rarely been measured at any *E. imbricata* rookery in Australia.

**Queensland**

Few Queensland *E. imbricata* rookeries have been surveyed for incubation success and hatchling production.

1. Lacey Island, a continental island in Torres Strait, in 1974–1975 breeding season (Limpus, 1980):
   - Almost complete predation of *E. imbricata* clutches by monitors (Varanus sp.).
2. Campbell Island, a sand cay in Torres Strait, in 1978–1979 breeding season (Limpus *et al*. 1983a):
   - The mangrove monitor, Varanus indicus, was the only terrestrial predator of eggs and hatchlings. These monitors removed some eggs from 60 of the 72 clutches under observation and completely destroyed 18 of these clutches. The total egg loss to monitors was estimated at approximately 55% of the season's egg production.
   - One clutch was lost through natural erosion under storm conditions (Seasonal egg loss to erosion = 0.014). Loss from erosion can be expected to be low given that 96% of clutches were laid on or inland of the dune crest,
3. Fourteen inshore *E. imbricata* coral cay rookeries in the northern GBR examined during the 1974–1975 and 1976–1977 breeding seasons (Limpus, 1980):
   - No evidence of clutch loss from predation or erosion.
   - Hatchling emergence success to the beach surface from undisturbed clutches on Bird and Saunders Islands = 90.9% (n = 18 clutches).
4. Milman Island, a coral cay in the northern GBR in 1990–1995 (Dobbs *et al*. 1999):
   - No varanids or terrestrial mammals were present on this or adjacent islands.
   - Zero hatchling emergence success was recorded for 1.4% of clutches under observation (2 with zero hatch success, 1 with a single egg hatching but not emerging).
   - A few eggs lost through dune erosion. This is consistent with 94% of *E. imbricata* clutches being laid inland of the dune crest.
   - Between 0 and 4.8% of clutches were disturbed by nesting turtles (Dobbs *et al.* 1999.
   - Hatchling emergence success to the beach surface from undisturbed clutches = 80.0% (n = 226 clutches).
5. Milman Island in 1995–2000 (Miller *et al*. 2000a):
   - 0.03% and 0.12% of the season's egg production was destroyed by nesting turtles in the 1996–1997 and 1997–1998 breeding seasons respectively.
   - Hatchling emergence success to the beach surface from undisturbed clutches = 87.14% (SD = 13.82, range = 6.8 – 100%, n = 255 clutches). There was no significant difference among annual samples. The mean emergence success in this second five years of the study was significantly higher than the mean emergences success from the first five years.
6. Mainland coast of Western Cape York Peninsula with low density nesting beaches and at least one moderate density nesting beach north of Cotterell River:
   - There are very high levels of pig, dog and varanid predation of all species of turtle eggs on all beaches along the northwestern Cape York Peninsula (EPA Turtle Conservation Project unpubl. data). This has not been quantified for the hundreds of *E. imbricata* clutches laid annually on this coast but it is presumed to approach 90% clutch loss.

**Arnhem Land**

There has been even less study of incubation success for *E. imbricata* clutches in Arnhem Land than in Queensland. There is probably a low level of egg loss from terrestrial predation on the islands along the Arnhem Land coast where the majority of nesting occurs (Limpus and Preece, 1992). In contrast, there are probably high levels of egg predation by varanid and dog on the low density *E. imbricata* rookeries along the mainland and large continental island beaches (Hope and Smit, 1998). This needs quantification.

The success of incubation and emergence of hatchlings onto the beach surface from natural clutches that produce hatchlings from several islands visited in 1992 was 79.9% (n = 31 clutches) (Limpus and Preece, 1992).

The survivorship of hatchlings during the beach crossing from nest to sea, including impact of bird, dog, varanid, crocodile and crab predation (Limpus and Preece, 1992; Dobbs *et al*. 1999; Miller *et al*. 2000a), has not been measured at any *E. imbricata* rookery in Australia. Similarly, survivorship of hatchlings in the water while crossing from beach to deep water has not been measured at any *E. imbricata* rookery in Australia. This survivorship value may be low at rookeries surrounded by coral reef flats (Dobbs *et al*. 1999).

### 2.2.10 HATCHLING SEX RATIO

The sex of *E. imbricata* hatchlings is a function of the temperature of the nest during middle incubation, cool nests producing males and warm nests producing females (Mrosovsky *et al*. 1992; Yntema and Mrosovsky, 1982). The pivotal temperature (the temperature that theoretically produces a 50:50 sex ratio) has not been measured for any Australian *E. imbricata* rookery.

Hatchling sex ratio has not been measured for any Australian *E. imbricata* rookery. However, it can be expected to vary among the rookeries, depending on sand temperatures at nest depths and throughout the year. At Milman Island, unshaded nests produced a very high proportion of females (92–100%) and shaded nests produced a lower proportion of females (44–64%) (Loop *et al*. 1995).

### 2.2.11 AGE and GROWTH

Absolute age has not been directly measured on wild *E. imbricata*.

The growth rates of wild turtles have been measured in coral reef habitat in the southern GBR (Chaloupka and Limpus, 1997):

- Distinct sex-specific growth patterns with immature females growing at about 0.5 cm/yr faster than immature males at all recorded sizes;
- The mean-size specific growth rate function was non-monotonic, rising rapidly from recruitment size to a maximum growth rate for females of 2.2 cm/yr at 60 cm CCL before declining to negligible growth approaching sexual maturity. Males displayed a similar growth pattern, reaching a maximum growth rate of 1.7 cm/yr at 60 cm CCL.

Growth slows with maturity and almost ceases with older adults. At Milman Island, the mean annual growth rate of adult females was 0.14 cm/yr (n = 81) (Dobbs *et al*. 1999).

Given that the average female commences breeding at about the size of an average breeding adult (approximately CCL = 80 cm (Table 1) and given the slow growth of immature turtles (Chaloupka and Limpus, 1997), adults should commence breeding when decades old, probably more than 30 years of age.

### 2.2.12 POST-HATCHLING

*E. imbricata* post-hatchlings are believed to follow an oceanic, surface-water-dwelling, planktonic life (Bolten, 2003). The distribution and biology of this age class is poorly understood for Australian waters. The age class is rarely encountered within GBR waters or other inshore waters (Limpus *et al*. 1994; Walker, 1994). Appreciable numbers of small *E. imbricata*, CCL < 30 cm, are recorded in ghost nets encountered floating in the Arafura Sea north of Tiwi Islands (White, 2004) and beachwashed in northeastern Arnhem Land (Roeger, 2004) and are expected to be from this age class.

This size class feeds on macro zooplankton and appears to spend about five years in the oceanic pelagic phase (Limpus and Limpus, 2000)

### 2.2.13 ADULT and IMMATURE TURTLES

**Feeding habitat**

Foraging *E. imbricata* are most frequently encountered in tidal and sub-tidal coral and rocky reef habitats throughout tropical Australia and in warm temperate areas to as far south along the east coast as northern New South Wales (Limpus, 1992; Miller *et al*. 2000b; Speirs, 2002).

The *E. imbricata* that inhabit the GBR are mixed genetic stocks from at least the Torres Strait–northern GBR breeding unit and the Solomon Islands unit (Figure 6. Broderick *et al*. 1994).

**Diet**

*E. imbricata* is omnivorous: in the Caribbean Sea, it feeds primarily on sponges and algae (Meylan, 1988); in Fog Bay, western Northern Territory, it feeds primarily on algae and sponges (Whiting, 2000) and on the reefs of Cocos Islands it feeds on algae, seagrass and sponges (Whiting, 2004).

**Population structure and dynamics**

The population structure in feeding areas have been described from throughout eastern Queensland from Torres Strait to Moreton Bay (Limpus, 1992b; Limpus *et al*. 2000; Limpus and Limpus, 2000) and from Julian Rocks in northern New South Wales (Speirs, 2002):

- Young turtles recruit to take up residence in the habitats of the continental shelf at a size of CCL = ~35 cm or larger.
- Once a turtle chooses a feeding area, it appears to remain associated with that area for an extended period of time, possibly decades.
- Feeding home ranges have not been precisely measured, may be variable between habitats and are of the order of tens of square kilometres for individual turtles on coral reefs. Many turtles can have overlapping home ranges.

*Eretmochelys imbricata* foraging populations were structured differently in different areas (Limpus *et al*. 2000). When the total capture set for the entire eastern Queensland coast is examined, there was a consistently high representation of adult turtles in the samples obtained from the far northern GBR (11°–14° latitudinal blocks) and a low proportion of adults within the sampled populations along the remainder of the coast to the south (Figure 6). This trend applies to both sexes. Other smaller studies have produced results consistent to the above: Limpus and Parmenter (1986 recorded a bias to adult-sized *E. imbricata* among foraging turtles in Torres Strait (9°–10°S) and Speirs (2002) recorded a population strongly biased to immature turtles at Julian Rocks (28°S).

A similar strong bias to females was present among all maturity classes sampled throughout eastern Queensland (Limpus *et al*. 2000) (Table 5).

**Table 5.** Sex ratio of *Eretmochelys imbricata* sampled from foraging areas throughout eastern Queensland from 11°S to 27°S. Results derived from Limpus *et al*. (2000).

| Maturity class | Proportion of females in sample | No. of turtles sampled |
|---|---|---|
| Adult | 70.8% | 298 |
| Pubescent immature | 73.8% | 168 |
| Large prepubescent immature (CCL > 60 cm) | 74.3% | 214 |
| Small prepubescent immature (CCL < 60 cm) | 72.6% | 277 |

When sex ratio was examined at a finer scale along the north-south latitudinal spread of areas sampled in this study, the sex ratio of both adult and immature turtles was strongly biased to female at most areas where large numbers of turtles were sampled.

The exception among the large sample sizes was the latitude 11° block where the adult sex ratio was approximately reversed to 32.3% female, i.e. approximately 1 female to 2 males. This atypical sex ratio of the adult *E. imbricata* in the latitude 11° block is not consistent with the growth of immature turtles to occupy the same habitat as adults, given the female bias among immature turtles within the same area. This block supports a large nesting population for the species, including the Milman Island population. Limpus *et al*. (2000) hypothesised that the adult male bias in this area could occur if either male *E. imbricata*, as they approach adult status or during their early breeding migrations, aggregated within the vicinity of the nesting beaches or if females as they approached maturity were to disperse from feeding in the vicinity of the nesting beaches.

Either scenario would represent a special case of developmental migration. No tag recoveries have been obtained in support of this hypothesis.

Annual survivorship is not often measured in marine turtle studies. Limpus (1992b) provided a first attempt to measure the annual survivorship of immature *E. imbricata* in the southern GBR (0.72 per year). This value needs better quantification from large samples of both sexes and the full range of maturity classes.

Survivorship of adult females is high when they are ashore on the nesting beaches (Table 6).

Limpus (1992b) estimated a mean annual recruitment rate of 22 *E. imbricata* to residency within the foraging population on Heron Island Reef in the southern GBR. This recruitment was equivalent to 23% of the existing resident foraging population.

**Table 6.** Survivorship of adult female *Eretmochelys imbricata* while they are ashore for nesting.

| Rookery | Survivorship of the annual nesting population | Reference |
|---|---|---|
| **QUEENSLAND** | | |
| Milman Island | 0.994 | Loop *et al*. 1995, Dobbs *et al*. 1999? |
| Campbell Island | 0.98 | Limpus *et al*. 1983a |
| **ARNHEM LAND** | | |
| NE Arnhem Land, several rookeries | 0.99 | Limpus and Preece, 1992 |

**Adult recruitment**
Miller *et al*. (2000a) estimated that the mean annual rate of recruitment of first time breeding females was equivalent to 15.8% (range = 8.3–27.3%) of the surveyed nesting population at Milman Island. This value was derived from visual examination of ovaries to detect the presence or absence of corpora albicantia from prior breeding seasons.

**Developmental migration**
Limpus (1992b) hypothesised developmental migration of immature *E. imbricata* northward through the GBR to account for the bias to immature turtles in the south and large turtles in the north. However, this hypothesis has not been supported by the extensive tagging-recapture studies during the 1990s (Limpus *et al*. 2000). As individuals, the *E. imbricata* that live in the GBR show considerable foraging site fidelity for extended periods of time and there have been no tag recoveries of turtles making major shifts except for breeding migrations. However, this long term fidelity is not consistent with the results of other aspects of the eastern Australian *E. imbricata* population (Limpus *et al*. 2000) that are summarised above, namely:

- the north-south differential within each sex of the proportion of adult *E. imbricata* within the population and
- the atypical strong bias towards males within adult *E. imbricata* within the latitude 11° block while in the same area the immature turtles remain strongly biased to female.

In the absence of tag recoveries, the concept of developmental migration of larger turtles towards the northern GBR as they grow older or the movement of adults to aggregate towards or disperse from breeding areas remains an unproven hypothesis to explain these results. If developmental migration is not occurring, we must consider the possibility of a north-south change in habitat usage by *E. imbricata* within the GBR which may account for the latitudinal differences in maturity and the atypical adult sex ratio near the nesting beaches. This warrants further investigation.

## *2.3 WESTERN AUSTRALIAN STOCK*

### 2.3.1 ROOKERIES

Western Australia supports one genetic stock of *E. imbricata* turtles with nesting centred on the Dampier Archipelago (Broderick *et al.* 1994; Broderick and Moritz, 1996). This is one of the largest hawksbill turtle populations remaining in the world and is the largest in the Indian Ocean (Figure 7a).

The breeding distribution in Western Australia has been generally surveyed over the past 25 years by K. Morris and R. Prince (Prince, 1994; WACALM Marine Turtle Database, unpublished data; Butler, 1970). The most significant breeding areas are within the Dampier Archipelago and the Montebello Islands with hundreds of *E. imbricata* nesting annually. Lower density nesting is also known from Lowendal Islands, including Varanus Island (Figure 7b), Barrow Island, Muiron Island and on the mainland at Cape Range – Ningaloo and Gnaraloo – Red Bluff (via Carnarvon).

The presence of ancient petroglyph art depicting marine turtles (Figure 8) on the mainland coast adjacent to the Dampier Archipelago indicates that a marine turtle population, presumably this *E. imbricata* nesting population, has existed from long before European colonisation.

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

**7a**. Rosemary Island in Dampier Archipelago

**7b.** Varanus Island in the Lowendal Islands

**Figure 7.** *Eretmochelys imbricata* nesting habitat in Western Australia.

**Figure 8.** Marine turtle representations in ancient Aboriginal petroglyph art on basalt boulders, Dampier. Photo by K. Morris.

**Nesting census**

While some rookeries have been surveyed in part for some breeding seasons, no Western Australian *E. imbricata* rookery has a reliable quantified estimate of the size of the annual nesting population. As a consequence, there are no long-term quantified census statistics by which one can judge whether or not representative *E. imbricata* populations in Western Australia are stable or otherwise.

Rosemary Island (Figure 7a) within the Dampier Archipelago may support of the order of 1000 nesting females annually and may be the largest remaining hawksbill nesting population globally.

Sporadic to low density nesting occurs over a much wider area, including the Ashmore Reef National Nature Refuge (Guinea, 1995). However, given the proximity of these rookeries to Timor (Figure 3b), these *E. imbricata* should be investigated to determine if they are part of an Indonesian stock.

### 2.3.2 FIDELITY TO NESTING SITES

All nesting recaptures of previously tagged nesting female *E. imbricata* in Western Australia have occurred at the respective beaches where they were tagged (Robinson, 1990; WACALM Marine Turtle Database, unpublished data).

### 2.3.3 MIGRATION

There are no feeding area recaptures of *E. imbricata* tagged at the Western Australian rookeries (Prince, 1998).

### 2.3.4 BREEDING SEASON

The Western Australian nesting season appears to occur primarily during October to January (Robinson, 1990). The complete breeding season remains undefined.

### 2.3.5 BREEDING ADULTS

The adult female *E. imbricata* nesting in the Northwest Shelf (Table 7) appear to be much larger than the eastern Australian adult females.

### 2.3.6 BREEDING CYCLES

The breeding cycles of female *E. Imbricata* nesting in the Northwest Shelf (Table 8) appear to be much shorter than for the eastern Australian nesting females.

**Table 7.** Size of adult *Eretmochelys imbricata* in Western Australia.

| | | Measurement | | | | References |
|---|---|---|---|---|---|---|
| | | Mean | SD | Range | n | |
| **Curved Carapace length (cm)** | | | | | | |
| Pooled samples of nesting females of all ages | | | | | | |
| Female | Varanus Island | 87.3 | 4.43 | 76.0–102.0 | 187 | Robinson, 1990 |

**Table 8.** Adult *Eretmochelys imbricata* breeding cycles in Western Australia.

| | | Measurement | | | | References |
|---|---|---|---|---|---|---|
| | | Mean | SD | Range | n | |
| **Remigration interval (yr)** | | | | | | |
| Pooled samples of nesting females of all ages | | | | | | |
| Female | Varanus Island | 3.7 | 1.2 | 1–6 | 49 | Pendoley, 1999, Robinson, 1990, Prince, 1994 |

## 2.3.7 CLUTCHES, EGG and HATCHLING SURVIVORSHIP

*E. imbricata* from this stock may be laying unusually small clutches for the species (Table 9).

The mainland coast from Northwest Cape to Carnarvon supports low density *E. imbricata* nesting. Clutches laid on these beaches will have been exposed to high levels of fox predation. With increased fox control measures in recent years, this egg mortality should be reduced. (unpublished data, WA CALM)

In the absence of disturbance, *E. imbricata* clutches laid above the high tide level can be expected to have a high incubation success but lower than the Great Barrier Reef, Torres Strait and Arnhem Land. (Table 9).

**Table 9.** Incubation and emergence success from *Eretmochelys imbricata* clutches in Western Australia.

| | | Measurement | | | | References |
|---|---|---|---|---|---|---|
| | | Mean | SD | Range | N | |
| **Eggs per clutch** | | | | | | |
| | Varanus Island | 111.5 | 26 | – | 54 | Pendoley, 1999 |
| **Incubation success (%)** | | | | | | |
| Pooled samples of nesting females of all ages | | | | | | |
| | Varanus Island | 0.708 | – | 3 seasons | 73 nests | Robinson, 1990 |

## 2.3.8 ADULT and IMMATURE TURTLES

### Feeding habitat

Immature *E. imbricata* have been recorded widely in Western Australia, with occasional strandings occurring as far south as Perth but regularly frequenting areas from Exmouth Gulf northward. The species has been recorded as commonly feeding on reefs adjacent to the Kimberley Coast (Prince, 1994). The biology of the species in Western Australian feeding areas is largely undocumented.

The extent to which the Western Australian stock is represented in feeding areas in the Northern Territory, such as at Fog Bay (Guinea and Whiting, 2000), is undetermined at present. This Fog Bay foraging population is characterised by:

- 95% of population is immature; size range, CCL = 26.3 – 83.0 cm.
- Size of recruits from pelagic life history phase, CCL = 30.8 cm (SD = 2.4, range = 29.1–32.5 cm, n = 2).
- Sex ratio: strongly biased to females, 1 male to 3.8 females.
- Slow growth rates: mean = 2.44 cm/yr.
- Omnivorous diet: 76.2% algae, 20.4% sponge.
- Evidence of short-term foraging area fidelity and homing following displacements of a few kilometres.

Adult and immature *E. imbricata* are also known to forage at low density over seagrass and reefal habitats within Darwin Harbour (Whiting, 2001).

Similarly, the origin of the low density foraging immature and adult-sized *E. imbricata* population on the Ashmore Reefs in the Timor Sea (Guinea and Whiting, 2000) has not been identified.

Increasingly there are *E. imbricata* foraging areas being managed as protected habitats for this stock:

- Ningaloo Marine Park, Western Australia, significant habitat. This Park is in the process of being substantially expanded (Anon, 2004a);
- Rowley Shoals Marine Park, minor habitat. This Park is in the process of being substantially expanded (Anon, 2004b); and
- Coburg Marine Park, Northern Territory, undetermined significance for the species.
- The Montebello/Barrow Islands Marine Conservation Reserves are being implemented (Anon, 2004c).

## *2.4 AUSTRALIAN INDIAN OCEAN TERRITORY*

The Australian Indian Ocean Territory includes Christmas Island and Cocos (Keeling) Islands.

**Christmas Island**
Christmas Island is an oceanic island of volcanic origin, rising out of deep water. There are few sand beaches in the otherwise rocky coast. *E. imbricata* forage on the fringing coral reefs (Gray, 1981).

**Cocos (Keeling) Islands**
Cocos (Keeling) Islands consist of 27 islands within two atolls in oceanic water 1000 km southwest of Java and 975 km west southwest of Christmas Island. Based on mark-recapture population estimates from two sections of reef habitat, there are probably several thousand immature and adult sized *E. imbricata* (CCL = 31.5 – 86.4 cm) that are foraging residents of the coral reefs of these atolls (Whiting, 2004). In contrast, *E. imbricata* does not breed on Cocos (Keeling) Islands (Whiting, 2004). Although, collection of skin samples for genetic analysis is in progress, the breeding stock(s) of origin of the foraging *E. imbricata* remains undetermined.

These turtles display a high level of fidelity to localised foraging sites where they eat algae, seagrass and sponges (Whiting, 2004). As is common for the species, the immature turtles are slow growing: mean CCL growth increment = 3.6 cm/yr (SD = 1.9, range = 0.1–7.8, n = 51) (Whiting, 2004).

## *2.5 SOLOMON ISLANDS STOCK AND OTHER INTERNATIONAL STOCKS*

### 2.5.1 ROOKERIES

Based on DNA genetic analysis, the Solomon Islands stock is an independent breeding unit when compared to the *E. imbricata* stocks that breed in Australia (Broderick *et al*. 1994).

*Eretmochelys imbricata* breeds in low density at numerous sites in the Solomon Islands (Figure 3a). However, the principal nesting sites are in the Arnavon Islands (especially

Sikopo, Kerehikapa and Maleivona Islands) and in the less surveyed Santa Cruz Islands (McKeown, 1977). There is a continuum of small nesting populations that extends from the Solomon Islands across to eastern Papua New Guinea (Figure 6) (Spring, 1982). The genetic relationship(s) of these dispersed rookeries has not been evaluated.

### 2.5.2 FIDELITY TO NESTING SITES

The limited number of reported recaptures of tagged breeding females indicates that the nesting female usually returns to nest at the same beach (Leary, 1992; McKeown, 1977). Traditional knowledge also supports this. See Section 2.2.2 for general comments.

The low frequency recapture rates for tagged turtles on the nesting beaches is consistent with a high harvest rate of the turtles in the internesting habitat; however this remains to be quantified.

### 2.5.3 MIGRATION

Adult female *E. imbricata* from foraging areas throughout the GBR migrate to breed at widely scattered rookeries throughout Papua New Guinea, Solomon Islands and northern Vanuatu as well as at the northern GBR rookeries (Figure 6) (Parmenter, 1983; Vaughan and Spring, 1980; Miller *et al*. 1998. The few tag recoveries of adult males from the northern GBR also were recaptured in Papua New Guinea and Solomon Islands, indicating that the breeding males are as migratory as the breeding females (Figure 6).

Almost all tag recoveries from neighbouring countries are of turtles killed when captured in these countries. This indicates that adult *E. imbricata* that live within the protected habitats of the Great Barrier Reef World Heritage Area are subjected to intense harvest as they migrate to breed outside of Australia.

*Eretmochelys imbricata* foraging in the GBR are of mixed genetic stocks (Broderick *et al*. 1994) and breeding migration distances may cover a few hundred kilometres or may extend to 2369 km (Miller *et al*. 1998).

### 2.5.4 BREEDING SEASON

In the Solomon Islands, there is year round nesting but with two peaks in nesting activity: in May–August and December–January (McKeown, 1977).

### 2.5.5 BREEDING ADULTS

See Section 2.2.5 for general description. The breeding females in the Solomon Islands (Table 10) are larger than the breeding females at eastern Australian rookeries (Table 1).

**Table 10.** Size of adult *Eretmochelys imbricata* in the Solomon Islands.

| | | Measurement | | | | References |
|---|---|---|---|---|---|---|
| | | **Mean** | **SD** | **Range** | **n** | |
| **Curved Carapace length (cm)** | | | | | | |
| Pooled samples of nesting females of all ages | | | | | | |
| Female | Kepehikapa, 1977 | 85.46 | 4.47 | 75–93 | 40 | McKeown, 1977 |
| | Kepehikapa, 1991 | 84.33 | 2.27 | 82–90 | 11 | Leary, 1992 |

As has been reported in the Great Barrier Reef (Loop *et al*. 1995; Dobbs *et al*. 1999), mating hawksbills are rarely seen around the Arnavon Islands.

## 2.5.6 BREEDING CYCLES

The limited number of recaptures of tagged breeding females indicates that the nesting female usually returns to nest at the same beach at approximately two weekly intervals within the same breeding season (Leary, 1991; McKeown, 1977). Traditional knowledge also supports this. See Section 2.2.6 for general comments.

Remigration recaptures of nesting females at beaches where they had been tagged while nesting in previous seasons are infrequently recorded at the Solomon Islands rookeries, even after years of tagging effort. Based on examination of gonads of harvested turtles at the Arnavon Islands in 1995, there are less than 10% of the nesting population that have bred in a previous season (Broderick, UQ, unpublished data). Such an abnormally low proportion of adult females returning from previous breeding seasons is consistent with an excessively harvested nesting population.

## 2.5.7 EGGS

See Section 2.2.7 for general description. The number of eggs per clutch and the sizes of eggs and nest depths recorded for *E. imbricata* nesting in the Solomon Islands are summarised in Table 11.

**Table 11.** Egg and nest dimensions for *Eretmochelys imbricata* in Kepehikapa Solomon Islands.

| | | **Measurement** | | | | **References** |
|---|---|---|---|---|---|---|
| | | **Mean** | **SD** | **Range** | **n** | |
| **Eggs per clutch** | | | | | | |
| | 1977 | 137.5 | 29.8 | 75–250 | 175 | McKeown, 1977 |
| | 1991 | 154.7 | 22.2 | 113–192 | 12 | Leary, 1992 |
| **Eggs diameter (cm)** | | | | | | |
| | 1977 | 3.40 | 0.08 | 3.29–3.54 | 119 | McKeown, 1977 |
| **Eggs weight (g)** | | | | | | |
| | 1977 | 21.5 | 1.5 | 19.0–24.4 | 119 | McKeown, 1977 |
| **Nest depth (cm) Bottom** | | | | | | |
| | 1977 | 38 | 4 | 32–44 | 12 | McKeown, 1977 |
| **Incubation period (d)** | | | | | | |
| | 1977 | 64.4 | 6.37 | 43–90 | 174 | McKeown, 1977 |

# 3. ANTHROPOGENIC MORTALITY and DISEASE

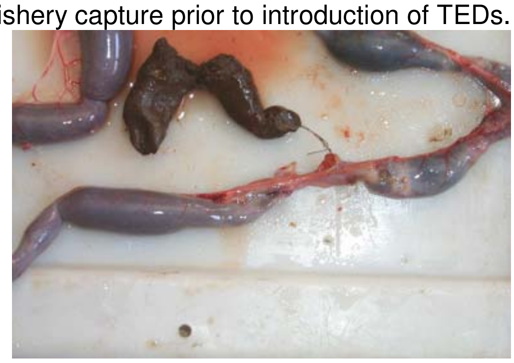
The eggs and meat of *E. imbricata* are taken for food, its skin has been used for making leather and its thick keratinised scales used to make tortoiseshell jewellery, combs, spectacle frames and ornaments (Milligan and Tokunaga, 1987). Whole turtles may be stuffed and carapaces polished to make wall ornaments. Globally, the species has been actively harvested in almost all countries throughout its distribution in recent decades (Groombridge and Luxmoore, 1989). While there has been a substantial harvest in the past, in Australia in recent years, commercial harvest has not been permitted under any State or Federal legislation. However, there has been an increasing diversity and frequency of unintentional interactions between human activities and *E. imbricata*, many of which can be detrimental to the functioning of populations.

**9a**. Juvenile *E. imbricata* dead in a beach-washed trawl net, Hawk Island, Northern Territory, August 1992.

**9b.** Juvenile *E. imbricata* dead in a beach-washed trawl net, Duyfken Point, Weipa, November 2000.

**9c.** Adult sized *E. imbricata*, Northern Prawn Fishery capture prior to introduction of TEDs.

**9d.** X-ray of immature *E. imbricata* with three ingested fish hooks, Moreton Bay, 1991.



**9e.** Fishing line in the compacted gut blockage in an immature *E. imbricata*, Sunshine Coast, December 1999.

**9f.** Adult sized *E. imbricata* trapped and killed in a discarded tyre, Townsville, November 2002.

**Figure 9.** Illustration of a range of anthropogenic impacts on *Eretmochelys imbricata* in northern Australia.

## 3.1 PAST COMMERCIAL HARVESTS IN NORTHERN AND EASTERN AUSTRALIA

Large scale commercial trade in tortoiseshell (the thick keratinised scutes of *E. imbricata*) occurred in northeast Arnhem Land during the 17th and 18th centuries between coastal people and the visiting Malays who in turn traded the tortoiseshell back to present-day Unjung Pandang in central Indonesia (MacKnight, 1976). For the brief period that this Malay trade was monitored in the late 1880s–1890s, in excess of over a ton of tortoiseshell per year was exported annually (South Australian Parliamentary Papers, 1851–1940); this is equivalent to an annual harvest of over 1000 adult *E. imbricata*.

Commercial trade between North Queensland and Europe began in the late 1700s. The trade was extensive, at least during the latter half of the 1800s and early 1900s and, for decades, over a ton of tortoiseshell was exported annually from Torres Strait. Again, this represented an annual harvest of over 1000 adult *E. imbricata* from the northern GBR and Torres Strait (Figure 10) (New South Wales Parliamentary Papers, 1851–1940, Minutes of the Proceedings of the Legislative Council and Annual Reports of the Marine Department and Department of Harbours and Marine in the Queensland Parliamentary Papers, 1880–1969). The industry effectively ceased during the 1930s and became illegal with the protection of *E. imbricata* in Queensland in 1968.

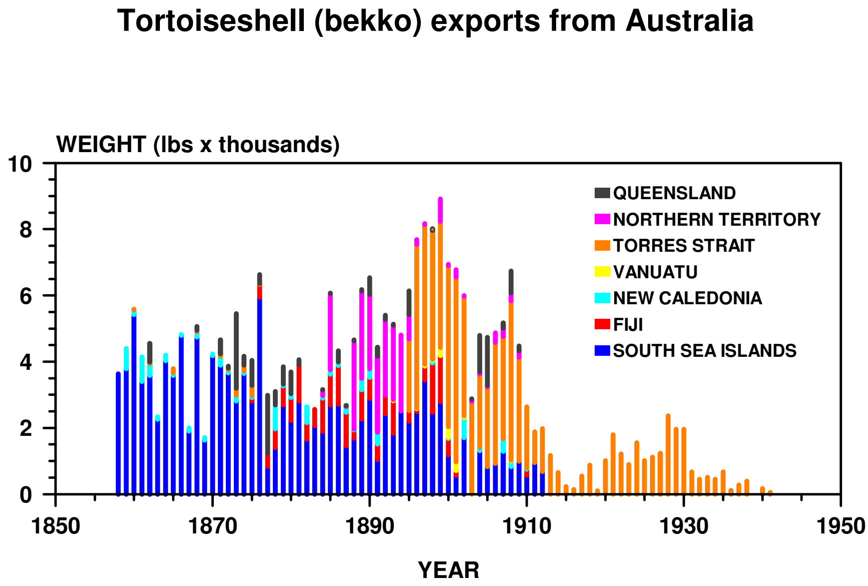



**Figure 10.** Tortoiseshell (bekko) exports from Australia. Data derived from Colonial, Australian and State Customs data. Australia was a transhipment site for much of this trade and the countries of origin are identified for the exported tortoiseshell. Approximately 2 lb of tortoiseshell can be obtained from an adult *E. imbricata*.

There had to have been a huge *E. imbricata* nesting population in the mid 1800s throughout the southwest Pacific Ocean to have supported the above tortoiseshell trade for almost a century. Although there were no census data associated with this harvest, the nesting populations must have been severely depleted as a result. It would be impossible to replicate this long term harvest from the present day populations in the region.

At Cocos (Keeling) Islands in the Indian Ocean, the resident foraging *E. imbricata* population was extensively harvested during the 19th and early 20th Centuries for food by local residents, provisioning of visiting ships and for the tortoiseshell trade. Whiting (2004) presents a case for significant depletion of the foraging population by the mid 20th Century followed by some recovery of the population.
There is no evidence that the Western Australian *E. imbricata* rookeries were ever subjected to intense long term harvests of tortoiseshell.

It is surprising that there are so few records of hawksbill turtle harvest in Western Australia. This is particularly so given that hawksbill turtles have been targeted for extensive harvest and international trade of their scale (= tortoiseshell or bekko) during the late 1800s and early 1900s and then again from the 1950s until 1991.

The Australian hawksbill turtle populations appear to have been largely excluded from these harvests and trade since World War II. The consequence of this is that Australia now supports what appears to be the last remaining large hawksbill nesting populations in the world.

## *3.2 INDIGENOUS HARVESTS IN NORTHERN AND EASTERN AUSTRALIA*

Coastal indigenous communities regarded marine turtles as a significant resource and cultural icon long before European colonisation (Figure 8). Indigenous people with a recognised Native Title right can legitimately hunt marine turtles in Australia for personal, domestic, communal, non-commercial purposes.

*E. imbricata* has been hunted for centuries in Australia by indigenous people for tortoiseshell to manufacture items of everyday use (fish hooks, combs) and items for ceremonial use (masks, images) (MacGillivray, 1852; Thomson, 1934; Allen and Corris, 1977). Its eggs were eaten as was its meat (Moore, 1979; Johannes and MacFarlane, 1991). However, *E. imbricata* is at times toxic to eat, causing illness and deaths especially among children and breast-fed babies (Limpus, 1987). In past times women were restricted from eating *E. imbricata* meat and eggs; only selected members of the villages were/are considered to be sufficiently knowledgeable to safely prepare the meat for eating (Moore, 1979; Smith, 1989). It is highly likely that there is no "safe" way to prepare a toxic turtle for eating. Specific poison glands, that could be removed, cannot be identified for the species. It is more likely that it is a matter of chance as to whether an individual turtle is toxic.

**Queensland**
*E. imbricata* continues to be harvested in small numbers by Aboriginal and Torres Strait communities in Queensland. However, the harvest is largely unquantified.

**a. Hopevale**

- At least 2 *E. imbricata* were caught during 15.5 months of monitoring of the turtle catch in 1984–1986 (Smith, 1989).

**b. Lockhart River**

- In former times, green turtles were the favoured species, but loggerheads and hawksbill turtles were also taken; with mating turtles, the female with immature eggs was preferred (Thomson, 1934). In 3 months (late September–late December) in 1985, at least 1 *E. imbricata* was captured (Smith, 1989).

**c. Torres Strait**

- It appears that low numbers of *E. imbricata* are harvested annually in present times in Torres Strait. During 271 days of sampling turtle catch at islands in the Torres Strait Protected Zone in May 1991–June 1992, 3 *E. imbricata* were recorded and, on extrapolation, this indicates an annual harvest of approximately 50 per year (Harris *et al*. 1992a, b).

A substantial but unquantified number of eggs are harvested from rookeries throughout western and central Torres Strait annually (Johannes and MacFarlane, 1991; Limpus and Parmenter, 1986). Almost all *E. imbricata* eggs laid on the inhabited islands of Torres Strait plus substantial numbers of clutches are harvested from the neighbouring adjacent uninhabited islands.

The annual indigenous harvest for all of Queensland has not been quantified but is probably of the order of 50–100 *E. imbricata* plus probably hundreds of clutches of eggs.

**Arnhem Land**

- Eggs are harvested from relatively remote locations such as Crocodile Islands (Guinea, 1994).
- During a detailed rapid assessment of turtle nesting at three islands in Northeast Arnhem Land in August 1992, Limpus and Preece (1992) recorded approximately 100% harvest of all recently laid *E. imbricata* clutches at Bremer Island, a minor rookery and no evidence of egg harvest at Hawk and Truant Islands. However in October 1997, the author was informed by the Indigenous community at Gove of a helicopter being used to collect a large number of eggs from Truant.
- During the 1995 Nanydjaka beach survey (northeast Arnhem Land), *E. imbricata* accounted for 24% of clutches of eggs harvested from this 11 km 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.
- Guinea and Whiting (2000) indicated a low annual of harvest of *E. imbricata* from the immature population foraging in Fog Bay.

It can be expected that residents of Arnhem Land communities with ready access to *E. imbricata* eggs will exercise their traditional rights to harvest. While there are no data available on the total size and distribution of the harvest of *E. imbricata* turtles and eggs in Arnhem Land, the annual harvest is presumed to be comparable or greater than in Queensland.

**Western Australia**

Hawksbill turtles (*Eretmochelys imbricata*) have not featured prominently in any reports of indigenous harvest of turtles and or their eggs in Western Australia.

## *3.3 ACCIDENTAL CAPTURE IN FISHING GEAR*

### 3.3.1 QUEENSLAND SHARK CONTROL PROGRAM

*Eretmochelys imbricata* is rarely captured in the Queensland Shark Control Program (QSCP) (EPA Queensland Turtle Research Project, unpublished data). There have been five immature *E. imbricata* killed in QSCP in the 11 years since tagging of the captured turtles commenced in 1993. The annual *E. imbricata* mortality rate in this fishery has been 0.5 immature turtles per year.

### 3.3.2 COMMERCIAL FISHERIES

**Gill nets**

*Eretmochelys imbricata* mortality in gill-net fisheries in northern Australia remains unquantified.

- An onboard observer on a Taiwanese gillnet boat (Chyun Fure No.7) off the Arnhem Land coast in 1985–1986 recorded six *E. imbricata* out of 16 turtles captured (56% mortality for pooled species. Records over approximately a four month period documented 81 sets of a 10.5 km monofilament net, surface headline, 15 m drop, 14–15 cm mesh) (Hembree, 1985–1986). This fishery has been closed within Australia but the same type of fishery continues in Indonesian waters of the Arafura Sea.
- During 15 days in late November 1991 off Fog Bay, Northern Territory, one shark fisherman using a 2000 m net (monofilament, 42.5 cm mesh, 12 m drop, bottom set) drowned an estimated 300 turtles among which there were 1% *E. imbricata* (Guinea and Chatto, 1992). Following this event, this type of fishery was closed in the Northern Territory but possibly continued in Western Australian waters.
- There were two (4%) immature *E. imbricata* in a sample of 47 marine turtles tagged by one fisher in the inshore N3 gill net fishery in the southeastern Gulf of Carpentaria in 1993 (EPA Turtle Conservation Project data). Although not well quantified, it is expected there will be low mortality within this type of fishery throughout eastern Queensland, Gulf of Carpentaria and Arnhem Land.
- There have been captures of some immature *E. Imbricta* in Victorian net fisheries although this information has never been quantified accurately.

**Trawling**

The interaction between *E. imbricata* and the Australian trawl fisheries has been largely ignored until recent years. Since the 1960's the number of boats, the length of the shot-times and the number and size of nets towed have increased., The following summarises the more significant available data pertaining to the interaction of *E. imbricata* and trawling in Australian waters:

- There has been a low incidence of *E. imbricata* capture in prawn trawls relative to other species recorded by trained observers on trawlers prior to 1990: 5.6% of 90 turtles captured in Gulf of Carpentaria; 4% of 45 turtles captured in the area of Cape York to Princess Charlotte Bay; 0% of 30 turtles captured off Townsville.
- During a two year CSIRO study of turtle bycatch in the Northern Prawn Fishery, *E. imbricata* made up 4–6% of the 165 and 161 turtles trawled in 1989 and 1990, respectively. The *E. imbricata* impacted by this fishery encompassed the adult and large immature size ranges. The catch rate equalled 0.0018 ± 0.0007 turtles per trawl in 1989 and 0.0029 ± 0.0010 with a 19.2% probability of being landed dead in the sorting tray in 1989 and 33.3% probability in 1990. This study estimated that the Northern Prawn Fishery killed approximately 68 and 64 *E. imbricata* in 1989 and 1990 respectively (Poiner and Harris, 1994, 1996).
- In the Northern Prawn Fisheries (NPF) studies (Poiner and Harris, 1996), there were large interspecific differences in probability of drowning when a turtle is captured in a trawl (Table 12). *E. imbricata* was the most susceptible to drowning when compared to the other marine turtle species in Australia.

**Table 12.** Probability of marine turtle mortality with trawling capture in the Northern Prawn Fisheries, 1989–1990 (Poiner and Harris, 1994).

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

- 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 and Mayer, 1998). This study found that *E. imbricata* was not commonly captured in the ECTF bycatch (1.5% of 1527 turtles reported; range per year = 0.4–2.3%). *E. imbricata* was also uncommon among turtles in the TSPF bycatch (1.3% of the 151 turtles reported). The *E. imbricata* impacted by both fisheries encompassed the adult and large immature size ranges. The extrapolated mean annual catch of *E. imbricata* within the entire fishery was estimated at 80 in ECTF and 6 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 4–8% (n = 3–6) in ECTF and possibly less than one in TSPF. The majority of *E. imbricata* were trawled in inshore waters off Townsville to Princess Charlotte Bay.
- 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 ~1% of the turtles reported captured were *E. imbricata* (Figure 9c). The introduction of TEDs to the fishery resulted in a two order of magnitude reduction in turtle captures in the NPF trawls.

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

The trawl fisheries off the coast of New South Wales, Queensland, Northern Territory and Western Australia have had the potential to kill 50–100 *E. imbricata* annually since the late 1970's. Fortunately this situation has for the most part changed as we moved into the 21st Century. The compulsory use of TEDs has been regulated in the NPF since April 2000, ECTF since December 2000, TSPF since March 2002 and Western Australian prawn and scallop trawl fisheries since 2002. TEDs are currently used voluntarily in the T4 stout whiting trawl fishery in southern 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 fisheries of New South Wales or in the Northern Territory fish trawl fishery.

The process for regulating the compulsory use of TEDs in trawl fisheries was partly facilitated by the incidental catch (bycatch) of sea turtles during coastal otter-trawling operations within Australian waters north of 28 degrees being listed under the EPBC Act as a key threatening process (KTP) in 2001 due to the level of bycatch of marine turtles.

**Benthic long-line fisheries**

There appears to be no turtle bycatch data available from the Northern Territory bottom-set long-line fishery for sharks.

**Oceanic fisheries**

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

**Indian Ocean**

No suitable longline bycatch data are available to estimate the *E. imbricata* bycatch for the Indian Ocean.

**South Pacific Ocean**

*Eretmochelys imbricata* is part of the bycatch within the pelagic longline fisheries of the Eastern Tuna and Billfish Fishery and the Southern and Western Tuna and Billfish Fishery (Robins *et al*. 2002). These fisheries may catch around 400 turtles (all species) per year. The species composition of the catch is poorly reported and observer coverage of the effort is low (5%).

*Eretmochelys imbricata* is part of the longline bycatch of the Western and Central Pacific Ocean Tuna Fisheries of the Pacific Island countries and monitored by the Secretariat of the Pacific Community (Oceanic Fisheries Program, 2001). The impact of these fisheries on turtles could not be quantified because the turtle bycatch was not normally identified and the observer coverage of the effort was < 1%.

Oveall, there is a need to increase information on incidental catch of *E. Imbricata* in commercial fisheries so that mitigation strategies can be developed.

## *3.4 MARINE DEBRIS*

The EPA Marine Wildlife Stranding and Mortality Database records strandings, fisheries bycatch and other mortality for marine turtles in Queensland. Given that some carcasses will be destroyed by predators or decay before they strand, not all turtle mortality will be recorded. However, this database provides a substantial coverage of inshore mortality since about 1990 for southeast Queensland and since 1995 from Cairns south. A wide range of sources of mortality from human related marine debris have been identified for the 9 years (1995–2003) (Limpus *et al*. 1993; Greenland *et al*. 2004):

- Entanglement in fishing line (n = 3), in a frayed sack (n = 1);
- Ingested synthetic material (n = 3);
- Trapped in a tyre (n = 1) (Figure 9f)

The annual mortality from these diverse sources is estimated to be a few tens of *E. imbricata* annually for Queensland.

### 3.4.1 Ghost net entanglement

Large amounts of net are discarded or lost in the fisheries of the Arafura Sea and northern Australia but the turtle mortality in this "ghost fishery" is mostly unquantified. The time frame over which this mortality has been in place is not clear.

- In July 1992, a drowned immature *E. imbricata* was found tangled in a beach-washed prawn trawl net on Hawk Island (Figure 9a. Limpus and Preece, 1992).
- February 1994, a dead immature was found with beachwashed net at Darwin (Chatto *et al*. 1995).

Since the mid 1990's, it has become widely publicised that large amounts of fishing net are discarded or lost from the fisheries of the Gulf of Carpentaria and Arafura Sea and end up beachwashed on the Queensland and Northern Territory beaches of the Gulf of Carpentaria (Limpus and Miller, 2002; White, 2003; Roeger, 2004). As awareness of the issue has increased, an area to the north of the Tiwi Islands in the Arafura Sea has been identified where turtles entangled in drifting ghost nets are regularly encountered (White, 2004). Not all ghost nets drift at the surface. Some may drift across unobstructed bottom (White, 2004). However, both surface drifting and bottom drifting nets can be snagged on reefs and remain stationary while continuing to catch. This appears to be common on the reefs offshore from the Marpoon-Weipa coast of western Cape York Peninsula (V. Wallin and Lawry Booth, pers. comm.).

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 measuring many thousands of metres in length can be returned to the sea only to drift and re-strand in the weeks that follow. 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 (Limpus and Miller, 2002). Similar stranding of nets and entangled turtles has been recorded following cyclones in the three years since 2001 (Limpus and Miller, 2002; V. Wallen, pers. comm.; EPA Marine Wildlife Stranding and Mortality Database). There are, thus, two separate issues with regard to the entrapment of turtles in these “ghost nets”: (1) new nets drifting to arriving at the beaches or entangle on reefs each year and (2) recycling of nets from the beaches back to the sea and their subsequent re-stranding.

In addition to foraging turtle entanglement in these nets in the sea, nesting turtles may become entangled when the nets and associated ropes are shore on the beaches.

Turtle entanglement in beachwashed ghost net has been monitored in the vicinity of Cape Arnhem and Port Bradshore during 1996–2003 (Leitch, 1997, 2001; Roeger, 2004). In northeast Arnhem Land, turtles entangled in ghostnets appear to strand mainly in the early dry season, April–August (Roeger, 2004).

The mortality of all species of marine turtle throughout the Gulf of Carpentaria within this "ghost net" fishery is unquantified but appears to be many hundreds of turtles annually. An unquantified but obvious proportion of the turtles stranding in these nets are immature *E. imbricata* (Figure 9b) (EPA Marine Wildlife Stranding and Mortality Database; Leitch, 1997, 2001; Roeger, 2004; White, 2004). In northeastern Arnhem Land, there have been 53 (27.3%) *E. imbricata* among a sample of 194 marine turtles recorded entangled in discarded or lost fishing net which drifted ashore during 1996–2003 with 45% of *E. imbricata* released alive (Roeger, 2004). The extent to which this type of mortality extends further across northern Arnhem Land mostly is undetermined. *E. imbricata* has been identified in 90% of ghost net entanglement in offshore drifting nets which are being mostly reported from north of Tiwi Islands in the Arafura Sea (White, 2003).

Collectively, ghost nets have the potential to kill at least hundreds of immature *E. imbricata* annually.

## *3.5 OTHER ACCIDENTAL MORTALITY*

During the 9 years (1995–2003) in Queensland, low levels of *E. imbricata* mortality were recorded for a range of additional sources via the EPA Marine Wildlife Stranding and Mortality Database:

- Fractured from boat strike or propeller cuts (n = 8)
- Ingested hooks and line (n = 4) (Figure 9d);
- Trapped inside wide-opening, collapsible crab traps (n = 2).

The annual mortality from these diverse sources is expected to be a few tens of mostly immature *E. imbricata* annually for Queensland.

Incidental turtle mortality is less comprehensively recorded elsewhere in northern Australia. However, there are indications that there is at least a low level of *E. imbricata* mortality for human related factors across northern Australia: *Eretmochelys imbricata* were recorded with boat-strike fractures in Fog Bay, western Arnhem Land (Guinea and Whiting, 2000).

## *3.6 DISEASE*

There has been limited study of disease in wild *E. imbricata* in Australia (Glazebrook and Campbell, 1990; Platt and Blair, 1998; Kelly and Gordon, 2000).
A high frequency of fluke infection has been associated with debilitated but uninjured *E. imbricata* in southeast Queensland and Fog Bay (EPA Marine Wildlife Stranding and Mortality Database; S. Whiting, pers. comm.). Six genera of flukes have been identified in Australian *E. imbricata* (Table 13).

**Table 13.** Summary of parasitic worms identified from *Eretmochelys imbricata* in Australia.

| Species | Biology | Reference |
|---|---|---|
| **Platyhelminthes, Digenea** | | |
| Calcodes sp. | In gall bladder | Glazerook and Campbell, 1990 |
| Cricoephalus sp. | In stomach and small intestine | Glazerook and Campbell, 1990 |
| Diaschistorchis sp. | In stomach and small intestine | Glazerook and Campbell, 1990 |
| Orchidasma amphiorchis | In stomach and intestine | Blair and Limpus, 1982 |
| Hapalotrema sp. | In circulatory system, eggs in body organs | Platt and Blair, 1998, Glazebrook and Campbell, 1990 |
| Learedius sp. | In circulatory system, eggs in body organs | Glazebrook and Campbell, 1990 |

In a recent study of fungal infection of turtles and their eggs, two soil fungi (*Chrysosporium sp., Penicillium sp.)* were identified within the cloaca of nesting *E. imbricata* at Milman Island (Phillott *et al*. 2002).

There is a low frequency of “green turtle fibropapilloma disease” tumours on foraging *E. imbricata* in Moreton Bay: 9% of 34 turtles examined (EPA Turtle Conservation Project database).

## *3.7 SEISMIC SURVEY*

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

### *3.8 HARVESTS IN NEIGHBOURING COUNTRIES*

**Papua New Guinea**
Low intensity harvest of *E. imbricata* probably occurs at each coastal village in southern PNG (Hirth and Rohovit, 1992).

Kwan (1989, 1991) implies that some 20–100 *E. imbricata* per year were harvested in the Daru area of Western Province in the mid 1980's.
At least one jewellery manufacturer in Port Moresby specialises in tortoiseshell items and hand-crafted jewellery and carapaces can be seen for sale in markets near Port Moresby (C. Limpus, unpublished data).

**Solomon Island and Fiji**
Many thousands of *E. imbricata* turtles have been killed annually in the Solomon Islands and in Fiji in recent decades. This conclusion is based on international trade statistics in tortoiseshell (bekko) from the southwestern Pacific region (Table 14, Figure 11) (Milliken and Tokunaga, 1987). For adult turtles, an approximate conversion factor of approximately 1000 turtles to the tonne of tortoiseshell can be used.

In addition, turtles are killed and their scutes used within the Solomon Islands. The above figures provide for a minimum estimate of annual harvests. A major proportion of these turtles are used for food within the country at the village level. A Japanese ban on international trade in tortoiseshell (introduced in 1994) may therefore not be an incentive for reduction in *E. imbricata* harvest in countries like Solomon Islands and Papua New Guinea.

There have been strong indications since 1977 that the Solomon Islands *E. imbricata* nesting populations are in decline (McKeown, 1977; Broderick and Moritz, 1996). There is a high probability that the current rates of harvest are not ecologically sustainable.

In 1994, the annual harvest in Fiji was estimated at ~2000 *E. imbricata* annually. This Fijian harvest probably also targets turtles that breed in the Solomon Islands and Papua New Guinea and most likely is not sustainable at that level.

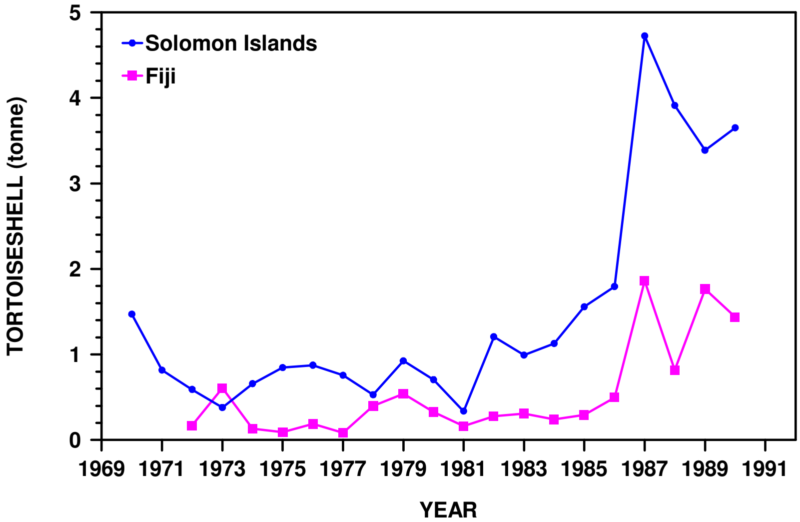



**Figure 11.** Tortoiseshell exports from Solomon Islands and Fiji, Southwest Pacific Ocean. Data from Japanese Trade Statistics. 1 tonne of tortoiseshell is approximately equivalent to 1000 harvested large *Eretmochelys imbricata*.

**Table 14.** Export statistics for tortoiseshell (bekko) exports from Solomon Islands and Fiji. There are discrepancies between Solomon Islands export statistics (SI) and Japanese import statistics (JIS) (Solomon Islands Department of Natural resources, unpublished data; *Traffic Japan* trade statistics).

| Year | Tortoiseshell exported to Japan (kg) | | |
|---|---|---|---|
| | Solomon Islands | | Fiji |
| | JIS | SI | JIS |
| 1970 | 1469 | | |
| 1971 | 816 | | |
| 1972 | 590 | | 169 |
| 1973 | 378 | | 607 |
| 1974 | 657 | | 131 |
| 1975 | 846 | | 91 |
| 1976 | 873 | | 189 |
| 1977 | 756 | | 82 |
| 1978 | 528 | | 399 |
| 1979 | 924 | | 539 |
| 1980 | 704 | | 328 |
| 1981 | 336 | | 162 |
| 1982 | 1206 | | 280 |
| 1983 | 992 | | 309 |
| 1984 | 1127 | 1318 | 242 |
| 1985 | 1556 | – | 294 |
| 1986 | 1793 | 1841 | 497 |
| 1987 | 4723 | 2432 | 1859 |
| 1988 | 3911 | 1978 | 817 |
| 1989 | 3387 | 3099 | 1765 |
| 1990 | 3650 | | 1438 |

## Indonesia

*Eretmochelys imbricata* are harvested in large amounts in Indonesia but the annual harvest is imprecisely described. H. Reichart (WWF Indonesia, 1990) indicated an annual harvest of 20 000 *E. imbricata* in Indonesia in the mid 1980's (Figure 12a).

**12a.** Portion of a stockpile of 5 tonne of bekko (tortoiseshell) exported to Japan from Unjung Pandang, Sulewasi, Indonesia, mid 1980's.

**12b.** *Eretmochelys imbricata* eggs on sale in street market, Jakarta, Indonesia, 1997.

**Figure 12.** *Eretmochelys imbricata* harvest in Indonesia.

In 1992 there were reported to be 20 000 kg of tortoiseshell stockpiled for sale and in early 1993 the stockpile was quoted as 14 000 kg. The internal trade usage of tortoiseshell within Indonesia is approximately 5000 kg per year (Dr. I. Suwelo, pers. comm.). Three months after total protection of *E. imbricata* in Indonesia in late 1992, *Eretmochelys imbricata* still were being killed in turtle slaughter houses in Bali. In 1994, approximately 3000 *E. imbricata*, ranging from small immatures to breeding adults, were imported into Bali from elsewhere in Indonesia for slaughter (Limpus, 1997). Most *E. imbricata* harvest appears to occur in central and eastern Indonesia.

In addition to the harvest of turtles, there is also an extensive *E. imbricata* egg harvest throughout many parts of Indonesia (Figure 12b).

There are no known large breeding aggregations remaining for the species in Indonesia that can sustain this level of harvest. It is highly likely that at least the bekko harvest has included turtles from the Australian breeding and foraging populations.

### *3.9 DISORIENTATION FROM ALTERED LIGHT HORIZONS*

Hatchlings can be disoriented by alterations to the light horizons. There are no current significant on-going impacts on rookeries in this regard in eastern and northern Australia. However, boats at anchor with deck lights on at night adjacent to major rookeries such as Milman Island have trapped hatchlings dispersing beyond the reef and held them in the glow of the lights around the boat for an extended time (EPA Turtle Conservation Project, unpublished data). Intense predation of these concentrations of light-trapped hatchlings can occur.

The western Australian *E. imbricata* nesting population occurs within the Western Australian coastal habitats with the greatest industrial development. The impacts throughout the stock of altered light horizons on hatchling disorientation and associated mortality on the beach, on increased predation in adjacent waters and on possible reductions of the nesting population as females avoid illuminated nesting habitat has not been comprehensively quantified (Pendoley, 1991). Similarly the impact of increased human populations on the islands through disturbance of nesting turtles, increased habitat disturbance on the islands and inshore marine habitats and the increased potential for boat strike are not being quantified. In addition, *E. imbricata* nesting islands such as Rosemary and other islands in the Dampier Archipelago have holiday huts and are regularly used for bush camping. The impact of these activities on turtle reproductive success appears not to be monitored.

There are no data available to determine the extent to which altered light horizons associated with oil and gas industry burn-off flares, loading facilities and exploration and production platforms of the Northwest Shelf are negatively impacting the dispersal of hatchling turtles from the rookeries. This information should be collected.

# 4. POPULATION STATUS

## *4.1 STOCK DYNAMICS*

The following status conclusions are based on information summarised in the above review.

**TORRES STRAIT-NORTHERN GBR AND ARNHEM LAND STOCK(S)**
**Queensland sub-population**
The large *E. imbricata* nesting population, one of the few large remaining populations in the world has been declining at 3–4% per year since at least 1990 (based on tagging census at the Milman Island index beach). The nesting turtles have not been part of the global tortoiseshell trade since before World War II. There is a substantial but unquantified harvest of eggs on the Torres Strait nesting beaches. Within the foraging range for this stock, there has been:

- A wide spread but unquantified harvest. The harvest is usually at low level at any one site.
- Probably many tens of *E. imbricata* killed annually as bycatch in northern and eastern Australian fisheries over recent decades. Since 2002, the trawl bycatch component should have been substantially reduced with the compulsory use of TEDs.
- A wide spread, substantial but unquantified mortality of *E. imbricata* in ghost nets.

A 3–4% per year rate of decline in the annual nesting population projects to an expected > 80% reduction in the size of the breeding female population in less than one generation for this stock. Under IUCN Red List Categories, the Queensland *E. imbricata* breeding population could qualify as "critically endangered".

**Northern Territory sub-population**
The Northern Territory sub-population is another of the few very large *E. imbricata* nesting populations remaining in the world. There are no long term census data available for judging the stability or otherwise of the nesting population. There is a widely dispersed and at times locally intense but largely unquantified harvest of eggs from these rookeries. Within the foraging range for this stock, there has been:

- Probably many tens of *E. imbricata* killed annually as bycatch in northern Australian fisheries over recent decades. Since 2002, the trawl bycatch component should have been substantially reduced with the compulsory use of TEDs.
- A wide spread, substantial but unquantified mortality of *E. imbricata* in ghost nets.
- An undetermined proportion of the population included in the intense harvest of *E. imbricata* in neighbouring Indonesia.

It is expected that the combined mortalities impacting this Arnhem Land sub-population exceeds sustainable levels.

**Western Australian stock**
The Western Australian stock is another of the few very large *E. imbricata* nesting populations remaining in the world. There are no long term census data available for judging the stability or otherwise of the nesting population. The majority of hawksbill turtle nesting in Western Australia occurs on islands and is largely excluded from the impact of introduced predators and because this species feed primarily on reefs, hawksbill turtles have not featured commonly in trawl bycatch and inshore gillnet fishery bycatch. A substantial proportion of the nesting habitat is in close proximity to oil and gas industry infrastructure that substantially alters light horizons in the surrounds. The impact of these altered light horizons with respect to causing increased hatchling mortality and in causing declines in the size of nesting populations at the adjacent rookeries has not been quantified. There are additional

poorly quantified losses to the population in its dispersed coastal foraging areas and within the pelagic habitats for the stock.

With the limitations of the available data, the possible trends in the Western Australian hawksbill stock cannot be judged. As a precaution, it is recommended that there be a more concerted effort of collaboration between the oil and gas industry and the DCLM to focus on long-term monitoring to judge the success of management of the region's turtle populations and to quantify the spatial and temporal distribution of hawksbill hatchling mortality and/or debilitation and adult female disturbance resulting from altered light horizons.

There is a reasonable chance that the combined mortalities impacting this stock exceed sustainable levels.

## *4.2 GREAT BARRIER REEF WORLD HERITAGE AREA*

*Eretmochelys imbricata* are one of the values associated with the 1981 listing of the Great Barrier Reef as a World Heritage area. The Great Barrier Reef World Heritage Area is one of the largest areas of coral reef in the world and supports probably the greatest number of foraging *E. imbricata* than any other marine protected area in the world. These foraging turtles originate from mixed stocks, including:

- The declining nesting population of the northern GBR–Torres Strait and
- A dispersed nesting population across northern Vanuatu, Solomon Islands and eastern Papua New Guinea. This has been an area of intense harvest of adult turtles from the vicinity of the nesting beaches.

Even though the Great Barrier Reef World Heritage Area and the associated Great Barrier Reef Marine Park and Queensland State Marine Parks provide the largest marine protected area in the world, it is not large enough to adequately protect this highly migratory species.

There is a high probability that this major *E. imbricata* foraging assemblage within the Great Barrier Reef is in serious decline. A project dedicated to monitoring the population dynamics of *E. imbricata* foraging throughout the Great Barrier Reef is warranted.

# 5. CONSERVATION STATUS WITHIN AUSTRALIA

Conservation management of hawksbill turtles, *Eretmochelys imbricata*, within Australia had its beginning with the 18 July 1968 Order in Council under the Queensland Fisheries Act that declared a year-round closed season for the harvest of all species of marine turtles and their eggs in Queensland.

*Eretmochelys imbricata* currently is recognised as a threatened species in Queensland, Western Australia and Australia generally (Table 15). It warrants consideration for listing as an endangered species for New South Wales, Queensland and the Northern Territory and as a vulnerable species in Western Australia.

**Table 15.** Summary of the legally defined conservation status of *Eretmochelys imbricata* for 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<br>Migratory species<br>Marine species | *Commonwealth Environment Protection and Biodiversity Conservation Act 1999* |
| Tasmania | Not listed | *Threatened Species Protection Act 1995* |
| Victoria | Not listed | Advisory list of *Threatened Vertebrate Fauna* in Victoria 2003 |
| New South Wales | Not listed | *Threatened Species Conservation Act 1995* |
| Queensland | Vulnerable | *Nature Conservation Act 1992* |
| Northern Territory | Data deficient | *Territory Parks and Wildlife Conservation Act 2000* |
| Western Australia | Rare or likely to become extinct | *Wildlife Conservation Act 1950* |
| South Australia | Not listed | *National Parks and Wildlife Act 1972* |

Generally, the Australian Government has jurisdiction over waters beginning three nautical miles offshore to the end of the Exclusive Economic Zone (EEZ). In these waters, marine turtles are protected under the Environment Protection and Biodiversity Conservation Act (EPBC). The respective Australian States and Territories have jurisdiction over intertidal waters and coastal waters out to three nautical miles offshore from their State lands. An exception to this is in the Great Barrier Reef Marine Park, where Australian Government jurisdiction extends landward to mean low water. In these waters marine turtles are protected under the Great Barrier Reef Marine Park Act 1975. The respective State legislation is applicable to the management of marine turtles in these State and Territorial waters. Under the EPBC Act, actions in all Australian waters that have, will have or are likely to have a significant impact on marine turtles are subject to a rigorous referral, assessment, and approval process.

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