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RESEARCH PUBLICATION NO. 83

Monitoring Green Turtle Population Dynamics in Shoalwater Bay: 2000 - 2004

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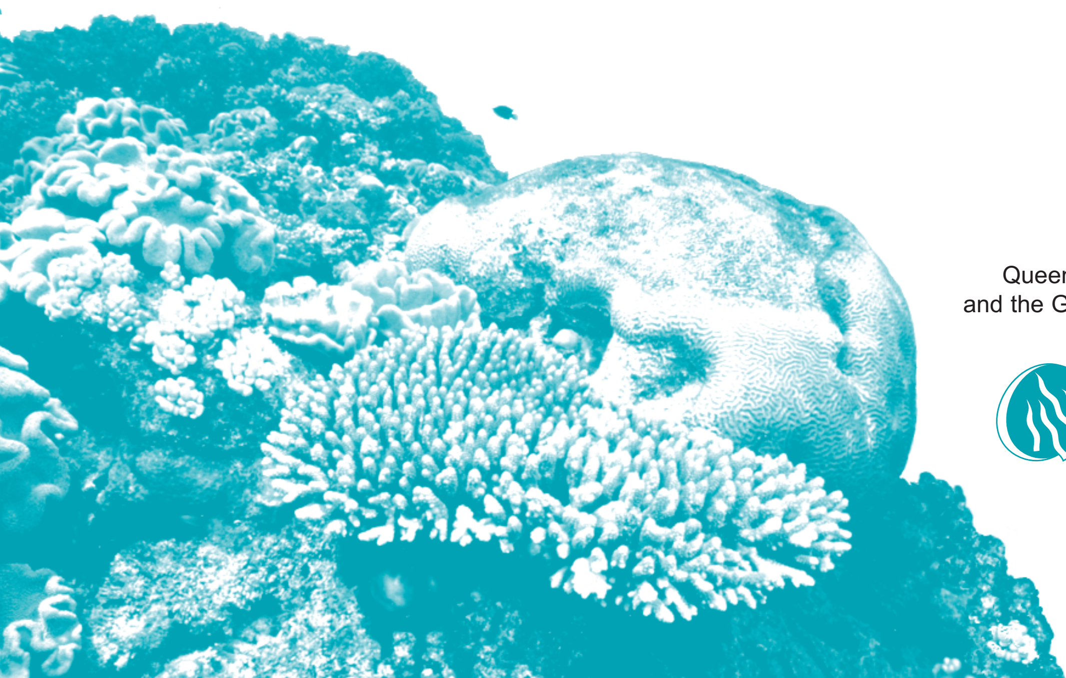

Report prepared for
Queensland Environmental Protection Agency
and the Great Barrier Reef Marine Park Authority

Queensland Government
Environmental Protection Agency
Queensland Parks and Wildlife Service

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Report prepared for Queensland Environmental Protection Agency and the Great Barrier Reef Marine Park Authority

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FOREWORD

The Great Barrier Reef Marine Park Authority (GBRMPA) and the Queensland Environmental Protection Agency (QEPA) are pleased to publish this report on the monitoring of a foraging ground population for the southern Great Barrier Reef green turtle genetic stock.

The Queensland Turtle Conservation Project of the QEPA continues to provide the only source of long term monitoring data on marine turtles in Queensland. As highlighted by the peer review comments,

> *The study is the clear example of highest standards currently attainable by sea turtle biologists worldwide and GBRMPA can be commended in deciding to lend to project. It provides highly detailed monitoring of the population dynamics of green turtles, and has added value because of its long-term nature and detailed encounter histories. The studies yield significant new insights into the biology of green turtles through its published studies, including polyphasic growth models, long-term sight fidelity, and influences of harmful algal blooms on reproductive status, to cite a few of its highlights. There is a strong case made that the study site receives an unequalled combination of marine and terrestrial habitat that allow it to function as a reference population…. The report establishes the value of Shoalwater Bay as a benchmark population for Queensland green turtles. …The methodology is pioneering and should be held as an example to those who wish to tackle the demanding task of investigating the population dynamics of sea turtles.*

The monitoring reported in this publication highlights the importance of collecting data from populations in habitats that are minimally impacted from human activities. The area of Shoalwater Bay has been consistently recognised for its importance to marine turtles, in addition to other wildlife such as dugongs and migratory birds. The relatively un-impacted catchment and inaccessibility of the region to major urban centres offers protection for the Shoalwater Bay region and to the wildlife that inhabit the location.

The Great Barrier Reef Marine Park Authority and the Queensland Environmental Protection Agency are pleased to make this report generally available.

Hon Virginia Chadwick
Chair
Great Barrier Reef
Marine Park Authority

James Purtill
Director General
Queensland Environmental
Protection Agency

April 2005

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ACKNOWLEDGEMENTS

The study was conducted as part of the EPA Turtle Conservation Project. It was funded in part by a Great Barrier Reef Marine Park Authority grant to EPA and a Sea World Research and Rescue Foundation grant and University of Queensland support for KA.

Numerous volunteers and EPA/QPWS staff provided assistance in capturing and processing the turtles. The study was conducted with QPWS Animal Research Ethics approvals for Projects 006 and 010.

GBRMPA/State Marine Parks Permit G00/240. Annual authorisation to enter Shoalwater Bay Training Area was received from Department of Defence, Rockhampton. The Department of Defence staff also provided access to their rainfall data for the area. This assistance is gratefully acknowledged.

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EXECUTIVE SUMMARY

The combination of catchment protection and marine habitat protection affords the resident foraging turtle population of Shoalwater Bay the greatest level of protection with the least anthropogenic impacts when compared with the other large foraging populations of green turtles (*Chelonia mydas*) in eastern Australia.

The annual tagging-recapture sampling of the green turtle foraging population of western Shoalwater Bay was successfully completed during 2000-2004.

- 1779 green turtles were captured in western Shoalwater Bay during 2000-2004. All were measured and scored for sex, maturity and breeding status.
- Three other species of marine turtles, *Caretta caretta, Eretmochelys imbricata* and *Natator depressus,* also forage in Shoalwater Bay in much smaller numbers. However, the following information pertains solely to the green turtle, *Chelonia mydas*.
- The present study has provided the first record of the east Pacific black turtle, *Chelonia mydas agassizii*, for the Great Barrier Reef.
- The vast majority (approximately 94%) of adult *C. mydas* that forage in Shoalwater Bay originate from the breeding areas of the southern GBR genetic stock. The remainder are derived from the other stocks that breed in the Coral Sea: northern GBR, Coral Sea and New Caledonian stocks.
- The resident green turtle population continues to be strongly female biased to with sex-ratios in the range of 1:1.7 M:F for small immature and adult turtles and 1:3.3 M:Ffor large immatures.
- Small immature green turtles recruit to the bay from the pelagic life history phase at a mean CCL = 43.6 cm, irrespective of sex.
- Females commence breeding at a mean CCL = 97.97 cm.
- No change in mean size of adult males or females was detected across the five years of the study.
- Seagrass forms the dominant part of the diet for these turtles, which also forage on variable amounts of red algae and mangrove fruit. Diet composition is temporally variable across the years.
- While many of these *C. mydas* are displaying a strong fidelity to the area across decades, a small proportion of turtles undertook major developmental shifts in foraging area to take up residency in the Bay from other foraging areas in Queensland.
- At the finer scale of western Shoalwater Bay, there is accumulating evidence indicating that different age classes of turtles are utilising different habitats. Small immatures occur mostly in the upper intertidal mangrove forest and rocky habitat and in drainage gutters across the flats. Adults and large immature turtles are more frequently encountered in the mid intertidal to subtidal waters.
- Annual breeding rates are highly variable between years with approximate synchrony of breeding fluctuations between males and females.
- In poor breeding seasons (when low numbers of adults migrate for breeding), when breeding rate is corrected for population sex ratio, the sex ratio of adults migrating to breed is approximately 1:0.20 M:F. In very good breeding years, the sex ratio of adults migrating to breed is approximately 1:0.47 M:F. The effective population size or breeding sex ratio is male biased even though the foraging population as a whole is female biased.

- The somatic growth function for *C. mydas* foraging in Shoalwater Bay is non-monotonic with a juvenile growth spurt maximised at CCL = 60-70 cm. Growth is minimal in recently recruited immatures and approaches zero for adults.
- There is temporal variability in immature growth rate across the years. The underlying environmental factors are not clear at present.
- The *Lyngbya majuscula* bloom in winter 2000 had a negative impact on the foraging *C. mydas* with decreased calcium and glucose in the blood. In addition, 38% of the vitellogenic females commenced atresia of developing ovarian follicles at the same time.
- This *L. majuscula* bloom in winter of 2002 is circumstantially linked to the occurrence of excessively hot weather in the preceding summer that caused debilitation of intertidal seagrass.
- 2% of adult males have tail injuries and/or abnormalities that will prevent them from successfully copulating.
- Green turtle fibropapilloma disease (GTFD) tumours were recorded on 0.5-2.1% of turtles annually.
- GTFD has not been recorded with small immature turtles that have recently recruited to residency in the Bay.
- GTFD tumours are found primarily on immature turtles in the size range of CCL = 40-85 cm.
- An undetermined proportion of the turtles displaying GTFD tumours recover and progress to become normal functioning turtles in the population.
- 1.2% of *C. mydas* were diagnosed with severe parasitic infection of the lower digestive tract.
- 1.4% of *C. mydas* have fractures from previous interaction with boats and/or propellers.
- A low incidence of other injuries, diseases and deformities was recorded in the population, including abnormal reproductive system, deformed tails, deformed plastrons, kyphosis, split mandibles, decalcified bones, skin lesions, lung lesions.
- Basking on the intertidal flats at low tide is common in the winter. These turtles are not stressed and do not attempt to re-enter the water.
- Basking turtles have a body temperature that is elevated by 0.9^{o}C above the temperature of the substrate on which they are stranded.

INTRODUCTION

Green turtles were recorded as a globally abundant species when Europeans first explored the tropical oceans in past centuries: Columbus in the Caribbean in the late 1400s (Morison 1942); Dampier in Indonesia and Western Australia in the late 1600s (Masefield 1906); and Cook in eastern Australia in 1770 (Reed 1969). In the years since, some green turtle populations have been over-harvested to extinction in Cayman Islands, Bermuda and Isle de Reunion (Parsons 1962, Groombridge and Luxmoore 1989). Within the Southeast Asia – Western Pacific region, most large green turtle populations have declined significantly in response to long term harvests: Sarawak and Terengganu in Malaysia; Ko Kram in Thailand; West Java in Indonesia; Long Island in Papua New Guinea; Bouin Island in Japan; Scilly Atoll in French Polynesia (Limpus 1997). In no country has anyone succeeded in managing sustainable green turtle populations in the face of intensive harvests. Green turtle populations that are on the increase in Sabah in Malaysia and French Frigate Shoals in Hawaii are exceptional populations that were depleted under past harvests and are only now increasing after decades of strict total protection (Limpus 1997).

Some of the world's last remaining large green turtle stocks breed in Australia and in particular in Queensland (Limpus in press). Green turtles in Queensland are scheduled as Vulnerable under the *Nature Conservation Act* 1992. The largest sources of human related losses to Queensland green turtle populations are caused by Indigenous hunting, from boat strike and entanglement in fishing gear (Limpus in press) and possibly from habitat degradation. Chaloupka (2002) has demonstrated that these levels of loss are not sustainable and the southern Great Barrier Reef green turtle stock should be at risk of a significant population decline if the current management regime continues.

Because native title rights currently preclude the option of an enforced total protection of green turtles under the *Nature Conservation Act 1992*, the conservation management agencies of eastern Australia are faced with a task that no management agency has succeeded in achieving over the past three centuries, *viz*. sustainably managing a green turtle population under an active harvest strategy.

Marine turtles are proving to have extremely complex life histories. Understanding their population dynamics and defining the key demographic parameters quantitatively will be critical for devising management strategies for sustainable harvest by Indigenous communities.

Shoalwater Bay supports a large foraging population of green turtles in one of the least disturbed major embayments in eastern Australia. It represents one of the least impacted foraging populations for the species in eastern Australia. Consequently the area has been selected as a key index sites for monitoring green turtle population dynamics. The data from these studies will integrate into population modelling studies similar to Chaloupka (2002) that should improve our capacity for testing management strategies for this difficult to manage species.

METHODS

This study in western Shoalwater Bay (22º20'S, 150º12'E) extends the detailed foraging area studies for green turtles, *Chelonia mydas,* previously conducted on the coral reefs adjacent to Heron Island in the southern Great Barrier Reef (Limpus and Reed 1985) and in Moreton Bay (Limpus et al. 1994).

Monitoring of the population structure and dynamics of the resident *C. mydas* foraging population in western Shoalwater Bay was conducted annually during winter over a five year period, 2000-2004. These five years of sampling form the third set of sampling of this turtle population for the Queensland Parks and Wildlife Service (QPWS) marine turtle conservation project:

- 1986: Pilot investigation to assess the potential of the study site;
- 1987-1991: Annual winter sampling to establish a tagged population for mark recapture studies to facilitate long-term population dynamics assessment;
- 1994-1997: Annual winter sampling of the population with an emphasis on the population dynamics of males; a collaborative study between QPWS and Zoology Department, University of Queensland.
- 2000-2004: Annual winter sampling of the population to describe the population dynamics of the population. A study funded in part by the Great Barrier Reef Marine Park Authority (GBRMPA).

All tagging, capture and observational data for the turtles have been recorded in the QPWS computerised turtle research database. This database and its codes are defined in the associated database manual. Each turtle was tagged with a standard titanium turtle tag in a front flipper axillary tagging position (Limpus 1992a). All turtles recaptured from past studies were released with a minimum of two secure titanium tags, one on each front flipper. Midline curved carapace length (CCL) was the standard size measure of the turtles. Body Condition Index (BCI) as an indicator of turtle health was determined by comparing the cubed length (cm) of the turtle with the mass (kg) of the turtle: BCI = CCL^3/Mass (Bjorndal et al. 2000). Gonads were examined visually using laparoscopic examination (Limpus et al. 1994). Given that the breeding season for green turtles in eastern Australia extends from October to April, the breeding season is defined by the year in which the breeding season commences. The mid-year timing of the sampling periods was chosen to ensure that all turtles associated with this foraging area were available for capture, i.e. all turtles preparing to breed for the year were in their pre-migratory phase and were still at home in their foraging area.

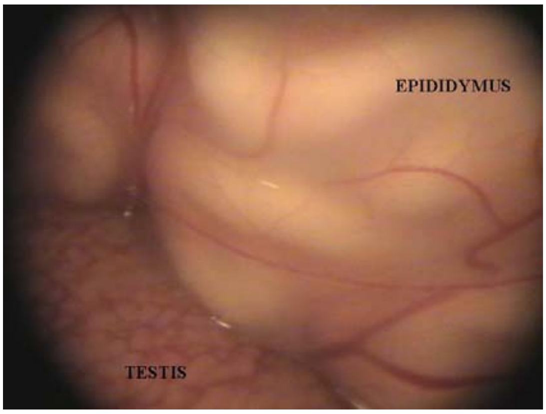
Turtles were captured by the turtle rodeo method (Limpus 1978) or by hand capture for turtles stranded in the shallows or for basking turtles. To reduce bias in which turtles were selected for capture, when groups of turtles were encountered, the first turtle seen was pursued until it was captured or lost into deep or turbid water.

Gonads were visually examined by laparoscopy and the turtles were scored by sex, maturity and breeding status following the methods of Limpus (1992b) and Limpus and Limpus (2003). Puberty in the context of marine turtles continues to be defined as the life history stage during which the gonads and associated ducts differentiate from the generalised immature structures to those of the adult turtle.

Males were scored as

- preparing for breeding in the coming breeding season if testis had distended seminiferous tubules and epididymis had a distinct enlarged white tube (Fig. 1a).

- not preparing for breeding in the coming breeding season if the testis did not have distended seminiferous tubules and the epididymus had a non-distended translucent tube (Fig. 1b).



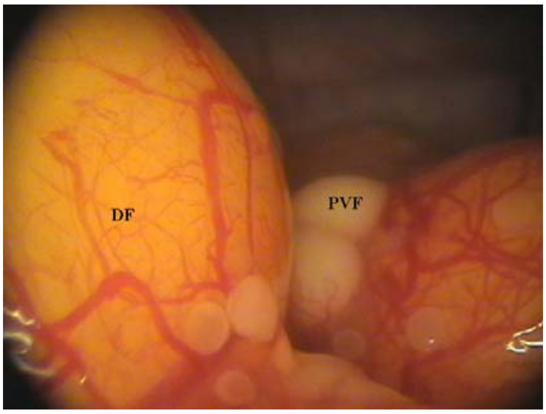
a. K56282: adult male preparing for its breeding season with distended seminiferous tubules in the testis (lower left) and a distended white duct in a pendulous epididymis (upper right), July 2003.

b. K56211: Adult male in a non-breeding year with no distended white duct visible in a pendulous epididymis, July 2003.

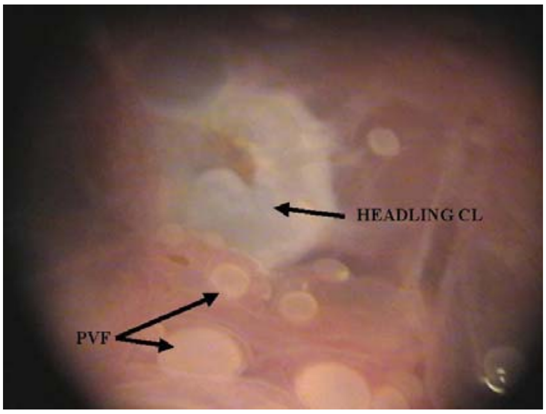
Figure 1. Adult male green turtle gonads and ducts.

Females were scored as (each of these conditions is mutually exclusive of the others):

- preparing for breeding in the coming breeding season if the ovary had enlarged (> 1 cm diameter) vitellogenic follicles (Fig. 2a);
- bred in the previous breeding season if the ovary had large healing corpora lutea (> 3 mm diameter) on fluid filled vesicles (Fig. 2b) and enlarged atretic follicles (Fig. 3b);
- bred in the season before last if the ovary had corpora albicantia ~3 mm in diameter and surrounded by white radiating folds of connective tissue.



a. K56215: Developing vitellogenic follicles (DVF) and smaller pre-vitellogenic follicles (PVF), 30 June 2003.

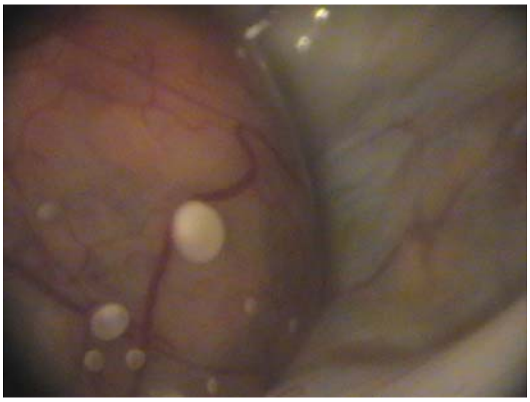


b. K56038: Healing corpus luteum (CL) on a vesicular ovary with adjacent pre-vitellogenic follicles (PVF), July 2003.

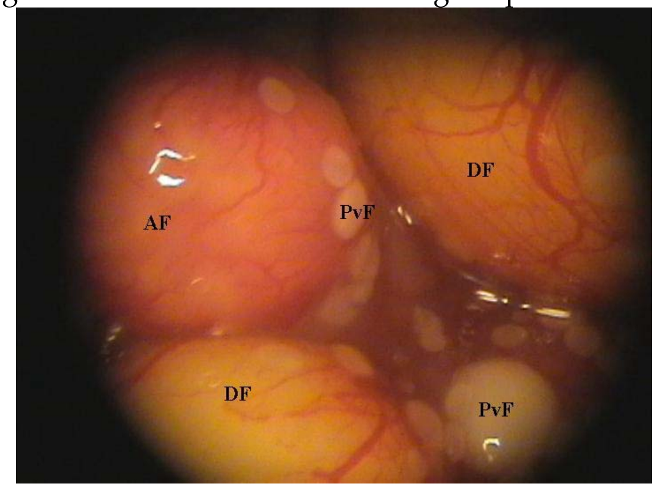
Figure 2. Adult female green turtle ovaries.

For some adult females, the size of developing or atretic ovarian follicles was measured using a Medison SA600 Ultrasound Scanner with a 3.5MHz probe (Fig. 3a). The thickness of the body wall adjacent to the ovary immediately anterior to the hind limb was also measured.

a. Ultrasound image of a post-breeding-season atretic ovarian follicles. K55740, June 2003: She had ovulated during the previous breeding season.



b. Image via laparoscopy of a post-breeding-season atretic ovarian follicle. K55740, June 2003: She had ovulated during the previous breeding season.



c. An example of a laparoscopic view of an atretic follicle in the ovary during preparation for a breeding season. **K49454** on 30 June 2002, western Shoalwater Bay. **DF** identifies large, uniform-yellow, developing follicles approximately 20 mm in diameter. **AF** identifies an atretic pink follicle with the beginnings of granular texture. This atretic follicle is slightly smaller than the developing follicles. **PvF** identifies small white previtellogenic follicles up to approximately 5 mm in diameter.

Figure 3. Atretic ovarian follicles in adult female *Chelonia mydas*

The identification of breeding status was supplemented with tagging data from the nesting beach and courtship area studies that were conducted in parallel to the foraging area studies. The interpretation of the breeding history of individual turtles could project two years into the past for adult females examined in any one year but the interpretation of male breeding history could only be applied for the year of observation.

Juvenile *C. mydas* that had recently recruited to coastal waters from the pelagic environment were identified by their white ventral surfaces, sharp edges to their carapaces and two pronounced longitudinal plastronal ridges (Fig. 4). See Limpus and Limpus 2003 for discussion of recently recruited *Caretta caretta* to coastal waters. Within a few months, the white ventral surfaces becomes discoloured by green algal growth and the plastron colour changes to pale yellow while the sharp edges are abraded (Fig. 4).

Figure 4. Juvenile *Chelonia mydas* captured in western Shoalwater Bay in June 2004. The turtle on the right has recently recruited from the pelagic habitat to residency in the bay. The turtle on the left has been in residence in coastal waters for many months or longer.

Turtle diet studies were part of the present study and have been described independently (Limpus and Limpus 2000, Arthur et al. submitted). A food sample of the most recent feeding event was obtained from the mouth, oesophagus and crop using the stomach flush technique (Forbes and Limpus 1993). Samples were immediately frozen and maintained at < 0° C until analysed.

Air and water temperature and water depth were measured using Vemco™ temperature and temperature-depth Minilog data-loggers. To record air temperature, a temperature data-logger was deployed in the shade of a tree at the camp, recording at 0.5 hr intervals for the duration of each survey trip. To record sub-tidal water temperate and tidal range, a temperature-depth data-logger was deployed below low tide at McDonald Point, recording at 0.5 hr intervals for the duration of each survey trip. At this site, the water was well mixed vertically by tidal flushing and turbulence.

Recent extremely hot summers and elevated water temperatures have caused coral bleaching, so intertidal water temperature was monitored to determine the potential for heat stress to negatively impact intertidal seagrasses. A temperature data-logger was deployed on the lower intertidal flats at the southern end of the small bay (West Bight) immediately south of McDonald Point (22°20.058’S, 150°11.352’E) on 10 August 2001 to record surface water temperature on the seagrass flats for a year at 10 min intervals. This datalogger was retrieved on each survey trip, downloaded and redeployed at the end of each trip.

RESULTS AND DISCUSSION

Environmental parameters

Shoalwater Bay is one of the few large shallow embayments on the eastern Australian coast. Its catchment is largely unaltered due to the presence of the military training area which was reserved in 1965 and extends over most of the perimeter of the bay. The extreme western side of the Bay is contained within the Shoalwater Bay Conservation Park that was gazetted in September 1995. Prior to the reservation for military use and the gazettal of the Conservation Park, the catchment was used for grazing, timber harvest and gold mining (Gunn et al. 1972). Currently, there is little human disturbance in the catchment because of minimal development and no coastal towns (Long et al. 1997). The turtle study area in western Shoalwater Bay was within the buffer area surrounding the main area used for military training.

Within the marine habitat, there has been increasing protection of the marine environment with progressive removal of fishing activity from southern and western Shoalwater Bay:

- The commercial arrowhead fish trap at MacDonald Point ceased operation in late 1991.
- Net fishing was banned from 12 January 1998 within Shoalwater Bay when the area was declared a Dugong Protection Area A (Anon 1999).
- The area was officially closed to trawling when the Queensland DPI Trawl Management Plan was enacted on 21 December 2000.
- Commencing in 2004, as a result of rezoning of the Commonwealth's Great Barrier Reef Marine Park (as of 1 July) and the declaration of Queensland's Great Barrier Reef Coast Marine Park (as of 5 November), the turtle research area now occurs almost entirely within a "Green Zone" in which all fishing is prohibited.

The combination of catchment protection and marine habitat protection affords the resident foraging turtle population of Shoalwater Bay the greatest level of protection with the least anthropogenic impacts when compared with the other large foraging populations of turtles in eastern Australia.

Tidal range

The marine habitat is subject to a large tidal range (> 7 m during spring tides; Table 1) and strong currents with the waters often very turbid because of re-suspension of silt (Ayling et al. 1998) resulting from the tidal and wind generated currents.

Table 1. Tidal range, shaded air temperature and surface water temperature measured at MacDonald Point camp site, western Shoalwater Bay during field study periods.

Parameter	Study period				
	24 Jul – 5 Aug 2000	28 Jul – 11 Aug 2001	23 Jun – 5 Jul 2002	27 Jun-12 Jul 2003	26 Jun – 11 Jul 2004
Maximum tidal range	-	6.6m	6.4m	6.0m	7.0m
Sub-tidal Surface water temperature	18-21°C	18.3-23.1°C	16.6-21.4°C	18.1-22.7°C	18.0-22.1°C
Shaded air temperature	8-27°C	7.6-28.9°C	6.8-29.1°C	6.8-29.1°C	9.6-29.8°C

Rainfall and runoff

Monthly rainfall data from the Pine Mountain monitoring site within the Shoalwater Bay Training Area (Fig. 5) were supplied by the Department of Defence Corporate Services and Infrastructure, Rockhampton.

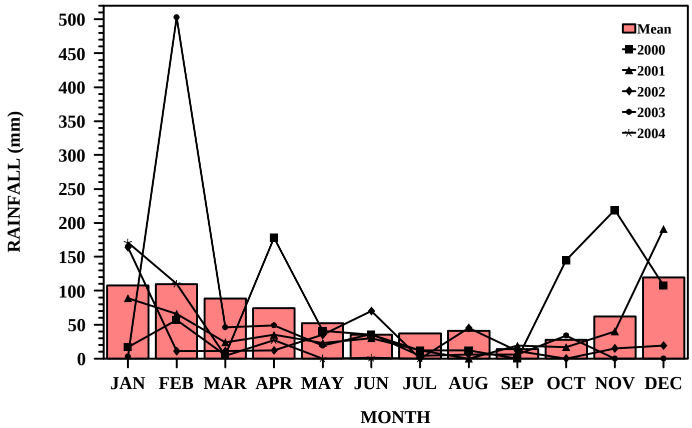


Figure 5. Mean monthly rainfall (mm) recorded at Pine Mountain, Shoalwater Bay, for 14 years commencing in 1988. Data supplied by Department of Defence.

Western Shoalwater Bay has a very limited catchment with no major streams draining into the area. It has variable and generally low annual rainfall (800-1600 mm) with most rainfall occurring in the summer months (Fig. 5; Commonwealth of Australia 1994). In most streams there is no surface runoff for much of the year, especially in winter.

Water temperature and air temperature

The subtidal water temperature range off MacDonald Point during the five annual study periods was in the range of 16.6-23.1^{o}C (Table 1). These temperatures are above the winter temperatures in Moreton Bay and within the range over which *C. mydas* will continue to feed (Read et al. 1996).

Shaded air temperature at the MacDonald Point campsite ranged 6.8-29.8^{o}C during the five annual study periods (Table 1).

Temperature stress on sea grass

It is well established that abnormally hot summers can cause heat stress to the symbiotic algae in corals with resulting coral bleaching and associated stress or even death of coral colonies (Hoegh-Guldberg 1999). Studies indicate that seagrasses are likely to be stressed or die when water temperatures exceed 35^{o}C (Marsh et al. 1986, Seddon and Cheshire 2001). The monitoring of water temperature on the lower intertidal seagrass flats of western Shoalwater Bay was initiated after a substantial die back in intertidal seagrass in the area was observed by the authors following the extremely hot summer of 1998-1999 (Hoegh-Guldberg 1999).

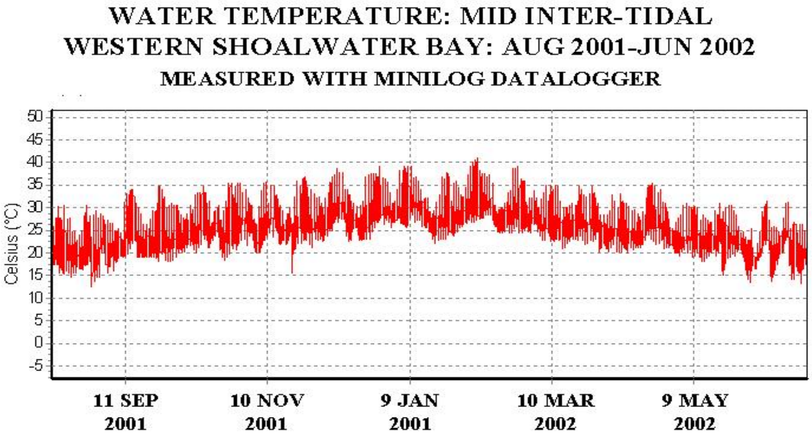
The intertidal temperatures recorded on the lower seagrass flats over the three years, August 2001–June 2004, are summarised in Fig. 6.

Fortuitously the study of water temperatures on the lower intertidal flats began in 2001 and coincided with one of the hottest summers on record during early 2002. The intertidal water temperature exceeded 35^{o}C on almost every late morning to afternoon low tide during November 2001-February 2002. On some summer days, intertidal low tide temperatures ranged up to 40.9^{o}C. Bleached coral colonies were common on the rocky reefs following this hot summer of 2002.

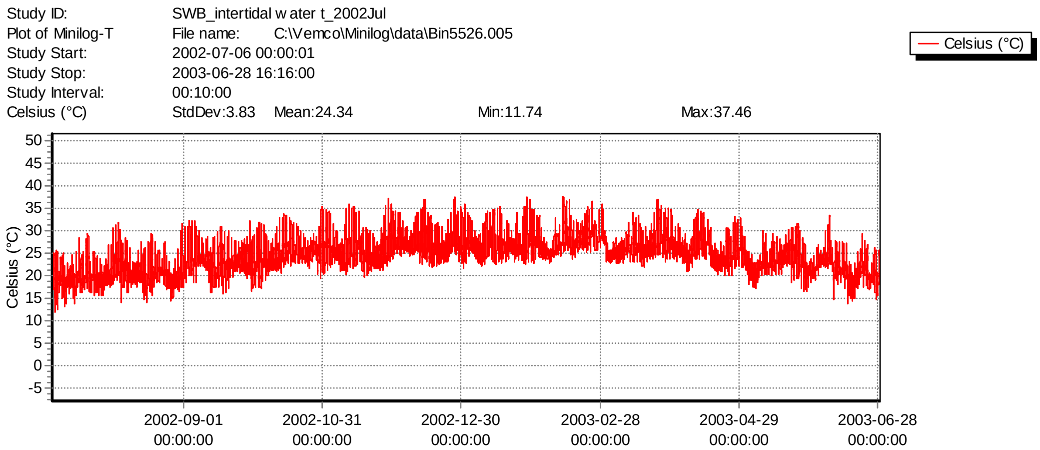
In contrast during the second year, for the majority of spring low tides from November 2002 to February 2003, the water temperatures on the lower inter-tidal flats did not exceeded 35^{o}C, with a maximum temperature of 37.5^{o}C. Coral bleaching was not in evidence during the winter of 2003.

During the third year many of the spring low tides from November 2003 to February 2004 had water temperatures on the lower inter-tidal flats that again exceeded 35^{o}C, with a maximum temperature of 40.9^{o}C.

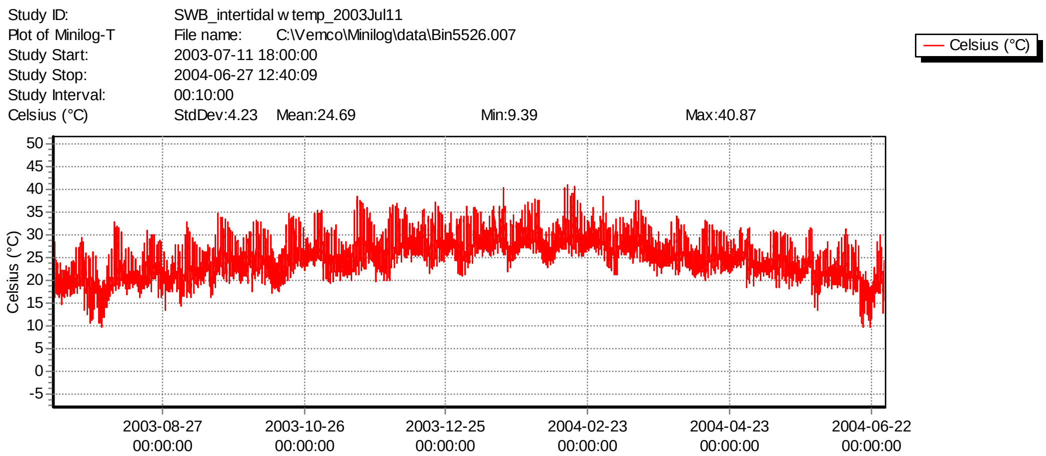
With the observed temperatures (Fig. 6), intertidal seagrasses should have been less heat stressed during the 2002-2003 summer than during the 2001-2002 and 2003-2004 summers. Any significant impact on the growth of seagrass can be expected to impact on the population dynamics of the green turtles and dugong foraging on these pastures.



a. August 2001 – June 2002



b. July 2002 – June 2003.



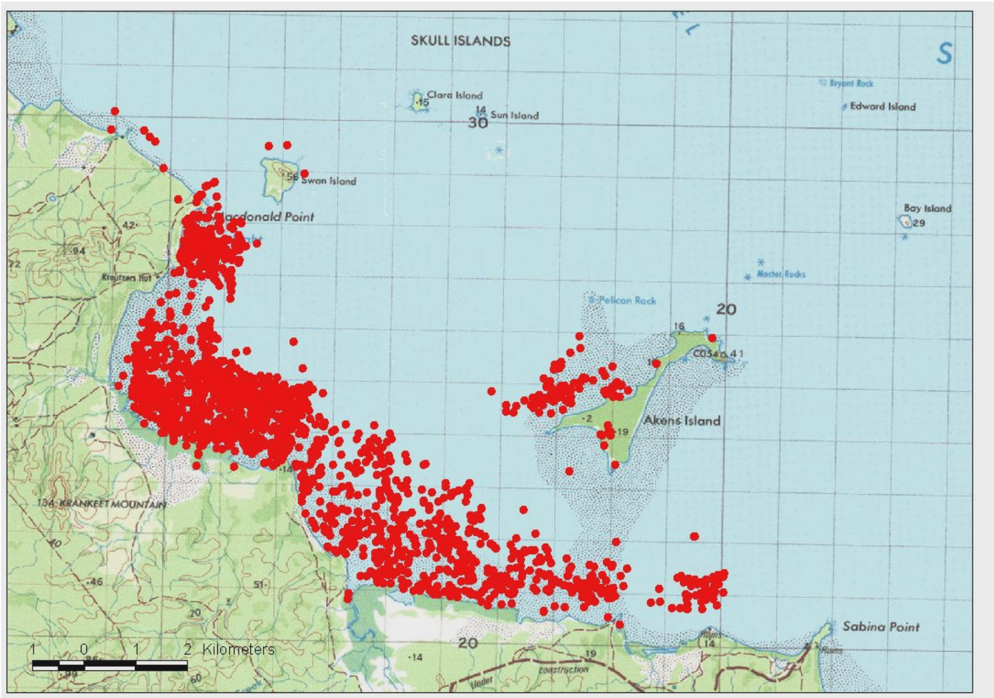
c.. July 2003 – June 2004.

Figure 6. Intertidal water temperature recorded on seagrass flats in Fish-trap Bay in western Shoalwater Bay, 2001-2004.

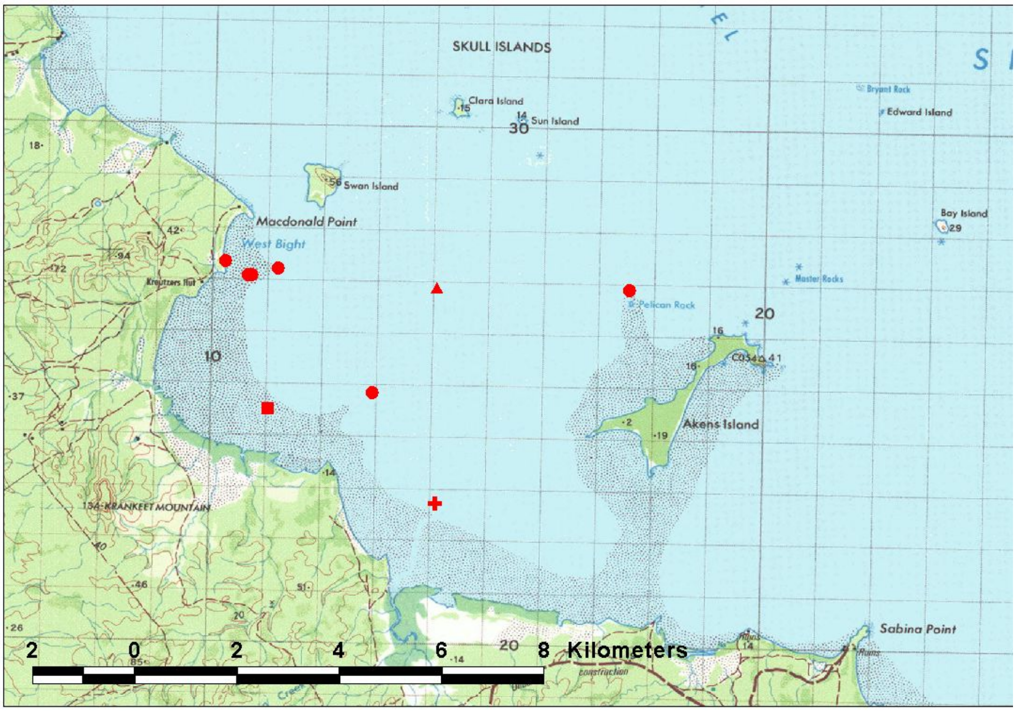
Turtle biology

Turtle species composition

Marine turtles were abundant in western Shoalwater Bay (SWB) throughout the standard sampling area spanning 18 km of intertidal flats along the mainland shore south and east from McDonald Point and 4 km of intertidal flats bordering Akens Island (Fig. 7).



a. Green turtles, *Chelonia mydas*. Dots denote recorded turtles.



b. Non "green turtles". Square denotes *Caretta caretta*, dot denotes *Eretmochelys imbricata*, triangle denotes *Natator depressus* and cross denotes *Chelonia mydas agassizii*

Figure 7. Distribution of turtle captures and sightings during the five winter sampling trips to western Shoalwater Bay, 2000-2004.

Four species of marine turtle were recorded in western Shoalwater Bay during the five annual sampling periods: green turtle (*Chelonia mydas*), hawksbill turtle (*Eretmochelys imbricata*), loggerhead turtle (*Caretta caretta*) and flatback turtle (*Natator depressus*). While the majority of the *C. mydas* observed were of the standard western Pacific morphology, there was, in contrast, one eastern Pacific black turtle (*Chelonia mydas agassizii)* that was captured. The distributions of sightings of the non- "green turtles" are illustrated in Fig. 7b.

Caretta caretta
Only one *C. caretta* was observed over the five years (K38013: 29 July 2000; prepubescent female, CCL = 79.2 cm; recent recruit to inshore foraging).

Eretmochelys imbricata
Six *E. imbricata* were recorded during three of the five visits but only one was captured. All *E. imbricata* were observed associated with rocky reef habitat and they ranged in size from small immature turtles (K43237: 30 July 2001; immature female, CCL = 40.3 cm) to large adult sized individuals.

Natator depressus
Only one *N. depressus* was sighted but not captured during this five year study. It was observed at the surface in the deeper subtidal waters north of Aken Island.

Chelonia mydas agassizii
One eastern Pacific black turtle, *C. m. agassizii* (K61098: 1 July 2004; CCL = 52.2 cm, Immature female; Fig. 8) was caught in the Ross Creek gutter where it had been foraging on seagrass (*Zostera capricornii*) and jellyfish (*Catostylus mosaicus*). This subspecies of green turtle breeds only on the western coast of central America (Mexico) and in the Galapagos Islands.

This individual is the first record of the eastern Pacific black turtle within the GBR. It is the fifth black turtle recorded in the south western Pacific during Queensland Turtle Conservation Project studies. These turtles highlight the capacity for marine turtles to be dispersed throughout ocean gyres during their pelagic post-hatchling phase.

Figure 8. Black turtle, *Chelonia mydas agassizii* (K61098) captured off Ross Creek, western Shoalwater Bay, 1 July 2004.

The remainder of the following results and discussion will refer to *C. mydas* of normal western Pacific morphology unless otherwise stated.

Green turtles

There was a total of 2141 captures of 1779 individual *C. mydas* during the five annual samplings of the western Shoalwater Bay population during 2000-2004 (Table 2). Given the abundance of *C. mydas* captured, no attempt was made to record the many additional turtles observed while individual turtles were being captured.

Table 2. Composition of captured *Chelonia mydas* by recapture history and year. M denotes male, F denotes female.

Tagging history status	**2000**	**2001**	**2002**	**2003**	**2004**
Primary taggings					
First time tagged turtles	247 (63%)	253 (66%)	292 (70%)	230 (66%)	309 (67%)
Recaptures					
Turtles previously recorded at Shoalwater Bay	108 (28%)	92 (24%)	100 (24%)	96 (27%)	109 (24%)
Adult turtles originally tagged at nesting beaches and not previously recorded at Shoalwater Bay	6 (2%)	6 (2%)	6 (1%)	5 (1%)	8 (2%)
Adult turtles originally tagged at courtship areas and not previously recorded at Shoalwater Bay	2 (1%) = 1M + 1F	0	2 (1%) = 1M + 1F	0	1 (0.2%) = 1M
Turtles that have changed foraging area to Shoalwater Bay	1 (0.3%)	1 (0.3%)	0	0	1 (0.2%)
Turtles with tag scars from lost tags	26 (7%)	31 (8%)	17 (4%)	20 (6%)	35 (8%)
Total turtles	390	383	417	351	463
Additional within trip recaptures	7	10	37	42	41

Sex ratio

The frequency distribution by sex and maturity of the captured samples are summarised in Table 3 and Figure 9. The population was strongly biased to females in all maturity classes. The sex ratio for this population was variable across maturity classes, approaching 1:2 M:F for adults and small immature turtles and about 1:3 M:F for large immature turtles (Table 4).

Table 3. Composition of yearly samples of captured *Chelonia mydas* by sex and maturity.

Sex	Maturity	2000	2001	2002	2003	2004
Male	Adult	55	60	44	30	38
	Immature, pubescent	9	12	3	10	6
	Immature, prepubescent, CCL ≥ 65.0 cm	26	24	24	16	20
	Immature, prepubescent, CCL < 65.0 cm	23	37	63	66	89
	Subtotal	113	133	134	122	153
Female	Adult	92	88	73	62	78
	Immature, pubescent	62	51	41	34	38
	Immature, prepubescent, CCL ≥ 65.0 cm	70	47	48	48	49
	Immature, prepubescent, CCL < 65.0 cm	52	62	121	85	140
	Subtotal	276	248	283	229	305
Undetermined	Adult-sized	1				
	Immature, prepubescent, CCL ≥ 65.0 cm					2
	Immature, prepubescent, CCL < 65.0 cm		2			3
	Subtotal	1	2	0	0	5
Combined	Total	390	383	417	351	463

Table 4. Sex ratio (male:female) composition of yearly samples of captured *Chelonia mydas* by maturity. Sample sizes in parentheses.

Maturity	2000	2001	2002	2003	2004	Mean
Adult	1:1.67 (147)	1:1.47 (148)	1:1.66 (117)	1:2.07 (92)	1:2.05 (116)	1:1.78
Immature, CCL ≥ 65.0 cm	1:3.77 (166)	1:2.72 (134)	1:3.30 (116)	1:3.15 (108)	1:3.35 (113)	1:3.26
Immature, CCL < 65.0 cm	1:2.26 (75)	1:1.68 (99)	1:1.92 (184)	1:1.29 (151)	1:1.57 (229)	1:1.74

3.2.2 Size

The turtles captured in this study encompassed all size classes from small immatures from CCL = 38.7 cm to large adults up to CCL = 122.1 cm. The size of turtles of key age/maturity classes within this population are summarised in Table 5.

Sixty-three small immature *C. mydas* were captured that had recently recruited to foraging residency in Shoalwater Bay from the pelagic environment. There was no significant difference in size of the turtles with respect to recruitment year for either sex (Table 5). There was no significant difference in recruit size with respect to sex (1-way ANOVA: $F_{1,61} = 4.068$, $0.1 > p > 0.05$). The mean size (CCL) at which small immature *C. mydas* recruit from the pelagic environment to foraging in the coastal waters of western Shoalwater Bay = 43.60 (SD = 2.499, range = 38.7–48.5 cm).

With growth, these *C. mydas* have differentiated the development of reproductive maturity at different sizes for the sexes. Pubescent immature female *C. mydas* (mean CCL = 96.55 cm. Table 5) were larger than the pubescent males (mean CCL = 90.78 cm. Table 5) (2-way ANOVA: $F_{1, 276} = 45.20$; $p < 0.001$; Significant). There was no significant difference in the mean size of pubescent females or of pubescent males across years of this study (Table 5).

With continued growth and maturation of the reproductive system, females begin breeding at a mean CCL = 97.97 cm (Table 5). This mean size of primiparous adult females is based on the first ovulation of mature follicles from the ovaries with resulting formation of corpora lutea. Unfortunately there is no comparable characteristic available by which males in their first breeding season can be identified. There was no significant difference in the mean size of adult females in their first breeding season across years of this study (Table 5).

The size differential between the sexes is evident when adults of all ages were pooled by sex (Table 5). There was no significant difference in the mean size of adult females or of adult males across years of this study (Table 5) with adult females having a mean CCL = 103.51 cm and adult males having a mean CCL = 96.43 cm.

Table 5. Size of *Chelonia mydas* foraging in western Shoalwater Bay, 2000-2004.

	Curved carapace length (cm)							
	Female				**Male**			
	Mean	**SD**	**Range**	**N**	**Mean**	**SD**	**Range**	**N**
Recent recruited immature								
2000	44.78	1.721	43.2-46.8	4	44.0	2.404	42.3-45.7	2
2001	45.25	2.204	43.1-48.0	4	42.9	-	42.9	1
2002	43.77	2.171	39.2-46.5	21	42.72	2.136	38.9-45.5	10
2003	43.50	2.315	40.4-46.0	5	41.83	2.879	38.8-45.5	4
2004	43.94	3.086	38.7-48.5	10	42.50	3.253	40.2-44.8	2
Pooled	**44.00**	**2.407**	**38.7-48.5**	**44**	**42.65**	**2.515**	**38.8-45.7**	**19**
all years	1-way ANOVA: $F_{4,39} = 0.45$; $p > 0.5$, NS				1-way ANOVA: $F_{4,14} = 0.21$; $p > 0.5$, NS			
Pubescent immature								
2000	96.33	4.944	85.4-110.1	66	89.93	2.373	86.8-93.3	9
2001	95.92	5.328	84.1-113.5	55	91.09	3.431	83.6-95.0	12
2002	96.53	5.818	84.8-113.4	43	90.43	3.197	87.6-93.9	3
2003	96.54	5.899	88.3-117.3	34	92.72	4.551	84.1-99.6	10
2004	97.78	3.593	85.7-108.2	40	88.4	5.712	82.0-97.6	6
Pooled	**96.55**	**5.148**	**84.1-117.3**	**238**	**90.78**	**4.11**	**82.0-99.6**	**40**
all years	1-way ANOVA: $F_{4,233} = 0.80$; $p > 0.5$, NS				1-way ANOVA: $F_{4,35} = 0.20$; $p > 0.5$, NS			
Adult **1st breeding cycle**								
2000	97.61	4.720	90.4-106.0	8	-			
2001	100.5	3.851	94.2-105.2	8	-			
2002	97.1	3.897	91.6-102.1	7	-			
2003	95.16	4.873	87.8-101.1	5	-			
2004	98.39	3.654	93.0-104.3	7	-			

	Curved carapace length (cm)							
	Female				Male			
	Mean	SD	Range	N	Mean	SD	Range	N
Pooled all years	**97.97**	**4.581**	**87.8-106.0**	**35**				
	1-way ANOVA: $F_{4,30} = 1.20$; $p > 0.5$, NS							
2nd breeding cycle								
2000	-			0	-			
2001	105.07	2.715	102.2-107.6	3	-			
2002	107.9	-	107.9	1	-			
2003	99.70	8.768	93.5-105.9	2	-			
2004	-			0	-			
Pooled all years	**103.75**	**6.799**	**93.5-107.9**	**6**				
	1-way ANOVA: $F_{2,3} = 0.47$; $p > 0.5$, NS							
Combined adults								
2000	104.20	6.517	90.4-122.1	86	97.23	5.851	84.0-108.6	55
2001	104.38	5.422	86.0-116.5	83	96.89	5.099	83.0-108.4	60
2002	103.05	6.276	88.2-113.6	71	95.37	4.926	81.9-107.5	44
2003	103.12	6.309	87.8-114.5	62	96.11	5.353	83.7-110.6	30
2004	102.53	5.477	89.5-118.7	76	96.05	4.816	87.4-107.1	38
Pooled all years	**103.51**	**6.019**	**86.0-122.1**	**378**	**96.43**	**5.247**	**81.9-110.6**	**227**
	1-way ANOVA: $F_{4,373} = 1.39$; $0.5 > p > 0.2$, NS				1-way ANOVA: $F_{4,222} = 0.96$; $p > 0.5$, NS			

The increased proportion of small immature turtles captured during 2002-2004 (Fig. 9) resulted from a changed emphasis with capture methods. Firstly, when high tide heights and water clarity allowed, turtle rodeos were run inside the mangrove forest where more small immature and few medium-sized to adult turtles were encountered. Secondly, small teams walked the intertidal flats south of MacDonald Point on most daylight low tides and opportunistically at other sites around western Shoalwater Bay. These walking teams beach-jumped basking turtles and turtles out of water in rock crevices or turtles in small intertidal pools. The turtles that were captured on the intertidal flats at low tide were predominantly small immature turtles.

2000 **2001**

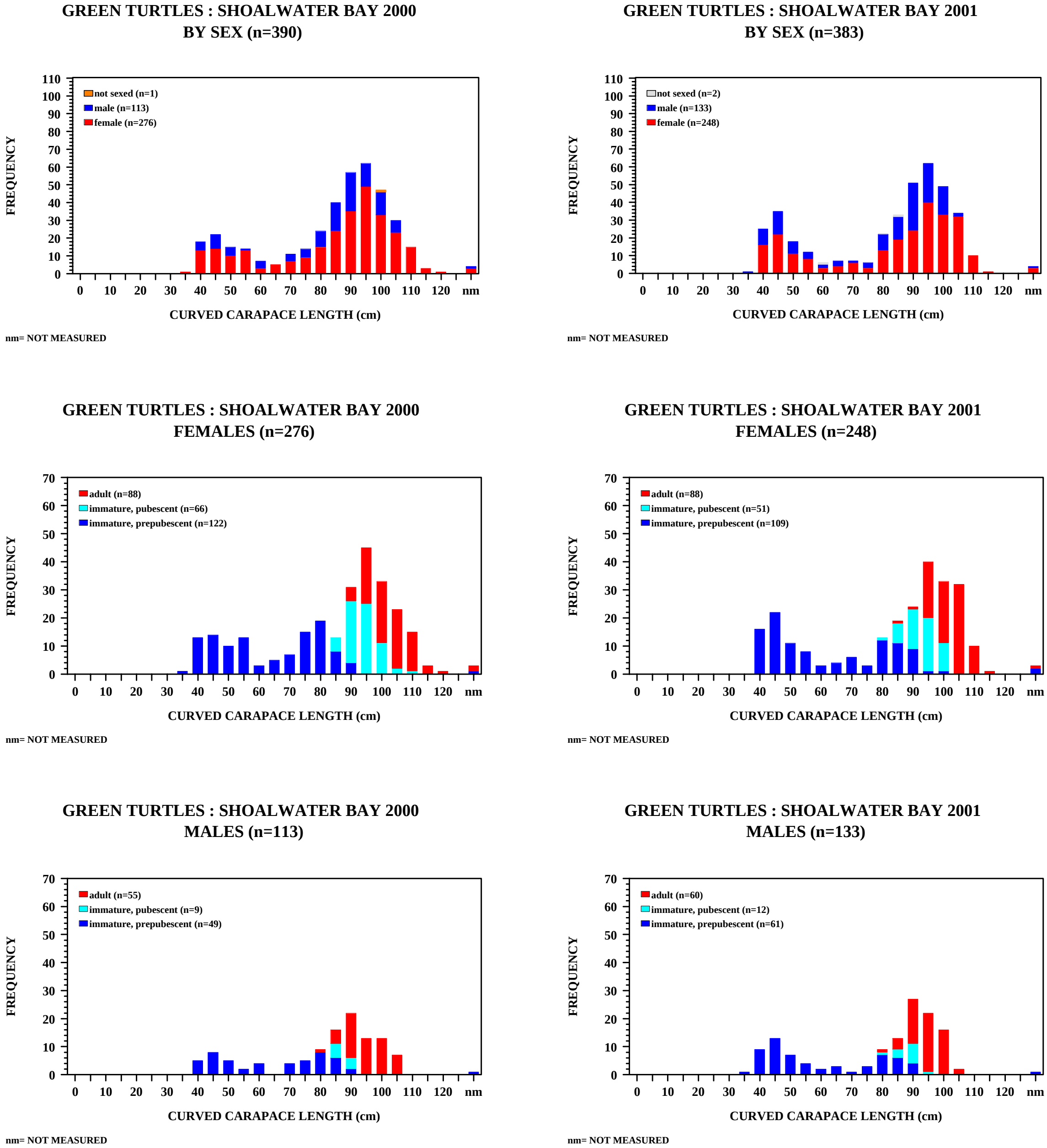
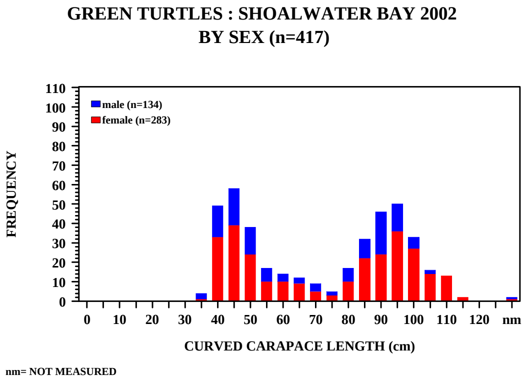
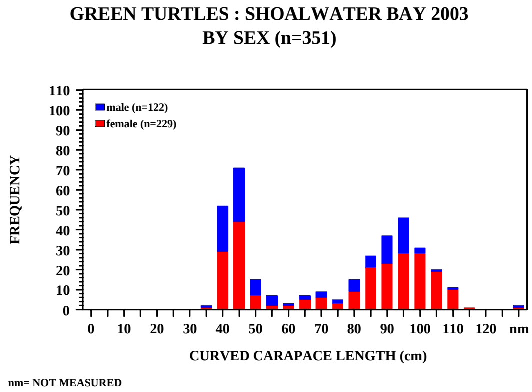
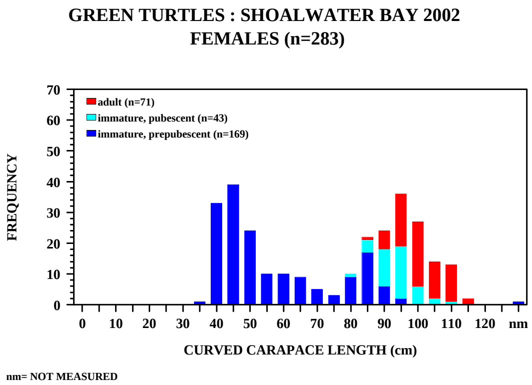


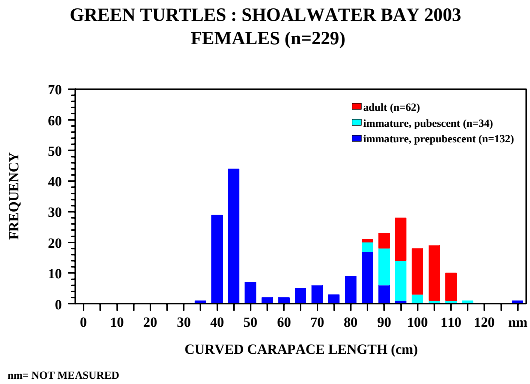
Figure 9. Size class distribution by sex and maturity of the green turtles, *Chelonia mydas*, sampled from western Shoalwater Bay during 2000-2004.

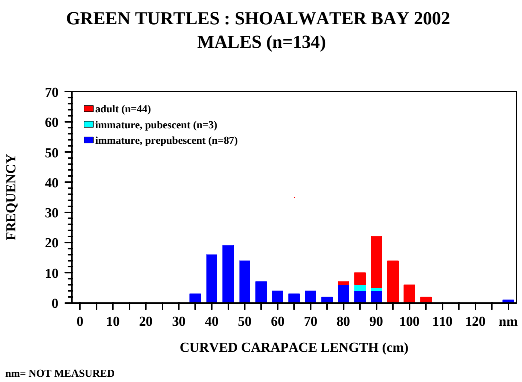
2002 **2003**











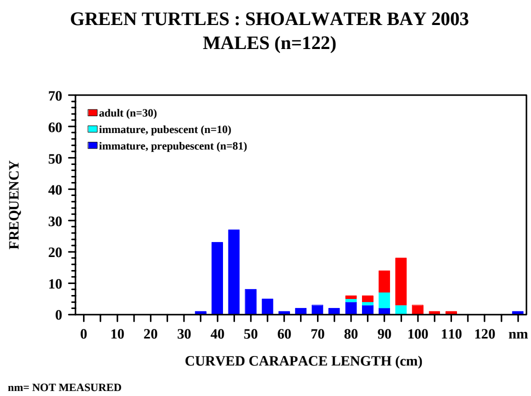
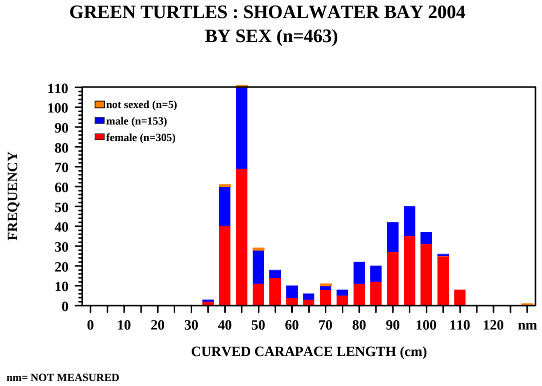
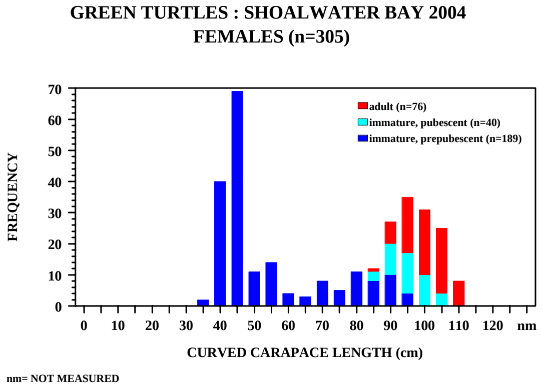


Figure 9. (continued)

2004





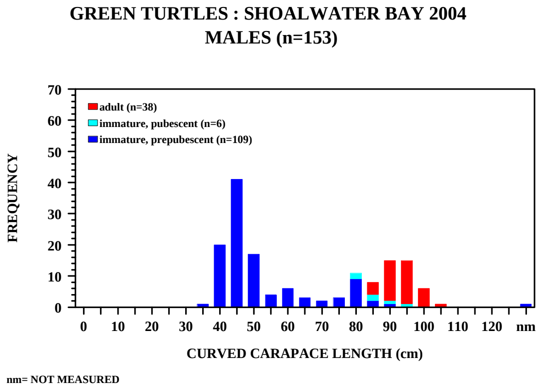


Figure 9. (continued)

Diet

The *C. mydas* that forage in western Shoalwater Bay are primarily herbivorous. In addition to the expected diet of seagrass and algae, these turtles also feed extensively on fruit and/or seedling cotelydons of the white mangrove, *Avecinnia marina* (Limpus and Limpus 2000). The ingestion of mangroves should be variable since the intensity of fruiting by these trees is highly variable across the years.

The following summaries the results of analysis of diet samples collected during this five-year study (Arthur et al. submitted). The diets of juvenile and sub-adult turtles in Shoalwater Bay during winter of 2001 were predominantly of seagrasses with smaller amounts of red algae, mangrove propagule, blue green algae and animal matter. Table 6 outlines the types of material found, the frequency with which they were encountered in each sample and the proportion of the sample. The most frequently observed species was the seagrass *Halodule sp.* (96.6% of samples), followed closely by other seagrass species *Zostera muelleri* and *Halophila ovalis*. Red algae also contributed a significant wet weight component of the animal's diet, particularly in those animals caught in rocky reef or basking on rocks at low tide. Mangrove material was found in animals from the mangrove forest where they may have been opportunistically feeding on the submerged plants at high tide. Although these animals had a low proportion of red algae in the crop sample, the mangroves was the only habitat where *Bostrychia tenella* was observed in crop samples. This red alga grows on mangrove roots and trunks (Cribb 1996).

Table 6. Types of material and frequency of occurrence in samples of *Chelonia mydas* diet from western Shoalwater Bay, winter 2001 (n = 30)

Diet component	**No. of samples in which found**	**Percentage samples in which found**	**Mean proportion of sample when present**
Seagrasses:			
Halodule sp.	29	96.6%	49.8%
Zostera muelleri	26	86.6%	16.2%
Halophila ovalis	15	50.0%	14.1%
Red Algae:			
Hypnea sp.	15	50.0%	23.0%
Gracilaria edulis	8	26.6%	31.3%
*Gracilaria verro*cossa	2	6.6%	12.4%
Laurencia sp.	2	6.6%	50.0%
Bostrychia tenella	2	6.6%	3.8%
Blue/green algae:			
Hormothamnion enteromorphoides	2	6.6%	15.4%
Mangrove propogules	4	13.3%	25.7%
Animal material:			
Prawn (larvae)	1	3.3%	2.5%
Top Snail (Trochacea)	1	3.3%	4.9%
Ant	1	3.3%	0.2%
Unidentified mollusc material	2	6.6%	1.5%
Unidentified material	4	13.3%	5.3%

Although it appeared that red algae contributed a comparable amount to the diets of turtles as seagrass, it should be noted that the number of turtles sampled in each habitat was unequal. The majority of turtles captured were from the seagrass meadows and the seagrass component of the crop sample for these animals was approximately 70%. A Kruskal Wallace analysis of variance on ranks showed there to have been significantly more seagrass found in this study than red algae ($H = 11.791$, $df = 1$, $p < 0.001$). This suggests that as different habitats become available for the turtles (i.e. due to tidal changes), the major food types consumed may change. It should also be noted that this study focussed primarily on smaller animals and thus is not necessarily representative of the entire population. For example, the blue-green algae, *Hormothamnion enteromorphoides* was only observed in one sample and this was an animal deemed to be a new recruit.

Table 7 and Figure 10 summarise the crop contents from a series of *C. mydas* sampled during winter 2003.

Table 7. Dietary items observed in turtle crop samples collected in western Shoalwater Bay, June-July 2003 (n = 56).

Diet component	**Percentage of samples in which found**	**Overall mean proportion of diet**	**Standard deviation**
Seagrass:			
Zostera muelleri	100.0%	65.0%	4.2
Halodule sp.	92.3%	18.7%	3.4
Halophila ovalis	40.4%	0.8%	0.3
Cymodocea serrulata	17.3%	1.4%	1.0
Rhizome material	25.0%	0.2%	0.1
Red Algae:			
Hypnea sp.	82.7%	5.9%	1.3
Gracillaria sp.	34.6%	3.7%	1.7
Laurencia sp.	1.9%	< 0.1%	0.0
Polyphiphonia sp.	25.0%	0.3%	0.1
Pterocladia sp.	3.8%	0.1%	0.1
Coelarthrum sp.	3.8%	0.3%	0.2
Centroceras sp.	1.9%	< 0.1%	0.0
Ceramium sp.	15.4%	0.1%	0.1
Blue/Green Algae			
Lyngbya majuscula	3.8%	< 0.1%	0.0
Mangrove material:			
Avicennia marina fruit	13.5%	1.6%	1.0
Animal material:			
Crustacean (unidentified)	11.5%	0.1%	0.0
Shell material (various)	15.4%	0.1%	0.0
Mollusc egg mass (unidentified)	3.8%	0.1%	0.1
Unidentified sponge	3.9%	0.1%	0.1
Unidentified plant material	76.9%	1.4%	0.2

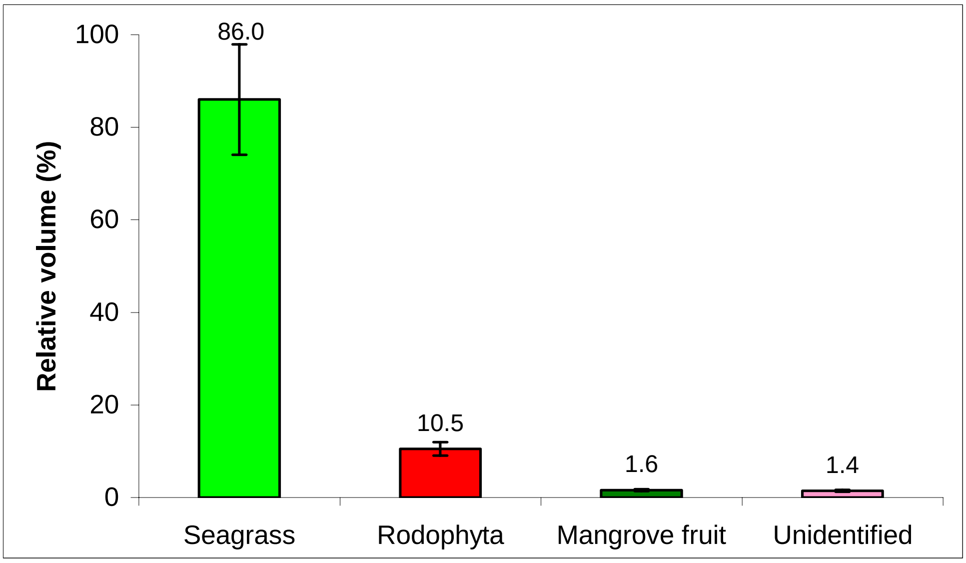


Figure 10. The mean proportion of each major food type found in crop contents of green turtle crop samples from Shoalwater Bay, June/July 2003 (n = 52). Error bars represent standard error.

This study reconfirms the importance of mangrove fruit in the winter diet of *C. mydas* in western Shoalwater Bay. *Avicennia marina* fruit was in diet samples from 13.3% of turtles when there was abundant fruiting by mangroves in 2001 (Table 6). *A. marina* fruiting density was subjectively assessed while boating under the canopy of the mangroves. In 2002, *A. marina* were not heavily in fruit and was absent from turtle diets. As mangroves fruited again in 2003, 13.5% of turtles fed on the fruit in that winter (Table 7). When the fruit is available, it is commonly eaten by the turtles (Limpus and Limpus 2000).

The diet data from winter 2001, 2002 and 2003 (Table 6, Arthur et al. submitted and Table 7, respectively) illustrate the interseasonal variability in diet for the *C. mydas* in this area.

Breeding migrations

Sixty-nine adult *C. mydas* (66 females, 3 males) were recaptured while foraging in western Shoalwater Bay during 2000-2004 that had been previously recorded at distant breeding areas throughout the Coral Sea (Table 8).

Most of the adult females had been recorded nesting at rookeries within the Capricorn-Bunker Groups of the southern GBR (n = 58, 88%: Northwest, Tryon, Wreck, Heron, Hoskyn, Lady Musgrave and Lady Elliott Islands) or on adjacent beaches of Wreck Rock (n = 1) and Sandy Cape (n = 3) at 193-412 km by shortest migration distance from their western Shoalwater Bay foraging area. These rookeries are from the southern Great Barrier Reef genetic stock (Moritz et al. 2002). One adult female was recorded that had nested within the Coral Sea Nature Reserve at 604 km from SWB and thus of the Coral Sea genetic stock (Moritz et al. 2002). Three adult females had been recorded nesting on the coral cays of the d'Entrecasteau Reefs of northern New Caledonia at 1397 km from Shoalwater Bay and thus of the New Caledonian genetic stock (Moritz et al. 2002). Additional adult females tagged in Shoalwater Bay have been recaptured at nesting beaches throughout the Coral Sea during other studies, at rookeries including the above locations and at Raine Island (Limpus et al. 2003) at 1361 km from Shoalwater Bay (Fig. 11a). Raine Island lies within the breeding area of northern GBR genetic stock (Moritz et al. 2002).

The three adult males from known breeding sites were recorded at the Sandy Cape courtship area (412 km from Shoalwater Bay). Earlier studies found additional captures of adult males tagged in Shoalwater Bay that were recaptured at courtship areas within the Coral Sea, including the Sandy Cape courtship area, the Heron Island courtship area (220 km away) and in Torres Strait (1571 km away) (Fig. 11b). The courtship areas of Heron Island and Sandy Cape lie within the breeding area of the southern GBR stock and Torres Strait is within the breeding area of the northern GBR stock.

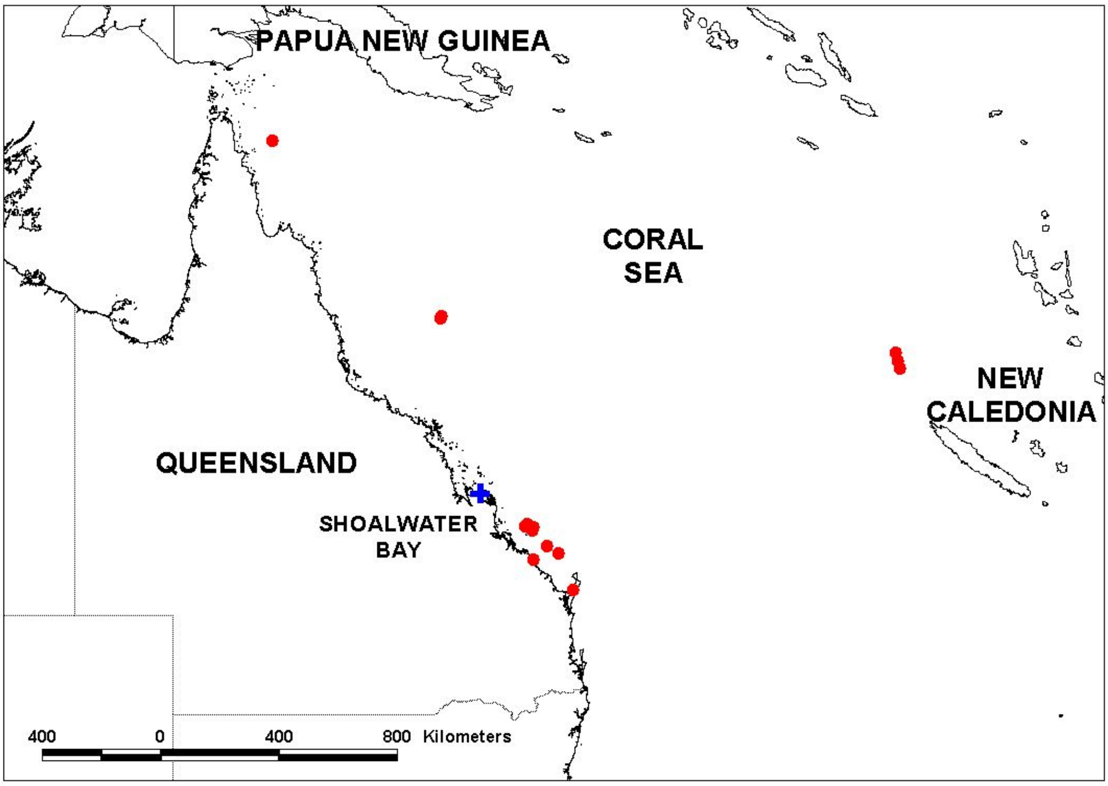
Based on these recaptures, the *C. mydas* that forage in Shoalwater Bay are a mixed assemblage of genetic stocks for the species. Approximately equal numbers of nesting female *C. mydas* have been tagged within each of the two major breeding aggregations of the Coral Sea in the northern and southern GBR (Limpus et al. 2003). In addition, the Coral Sea stock and New Caledonian stock are much smaller populations than the stocks that breed in the GBR (Limpus in press). Therefore, based on the above tag recoveries, the vast majority (approximately 94%) of the adult *C. mydas* that forage in Shoalwater Bay can be accepted as part of the southern GBR stock.

For 39% of these turtles (Table 8: 26 adult females and 1 adult male), they had been recorded at this western Shoalwater Bay feeding area both before and after their respective breeding migrations. The round trip migration from foraging to breeding and back to foraging for these adult turtles ranged between 386–2794 km (Table 8). These recaptures of turtles across successive legs of their migration journeys demonstrate that individual adult *C. mydas* have strong fidelity to their respective feeding areas, even though they may migrate thousands of kilometres during the brief breeding migration. This fidelity is maintained even when the turtles cross deep oceanic waters during both legs of the breeding migration (Table 8: T77864, T85488).

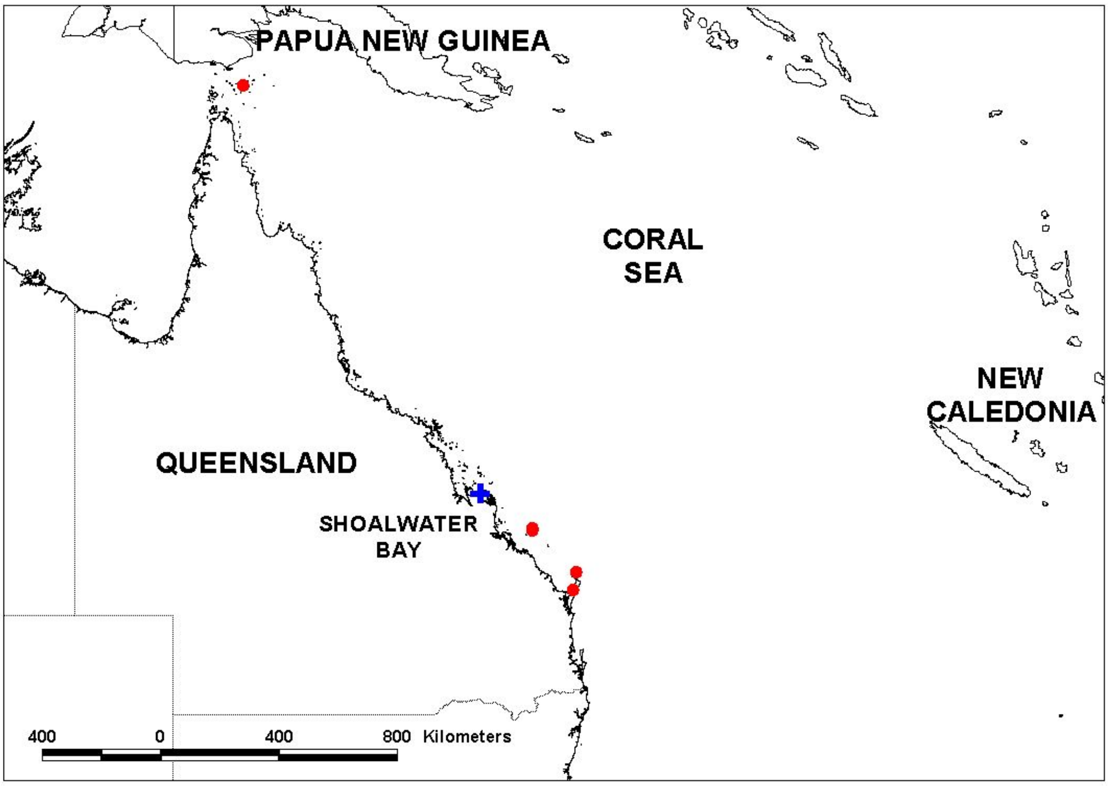
Table 8. Adult *Chelonia mydas* that have been captured in Shoalwater Bay during 2000-2004 that had known breeding areas. Parentheses denote turtles that had been recorded nesting at the same rookery in later years. "2 way" denotes a record of migration from Shoalwater Bay to a distant nesting beach and back to Shoalwater Bay. Similarly, "3 way" denotes a record of three successive back and forth migration events for the turtle. Turtles captured at the Fraser Island courtship area include females (F) and males (M). "a" denotes that the turtle changed nesting beaches.

Breeding Season	**Nesting beach**										
	Northwest Is.	**Tryon Is.**	**Wreck Is.**	**Heron Is.**	**Hoskyn Is.**	**Lady Musgrave Is**	**Lady Elliott Is**	**Wreck Rock beaches**	**Courtship Area: Fraser Is**	**Coral Sea Reserve**	**New Caledonia**
1985											
1986	(T29785)										
1987	T32011 T32056 (T32203) T32286			-							
1988											
1989			T49023	T39037		T37192 [3-way] T44399 T44692					
1990											
1991	T62530										
1992	T50727 [3-way] T77449 [3-way]										
1993											
1994	T29785 [3-way] T57115 [3-way] T77513 [3-way]		T83858 T84150	(T83878)		(T83625) T83676					
1995			(T39721)	T88434							

Breeding Season	Nesting beach									
	Northwest Is.	Tryon Is.	Wreck Is.	Heron Is.	Hoskyn Is.	Lady Musgrave Is	Lady Elliott Is	Wreck Rock beaches	Courtship Area: Fraser Is	Coral Sea Reserve	New Caledonia
1996	T32203 3-way T94461 3-way K2819	T21232 2-way K3731	T50862 3-way T57117 3-way	T3950 T12544 3-way T96066 K5169		T57107 3-way T77435 3-way	T77744 3-way		T78307 3-way (M) T92833 (F) T97709 (F) T97743 (M)		T77864 3-way
1997					K37459					T93898	R15348
1998											
1999	K37526 K37870		T35112	T35755 3-way T55278 3-way T75161 3-way K28681 K28862 K36162		T55280 3-way K33684			K26728 (M)		
2000											
2001	K25768		K39181 (a)	K39181 (a)		T83625 3-way					
2002	T31419 2-way K54625		T39721 5 way T83878 K54889	T50350 3-way T25882 3-way K49179 K53625		K54015		K56487	K44898 (F)		
2003											T85488 3-way
TOTAL	**17**	**2**	**10**	**17**	**1**	**10**	**1**	**1**	**3 (F) 3 (M)**	**1**	**3**
Migration distance	**193 km**	**194 km**	**124 km**	**220 km**	**278 km**	**289 km**	**331 km**	**300 km**	**412 km**	**604 km**	**1397 km**



a. Nesting females



b. Courting males

Figure 11. Distribution of breeding sites recorded from tag recoveries of adult *Chelonia mydas* that migrate from foraging in Shoalwater Bay, central Queensland. Dots denote breeding sites. Cross denotes western Shoalwater Bay study site.

Opportunistic observations were made on adult females that had returned from breeding at a known nesting site in the immediately preceding breeding season as part of an on-going study of the relationship between migration distance and reduction in egg production.

T35755 was recorded nesting at Heron Island in 1987 and recaptured at west Shoalwater Bay in July 1990. She was again nesting at Heron Island in 1993 and 1999 breeding seasons (remigration interval = 6+6 years). On 28 July 2000 she was again recaptured in Shoalwater Bay, CCL = 100.0 cm.

- Gonad examination by laparoscopy showed that during this last breeding season she had ovulated the maximum number of clutches possible from her prepared follicles - the follicles in atresia were less than a normal clutch in number or were follicles that had failed to reach mature size during the breeding season.

K28862 was recorded nesting at Heron Island in 1999 breeding season and recaptured at Shoalwater Bay on 02 August 2000, CCL = 102.3 cm.

- Gonad examination by laparoscopy showed that during this last breeding season she had ovulated the maximum number of clutches possible from her prepared follicles. No large atretic follicles were observed during laparoscopic examination.

These two adult females that had migrated a distance of 224 km between foraging and nesting had not resorbed any clutches of follicles but laid their full complement of clutches of mature follicles as eggs.

Developmental migrations

Prior studies of *C. mydas* in eastern Australia indicate that individual immature and adult turtles occupy very localised areas for many years (Limpus and Chaloupka 1997; Chaloupka et al. 2004). This concept of foraging area fidelity was strongly reinforced by the recapture of 505 individuals during the current study that had been originally recorded at Shoalwater Bay (Table 2).

However, there were three notable recaptures of tagged turtles that had made major shifts of foraging area between captures (Table 2). These individuals, summarised in Table 9, displayed a behavioural characteristic of marine turtles consistent with the "developmental migration" hypothesis (Carr 1980). This concept of developmental migration implies that the individual turtle utilises a series of different habitats during its life.

Table 9. Summary of captures recorded for turtles illustrating developmental migration to Shoalwater Bay during 2000-2004.

Tag Number	Sex	Original capture					Shoalwater Bay captures		
		Date	**Locality**	**CCL**	**Maturity**	**Notes**	**Date**	**CCL**	**Maturity**
K25077	Male	21 Aug 99	Heron Reef	44.4cm	Immature	Recent recruit	26 Jul 00	45.0cm	Immature
T12128	Male	8 Jul 85	Heron Reef	92.7cm	Immature		30 Jul 01	94.9cm	Immature
K8737	Female	16 Aug 97	Wistari Reef	91.8cm	Pubescent		7 Jul 04	91.8cm	Pubescent

Limpus et al. (1994) recorded only one example of developmental migration among the hundreds of *C. mydas* captured in Moreton Bay in the early 1990sto support the concept of developmental migration. In contrast, the accumulating information from the

Shoalwater Bay study suggests that different age classes of turtles used different habitats within the localised geographical scale of Shoalwater Bay.

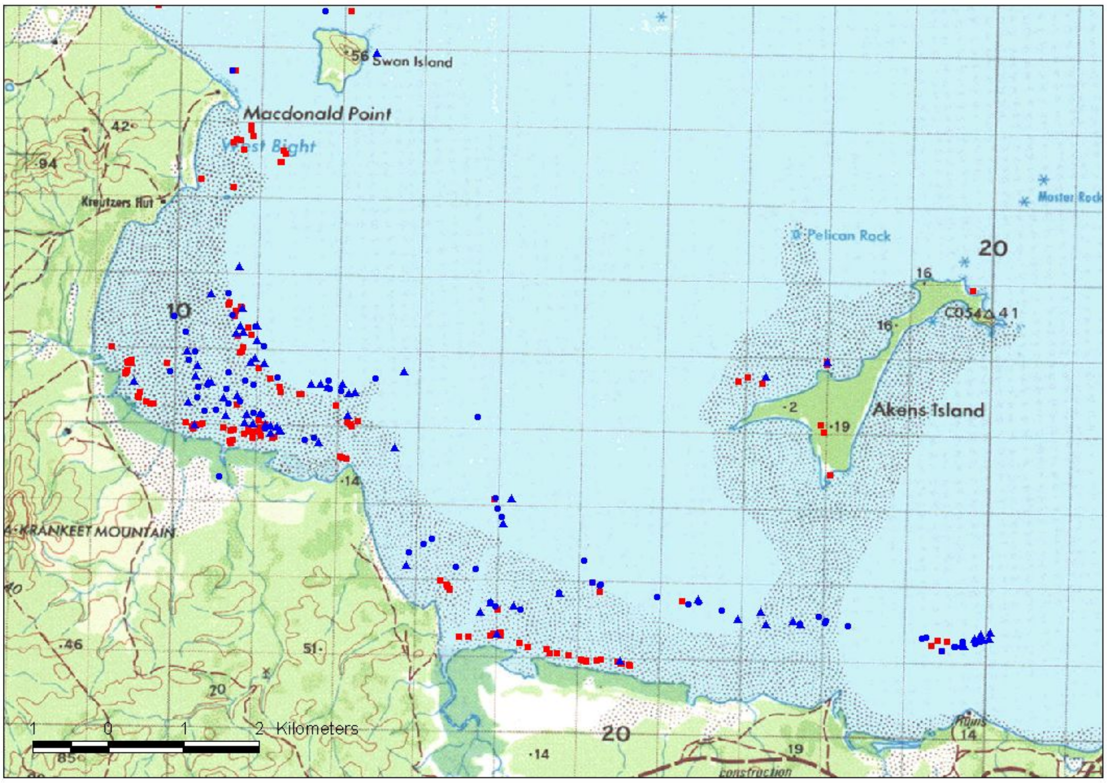


Figure 12. Distribution of captures of *Chelonia mydas* in western Shoalwater Bay during 2004 by maturity of the turtles. Squares denote small immatures (CCL < 65 cm); triangles denote large immatures (CCL > 65 cm); dots denote adults.

The capture data from 2004 (Fig. 12) give clear indications that different age classes of turtles segregated into different habitats within western Shoalwater Bay. The small immature *C. mydas* mainly occupied the upper intertidal areas within the mangrove forest, estuaries of the small streams and the vicinity of intertidal rocky habitat. In contrast the large immature turtles (CCL > 65 cm) and adults were uncommon there but were abundant in the mid to lower intertidal and subtidal seagrass flats. These data indicate developmental habitat partioning by size classes of turtles, presumably during the course of their life in Western Shoalwater Bay.

The consistent paucity of large prepubescent immature turtles within the total capture sample in each year of this study (Fig. 9) suggests that this size class may be moving into a habitat that is not being sampled as comparably as the habit utilised by small immature and adult turtles. The reduced frequency of large prepubescent immature turtles has been a feature of all annual samples of this population since 1986 (CJL unpublished data). This observation associated with the higher frequency of capture of adults across the 18 years of sampling indicates that the reduced numbers of large immature turtles can not be attributed to mortality factors. In addition, the changing sex ratio across the size classes from small immatures, large immatures to adults (Tables 3 and 4) illustrate a differential use of habitat by sex among the large immature turtles. Collectively these data suggest that there is a wider habitat use within western

Shoalwater Bay by this turtle population than we have sampled during the current study.

Annual breeding rates

In June-July, adult female *C. mydas* in vitellogenesis for the coming breeding season had developing ovarian follicles (Fig. 2a) with a mean diameter = 21.7 mm (SD = 2.07, range = 19-26 mm, n = 25. Measured by ultrasound) and a mean inguinal body wall thickness of 33.9 mm (SD = 8.14, range = 17-47 mm, n = 15). At the same time, adult females that had bred in the preceding nesting season had atretic ovarian follicles (Fig. 3b) with a mean diameter = 22.0 mm (SD = 3.5, range = 18-27 mm, n = 6).

None of the 425 individual adult females recorded breeding or in preparation for a breeding season from Shoalwater Bay were recorded breeding or preparing to breed in consecutive years or within two years of a breeding season. The shortest interval between breeding seasons detected by gonad examination of the Shoalwater Bay resident *C. mydas* was three years. The same female does not breed annually but skips a number of years between breeding seasons.

The annual breeding rates recorded from both sexes of adult *C. mydas* resident in Shoalwater Bay are summarised in Table 10. A striking feature of these *C. mydas* breeding rates is the approximate synchrony of fluctuations of the sexes across almost two decades (Fig. 13).

Table 10. Annual breeding rate calculations for adult *Chelonia mydas* resident in Shoalwater Bay

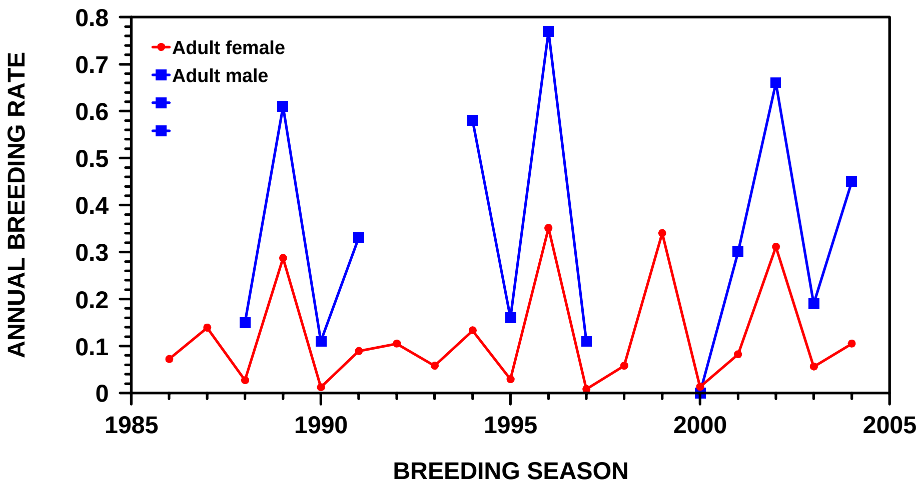
Year	Adult female			Adult male			M:F breeding rate
	Total sample Assessed	No. vitellogenic or breeding	Breeding rate	Total sample Assessed	No. in spermatogenic cycle or breeding	Breeding rate	
1986	111	8	0.072	-		-	
1987	165	23	0.139	-			
1988	223	6	0.027	17	3	0.15	1 : 0.18
1989	223	64	0.287	23	14	0.61	1 : 0.47
1990	170	2	0.012	35	4	0.11	1 : 0.11
1991	112	10	0.089	30	10	0.33	1 : 0.27
1992	114	12	0.105	-			
1993	206	12	0.058	-			
1994	293	39	0.133	31	18	0.58	1 : 0.23
1995	307	9	0.029	45	7	0.16	1 : 0.18
1996	242	85	0.351	47	36	0.77	1 : 0.46
1997	125	1	0.008	38	4	0.11	1 : 0.07
1998	155	9	0.058	-			
1999	191	65	0.340	-			
2000	237	3	0.013	55	0	0	
2001	255	21	0.082	56	17	0.30	1 : 0.27
2002	228	71	0.311	44	29	0.66	1 : 0.47
2003	144	8	0.056	31	6	0.19	1 : 0.29
2004	76	8	0.105	40	18	0.45	1 : 0.23

A higher proportion of adult males than females prepare for breeding in any one year (Fig. 13). There was not a constant relative male:female breeding rate across the years. A higher proportion of males relative to females prepared for breeding during the poorer breeding seasons (mean M:F = 1:0.20 [range = 0.07-0.29]) than during the good breeding seasons (mean M:F = 1:0.47 [range = 0.46-0.47] (Fig. 13b). The product of these relative M:F breeding rates and the sex ratio for this population (M:F = 1:1.178; Table 4) provides a measure of the sex ratio of the adults migrating to the courtship areas, i.e. the mean sex ratio of the adults migrating to the courtship areas from Shoalwater Bay was:

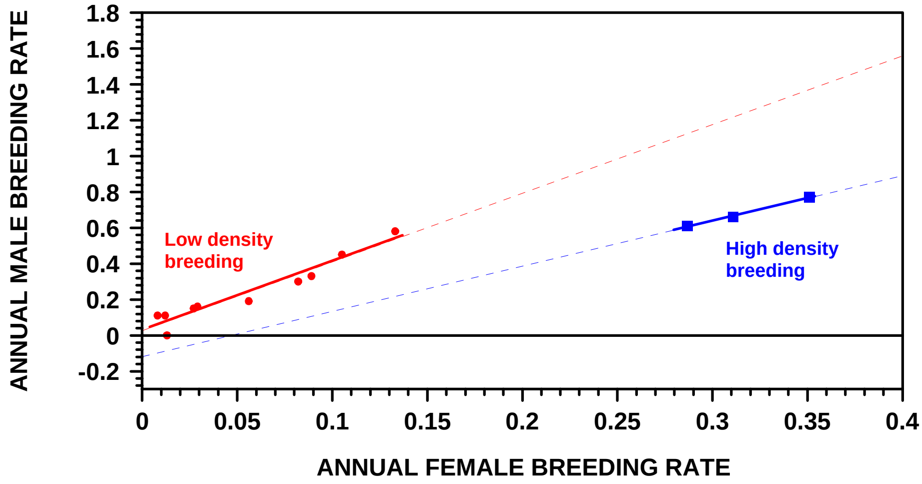
- M:F = 1:0.24 during lower density breeding seasons and
- M:F = 1:0.55 during higher density breeding seasons.

These results translate to the sex ratio at courtship being male biased even though the total foraging population is strongly female biased. In addition, approximately twice as many males per female were present in the courtship areas during poor breeding seasons as occurs in high density breeding seasons.

The reason for the apparent lack of continuity in range of relative breeding rates of M:F (Fig. 13b) is not apparent, even though these data were derived from 18yr of monitoring this population. Whether there is a progressive transition is relative breeding rates across the full spectrum of potential breeding rates for the sexes or whether there is a step function that operates between the extremes of the breeding rates cannot be tested using the available data from this study.



a. Seasonal variability in annual breeding rate by sex.



b. Relative breeding rates of adult males with respect to adult females. Dots denote male:female comparison during seasons when a low proportion of females prepare for breeding. Squares denote this comparison during seasons when a high proportion of females prepare for breeding. Solid lines denote trend lines for each of the disjunct breeding season categories.

Figure 13. Annual fluctuations in the proportion of adults within the resident *Chelonia mydas* foraging population that prepares for breeding (= breeding rate) in Shoalwater Bay. Data derived from Table 8.

These fluctuations in annual breeding rate are driven largely by fluctuations in the El Niño Southern Oscillation (ENSO) climate phenomenon approximately 18 months before the breeding season (Limpus and Nicholls 2000, Limpus et al. 2003). El Niño years are associated with high density *C. mydas* breeding two seasons later while La Niña years are associated with poor breeding seasons two summers later. Because physiological preparation for a breeding season commences more than a year before the breeding season (Hamann et al. 2003) and can encompass a combination of El Niño and La Niña years, the fluctuations in breeding rate are driven by more than the elevated physiological capacity of an ecotothermic herbivore in warmer El Niño years. Because of the time lag, a causal linkage between the climate events and the proportion of adults preparing to breed in any one year is unclear. However it must include a linkage through the seagrass or algal abundance or nutritional quality supporting the foraging population. The decline in breeding rates from Shoalwater Bay during the early 1990s was attributed to the impact of Cyclone *Joy* severely eroding the seagrasses of western Shoalwater Bay in early 1990 (Limpus and Nicholls 2000).

Growth rates

Analysis of growth data from the Shoalwater Bay *C. mydas* foraging population was included in a growth modelling study for multiple foraging areas to investigate temporal and spatial variability of growth within the southern GBR *C. mydas* stock (Chaloupka et al. 2004). This is the latest publication from an ongoing study to understand the ramifications of variable slow growth for conservation management of

Queensland marine turtle stocks (Limpus and Walters 1980, Limpus and Chaloupka 1997, Chaloupka and Limpus 1997, Chaloupka 1998, 2001).

Chaloupka et al. (2004) found that the somatic growth rate function of *C. mydas* foraging in Shoalwater Bay is non-monotonic (illustrated in Fig. 14):

- Recently recruited small immature turtles have a very slow growth rate;
- Growth rate increases with size to a maximal annual growth rate at CCL = 60-70 cm;
- Growth rate decreases with growth beyond about CCL = 70 cm;
- Growth rate approaches a negligible level with adults.

There is sex specific growth with females growing faster than males after the juvenile growth spurt.

Within each study site, there was temporal variability in growth rate, presumably in response to environmental stochasticity.

This same study found that, across the widely dispersed foraging areas for the southern Great Barrier Reef genetic stock, somatic growth is geographically variable but that this variability was not a function of latitude or a dominance of either seagrass or algae in the diet. For the four study sites investigated (Clack Reef, Shoalwater Bay, Heron-Wistari Reefs and Moreton Bay), Shoalwater Bay *C. mydas* that feed predominantly on seagrass (Section 3.2.3) at 22ºS were the slowest growing.

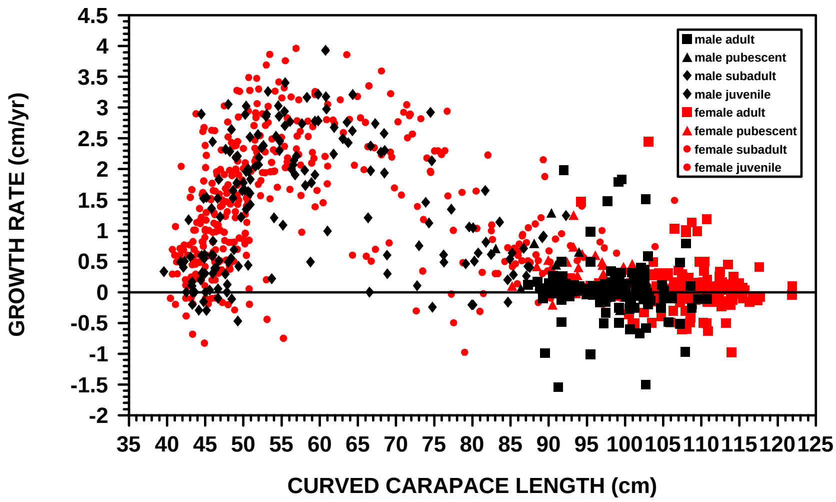


Figure 14. Summary of annual growth rate data recorded for *Chelonia mydas* foraging in western Shoalwater Bay, 1986-2004.

During the present study, we are endeavouring to explore further the significance of the Chaloupka et al. (2004) study for the population dynamics of Shoalwater Bay *C. mydas*. In Table 5 it was established that adult females at this site commence breeding at a mean CCL = 97.97 cm which is considerably smaller that the mean size of first time breeding females pooled across all foraging area (CCL = 104 cm measured at the Heron Island rookery. C. Limpus unpublished data). This indicates that the slow growing Shoalwater Bay *C. mydas* are not necessarily older when they commence breeding but that they are considerably smaller.

To evaluate the impact of environmental stochasticity on growth, the annual growth (restricted to data derived from growth increments spanning only 1 year) for immature turtles at or near the size at which there is the peak of the immature growth spurt (CCL = 50-70 cm), were analysed (Fig. 15). There have been substantial fluctuations in the mean annual growth rate of these immature turtles within the past two decades. The very low growth rate recorded in 1990 coincides with the period when seagrass had been severely damaged by Cyclone Joy (Limpus and Nicholls 2000). The very low growth rate recorded in 2003 follows years of exceptionally hot weather that impact on intertidal seagrass growth and follows a period with toxic algal blooms (Section 3.2.8). At present there is no clear relationship between annual breeding rate of adult females and the annual growth rate of immature turtles. However, both these demographic parameters should be dependent on the quality and/or quantity of forage available to the grazing turtles. This area of investigation warrants further exploration.

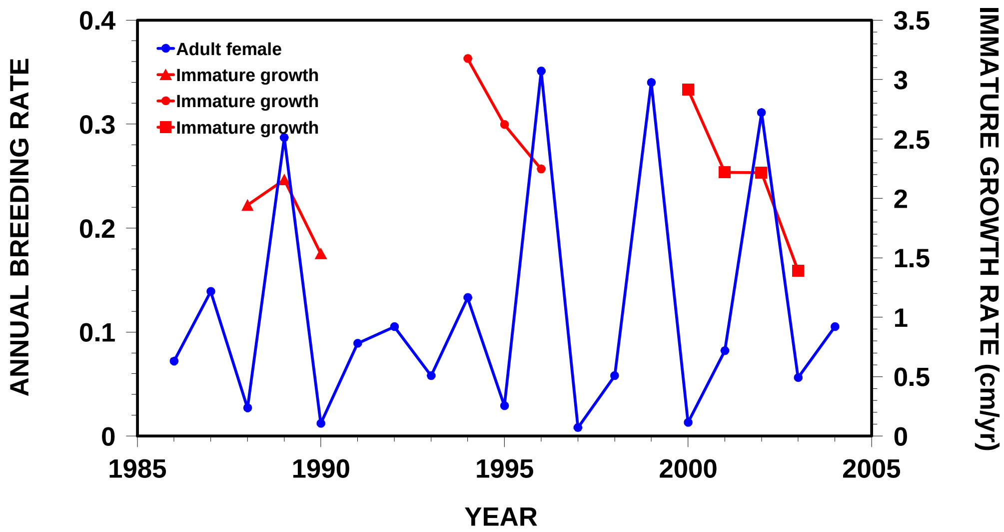


Figure 15. Comparison of variability adult female annual breeding rates and mean annual growth rate of immature (CCL = 50-70 cm) *Chelonia mydas* in western Shoalwater Bay. Growth data restricted to growth increments spanning only ~1 year.

Response to abnormal habitat condition during winter 2002

Lyngbya majuscula, a toxic cyanobacterium, was observed blooming during June-July (winter) 2002 in Shoalwater Bay by the Queensland Turtle Conservation Project research team.

The following is a summary from a companion study to the turtle population dynamics study (Arthur submitted, Arthur et al. submitted). The bloom was mapped and extensive mats of *L. majuscula* were overgrowing seagrass beds along at least 18 km of coast and covering a surface area of more than 11 km^2. Higher than average rainfall (Fig. 5) preceded the bloom and high water temperatures in the 2002 summer (Fig. 6a) may have contributed to the bloom. Lyngbyatoxin A was present in low concentration (26 µg.kg^{-1} dry weight), but Debromoaplysiatoxin was not detected. Turtle diet was assessed during the bloom and 51% of animals examined had consumed the cyanobacterium. However, overall it contributed only 2% of the animals' diets. The bloom appeared to have no immediate impact on turtle body condition, although, decreases in plasma concentrations of calcium and glucose suggested that the turtles were possibly malnourished or starving during the bloom. This is the first confirmed report of *L. majuscula* blooming in winter in Shoalwater Bay, demonstrates that turtles consume the toxic cyanobacteria in the wild, and that they are potentially exposed to tumour promoting compounds produced by a toxic cyanobacteria.

During July-August 2002, six (38%) of the 16 adult females in vitellogenesis had commenced resorption of developing follicles on the ovaries (Fig. 3c). This has not been observed in any previous year of the studies in western Shoalwater Bay. A cessation of follicle development and associated resorption (atresia) of follicles is noted in female turtles that have been severely stressed (Hamann et al. 2003). In 2000 in Moreton Bay, a similar occurrence of atresia among a suite of adult female *C. mydas* in preparation for the 2000 breeding season coincided with a large toxic algal bloom (*L. majuscula*) across the main seagrass pastures of eastern Moreton Bay. This second case of multiple vitellogenic females starting atresia before breeding was also associated with a large *L. majuscula* bloom in western Shoalwater Bay and within a turtle population under physiological stress (Arthur et al. submitted). Both cases are circumstantial evidence that *L. majuscula* blooms can negatively impact on the reproductive physiology of *C. mydas*. The full ramifications of the impact of the 2002 *L. majuscula* bloom on the *C. mydas* population in western Shoalwater Bay cannot be determined from a study of only two weeks duration.

Arthur et al. (submitted) noted from stomach lavage samples more damaged and old seagrass in the diet in winter 2002 than in 2003 (T-test: $F = 2.34$, $df = 99$, $P = 0.028$). A difference in seagrass quality is presumed to result from extreme summer temperatures impacting the intertidal seagrass. The high summer temperatures of 2001-2002 would have caused problems in seagrass growth (Section 2.4), resulting in the higher frequency of blades with dead tips or damaged areas. While not tested, it is presumed that these dead and damaged seagrass blades were below normal in food value for the turtles (Mortimer 1981).

These observations indicate that environmental perturbations in the quality or availability of food resources may reduce the proportion of adult turtles preparing to breed in a particular year.

A small amount (< 1% coverage)of *L. majuscula* was recorded in the feeding grounds between 28 June-5 July 2003. Most of the *L. majuscula* was in the potential bloom phase of sediment growth, however, high winds and rough water after this time dispersed the potential bloom. *L. majuscula* collected prior to the stormy weather contained 27 µg/kg (dry weight) Lyngbyatoxin A but no Debromoaplysiatoxin (K. Arthur, pers. comm.). This toxin content is very similar to levels measured during the 2002 bloom (Arthur et al. submitted). These observations again demonstrate variability in environmental condition for these foraging turtles.

Courtship anomalies

Only one courting pair of *C. mydas* was observed in Shoalwater Bay during the five winter sampling trips. On 27 June 2004, an adult male *C. mydas* (**T18465**) was engaging in preliminary courtship activity with an adult female (**K49553**) that was not in vitellogenesis for the coming breeding season but she had her 1st breeding season in 2002-2003. On this occasion, the male's courtship behaviour was ineffective. Both these turtles had a prior capture history from Shoalwater Bay.

In addition, some males will be permanently excluded from the breeding population. Of the 206 adult males examined during the five year study, three (1.5%) had healed damage to tails from past injuries that would prevent them from successfully copulating. For example, adult male **K56035 (**Fig. 16a) was incapable of breeding because of a deformed tail that would prevent successful copulation. The tail had been shortened, exposing the tip of the penis from the cloaca. This damage and the adjacent healed damage to the hind flippers were presumably caused by a past shark or fish attack. The tail was rigid posterior to the cloaca. Its testis and epididymis were normal for an adult male that was not in the breeding cycle for the year.

a. K56035: 10 July 2003; CCL = 93.7 cm, with damaged tail that would prevent it from successfully copulating.

b. K8693: July 2004; CCL = 98.8 cm. Vent opens laterally on the tail.

Figure 16. Adult male *Chelonia mydas* with damaged or deformed tails that would negatively impact on their breeding potential.

0.5% of adult males (n = 1) were congenitally deformed with the cloacal opening on the side of the tail (**K8693**, Fig. 16b). This deformity would likely exclude the turtle from successful copulation. Its testis and epididymis were normal for an adult male that was not in the breeding cycle for the year.

Of 364 immature males examined over the five years, one prepubescent immature male (**K56036**: CCL = 45.9 cm) had an old healed injury to the tail that will render it incapable of copulation when it becomes an adult. The same turtle had other healed injuries as including loss of the right hind flipper and a portion of the right posterior carapace.

Turtle disease, deformities and injuries

Shoalwater Bay with its changing management (Section 2) has increasingly become an extensive habitat buffered from human activities. Western Shoalwater Bay in particular functions as an undesignated marine protected area for the marine turtle population. Consequently, this turtle population represents an ideal benchmark for quantifying the natural incidence of congenital deformities and injuries and disease derived during migrations and the local impact of disease and the low level of human activity within the bay.

This section addresses deformities, injuries and disease impacts other than those addressed above in relation to male breeding success.

Green turtle fibropapilloma disease (GTFD)

GTFD tumours were not found on any of the small immature *C. mydas* that had recently recruited to Shoalwater Bay from the pelagic life history phase.

Limpus and Miller (1994) recorded a low incidence (2-3%) of GTFD among *C. mydas* resident in Shoalwater Bay during 1988-1990. Over a decade later, this population still displays a low incidence of the disease (0.5-2.1%) as measured by external presence of tumours on the turtles (Table 11). One of the more severe GTFD tumour cases recorded in the present study is illustrated in Figure 17.

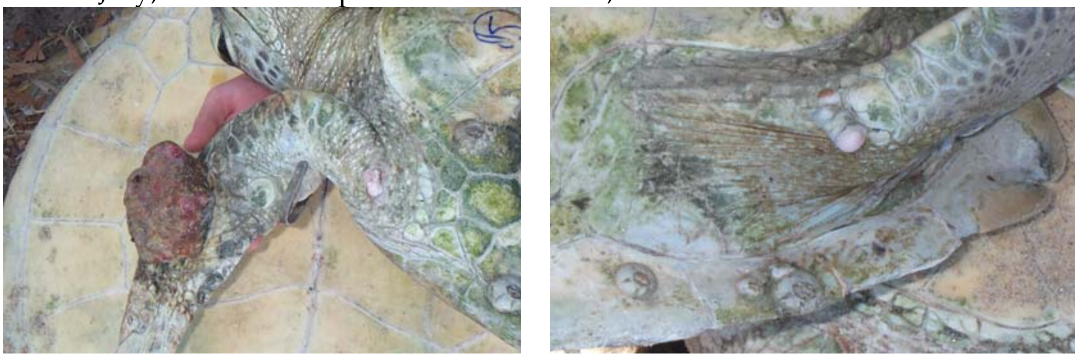
At present there is no measure of the impact of this disease on these turtles. However, recaptures of previously infected turtles (Table 11) have demonstrated that a proportion of the turtles with GTFD are recovering from this disease.

Table 11. Occurrence of externally developed green turtle fibropapilloma disease tumours on *Chelonia mydas* foraging in western Shoalwater Bay. * denotes that the tumours are regressing. Tumours were scored by number and size after Work and Balazs (1999).

Year	2000	2001	2002	2003	2004
Total no. turtles examined	390	383	417	351	463
Turtles with external GTFD tumours	K36713 (B1) K38026 (B1)	K43190 (A1) K43163 (B1) K43230 (B1)* K43301 (B1) K43323 (B1) T55174 (B1) K43362 (B2) K8544 (C3)	K49438 (A1) K49432 (B1) K49747 (B1) T53598 (B2) K43362 (C3)	K43149 (B1) K43362 (C3)*	T50773 (B1) K60802 (B2) K61128 (B2) K43357 (C1) K8544 (C2)*
Recaptures previously recorded with GTFD tumours which no longer had tumours	T39751 T39753 T50839 T55165	K37096	K43301 K43323 T77511		
Turtles with no past records but with scars and lumps consistent with healed GTFD tumours				K56256 K56284	
% of turtles with GTFD	0.5%	2.1%	1.2%	0.6%	1.1%
% of turtles recovered from GTFD. This is a minimal measure.	1.0%	0.3%	0.7%	0.6%	0

2001: 7 August; 28 tumours ranging 0.5 to 4.0 cm in diameter; CCL = 53.3 cm.

2002: 2 July; 23 tumours up to 5cm in diameter; CCL = 52.8 cm.



2003: 3 July; 6 tumours (measuring 9 and 2cm under right front flipper; up to 2.5 cm under right hind flipper). The smaller tumours were regressing; CCL = 53.1 cm

Figure 17. Changing occurrence of GTFD tumours with K43362, a prepubescent immature female *Chelonia mydas*.

The size class distribution of *C. mydas* with GTFD tumours is summarised in Figure 18. A comparison of the size class distribution for the entire population (Fig. 9) indicates that the disease is not randomly represented in the population but is expressed primarily among turtles in the 40-85 cm size range, i.e. primarily among immature turtles. Given that the disease is not in evidence among recent recruits, it can be assumed that immature turtles contract the disease during their residency in the Bay. Similarly, given the capacity for individuals to recovery from the disease, the low incidence of GTFD tumours with large immature and adult turtles may result from a developed immunity to the disease.

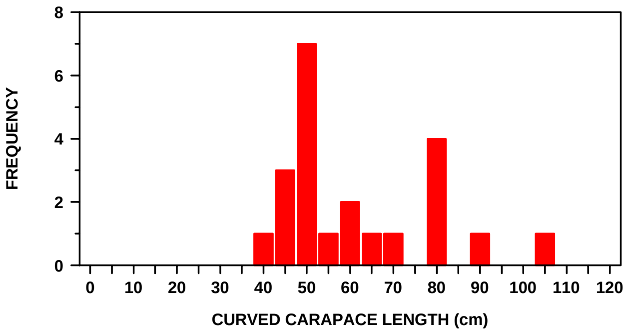


Figure 18. Size class distribution of *Chelonia mydas* with Green Turtle Fibropapilloma Disease tumours recorded in western Shoalwater Bay during 2000-2004.

The incidence of GTFD tumours on *C. mydas* in western Shoalwater Bay has been low since studies began in 1986. If the ingestion of tumour promoting toxins from *L. majuscula* is associated with the occurrence of GTFD in turtles (Davidson 2001), there should be a time delay, as yet unquantified, between the outbreak of *L. majuscula* blooms and an increased incidence of turtles with tumours in the area. The recent occurrence of a large *L. majuscula* bloom in western Shoalwater Bay in 2002 will provide a test of the hypothesis that a toxic algal bloom precedes the onset of increased incidence of tumours. With its low incidence of GTFD, Shoalwater Bay offers a significant reference site for contrast with high infection rate locations such as Moreton Bay for future studies to better understand this disease.

Parasitic infection of the lower digestive tract
Severe parasitic infection of the lower intestinal wall (Fig. 19b) was observed annually during visual examinations during laparoscopy of the smaller turtles but was rarely encountered among the larger turtles. Twenty-two *C. mydas* were recorded with extensive parasite cysts and or haematomas on the outside of the small intestine. These represent 1.2% of the total sample of turtles during 2000-2004. All severely infected turtles were immature. Of these, eighteen (82%) were small immature turtles with CCL < 55 cm. The parasite is unidentified but is presumed to be a worm.

a. Sunken plastron indicative of a prolonged illness.

b. Lesions on small intestine from parasite infection.

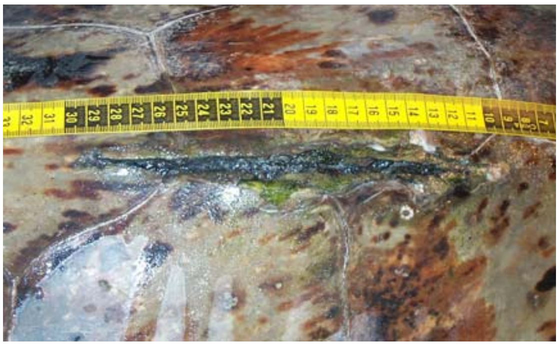
Figure 19. Prepubescent immature *Chelonia mydas* beachwashed fresh dead at McDonald Point, 29 June 2003. The white plastron and plastron keels indicate that this turtle had recently recruited to Shoalwater Bay from the pelagic environment.

The impact of this parasitic infection on the population is unquantified. It appears that at least some turtles with parasitic infection of the gut may die. An untagged, freshly dead, prepubescent male green turtle washed ashore at McDonald Point on 29 June 2003 was necropsied (Fig. 19). This turtle had recently recruited to SWB from the pelagic environment and was in poor body condition (concave plastron) with numerous haematomas on the small intestine. These lesions were consistent with lesions caused by blood fluke (spirorchid) blockage of capillaries. The intestine was adhering to the peritoneum, indicating a gut stasis for an extended period. This turtle had died after a protracted period of ill health. The source of this parasitic infection remains undefined.

Boat strike and propeller cuts
Compared to locations such as Moreton Bay, western Shoalwater Bay has a low density of boating traffic. During the present study, commercial fishers, particularly crabbers, recreational fishers and Government agencies (EPA/QPWS, DPI and Department of Defence) operated boats in the intertidal and subtidal waters where the turtles forage. Occasional carcasses that stranded prior to the present study have had fractures consistent with boating interactions as the cause of deaths.

During the present study 25 turtles had fractures consistent with propeller cuts (n = 16. Fig. 20a), skeg cuts (n = 2. Fig. 20b) and general boat collision (n = 7). Collectively these fractured turtles represent 1.4% of the turtle population sampled during 2000-2004. These turtles that have survived a boat strike or propeller chop represent an index of boating interactions for this turtle population. The number of turtles killed by boating interactions in these waters remains unquantified.

a. K43396: Propeller cuts to anterior carapace of adult female; 27 June 2004; CCL = 116.5 cm. These injuries were not present at first capture on 6 August 2001.



b. K61070: Skeg cut to carapace of prepubescent immature female; 30 June 2004; CCL = 88.0 cm.

Figure 20. *Chelonia mydas* from western Shoalwater Bay with fractures consistent with interaction with boats.

Entanglement
One *C. mydas* (K49416: 30 June 2002; prepubescent immature male, CCL = 42.2 cm) was recorded with its flipper entangled in short length of rope. At this first capture when the rope was removed, the turtle was in poor condition with a sunken plastron and a laparoscopic examination revealed a severe parasitic infection of the lower intestine. At two subsequent recaptures, 8 July 2003 and 4 July 2004, it was in good body condition.

A prepubescent immature male *C. mydas* (K36823: CCL = 51.0 cm) was captured immediately south of McDonald Point on 27 July 2000. It was subsequently recorded on 27 January 2001 as a recently dead, beachwashed turtle entangled in fishing line adjacent to its original capture site.

Presumed congenital deformities

Abnormal reproductive system
Two turtles were recorded with abnormal reproductive systems, presumably resulting from congenital abnormalities.

K61083: Adult female that has yet to breed, CCL = 102.7 cm, 6 July 2004. This turtle has only one functional oviduct. Both ovaries appeared to be normal.

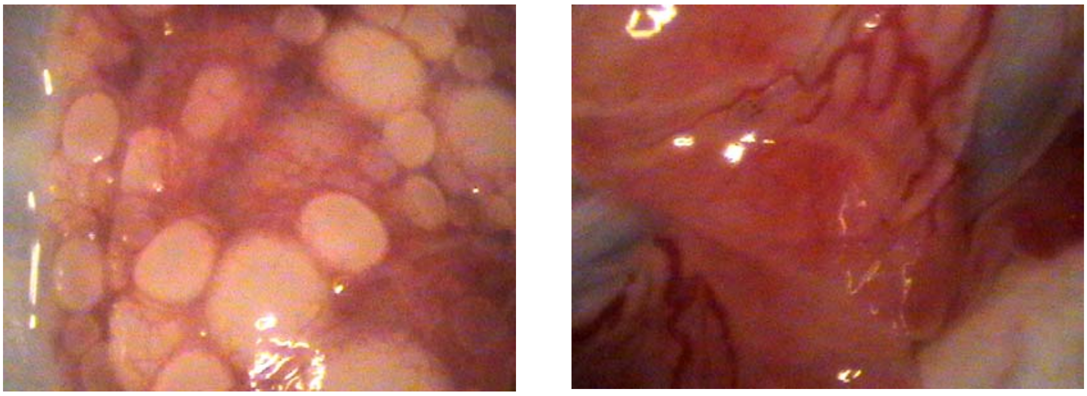
- No right oviduct. Right ovary appeared normal but not expanded and with abundant previtellogenic follicles. There was no evidence of ovarian scars (corpora albicantia or atretic discs).
- Left oviduct appeared to be abnormal (~15 mm diameter, white and very convoluted). Left ovary was very similar in appearance to the right ovary.

It is not unusual for follicles from one ovary to cross the body to form eggs in the opposite side oviduct. However, it is doubtful if one oviduct can accommodate the full complement of egg production derived from follicle production in two normal ovaries. It is expected that this turtle will experience future problems in egg production.

K61156: prepubescent immature female, CCL = 81.6 cm, 28 June 2004. This turtle has only one functional ovary. Both oviducts appeared to be normal.

- Left ovary normal with abundant previtellogenic follicles and associated normal white straight ~1 mm diameter oviduct (Fig. 21a).
- Right ovary abnormal with no follicles in evidence but normal white straight ~1 mm diameter oviduct (Fig. 21b).

This turtle should be able to reproduce but with reduced numbers of eggs per clutch or with a reduced number of clutches laid per breeding season.



a. Left ovary normal with previtellogenic follicles.

b. Right ovary abnormal with no previtellogenic follicles

Figure 21. K61156: Prepubescent female *Chelonia mydas* with an abnormal gonad.

Deformed tail

K49367 (Fig. 22a): prepubescent immature female, CCL = 70.4 cm. Superficially, the turtle appeared healthy and to be functioning normally but this turtle had no vent on the ventral side of the tail. Its vent opened dorsally on the tail. There was a gap in the vertebral column through which the cloaca passed and the "cloaca" was very tight and muscular. With this deformity with a dorsal positioning of the cloacal opening, this turtle will probably never be able to successfully copulate when it reaches adulthood. This is the first record of this type of deformity in marine turtles.

K61113 (Fig. 22b): 27 June 2004, pubescent immature female, CCL = 85.7 cm. The prominent knob on the end of the tail is not expected to compromise reproductive capacity of this female.

Deformed plastron

K56106 (Fig. 22c): 11 July 2003, adult female, CCL = 101.8 cm. There was extensive deformity of the plastron resulting in the pelvic girdle not being anchored ventrally by the plastron. This probably resulted from a congenital deformity and is expected to compromise the nest digging capability of this female.

Kyphosis

Two individuals with curvature of the spine were recorded over the five years:

- **K36728**: prepubescent immature male;
  30 July 2000, CCL = 44.9 cm; normal body condition;
  26 June 2002, poor body condition.
- **K49407**: prepubescent immature female; 23 June 2002; CCL = 61.7 cm.

If these turtles survive life to adulthood, kyphosis is not necessarily an impediment to functioning successfully as a reproductive adult.

Presumed injury induced deformities

Split lower jaw

T29785 (Fig. 22d): 3 July 2003, adult female, CCL = 102.4 cm. Each half of the jaw was able to operate independently. This turtle has not deteriorated in condition since its previous capture in July 2000 when it was first observed with this split jaw condition. The origin of this old injury is unknown. She had not bred in 6 consecutive years.

Other negative health conditions

Decalcified bone

T15208 (Fig. 22e): 2 July 2003, pubescent immature female, CCL = 89.8 cm. This was interpreted as the result of a possible virus or bacterial infection that has resulted in decalcification of the bone under the area of altered skin of the plastron (20 x 14 cm) that also extended to the carapace. There was a second smaller infected area on the plastron (6 x 8 cm). This lesion had not been recorded when this turtle was previously captured in July 1997.

Skin lesion

K56190 (Fig. 22f): 11 July 2003, Pubescent immature male, CCL = 99.6 cm. When captured, this turtle had an extensive ventral area on the front and rear flippers and neck with sloughed outer keratin layer of the skin. These areas were easily bruised with handling and appeared to have dilated capillaries in the skin. This was interpreted as resulting from infection.

Possible old sunburn injury

K61110 (Fig. 22g): 27 June 2004, adult female, CCL = 108.8 cm.
Three large areas on the carapace had damaged but healing skin. Scutes were absent over much of the area. This could be a possible old sunburn injury. The extent of this wound raises concern regarding the potential for secondary infection via the injured surface. At least three adults were observed with this type of extensive carapacial skin injury.

Lung lesion

K56371 (Fig. 22h): 4 July 2004, prepubescent immature male, CCL = 65.5 cm. Inflamed lesion on the left lung adjacent to the liver.

a. K49367: prepubescent female with a dorsally opening vent.

b. K61113: Pubescent female with a knob tail.

c. K56106: Adult female with a deformed plastron.

d. T29785: adult female with a split mandible, July 2000.

e. T15208: Pubescent immature female with an area of discoloured bridge-plastron overlies flexible, apparently decalcified bone.

f. K56190: Pubescent immature male, CCL = 99.6 cm, 11 July 2003.

g. K61110: Adult female, CCL = 108.8 cm, 27 June 2004; Injury to carapace from unknown origin, possibly from sunburn.

h. K56371: Prepubescent immature male, CCL = 65.5 cm, 4 July 2003. Laparoscopic view of lesion on left lung adjacent to liver.

Figure 22. Injuries, deformities and disease in green turtles captured in western Shoalwater Bay during 2000-2004.

Collectively only a low proportion of the *C. mydas* foraging in western Shoalwater Bay display injuries, abnormalities and disease and only a proportion of these can be construed as resulting from human activity. This study provides a base line index against which the impacts on the marine turtle population resulting from the on-going management of Shoalwater Bay can be judged. Similarly, Shoalwater Bay *C. mydas* population can be used as a quasi-control population for comparison with other populations subjected to more intense anthropogenic activities.

Basking

During each annual visit to Shoalwater Bay, numerous live *C. mydas* were observed stranded on the intertidal seagrass flats and among the exposing rocky reefs with the falling tides. Large turtles are visible at a distance on the intertidal flats from the catchboats working along the shallows. However, most small immature turtles are seen only during walking transects of the intertidal flats. The stranded turtles encompassed the full size spectrum from small immature turtles to very large adults (Fig. 23). Most of these stranded turtles observed from the boats were not examined for tags or measured.

Turtles in these situations were observed foraging over the intertidal flats as the tide receded and they continued foraging even as they grounded. Stranded turtles lying supported by the substrate but with their mouths under water still feed on the adjacent algae or seagrass (Fig. 24). As the tide receded, these turtles made no attempt to swim or crawl toward deeper water. This exposure of turtles on the intertidal flats resembles the behaviour of turtles elsewhere (e.g. Hawaii, Bountiful Island and Southern GBR) where they crawl from the water to bask (Barrett 1919, Balazs 1980, Limpus et. al. 1994) As the tide returned, some stranded turtles resumed feeding before there was sufficient water around them to swim.

Figure 23. A selection of *Chelonia mydas* encountered as basking turtles or in the process of being left out of water by the receding tide on the intertidal flats of western Shoalwater Bay.

Figure 24. Basking immature green turtle that continued to feed on the surrounding seagrass while its mouth was under the water.

Systematic walking-searches for stranded turtles during daytime low tides in the small bay immediately south of McDonald Point were part of the capture methods during 2002-2004. Many of these turtles were caught basking on multiple occasions within the same trip and between years, even after the turtle was transported to the research camp approximately 1 km to the north for tagging and measuring on the first capture for each year. The repeated stranding of the same turtle at the same locality, even after translocation to an adjacent site, is further evidence that these basking turtles recognise specific foraging sites where they may strand on the intertidal flats.

During June-July 2003, stranded immature turtles had a mean cloacal temperature of 23.4°C (SD = 1.114, range = 21.2-25.3, n = 21). This cloacal temperature was significantly warmer than the surface of the wet intertidal sand on which they were resting by 0.9°C ($F_{1,40} = 9.22$; $0.005 < p < 0.01$).

This elevation in body temperature may benefit the stranded turtles during the cooler months by causing an elevation in metabolic rates. However, during the summer months, elevation of body temperatures or even just elevation of the body surface temperatures could be detrimental to them. Nesting turtles stranded on north Queensland nesting beaches during the summer months can die of heat stress (Limpus et al. 2003). This aspect of summer stranding on the intertidal flats in Shoalwater Bay warrants further investigation.

The turtles that strand on the intertidal flats of Shoalwater Bay are not debilitated. They are foraging turtles that choose to remain in the shallows as the tide drops and they are exposed to the air and sunlight. This behaviour by turtles can therefore be defined as basking.

CONCLUSION

The long-term mark-recapture tagging study of the green turtle, *C. mydas*, foraging population in western Shoalwater Bay has been demonstrably effective for elucidating the population dynamics of the species. Results from this tagging study have been enhanced substantially by the use two additional research methods:

- Gonad examinations to define the sex, maturity and breeding status of the turtles and
- Extensive use of parallel tagging programs at the distant nesting beaches to provide definitive information on migration and site fidelity.

The *C. mydas* that forage in abundance in Shoalwater Bay are predominantly part of the southern GBR green turtle stock. This stock dominates *C. mydas* populations within the Great Barrier Reef World Heritage Area.

The combination of catchment protection and marine habitat protection affords the resident foraging *C. mydas* population of Shoalwater Bay the greatest level of protection with the least anthropogenic impacts when compared with any other large foraging populations of *C. mydas* in eastern Australia.

The present study has demonstrated that these turtles are very accessible for the comprehensive monitoring and research. Therefore, western Shoalwater Bay presents a unique opportunity for monitoring this benchmark population for eastern Australian green turtles in the absence of most anthropogenic impacts that characterise the other significant foraging aggregations in eastern Australia.

This present study provides a base line index against which the impacts and/or benefits of the on-going management of Shoalwater Bay on the marine turtle population can be judged. Similarly, Shoalwater Bay *C. mydas* population can be used as a quasi-control population for comparison with other populations subjected to more intense anthropogenic activities.

The full ramifications of the impact of the 2002 *L. majuscula* bloom on the *C. mydas* population in western Shoalwater Bay cannot be determined from a study of only two weeks duration. Its main value lies in monitoring the impact of this bloom on the turtle population in the years that follow. With its low incidence of GTFD, Shoalwater Bay offers a significant reference site for contrast with high infection rate locations such as Moreton Bay for future studies to better understand this disease.

It is recommended that this study site be ranked highly when considering the choice of future marine turtle monitoring and research projects in eastern Australia. Future projects would benefit from integration of turtle population dynamics studies with finer resolution local climate records, complementary physiological and health investigations of the turtles and in depth monitoring of the abundance and quality of seagrass and algal pastures and mangrove fruit as food resources.

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