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The Loggerhead Turtle, *Caretta caretta*, in Queensland: Breeding Migrations and Fidelity to a Warm Temperate Feeding Area

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ABSTRACT. – Tagging-recapture and satellite telemetry studies were used to describe the breeding migrations of 15 adult female loggerhead turtles, *Caretta caretta*, from feeding areas in seagrass habitats of Moreton Bay, Queensland, in subtropical eastern Australia. The females migrated to nesting beaches throughout the breeding range of the species in eastern Australia and New Caledonia, and returned to the same feeding area on the completion of the breeding migration. These turtles displayed a comparable high fidelity to both their respective feeding areas and nesting beaches during breeding migrations. Adult female *C. caretta* may be imprinted to their respective feeding areas during completion of immature growth.

KEY WORDS. – Reptilia; Testudines; Cheloniidae; *Caretta caretta*; sea turtle; feeding; breeding; migration; nesting; fidelity; Queensland; Australia; New Caledonia

Marine turtles have for centuries been recognized as migratory species (Dampier [1717] in Masefield, 1906) and tagging studies have demonstrated a strong fidelity by breeding females to traditional nesting beaches across successive breeding migrations (Carr et al., 1978; Limpus et al., 1984, 1992). The distribution of feeding areas that supply turtles to these breeding sites mostly has been elucidated using long-distance recapture data from females originally tagged on the nesting beaches (Meylan, 1982). Recent studies using radiotracking with satellite telemetry has provided information on the migratory routes of small numbers of females from the nesting beaches to distant feeding area for six species of marine turtles (*Caretta caretta*: Timko and Kolz, 1982; *Chelonia mydas*: Liew et al., 1995; Balazs et al., 1996; *Eretmochelys imbricata*: Ellis et al., 2000; *Lepidochelys kempii*: Byles, 1989; *L. olivacea*: Plotkin et al., 1995. *Dermochelys coriacea*: Morreale et al., 1996; see Plotkin [1998] for a more comprehensive review of references). Only with *L. olivacea*, a turtle having a one year remigration interval and feeding in oceanic waters, has it been possible to follow breeding females on a complete cycle from nesting to feeding to subsequent remigration for the next breeding season (Plotkin et al., 1995).

There remains a paucity of information on the breeding migration of marine turtles from their coastal feeding areas to the nesting beaches. Limpus et al. (1992) reported strong fidelity to both the nesting beach and specific feeding sites within the Great Barrier Reef of eastern Australia for breeding migrant loggerhead turtles, *Caretta caretta,* and green turtles, *Chelonia mydas*. To investigate this behavior further, the present study focuses on the two-way migrations of breeding female *C. caretta* from a warm temperate coastal feeding area to their rookeries and the post-breeding migration to feeding areas.

STUDY SITE

Moreton Bay (27.5°S, 153.3°E) is a large wedge-shaped bay partly enclosed by large sand islands in southeastern Queensland, Australia. The characteristics of the bay with respect to marine turtle habitat were summarized by Limpus et al. (1994a,b). This ca. 100 km long by ca. 30 km wide bay receives discharge from six rivers along its western coast. The maximum rainfall occurs in summer and the lowest rainfall season is winter. The mean monthly surface water temperature in the northeastern bay ranges between 16–28°C. The bay has two tidal cycles per day with a tidal range of 0.9–2.5 m. It is well flushed with oceanic water in the northeast but has reduced tidal flushing in the south. Low turbidity waters over sand substrates characterize the northeastern parts of the bay while high turbidity waters over mud substrates characterize the western and southern areas of the bay. Moreton Banks and adjacent Maroom Banks are large areas of intertidal and shallow subtidal seagrass habitats in the northeast of the bay.

Caretta caretta is listed as endangered under Queensland and Australian nature conservation legislation and Moreton Bay is a significant feeding area for the species in eastern Australia (Limpus et al., 1992, 1994). These same studies also have demonstrated that many of the loggerhead turtles that live in Moreton Bay migrate to breed on southern Great Barrier Reef islands and adjacent mainland beaches.

METHODS

The breeding migrations of female *C. caretta* that feed within Moreton Bay and adjacent waters have been investigated using two complementary methods: mark-recapture studies using titanium flipper tags and radiotracking using satellite telemetry.

Mark-Recapture Studies. — There has been an annual mark-recapture study of *C. caretta* on the Moreton and

Maroom Banks of eastern Moreton Bay as part of ongoing studies of the Queensland Turtle Research Project (QTR) of the Department of Environment and Heritage since 1990 (Limpus et al., 1994a,b). Turtles were captured by the turtle rodeo method (Limpus, 1978) with divers leaping onto the turtles from 4.2 m speedboats. Each turtle was identified using numbered standard titanium turtle tags applied through the axillary area of the trailing edge of a front flipper (Limpus, 1992a). Tag numbers have a "T" or "X" prefix. The standard measure of a turtle was its midline curved carapace length (CCL, ± 0.2 cm) measured with a flexible tape measure. The sex, maturity, and current breeding status of each turtle were assessed by visual examination of the gonads using laparoscopy (Limpus, 1992b; Limpus et al., 1994b): a female preparing for breeding was recognized by her enlarging, vascularized, vitellogenic ovarian follicles > 3 mm in diameter. The absence of corpora albicantia on the anterior ovary indicated that the turtle had not ovulated in the past. The presence of corpora albicantia indicated that the female had ovulated in a previous breeding season. Commencing in 1995, the latitude and longitude of the capture sites (± 100 m) for most turtles were recorded using a Phillips (mk8 or mk9) geographical positioning system (GPS) navigation aid on each boat. If a GPS position was not recorded for a turtle, its general position was recorded on the Moreton Banks with respect to obvious local topographic features, especially the drainage areas as seen at low tide (= sectors of Limpus et al., 1994). For each turtle captured, data summarizing tags, species, sex, age class, date, capture method, life history phase, measurements, breeding success, health, experiments performed, and location, including latitude and longitude, were stored in the QTR relational database.

In addition, QTR tagging census studies (Limpus, 1985; Limpus and Reimer, 1994) continue to be conducted each summer on numerous *C. caretta* nesting beaches in Queensland. Nesting females were tagged with titanium flipper tags as described above and measured for curved carapace length. Not all *C. caretta* rookeries in Queensland are included in these studies. There have been total tagging censuses of the annual nesting population, with effectively every female being examined in each breeding season, at Mon Repos (24.792°S, 152.439°E) and adjacent beaches on the south Queensland coast since 1968 and at Heron Island (23.433°S, 151.917°E) in the southern Great Barrier Reef since 1974. The beaches adjacent to Mon Repos include Oaks Beach (24.783°S, 152.433°E), which lies 3.1 km northward from Mon Repos, and Kelly's Beach (24.825°S,152.455°E) which is 3.8 km south from Mon Repos (Limpus et al., 1984). The annual nesting population on the 22 km of mainland beaches at Wreck Rock (24.317°S, 151.967°E) has been sampled with a 5-wk mid-season tagging census in most years since 1978. At Wreck Island (23.333°S, 151.950°E), the annual nesting population has been sampled with a 2-wk mid-season tagging census in most years since 1977.

Satellite Telemetry Studies. — Two separate satellite telemetry studies were conducted with adult female *C. caretta* that feed in Moreton Bay. Each transmitter broadcast on 401.650 Mhz. Their software was configured as follows: repetition cycle = 50 sec; duty cycle = 6 hr on and 6 hr off; fail-safe time = 12 hr; minimum time for a dive = 0.5 min; period for averaging dive time = 12 hr; last dive time held until updated. The turtles in both satellite telemetry studies were tracked using the ARGOS system (Anonymous, 1996a). The geographical locations obtained for each turtle have been displayed using ArcView GIS software (Anonymous, 1996b).

An adult female *C. caretta* with a capture history of feeding within Moreton Bay was selected while she was nesting at Mon Repos in January 1992 for a pilot satellite telemetry study. She was removed from the nesting beach after she had ovulated and retained in a brackish water pond for 36 hr while the transmitter was prepared for deployment. The transmitter deployed with this turtle was a Telonics ST-3 housed in an 8 cm diameter x 34 cm long PVC tube capped at both ends and tethered to the rear of the turtle's carapace. This transmitter was of the same design as that used in several previous marine turtle satellite telemetry studies (see for example, Keinath et al., 1989; Spring, 1994). The tether design was changed from the short 0.5 m lanyard and double bolt attachment described by Keinath et al. (1989) and Spring (1994) to a 3 m long and 4 mm diameter stainless steel wire lanyard. This wire lanyard was encased in a 19 mm tubular PVC electrical conduit pipe to provide the necessary rigidity to prevent the turtle from entangling in the wire. The lanyard was attached to the turtle via a non-galvanized 6 mm mild steel shackle attached in turn to an 8 mm stainless steel shackle through a single drilled hole in a posterior marginal scute. The non-galvanized shackle was the corrosible link in this attachment system and was expected to break and release the lanyard and transmitter after about three months. This longer semi-rigid tether design was based on the tether design used with satellite telemetry of dugong (Marsh and Rathbun, 1990). The change in tether design was an attempt to increase the surface time of the transmitter when the turtle surfaced to breathe and hence increase the transmission time and precision of the location data. The transmitter and tether weighed 1.9 kg out of water.

Five adult female *C. caretta* that were in vitellogenesis for the coming breeding season were selected for telemetry studies from among those captured during the annual loggerhead turtle population census studies on the Moreton and Maroom Banks during May–September 1996. The transmitters deployed with these turtles were Telonics ST14 (0.72 kg, 18 cm x 10 cm x 3.5 cm) fiberglassed to the carapace after the method of Balazs et al. (1996). Each was released at its

Table 1. Summary of defined accuracy of ARGOS location class categories (Anonymous, 1996a).

Location class	Estimated accuracy of locations
3	< 150 m
2	149 m < accuracy < 350 m
1	349 m < accuracy < 1000 m
0	> 1000 m
A	no estimate of location accuracy
B	no estimate of location accuracy

capture site on the Moreton–Maroom Banks. Turtles held for less than 36 hr were retained out of water, kept shaded and moist, while those held for > 36 hr were retained in a freshwater pool.

For reporting purposes, the two-way breeding migrations from feeding area to nesting and back to feeding area were subdivided into five behavioral segments.

1. Pre-migratory feeding and completion of vitellogenesis: this encompassed the period from deployment of the transmitters until the commencement of the breeding migration.

2. Breeding migration from feeding to breeding areas: this commenced when the turtle left its feeding area en route to her breeding area.

3. Internesting and nesting: commenced on arrival in the vicinity of the nesting beach and included the internesting periods between all clutches laid for the season.

4. Post-nesting migration from breeding to feeding areas: commenced immediately following the last oviposition for the breeding season and was completed when the turtle returned to its feeding area.

5. Post-migratory feeding: commenced once the turtle ceased her migration, i.e., arrived at and remained within a localized area or had returned to the original feeding area; and continued until the completion of the study.

Site data were analyzed by pooling the ARGOS location classes (Anonymous, 1996; Table 1) into two categories: "good" locations with accuracy < 1 km radius (location classes 3, 2, or 1); poor locations with accuracy > 1 km (location classes 0, A, or B).

RESULTS

Mark-Recapture Studies. — Nine adult female *C. caretta* feeding on the Moreton Banks of eastern Moreton Bay (not including the turtles selected for telemetry studies) have been recorded nesting in a later breeding season (Table 2). These nine turtles from a relatively localized feeding area of the Moreton Banks did not migrate to nest at a single rookery site, rather they were recorded at four widely scattered rookeries ranging ca. 30 km to 500 km from the feeding area. The breeding sites included mainland beaches (Mon Repos and Wreck Rock), a coral cay offshore in the southern Great Barrier Reef (Wreck Island) and a continental sand island adjacent to the Moreton Bay feeding area (Moreton Island). Subsequently, four of these have been recaptured in feeding areas and all had returned to the same feeding area in Moreton Bay where each had been originally captured (Table 2).

Table 2. Summary of flipper tagging mark-recapture records for adult female *Caretta caretta* captured while feeding on the Moreton Banks of eastern Moreton Bay and subsequently recaptured at a breeding site.

Tag no.	Prior nesting records	Moreton Bay capture(s)	Nesting records	Post-breeding capture(s) in Moreton Bay	Displacement: migration	Displacement: feeding to feeding
T1276	Mon Repos **04 Dec 83 - 04 Jan 84**: scars from lost tags from a previous season; CCL=96.5cm; laid 3 clutches **11 Dec 86 - 17 Jan 87**: 3yr remigration; CCL=97.5cm; laid 4 clutches **22 Nov 88 - 15 Jan 89**: 2yr remigration; CCL=98.0cm; laid 4 clutches	**08 Mar 92**: central western drainage of Moreton Banks; propeller cuts; CCL=97.6cm; not bred 1991-92; non vitellogenic for 1992-93	Mon Repos **18 Nov 93 - 13 Jan 94**: 5yr remigration; CCL=98.0cm; laid 5 clutches **18 Nov 95 - 10 Jan 96**: 2yr remigration; CCL=99.4cm; laid 5 clutches	not recaptured	380 km	-
T2429	**Mon Repos** **19 Nov 83 - 01 Jan 84**: scars from lost tags from a previous season; CCL=95.0cm; laid 4 clutches **21 Nov 86 - 12 Jan 87**: 3yr remigration; CCL=95.5cm; laid 5 clutches **20 Nov 89 - 16 Jan 90**: 3yr remigration, CCL=95.5cm, laid 5 clutches	**26 Apr 92**: central western drainage of Moreton Banks; CCL=95.5cm	**Mon Repos** **26 Nov 92 - 10 Dec 92**: 3yr remigration; CCL=95.6cm; laid 2 clutches	**10 Oct 95**: beach washed dead on Moreton Island (27.03°S, 153.45°E) down current from the Moreton Banks; CCL=~96.0cm. She had been dead for several days.	380 km	in same area
T14284	Mon Repos **18 Dec 84**: scars from lost tags from a previous season; CCL=96.0cm; 1 clutch only recorded	**16 Jun 91**: central western drainage of Moreton Banks; CCL=96.1cm; not bred 1989-90 or 1990-91; vitellogenic for 1991-92	Mon Repos **14 Dec 91 - 21 Jan 92**: 7 yr remigration; CCL=95.2cm; laid 4 clutches	not recaptured	380 km	-
T22667	**Wreck Rock** - incomplete annual censuses **07 Jan 1987**: CCL=101cm	**10 Jun 91**: south western Moreton Banks (Boorong Banks); CCL=101.5cm; not bred 1989-90 or 1990-91; vitellogenic for 1991-92	**Wreck Rock** - incomplete annual censuses **1991-92**: nesting not recorded. **21 Dec 93 - 04 Jan 94**: 2 yr remigration; CCL=101.5cm; laid at least 2 clutches	**13 Aug 95**: central western drainage of Moreton Banks (27.34°S, 153.37°E); CCL=100.7cm; not bred 1994-95; non vitellogenic for 1995-96 **03 Oct 95**: beachwashed dead on Nth Stradbroke Island (27.44°S, 153.53°E) down current from the Moreton Banks	438 km	< 3 km
T22706	**Wreck Rock** - incomplete annual censuses **11 Jan 1987**: CCL=96.5cm	**02 Sep 90**: south western Moreton Banks (Boorong Banks); CCL=96.2cm **17 Aug 91**: central western drainage of Moreton Banks; not bred 1989-90 or 1990-91; vitellogenic for 1991-92	**Wreck Rock** - incomplete annual censuses **20 Dec 91 - 10 Jan 92**: 5 yr remigration; CCL=96.0cm; laid at least 2 clutches	**08 Oct 93**: south western Moreton Banks (Boorong Banks); not bred 1992-93; non vitellogenic for 1993-94 **25 Apr 97**: south western Moreton Banks (Boorong Banks; 27.39°S, 153.37°E); CCL=96.3cm;	438 km	< 1 km
T23637	**Mon Repos & adjacent Kellys Beach** **22 Dec 86 - 31 Jan 87**: her 1st breeding season; CCL=87.5cm; laid 4 clutches **07 Dec 89 - 22 Jan 90**: 3yr remigration; her 2nd breeding season; CCL=88.5cm; laid 4 clutches	**25 May 91**: central western drainage of Moreton Banks; CCL=88.0cm; not bred 1990-91; non vitellogenic for 1991-92	**Mon Repos** **13 Dec 94 - 21 Jan 95**: 5 yr remigration; her 3rd breeding season; CCL=88.9cm; laid 4 clutches	**29 May 97**: north western Moreton Banks (27.33°S, 153.37°E); CCL=88.8cm; not bred 1995-96 or 1996-97; non vitellogenic for 1997-98; fibropapilloma growths	380 km	< 2 km
T64304	no records	**09 May 92**: Brown's Gutter, southern Moreton Banks; CCL=90.8cm; not bred 1990-91 or 1991-92; vitellogenic for 1992-93 **30 May 96**: central western drainage of Moreton Banks; CCL=90.5cm; not bred 1994-95 or 1995-96; non vitellogenic for 1996-97	**Moreton Island** - incomplete annual censuses **18 Dec 97**: eastern beach (27.142°S, 153.433°E); laid at least 1 clutch	not recaptured	≥ 30 km	-
T93038	no records	**28 May 97**: Chain Banks of south western Moreton Banks (27.4503°S, 153.3913°E); CCL=90.4cm; not bred 1995-96 or 1996-97; vitellogenic for 1997-98	Mon Repos **08 Dec 97 - 25 Jan 98**: her 2nd breeding season; CCL=90.9cm; laid 4 clutches	not recaptured	390 km	-
X44635	**Wreck Island** - incomplete annual censuses **14 Jan 83**: CCL=93.0cm; **24-25 Dec 86**: 4yr remigration; CCL=93.0cm **1989-92**: nesting not recorded	**31 Aug 91**: central western drainage of Moreton Banks; CCL=93.5cm; bred 1989-90; not bred 1990-91; non vitellogenic for 1991-92	**Wreck Island** - incomplete annual censuses **22 Dec 94**: ?5yr remigration; CCL=92.8cm	not recaptured	505 km	-

Satellite Telemetry Studies. — Results of the satellite telemetry on 6 females are presented in Table 3 and Figs. 1–5 and detailed for each female below.

T41196. — This turtle which nested at Mon Repos for her first breeding in the 1988–89 season was recaptured feeding on the Moreton Banks on 16 September 1991 (Table 3). She returned for her next breeding season to Mon Repos during the 1991–92 season. She was captured for transmitter attachment on 8 January 1992 on completion of oviposition of her third clutch for the season and released on 10 January. Laparoscopic examination of her ovaries indicated that she would only lay one additional clutch for the season. She returned to lay her fourth clutch for the season on 22 January (renesting interval = 14 d) less than 200 m from her previous nesting site on Mon Repos. The corrosible link in the tether was well corroded. The 3 good locations obtained during the 12 d she was in her internesting habitat were from an area within a few kilometers to the north of Mon Repos, between Mon Repos and the mouth of the Burnett River. These were within the most frequently occupied internesting habitat area for the Mon Repos nesting *C. caretta* (Tucker et al., 1996). There were no good locations obtained during her post-nesting migration, possibly because of cyclonic weather and rough seas. The 2 poor locations obtained on 29–30 January to the east of Fraser Island indicate that she migrated south via the ocean side of Fraser Island. She was back on the Moreton Banks (4 good locations in 36 hr) after 15 d. She had traveled 380 km from her nesting beach and was within 2 km of where she had been captured prior to the nesting season. During the third day back in her feeding area (8 February) the transmitter apparently detached and, during the next 2 months, drifted (without diving) from Moreton Bay, south to New South Wales waters, and subsequently across the Tasman Sea towards New Zealand. This turtle was recaptured ca. 4.5 yr later in 1996 in healthy condition < 2 km from the location where she ceased her migration on 6 Feb 1992. In 1996, she no longer had the stainless steel shackle attached through her carapace but the hole was present and well healed. She

Table 3. Data summary for the adult female *Caretta caretta* which feed in Moreton Bay and which have been tracked using satellite telemetry. *(Table continued on next page).*

Tag number	T41196	T14914	T50812	T50968	T85300	T92001
Capture records from past breeding seasons	Bred at Mon Repos **25 Dec 88 - 21 Jan 89:** CCL=85.0cm; laid 3 clutches; 1st breeding season confirmed by laparoscopy	Bred at Mon Repos **01 Dec 85 - 27 Dec 86**: tags scars from past breeding; CCL=91.1cm; laid 3 clutches	Nil. (Preparing for 1st breeding season.)	Nil. (Has bred before.)	Nil. (Has bred before.)	Nil. (Preparing for ?2nd breeding season.)
Pre-telemetry capture records from Moreton Bay	**16 Sep 90**: central western drainage of Moreton Banks; CCL= 86.3cm; healing propeller cuts	**15 Sep 96**: northern Maroom Banks; CCL=91.1cm; not bred 1994-95 or 1995-96; vitellogenic for 1996-97	**05 Aug 90**: Fisherman's Gutter, southern Moreton Banks; pubescent immature; CCL=86.5cm **31 Aug 91**: central western drainage of Moreton Banks; adult yet to breed **07 Nov 93**: Fisherman's Gutter, southern Moreton Banks; adult yet to breed; CCL=87.5cm **07 May 94**: central western drainage of Moreton Banks; adult yet to breed **15 Sep 96**: Fisherman's Gutter, southern Moreton Banks; in 1st breeding cycle; CCL=87.8cm; vitellogenic for 1996-97	**01 Sep, 29 Sep, 28 Oct 90**: central western drainage of Moreton Banks; adult; CCL=90.5cm; vitellogenic for 1990-91 **15 Jun 91**: Fisherman's Gutter, southern Moreton Banks; adult; CCL=90.7cm **30 Mar 96**: Fisherman's Gutter, southern Moreton Banks; vitellogenic for 1996-97 **25 Aug 96**: central western drainage of Moreton Banks; CCL=91.0cm; many maturing follicles in atresia	**26 May 96**: Blue Pool of northern Moreton Banks; CCL=98.4cm; not bred 1994-95 or 1995-96; vitellogenic for 1996-97; old propeller cuts to carapace.	**29 May 96**: northern Maroom Banks; CCL=99.1cm; not bred 1994-95 or 1995-96; vitellogenic for 1996-97; non-fibropapilloma lump on shoulder.
Weight	-	-	-	84.5 kg	114.0 kg	135.0 kg
Transmitter ID	5348	26040	26043	26039	26041	26042
Timing of "on" portion of duty cycle	1200-1800; 2400-0600 hrs	0600-1200; 1800-2400 hrs	0600-1200; 1800-2400 hrs	0600-1200; 1800-2400 hrs	1200-1800; 2400-0600 hrs	1200-1800; 2400-0600 hrs
Date released with transmitter	10 Jan 1992	18 Sep 1996	18 Sep 1996	29 Aug 1996	28 May 1996	31 May 1996
Pre-migratory feeding in	**Moreton Bay**					
Signal quality				No. of signals received		
Location class 3		2	3	0	1	1
2		1	4	0	6	2
1		8	3	3	11	2
0		9	2	3	11	9
A		10	20	12	14	5
B		31	29	14	22	10
		Total = 61	Total = 61	Total = 32	Total = 65	Total = 29
Signals with no location	-	26	19	100	55	~35
Duration of feeding observations	-	59d	61d	204d	181d	?
Pre-nesting migration						
Date of departure from Moreton Bay feeding area	-	~16 Nov 96	18 Nov 96	did not depart	did not depart*	not recorded
Signal quality	-			No. of signals received		
Location class 3	-	1	2			
2		5	0			
1		0	1			
0		3	1			
A		4	1			
B		4	2			
		Total = 17	Total = 7	-	Total = nil	Total = nil
Signals with no location		13	7	-	nil	~11
Date of arrival at rookery	-	~02 Dec 96	~04 Dec 96			at least by 24 Nov 96
Migration distance from feeding area	380 km	~390 km	462 km	-	~19-37 km	at least 1586 km
Duration of migration	-	~16 d	~16 d	-	-	-
Nesting and internesting						
Nesting area	Mon Repos Beach (observed nesting)	Mon Repos & Oaks Beach (observed nesting)	within or adjacent to the Solitary Islands area, NSW (presumed from telemetry & laparoscopy)	-	Moreton Island (presumed from telemetry)	New Caledonia (presumed from telemetry & laparoscopy)

remigrated to Mon Repos for her third breeding season on 22 December 1998 (CCL = 87.1 cm, remigration interval = 7 yr, clutches for season = 3; additional healing fractures to carapace since 1996; fibropapillomas still obvious).

T14914. — This female nested at Mon Repos in the 1985–86 breeding season. When she was recaptured on the northern Maroom Banks on 15 September 1996, the small size of her corpora albicantia indicated that she had not bred during at least the previous two summers. Her large maturing ovarian follicles indicated that she was preparing to breed in the 1996–97 season. Prior to commencing her breeding migration, 11 good locations (18% of location signals, 13% of all signals) were obtained over 59 d from within a 11 km radius of her 15 September capture site. These sites were within an area of ca. 12.7 km x 6.3 km encompassing the northern Maroom Banks, western Rous Channel, and open waters of the Bay to the west of the Moreton Banks (Fig. 1). All poor fixes were from the vicinity of Moreton Bay within a 65 km radius of the 15 September capture site.

She migrated northwards out of Moreton Bay and followed the coast to the northern tip of Fraser Island where she headed westwards across Hervey Bay to internesting habitat adjacent to Mon Repos (Fig. 2). During this migration, 6 good position fixes were obtained (35% of location signals, 20% of all signals). This ca. 390 km migration was completed in ca. 16 d, an average swimming speed of 24 km/d. There was no indication she stopped for courtship although she took 2 d to pass through a known *C. caretta* courtship area adjacent to Sandy Cape (Limpus, 1985) where two good locations were obtained.

She was ashore for her first nesting attempt for the season at Mon Repos on 6 December, 20 d after leaving her feeding area in Moreton Bay, 10–11 d after passing through her apparent courtship area near Sandy Cape and 5.5 d after arriving at the internesting habitat adjacent to Mon Repos.

Table 3. *(continued)*.

Tag number	**T41196**	**T14914**	**T50812**	**T50968**	**T85300**	**T92001**
Breeding history during telemetry study	**12 Dec 91 - 22 Jan 92**: 3 yr remigration; CCL=86.0cm; laid 4 clutches in her 2nd breeding season; fibropapillomas	**06 Dec 96 - 26 Jan 97**: 11yr remigration; CCL=91.1cm; laid 4 clutches for 8 beachings: • clutches 1 & 4 at Mon Repos • clutches 2 & 3 at Oaks B.	**within 4-9 Dec 1996**: presumed nesting crawl; ovulated ~1 clutch for season	nil - did not ovulate (confirmed by laparoscopy 25 Apr 97)	presumed to have laid 3 clutches **6 Dec 1996**: presumed nesting **24 Dec 1996**: presumed nesting **12 Jan 1997**: presumed nesting	**~9 Dec 96**: presumed nesting; ovulated at least 1 clutch (laparoscopy 28 Sep 97)
Signal quality				No. of signals received		
Location class 3	0	0	0		1	0
2	1	1	1		1	0
1	2	0	0		5	1
0	12	3	0		2	1
A	-	11	4		11	3
B	-	31	3		16	3
	Total = 16	Total = 46	Total = 8	-	Total = 36	Total = 8
Signals with no location		27	4	-	38	11
Duration of internesting	> 41 d	56 d	~5 d	-	~52 d	at least 43 d
Post-nesting migration						
Date of departure from rookery	22 Jan 92	~27 Jan 96	~9 Dec 96	-	12 Jan 97	>5 Jan 97
Signal quality				No. signals received		
Location class 3	0	1	1			
2	0	0	0			
1	0	4	1			
0	3	0	1			
A	-	4	7			
B	-	9	15			
	Total = 3	Total = 18	Total = 25	-	-	Total = nil
Signals with no locations		18	19	-	1	~0
Date of arrival in Moreton Bay	06 Feb 92	17 Feb 97	18 Jan 97	-	13 Jan 97	not recorded
Duration of migration	15 d	22 d	~40 d	-	~1 d	-
Post-migration feeding						
Area of locations		Moreton Bay	Moreton Bay	Moreton Bay	Moreton Bay	-
Signal quality				No. of signals received		
Location class 3	1	0	1		1	
2	1	0	1		5	
1	2	1	0		10	
0	0	1	0		8	
A	-	4	7		32	
B	-	9	11		58	
	Total = 4	Total = 15	Total = 20	-	Total = 114	Total = nil
Signals with no location		55	20	-	123	9
Date of last location signal (location code)	07 Feb 92 (lc=3)	12 Jul 97 (lc=1)	22 Feb 97 (lc=B)	11 Nov 96	26 Oct 97 (lc=B)	5 Jan 97 (lc=0)
Date of last signal received	after 07 Feb 92, transmitter was floating & drifted into New South Wales. Presumed to be detached from turtle	13 Jul 97	22 Feb 97	21 Mar 97	30 Oct 97	21 Jun 97
Post-migration recaptures in Moreton Bay	**25 Aug 96**: central western drainage of Moreton Banks; CCL=88.4cm; not bred 1994-95 or 1995-96; non vitellogenic for 1996-97; fibropapillomas; healing old propeller cuts	nil	**26 May 97**: southwestern Moreton Banks (Boorong Banks); healing corpora lutea from 1 clutch only; non vitellogenic for 1997-98 **29 May 97**: central western drainage of Moreton Banks **26 Apr 98**: central western drainage of Moreton Banks; non vitellogenic for 1998-99 **04 Oct 98**: central western drainage of Moreton Banks	**25 Apr 97**: central western drainage of Moreton Banks; CCL=90.6cm; atretic follicles, no corpora lutea - did not ovulate in 1996-97; transmitter removed. **26 Sep 98**: southern western drainage of Moreton Banks.	nil	**28 Sep 97**: northern Maroom Banks; CCL=99.0cm; healing corpora lutea from 1 or 2 clutches; non-vitellogenic for 1997-98; transmitter removed
Net displacement: pre-migration feeding to post-migration feeding	< 2 km 25 Aug 96 recapture is 2.0 km from the 07 Feb 92 location	3.6 km good location on southern boundary of pre-migration area	0.4 km within dispersal of post-migration captures	-	0.3 km	1.0 km
Condition of transmitter on recapture	25 Aug 96: transmitter no longer attached to turtle	21 Dec 96: transmitter reattached because of damage	26 May 97: transmitter no longer attached to turtle	25 Apr 97: transmitter firmly attached but antenna abraded off; removed	-	28 Sept 97: transmitter firmly attached but antenna abraded off; removed

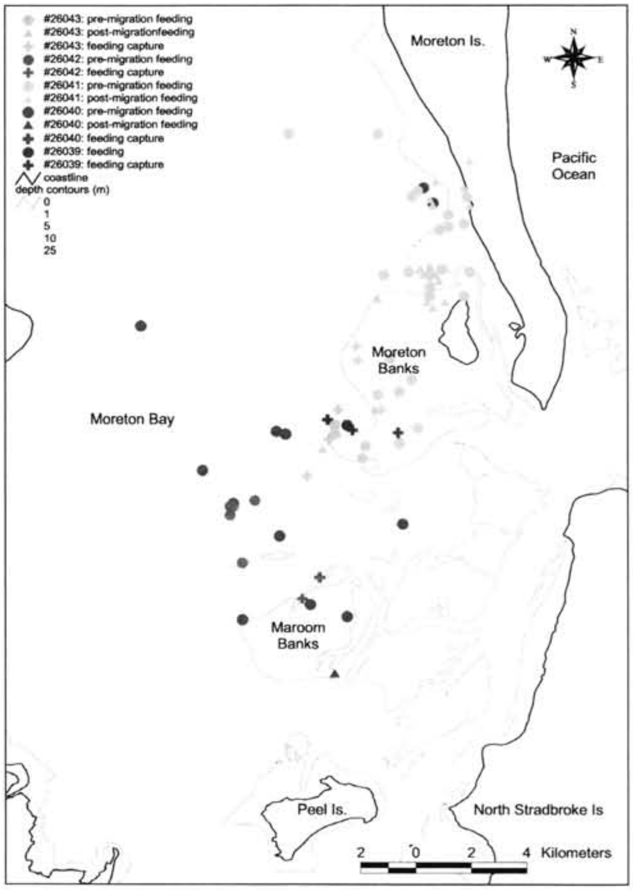

Figure 1. Distribution within Moreton Bay of capture sites of adult female *Caretta caretta* used in the satellite telemetry study and the good locations (location codes 1–3) obtained during pre-migration and post-migration phases of this study.

The period from possible courtship to first oviposition is very similar to the 12 d internesting interval between her first and second clutches for the season. During a ca. 51 d period, she was recorded ashore for 8 nesting attempts during which 4 clutches were laid (2 clutches at each of Mon Repos and Oaks Beaches). Such interchange between adjacent nesting beaches with repeated returns following unsuccessful nesting attempts is within the normal range of behavior for these *C. caretta* (Limpus, 1985). Only one good location was obtained from within the nesting and internesting habitat (2% of location signals, 1% of all signals). This good location was 7.2 km southward from Mon Repos adjacent to Barolin Rocks within the recognized internesting habitat of the *C. caretta* that nest at Mon Repos (Tucker et al., 1996). All poor locations occurred within the vicinity (54 km radius) of the Mon Repos – Oaks Beach nesting area.

The turtle was removed from Oaks Beach on 21 December when she returned to lay her second clutch (82 d after the transmitter had been deployed) and held for 24 hr to repair severely damaged fiberglass attachments. By 26 January when she was laying her final clutch for the season, the fiberglass layers at the base of the antenna were again fractured and 2 deep grooves were scraped in the top surface. This damage to the transmitter may have been caused by the turtle rubbing her carapace under hard objects.

Within 2.75 d of laying her last clutch for the season, she was in southern Hervey Bay, ca. 63 km southeasterly of her nesting beach. She then moved 77 km in a northeasterly direction to Sandy Cape. After rounding Sandy Cape she tracked southward along the coast to return to the vicinity of the Moreton Banks by 17 February (Fig. 2). During this post-nesting migration, 5 good locations were obtained (28% of location signals, 14% of all signals). The post-nesting migration of ca. 430 km back to within the vicinity of her starting point for the breeding migration was completed within 22 d of laying her last clutch for the season. She did not take the shortest route home but appeared to follow the coastline. The complete two-way breeding migration encompassed a total travel of ca. 820 km, not including repeated travel between nesting sites and the internesting habitat, and she was absent from her home feeding area for 93 d.

Signals continued to be received from this turtle from her post-migration feeding area for approximately another five months during which time only one good location was obtained (7% of location signals, 1% of all signals). This good location was on the Maroom Banks on 12 July 1997, ca. 3.6 km from the 15 September 1996 Maroom Banks capture site. All poor locations were from the vicinity of Moreton Bay within a 58 km radius of the 15 September 1996 capture site

T50812. — This turtle was captured 5 times on the Moreton Banks from 5 August 1990 until 15 September 1996. During this period she grew from a pubescent immature turtle to an adult preparing for her first breeding season. Ten good locations (16% of location signals, 13% of all signals) were obtained during the 61 d period from release with transmitter until she commenced her breeding migration on ca. 18 November. These good locations from within the feeding area were from within a 1.9 km radius of the 15 September capture site and occupied an approximate area of 3.8 km x 2.6 km within the southern Moreton Banks (Fig. 1). All poor fixes were from the vicinity of Moreton Bay (within 55 km radius of the 15 September capture site).

She migrated northwards out of Moreton Bay and rounded Cape Moreton to move southwards off the ocean side of Moreton Island. After day 5 of her migration, contact was lost off the southern Gold Coast (Fig. 3). Location signals recommenced 11 d later (4 December) from off Coff's Harbour in northern New South Wales at a swimming distance of ca. 462 km from her 15 September capture site. Within this 16 d migration period, 3 good locations were obtained, all from continental shelf waters (43% of location signals, 21% of all signals).

From off Coff's Harbour area, she returned northward to be off Grafton as indicated by a series of 8 locations (67% of all signals; 1 good, 7 poor, 4 no location) that were progressively received along a northerly track over a 6 d period from 4 to 9 December (Fig. 3). Given that the April 1997 laparoscopic examination showed that she had ovulated one clutch, it is presumed that she laid this clutch while in these New South Wales waters in the vicinity of the Solitary Islands or the adjacent mainland coast.

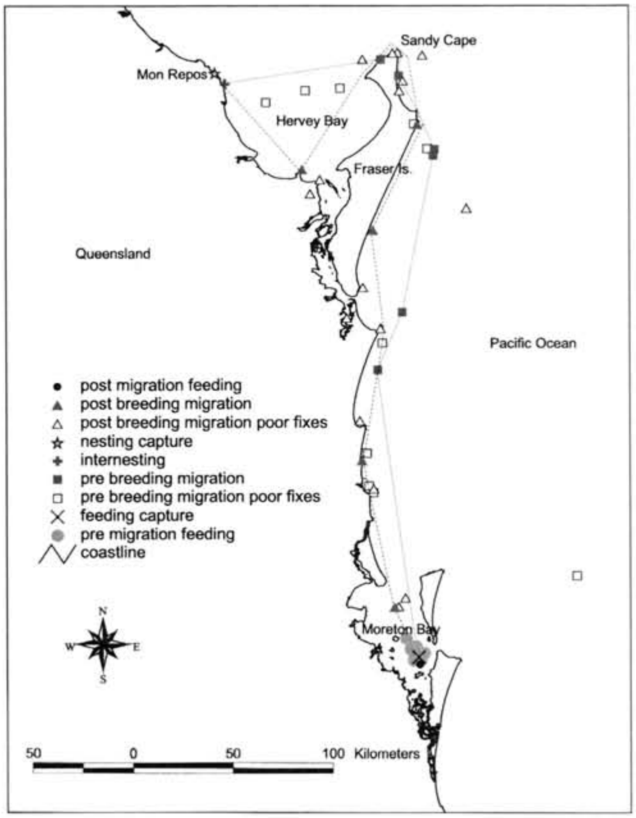

Figure 2. Two-way migration of female *Caretta caretta* T14914 between her feeding area in Moreton Bay and her nesting beaches at Mon Repos and adjacent Oaks Beach. Circle denotes feeding location, square denotes pre-breeding migration location, plus denotes internesting location, star denotes breeding location, triangle denotes post-breeding migration location. See Fig. 1 for detailed distribution of locations within the Moreton Bay feeding area. Solid symbols denote locations with precision < 1 km (lc = 1, 2, or 3). Open symbols denote poor locations (lc = 0, A, or B). The dotted line joins the good locations along the breeding migration and the dashed line joins the good locations along the post-breeding migration.

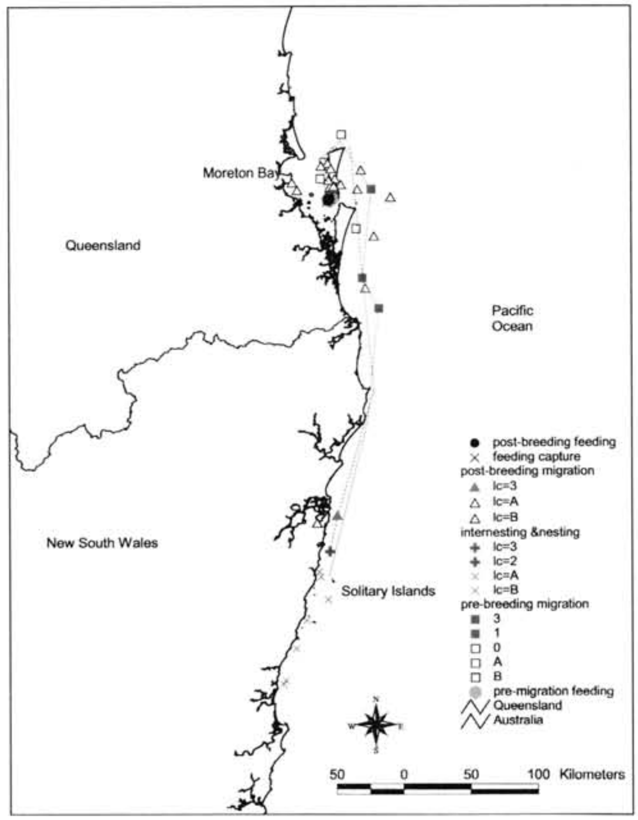

Figure 3. Two-way migration of female *Caretta caretta* T50812 between her feeding area in Moreton Bay and her breeding area in northern New South Wales. Circle denotes feeding location, square denotes pre-breeding migration location, plus denotes internesting location, and triangle denotes post-breeding migration location. Solid symbols denote locations with precision < 1 km (lc = 1, 2, or 3). Open symbols denote poor locations (lc = 0, A, or B). Cross denotes internesting location with poor precision (lc = 0, A, or B). See Fig. 1 for detailed distribution of locations within the Moreton Bay feeding area. The dotted line joins the good locations along the breeding migration and the dashed line joins the good locations along the post-breeding migration.

She appears to have returned home along approximately the reverse of the route she followed on her outward breeding migration. During this post-nesting migration, 2 good locations were obtained (8% of location signals, 5% of all signals, from within continental shelf waters. She returned to Moreton Bay from the north and was back at the Moreton Banks by 18 January within 40 d of her departure from off Grafton in New South Wales. This post-nesting migration coincided with a period of high winds and rough water conditions. The complete two-way breeding migration encompassed a total travel of ca. 924 km during a 61 d absence from her feeding area.

Signals continued to be received within the post-migration feeding area until 22 February 1997, during which time 2 good locations were obtained (10% of location signals, 5% of all signals). These good locations were 2.4 km and 0.2 km from the 15 September 1996 capture site. The last good location was obtained 160 d after attachment of the transmitter. This turtle has been subsequently recaptured 4 times on the Moreton Banks during 26 May 1997 – 4 October 1998 from within an area of 5 km x 2 km. Each of these recaptures occurred within a 3.3 km radius of the 15 September 1996 capture site. When recaptured on 26 May 1996, the transmitter was no longer attached; there was considerable abrasion to the fiberglass strips remaining on the carapace of the turtle; and laparoscopic examination established that she had ovulated one clutch during this breeding season (her first). All poor locations during the post-migration feeding period were from the vicinity of Moreton Bay within a 33 km radius of the 15 September 1996 capture site.

T50968. — This female had been captured 6 times on the Moreton Banks between 1 September 1990 and 25 August 1996. When first captured in 1990, she had bred in a previous season and was in vitellogenesis for the 1990–91 breeding season. She successfully bred during that season at an unknown location. In March 1996 she was again in vitellogenesis. When she was recaptured in August 1996 her vitellogenic follicles were considerably larger than they had been in March but many of the maturing follicles had commenced atresia. Only 3 good locations (9% of location signals, 2.3% of all signals) were received from this turtle between 29 August – 11 November 1996 (Fig. 1). Signals

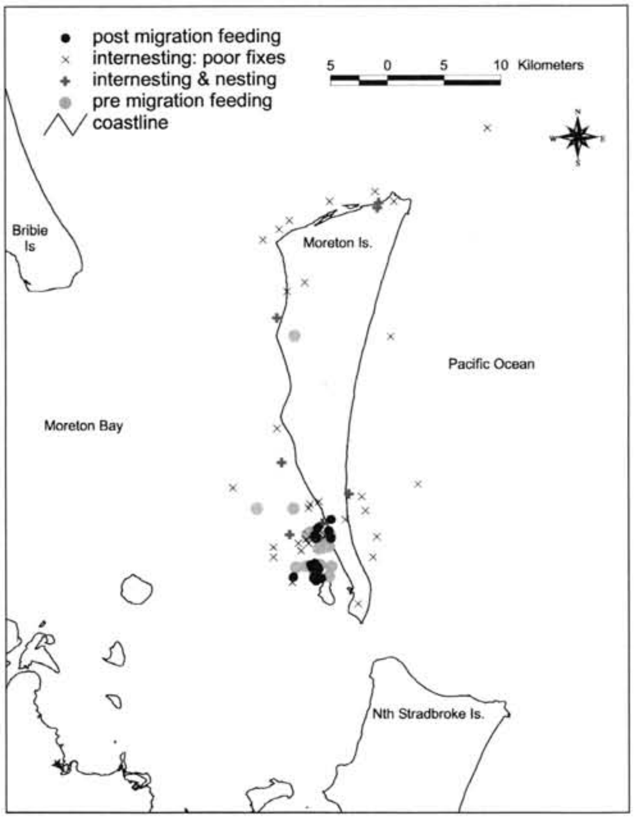

Figure 4. Two-way migration of female *Caretta caretta* T85300 between her feeding area in Moreton Bay and her breeding area on Moreton Island. See text for a detailed description of events. Circle denotes feeding location and plus denotes internesting location. Solid symbols denote locations with precision < 1 km (lc = 1, 2, or 3). Cross denotes internesting location with poor precision (lc = 0, A, or B). See Fig. 1 for detailed distribution of locations within the Moreton Bay feeding area.

with no location data continued to be received up to 21 March 1996. The 3 good locations were from within 9.3 km of the 25 August capture site and encompassed an approximate area of 11.1 km x 0.6 km along the western margin of the Moreton Banks. The 29 poor locations were all from the vicinity of Moreton Bay within a 27.2 km radius of the 25 August capture site.

On 25 April 1997, 254 d after release with the attached transmitter, she was recaptured 0.9 km from the 25 August 1996 capture site. The transmitter was still attached, coated with a thin layer of algae and damaged: the antenna was completely abraded; the front corner of the casing was broken; the upper part of the casing was worn down and there was considerable abrasion of the fiberglass attachments to the carapace. This damage could have been caused by the turtle rubbing her carapace up under abrasive habitat. The poor reception of location data from this turtle appears to have resulted from damage to the antenna. Laparoscopic examination showed that she had not ovulated in the 1996–97 breeding season and all large ovarian follicles were in atresia. Based on the satellite telemetry data, there is no indication that this non-breeding female migrated from her feeding area during the 1996–97 breeding season. Following the April 1997 capture, she was relocated and released 17.3 km distant in western Moreton Bay as part of a homing experiment (unpubl. data). She was again recaptured on 26 September 1998 on the Moreton Banks within 1.5 km of the April capture site.

No explanation is offered for why this apparently healthy turtle had commenced atresia of her large developing follicles between the March and August captures. Similar pre-breeding season atresia of developing follicles by turtles with a past breeding history has only been recorded twice among the thousands of adult females examined in previous years of the QTR project. In both those cases the turtle had been severely traumatized: one had been severely mauled by a shark prior to completion of vitellogenesis; the other, a beachwashed female, was dying from septicemia resulting from a protracted gut blockage.

T85300. — Although there were no breeding records for this turtle prior to her first capture on 26 May 1996, laparoscopic examination showed numerous small corpora albicantia, indicating that she had bred during at least one previous season, as well as being in vitellogenesis for the 1996–97 breeding season. Following release with the transmitter, 18 good locations (28% of location signals, 15% of all signals, Fig. 1) were obtained from within her Moreton Bay feeding area until 23 November. During this period her good locations were from within a radius of 21 km of the 26 May capture site and occupied an approximate area of 21 km x 6 km encompassing the northwestern Moreton Banks and adjacent subtidal waters to the west. All poor locations were from the vicinity of Moreton Bay within a 36 km radius of the 26 May capture site

This turtle apparently moved directly from her feeding area to the presumed nesting sites within 19–37 km of her feeding area, using an internesting habitat coincident with the feeding area while she laid three clutches for the season (Fig. 4). On 3 November, she commenced moving northwards from the northern end of the Moreton Banks and was located ashore on Moreton Island (lc = 3) on 6 December, ca. 37 km from the feeding area. She is presumed to have nested on this occasion. Within 4 d, she was back in her "internesting area" in subtidal seagrass pastures which coincided with her "feeding area." During this first "nesting cycle" 1 good and 3 poor locations were obtained. After 9 d she moved back towards the northern end of Moreton Island and was again ashore on the night of 24 December 1996 (lc = 1) adjacent to the site visited on 6 December. If the presumption of nesting is correct then her renesting interval was 18 d (3 good and 12 poor locations were obtained during this second "nesting cycle"). Two days later she was back in the same "internesting area" where she remained for at least 15 d before moving back towards the mid-western side of Moreton Island and ca. 19 km from her "internesting area." She appears to have gone ashore on the night of 12 January 1997 (lc = 2). The presumed renesting interval was 19 d with 4 good and 14 poor locations during this third "nesting cycle." The following day she was back in her internesting/feeding area. She was not recorded moving to the northern part of Moreton Island during the remainder of the study.

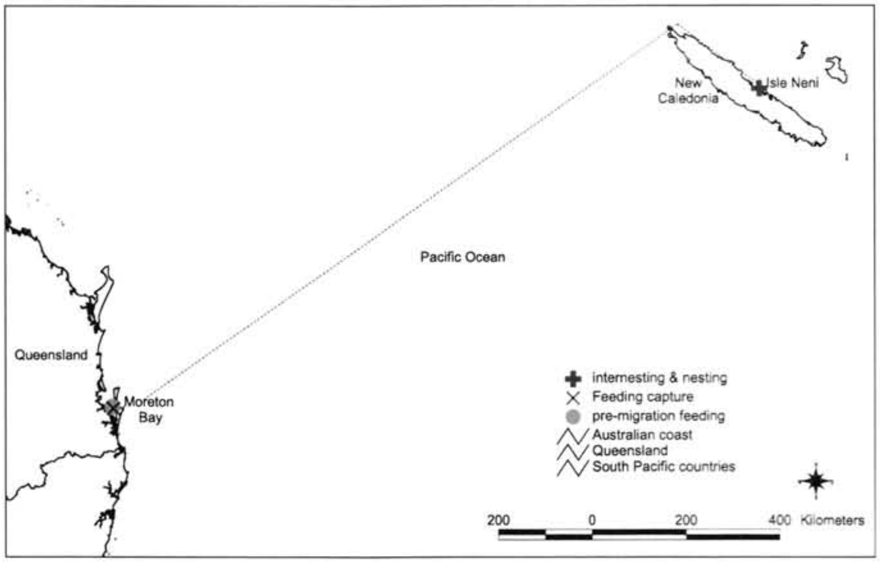

Figure 5. Two-way migration of female *Caretta caretta* T92001 between her feeding area in Moreton Bay and her breeding area in eastern New Caledonia. Circle denotes feeding location and plus denotes internesting location. Solid symbols denote locations with precision < 1 km (lc = 1, 2, or 3). Cross denotes internesting location with poor precision (lc = 0, A, or B). See Fig. 1 for detailed distribution of locations within the Moreton Bay feeding area. The dashed line indicates the shortest possible migratory route for this turtle.

Following her return to the Moreton Banks feeding area on 13 January 1997, 16 good locations (14% of location signals, 7% of all signals) were obtained during 286 d until 26 October 1997. During this period her good locations were from within a radius of 5 km of the 26 May 1996 capture site and occupied an approximate area of 6 km x 2.5 km encompassing the northwestern Moreton Banks and adjacent subtidal waters to the west. All poor locations were from the vicinity of Moreton Bay within a 38 km radius of the 26 May capture site. This turtle has yet to be recaptured to confirm that she ovulated during this breeding season. The transmitter was operational on this turtle for 1 yr 5 mo during which she did not leave Moreton Bay. Her courtship must have been within the vicinity of Moreton Bay.

T92001. — When first captured on 29 May 1996, this turtle which had no past recorded breeding history appeared to be preparing for her second breeding season (based on laparoscopic examination of the size and abundance of corpora albicantia). Five good locations (17% of location signals, 12% of all signals) were obtained from the feeding area (Fig. 1) in 58 d from release until 28 July when there was a cessation in transmission of location signals. The good locations were from within a 3.9 km radius of the 29 May capture site and occupied an approximate area of 2.5 km x 0.8 km encompassing the western Rous Channel. All poor fixes were from the vicinity of Moreton Bay within a 74 km radius of the 29 May capture site.

Non-location signals continued to be received until 24 November 1996 when she recommenced transmitting location signals, including one good location (13% of location signals, 5% of all signals) received from adjacent to Cap des Trois Sapins (in the vicinity of Isle Neni and east of Houailou) on the central eastern coast of New Caledonia. These signals were received during a 43 d period until 5 January (Fig. 5). The poor locations were all from within a 16.6 km radius of the good location. This good location was a minimum of 1586 km from the Moreton Bay capture site via the shortest swimming route passing around the north of New Caledonia.

Only intermittent non-location signals were received after 5 January until 21 June 1997. This turtle was recaptured on 28 September 1997 on the Maroom Banks within 1 km of the 29 May 1996 capture site. Laparoscopic examination of her ovaries showed that she had sufficient healing corpora lutea to have ovulated at least one clutch of eggs but no more than two clutches during the 1996-1997 breeding season. She had numerous large atretic follicles consistent with resorption of more than one clutch of large follicles from the previous breeding season. When captured on 28 September, the transmitter was still attached, coated with a thin layer of algae, and damaged: the antenna was completely abraded off, the top surface of the casing was deeply scratched, and there was considerable abrasion to the fiberglass strips. This damage was consistent with the turtle rubbing her carapace up under solid structures.

Based on the location data and the results of the laparoscopic examination, it is presumed that this turtle migrated to breed in eastern New Caledonia, having swum a round trip migration of at least 3172 km and returned with great precision to her home feeding area in Moreton Bay. There are no data to indicate the timing or path followed for either leg of her migration nor is there any indication of where courtship occurred.

DISCUSSION

In summary for the mark-recapture and satellite telemetry studies, the breeding female *C. caretta* from the relatively localized feeding area of the Moreton Banks and Maroom Banks of eastern Moreton Bay did not migrate to breed at a single breeding site. Rather they were recorded at

Table 4. Average number of good locations per day obtained during each phase of the migration study for each turtle. The duration of each phase for each turtle is shown in parentheses. Refer to Table 3 and the summaries of each turtle's activities for the raw data used to derive these values.

Transmitter type	Tethered ST-3	Carapace mounted ST-14				
Turtle tag number	T41196	T14914	T50812	T50968	T85300	T92001
Pre-migratory feeding	-	0.19 (59 d)	0.16 (61 d)	0.01 (204 d)	0.10 (181 d)	0.09 (58 d)
Pre-nesting migration	-	0.38 (16 d)	0.19 (16 d)	-	0.00 (?)	0.00 (?)
Nesting and internesting	0.25 (12 d)	0.02 (56 d)	0.20 (5 d)	-	0.13 (52 d)	0.02 (43 d)
Post-nesting migration	0.00 (15 d)	0.23 (22 d)	0.05 (40 d)	-	0.00 (1 d)	0.00 (?)
Post-migration feeding	2.00 (2 d)	0.01 (146 d)	0.06 (35 d)	-	0.05 (290 d)	0.00 (?)

many widely separated rookeries ranging ca. 30–1586 km from the feeding area. The breeding migrations encompassed mainland sites to the north (380–438 km) and south (462 km) of Moreton Bay, a southern Great Barrier Reef coral cay (505 km), a local sand island (ca. 30–39 km) and a site to the northeast across oceanic waters in New Caledonia (1586 km). Females with a past breeding history each returned to their respective previously recorded nesting sites. While the three females tracked from feeding area to breeding did not depart synchronously from their Moreton Bay feeding sites, they departed their respective feeding areas within a 16 d period in early to mid-November. Given that these turtles which lived in eastern Moreton Bay did not all breed at the same location, they could not have traveled together to their respective nesting beaches. This is clearly illustrated by the three turtles for which the migratory paths are partially identified (Figs. 2–4). Each turtle followed a relatively direct route between her respective feeding area and nesting beach for both legs of the breeding migration. All nine females that were subsequently recorded in post-migration feeding areas were recorded within 3.6 km of their respective pre-migration feeding capture sites (2 by satellite telemetry only, 3 by satellite telemetry and recapture, 4 by recapture only). These migratory female *C. caretta* have displayed a high level of fidelity to both their respective feeding areas and nesting sites.

The numerous poor locations with location codes of undefined precision (lc = 0, A, B) were obtained from within a 74 km radius of sites where the respective turtles had been observed feeding. This contrasted with the relatively localized areas within Moreton Bay over which the individual turtles were recorded feeding by physical capture or good locations from satellite telemetry (lc = 1, 2, 3: precision < 1 km). These good locations and capture sites all occurred within 11 km of the original capture site for the respective turtles. For this reason it has been considered inappropriate to use the poor location codes when determining locations where individual turtles were feeding. Their limited use was in identifying whether a turtle was in the vicinity of a particular area, especially during migration. The low frequency of high quality location data from both the mark-recapture and satellite telemetry studies precluded calculation of meaningful home ranges. However, the results demonstrate that each turtle occupied a feeding area that was small (maximum spread of locations = 21 km for any one turtle) relative to the size of Moreton Bay. All turtles occupied post-migration feeding areas that spatially overlapped with the respective feeding areas which they occupied prior to the breeding migration. These turtles that had been captured while feeding over the shallow intertidal and adjacent subtidal areas of Moreton and Maroom Banks of eastern Moreton Bay also occupied deeper waters in the 10–25 m depth range that lie to the west of these banks and the waters of the channels and gutters (Fig. 1). The satellite telemetry study demonstrated that some turtles occupied a wider depth range than the intertidal and immediate subtidal waters in which the turtle rodeo capture method is effective for capture.

The carapace-mounted telemetry system chosen for this study has given excellent results with green turtle and olive ridley turtle telemetry (Balazs et al., 1994; Liew et al., 1995; Plotkin et al., 1995). However, the present tracking study was disappointing with respect to the paucity of good location data obtained. Using transmitters which were specifically designed for marine turtles (Telonics ST-14), we received good location signals at a rate of less than one per day for all behavioral phases for each turtle (Table 4). Indeed for much of the study, good location signals were received at a rate of less than one per 10 d. Some of the periods of poor results coincided with periods of storms which would have impacted on the functioning of the saltwater switch when the turtle surfaced to breathe. Another contributing factor to the low rate of recording of good location signals was the damage that the turtles caused to the transmitters, presumably through abrasion against hard structures. Even though these turtles lived in soft-bottomed seagrass habitat, they were accessing hard substrate against which they rubbed their carapaces. This was in addition to the expected interaction with hard habitat at the breeding end of their migrations. That two of the transmitters were without antennas when recovered after 254 d and 485 d and that one had transmission problems after only 58 d indicate that abrasion of the transmitter can be a significant problem. While fiberglass-epoxy attachment of a transmitter to the carapace of hard-shelled turtles is not injurious to the turtle and may provide secure attachment for many months (Renaud et al., 1993), when turtles are exposed to hard structures they can cause structural damage to backpacked transmitters and their attachments and greatly reduce the effective transmission life. Past success in use of backpacked transmitters appears to have been greatest with species which do not inhabit abrasive habitat (Plotkin et al., 1995) or when turtles were tracked during oceanic post-breeding migrations with minimal inclusion of the internesting or post-migration feeding phases within the studies (Balazs et al., 1994; Liew et al., 1995).

The most significant factor contributing to the high incidence of poor location signals and signals giving no location must be the short surface time for the turtles when they breathe. Increasing the surface time of the transmitter while the turtle surfaces for a breath should increase the duration of the signal and hence increase the probability of obtaining a good location. The high rate of good location signals from T41196 with the long tethered ST-3 during the two days in the shallow water feeding area following her return from her breeding migration was encouraging and suggests that further experimentation with this type of deployment is warranted. An alternative approach could be to reduce the length of the repetition cycle from 50 sec to a much lower value, given that a signal train of 5 cycles is required to obtain the higher precision location codes. To achieve the higher precision location codes with a 50 sec duty cycle, a transmitter surface time of ≥ 2.5 min would be required. If a 30 sec duty cycle was used, a transmitter surface time of ≥ 1.5 min could produce the same result. To enhance the quality and quantity of data obtained from satellite telemetry studies of marine turtles, further experimentation with the configuration of the software and with the method of attachment of the transmitter to the turtle is recommended.

Because of the low incidence of good location data during the migration phases, this telemetry study failed to identify the location of courtship areas visited by *C. caretta* resident in Moreton Bay. Based on past reports from fishermen, it was expected that the major courtship area for *C. caretta* was located near the northern end of Fraser Island (Limpus, 1985). Given the present results obtained for the female that bred locally (T85300) and the female that migrated to breed in New South Wales (T50812), there is a high probability that at least some courtship is occurring in the vicinity of Moreton Bay. Similarly this telemetry study provided very limited location data that could be used to interpret the distribution of the internesting habitat in relation to the nesting beaches. Although good quality location data (location class 1–3) was obtained only intermittently for each turtle, the available data indicate that when the turtles were in a feeding phase, they remained within Moreton Bay. These turtles had overlapping home ranges that were small with respect to the total size of Moreton Bay. There is no indication of temporary seasonal feeding migration of *C. caretta* from inside the Bay to the warmer waters outside the Bay during the winter months. Similarly, these *C. caretta* which feed in warm temperate waters that reach as low as 15°C in winter (Read et al., 1996), displayed no evidence of a north-south feeding migration between summer and winter, as characterized by juvenile and adult *C. caretta* populations of the cooler waters of the northwestern Atlantic Ocean (Musick and Limpus, 1997).

The breeding female *C. caretta* of the present study have demonstrated their remarkable capacity to migrate varying distances (30–1586 km) from their localized feeding areas in eastern Moreton Bay to their respective nesting beaches and subsequently return, each to its same localized feeding area within eastern Moreton Bay. As with female *C. caretta* resident in the highly structured feeding areas of the coral reefs of the Great Barrier Reef (Limpus, 1989; Limpus et al., 1992), the adult female *C. caretta* resident on the sea grass pastures of Moreton Bay display a comparable high fidelity to a localized feeding area as they do to their respective nesting beaches. In both warm temperate seagrass habitat and Great Barrier Reef coral reef sites (Limpus, 1994), there is now increasing evidence that the feeding area to which the adult female returns so faithfully is the same area where she completed her immature growth and commenced her adult life.

These *C. caretta* living in relatively circumscribed feeding areas in Moreton Bay displayed no evidence of aggregated migration between feeding and breeding sites. Rather, they dispersed to breed throughout all the regularly frequented nesting areas for the species in the south Pacific Ocean (Dodd, 1988). For those for which the migratory path is described, each followed a relatively direct route between feeding and nesting sites during both the pre-nesting and post-nesting legs of the migration.

The high fidelity of nesting female *C. caretta* to their respective nesting beaches is well documented (Dodd, 1988). This fidelity can be attributed to a turtle returning to the natal breeding area to which it was imprinted as a hatchling (Bowen and Karl, 1996; Lohmann et al., 1996). However, the present study has reinforced the hypothesis (Limpus et al., 1992) that the adult female is imprinted to multiple, usually widely separated locations that include nesting and feeding areas. Given the fidelity to both the feeding areas and the nesting beaches demonstrated by the present study, the adult female *C. caretta* must also be imprinted to her particular feeding area. This imprinting is presumed to occur during the extended residency period while the female is completing her maturation (Limpus, 1994, and present study). Appropriately designed studies using experimental displacements of adult female *C. caretta* with known feeding area and/or nesting beaches should have comparable potential for investigating their navigation systems.

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