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Sea turtles of the Cocos (Keeling) Islands, Indian Ocean

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Abstract. The Cocos (Keeling) Islands support high density resident green and hawksbill turtles and low to moderate density nesting green turtles. Dedicated studies were conducted on resident foraging turtles of the southern atoll between 1999 and 2012 and opportunistic observations were conducted on nesting turtles on both atolls between 1999 and 2009. In-water capture surveys resulted in a species composition of 51% green and 49% hawksbill turtles while counts during boat-based strip transect surveys resulted in a composition of 93% and 7% respectively. Captured green turtles in the foraging grounds had a bimodal distribution with modal size classes at 45–50 and 105–110 cm curved carapace length (ccl) (mean size = 64.7 cm, sd = 20.0, range = 33.5–115.6 cm, n = 984) while hawksbill turtles had a modal size class of 50–60 cm ccl (mean size= 57.6 cm, sd = 13, range = 24.8–86.7 cm, n = 950). New recruits to the foraging grounds were observed annually. Green turtle diet was dominated by seagrass and algae while hawksbill turtle diet was dominated by algae and sponge. Blood chemistry values of both species captured on the foraging grounds were within the published reference ranges. Opportunistic beach surveys conducted on five islands between 1999 and 2012 revealed low density nesting by green turtles (highest: 10.2 tracks km^{-1} $night^{-1}$) with no other species recorded. Nesting success was low because of dry sand and natural and anthropogenic debris on the beaches. The mean size of nesting turtles was 107.2 cm ccl (sd = 3.7, range = 96.6–115.9 cm, n = 16). Sand temperatures at nest depth (50 cm) ranged between 25.0 and 29.1°C between January and April.

Key words. foraging, in-water, nesting, size structure, diet, threats

INTRODUCTION

Knowledge of eastern Indian Ocean sea turtle regional management units is limited in comparison to other regions of the world (Wallace et al., 2010, 2011). Further to this, our understanding of the non-nesting phases of these turtles is even less known, with fundamental population data lacking for post-hatchling and neonate oceanic phases and neritic juvenile, sub-adult and adult phases (Chaloupka & Musick, 1997).

The Cocos (Keeling) Islands consists of two atolls containing 26 islands and is located 1000 km from Indonesia and 2100 km from the Australian mainland. There have been no previous sea turtle studies at Cocos (Keeling) Islands but there are several important recorded observations and anecdotes since its settlement in 1826 (Gibson-Hill, 1947a). Prior to settlement, the islands were uninhabited with no prior use of turtles. The limited number of records for sea turtles during the period from settlement to the present day is surprising given the importance of turtles as food and commodities during early exploration and the East Indies Spice trade (early 1600s to late 1700s) (Ricklefs, 1991) and the commercialisation of turtles by most countries in the region including Australia from the late 1800s (Halkyard, 2009). The initial records indicate that resident turtles were abundant: "*turtles are very numerous, and may be caught, without difficulty, in all seasons*" (Owen, 1831) and "*the basin is plentifully stocked with turtles*" (Chamisso, 1833). The Beagle visited the islands in 1836 and both Darwin and Fitzroy described the capture of turtles (Fitzroy et al., 1839; Barlow, 1939) and the vessel took aboard two turtles daily during an 11-day visit (Covington, 1995) and left with a stock of turtles (Fitzroy et al., 1839). Neither Darwin nor Fitzroy mentions the nesting turtles, although their visit in April may have been outside the main breeding season. It is surprising that turtles were omitted or only briefly mentioned within extensive description of other taxa including fish and corals when the Cocos (Keeling) Islands were visited by well-known naturalists (Forbes, 1879; Guppy, 1889a, 1889b, 1889c; Wood Jones, 1909). Throughout the last 190 years on Cocos (Keeling) Islands, turtles have been described mainly as subsistence or as ship victualling resources (Anonymous, 1830; Van Der Jagt, 1831; Wood Jones, 1909) rather than as commercial products for known markets during that period (Halkyard, 2009; Rieser, 2012). Nevertheless, the in-water turtle numbers appeared to have waxed and waned (Gibson-Hill, 1947b, 1950) while nesting numbers appeared to have remained at low levels (Wood Jones, 1909).

The aim of this work was to provide a contemporary description of the sea turtles and the associated pressures

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at Cocos (Keeling) Islands and in doing so provide detailed ecological and biological data that would assist in the management of sea turtles locally, regionally and internationally. The specific objectives included describing the foraging turtles in terms of species composition and size class structure, health status, relative abundance and distribution and describing the relative abundance and composition of the nesting turtles.

MATERIAL AND METHODS

Study site. The Cocos (Keeling) Islands are located in the Indian Ocean 2950 km north-west of Perth, 975 km west south west of Christmas Island and 1000 km south-west of Java (Director of National Parks, 2004). The islands sit atop two atolls 24 km apart; the northern atoll containing one large horseshoe shaped island (North Keeling Island or Pulu Keeling) with native vegetation, and the southern atoll containing 26 islands, comprising predominately coconut palms that protect a shallow lagoon. Two islands on the southern atoll group are inhabited, with West and Home Islands containing 100 and 450 inhabitants respectively. The Cocos (Keeling) Islands are an Australian Territory and therefore the management of the natural resources fall under the responsibility of the Australian Government (Director of National Parks, 2004). For this study, the Cocos (Keeling) Islands were visited for a period of between two to three weeks annually between 1999 and 2012, except for the years 2000 and 2011. Trips were conducted between December and February each year.

Foraging turtles: species composition, size class structure and relative abundance. The species composition, size class structure and relative abundance were investigated primarily by capturing turtles randomly on the southern atoll within two designated catch areas. The lagoon was divided into 21 sectors and capture effort was focused on two main catch areas; Area 1 (Sect 5, 6, 7) near West Island and Area 2 (Sect 12, 13) near South Island (Fig. 1). These areas were selected because of the higher perceived numbers of turtles in these sectors and because they provided a wide spatial coverage being located on opposite sides of the lagoon. Capture periods were approximately three hours with 105 and 52 capture days for Area 1 and Area 2 respectively. Additional captures were made in sectors 2, 4, 14 15, 16, 17, 18 and 19 (Fig. 1) to help understand distribution and species composition and investigate fidelity. Turtles were captured by hand with one person jumping onto the turtle from a moving boat (see Limpus, 1978). The boat was driven systematically through each catch area and turtles were selected randomly as they were sighted either at or beneath the surface of the water. Once captured, each turtle was either processed onboard the vessel or brought to shore. Two individually numbered titanium tags weighing 4.1 g each (Stockbrands, Perth) were applied to the axial scale of each front flipper (Limpus, 1992a, 1992b). All turtles were measured using standard procedures (Limpus & Reed, 1985; Bolten, 1999) and all curved measurements were taken using a flexible fibreglass tape to the nearest mm. For green turtles, the curved carapace length (ccl) was measured from

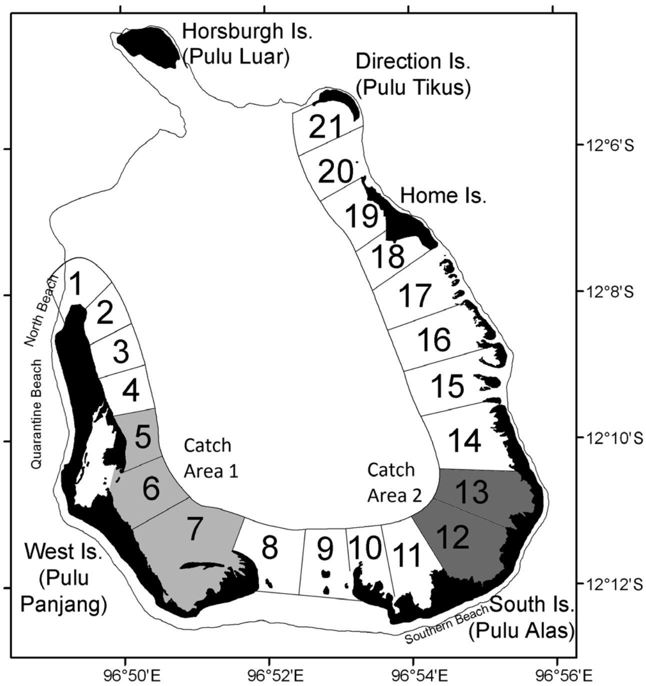

Fig. 1. Sectors and catch areas for the rodeo catch method used in the lagoon of the southern atoll. Light shaded area shows Area 1 and dark shaded area shows Area 2. The line around the atoll represents reef edge.

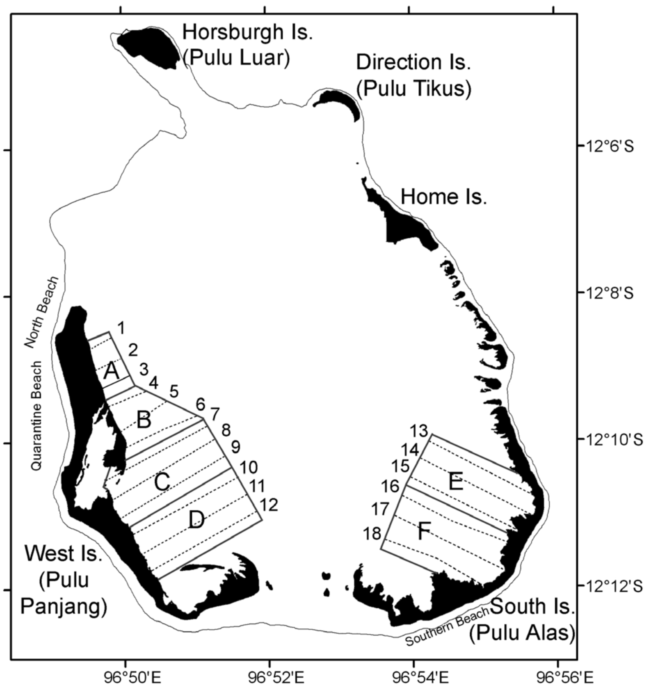

Fig. 2. Map of survey transects conducted during daylight hours. The line around the atoll represents reef edge.

the anterior of the nuchal scale, along the mid-line of the carapace to the posterior notch between the two post-central scales, while for hawksbill turtles it was measured to the end of the longest post-central scale. Curved carapace width (ccw) was measured at the widest part of the carapace. The tail length of large turtles was measured from the carapace to the tip of the tail. Turtles were weighed using a 40 kg digital scale (±0.01 kg) or a 150 kg (±0.5 kg) hanging clock-face scale.

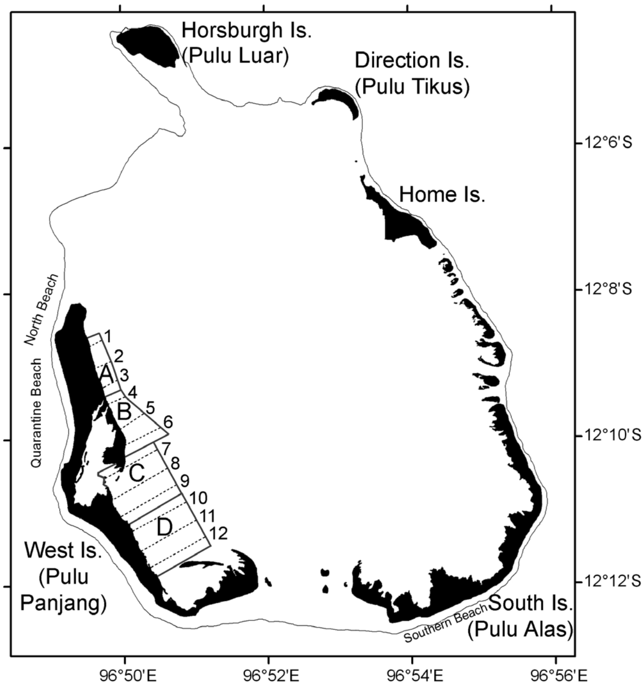

Fig. 3. Map of survey transects conducted during the night between 0800–1000 hours. The line around the atoll represents reef edge.

An alternative method of assessing species composition and size structure used boat-based strip transect surveys in 2004 and 2005 (Eberhardt, 1978; Hill, 2005; Skalski et al., 2005). This method also gave a measure of relative abundance and provided a day and night comparison to investigate behavioural differences which could not be obtained with the capture methodology. Turtles both at the surface and under the water were counted by species and size (adult or immature) in the lagoon adjacent to West Island and South Island during day and adjacent to West Island during both day and night (see Figs. 2, 3). Counting species only at the surface would require detailed knowledge to produce a correction factor to calculate the total number of turtles. The two periods of the day were used to investigate whether daytime captures were biasing the size or species composition. One observer stood on the bow of a 5 m vessel moving at 8 km per hour and counted turtles above and below the surface within separate independent strips (widths ranged from 10 to 20 m) on each side of the vessel as another crew member recorded the observations. A spotlight was used at night to see through the water. Spring high tides were used to conduct the surveys to ensure that all of the intertidal areas were accessible. A total of 18 transects were used; 12 in the vicinity of West Island and six in the vicinity of South Island (see Figs. 2, 3). Each transect was divided into segments to allow the deeper segments to be removed if sightability was lower during night or in higher seas states. Transects were orientated perpendicular to the shoreline and extended over intertidal and subtidal habitat to a depth at which turtles could be identified (3 m depth). For comparisons between day and night, only the inshore segments were used. Transects 13 to 18 (South Island) were not surveyed at night because of restricted vessel access. Only in Zones E and F in 2008 were strip widths reduced because of reduced visibility from cloud and some rain. The strip length, calculated by the Great Circle equation (Robinson et al., 1995), multiplied by the transect width was calculated to obtain the area surveyed and mean density of turtles for each strip. Line transects or distance methodology could not be used because the high density of turtles in some sectors meant limited time was available to observe and record details of multiple moving individuals.

Additional observations using manta tow (Moran & De'ath, 1992) and timed dives on SCUBA were used to gain insight into relative abundances in some deeper habitats (Kolinski et al., 2001).

Foraging turtles: sex ratio and maturity. Laparoscopy was performed on a sample of 34 green and 39 hawksbill turtles primarily to determine sex. Larger turtles were examined and maturity and breeding history were recorded. Laparoscopy for use on turtles has been modified from human laparoscopic procedures (Limpus & Reed, 1985) and is a powerful non-lethal tool for obtaining this type of demographic data (Chaloupka & Limpus, 2002).

Foraging turtles: recruitment. For green turtles, new recruits into the population were recorded as those with distinct external characters that indicate a long period in the open ocean. These include lack of fouling from invertebrate organisms and marine algae, white plastron and a distinct colour difference between the skin on the ventral and dorsal parts of the shoulder (Limpus et al., 2005; Arthur et al., 2008; Whiting et al., 2007). For hawksbill turtles, external distinguishing features include carapace and plastron free from fouling organisms and very sharp pointed marginal scutes. Because of the ambiguity and observer bias when interpreting external characteristics for both green and hawksbill turtles, we also used the percentage of captures within the first two size frequencies categories (5 cm bins) of each species (green <45 cm ccl and hawksbill <40 cm ccl) to monitor recruitment over time. Although not all new recruits are below these cut-off sizes, this method provides an alternate time series metric to track the presence and number of small turtles in the resident population.

Foraging turtles: diet. Diet samples were taken from 10 green turtles and five hawksbill turtles using gastric lavage (Forbes & Limpus, 1993; Forbes, 1999). This technique involved two plastic tubes of unequal diameter being inserted through the mouth, down the oesophagus and into the anterior part of the stomach. Samples were preserved in 3–5% formalin in seawater and sorted into taxa using a binocular microscope and the naked eye. Samples were dried to a constant weight at 70°C in an oven and the components weighed to obtain percentage composition. Percentages represent the mean of individual sample percentages and not percentages from all samples pooled together.

Foraging turtles: health assessment. External examinations of each turtle were conducted to record clinical health issues. Turtles were recorded as being in poor condition if they had low body weight in comparison to ccl and/or sunken plastron (Whiting et al., 2007; Flint et al., 2010). Marks consistent

Table 1. Catch composition by species and sector.

Area	Sector	Green		Hawksbill	
		Number	%	Number	%
Catch Area 1	5	15	75	5	25
	6	713	69	321	31
	7	39	70.9	16	29.1
Catch Area 2	12	177	27.6	463	72.3
	13	29	18.2	130	81.8
Other sectors	2	1	100	0	
	11	0		6	100
	14+15	0		6	100
	16+17	6	55	5	45
	18+19	13	86.7	2	13.3
Total		993	51	954	49

with boat collisions such as propeller or skeg marks were recorded as well as other injuries such as deformities and signs of fibropapilloma. Blood was drawn from the dorsal cervical sinus, centrifuged, plasma pipetted off and plasma frozen until analysis with an auto analyser (Cobas Mira Analyser) with Ion-Selective Electrodes (ISE) (all procedures followed previous studies; see Whiting et al., 2007, 2014).

Nesting turtles: distribution and abundance. Sea turtle nesting surveys were conducted during opportunistic visits to sandy beaches on Pulu Keeling (northern atoll) and several islands on the southern atoll in the months of November, January, February, and March between 1999 and 2009 (Figs. 1, 4). Two types of surveys were conducted, the first comprising daytime counts of sea turtle tracks and emerged clutches and the second comprising night surveys of nesting turtles on Pulu Keeling. Daytime surveys recorded the number of fresh tracks (last night) or old tracks (all others), emerged clutches and dead turtles by species. Where surveys were conducted on consecutive days, old tracks were recorded only on the first day and then fresh tracks on subsequent days. Old body pits (those not associated with tracks) and pieces of turtle egg shell on the surface of the sand indicated turtle nesting in the past few months. Turtle tracks were identified to species using standard techniques (Schroeder & Murphy, 1999). During nighttime surveys, all turtles encountered were tagged with titanium turtle tags in each of their front flippers and ccl was measured using the methods described above. Nesting attempts were observed from a distance and recorded as successful (eggs laid and seen by observer) or unsuccessful (nest abandoned) (Schroeder & Murphy, 1999). Habitat suitable for sea turtle nesting (accessible sandy beaches) was identified for Cocos (Keeling) Island and reports of nesting activity by the community were also recorded.

Sand temperatures. Sand temperature loggers (I-button, USA) (accuracy ±1.0°C) were deployed in 2005 at Pulu Keeling and South Island to a depth of 50 cm below the surface, approximating the depth of green turtle nests. One logger at Pulu Keeling was deployed in a shaded area while at South Island one logger was deployed in shade and the other exposed to sun. The location of the loggers were: North Beach, Pulu Keeling 10°31.286’S, 105°40.509’E; South Island shaded and South Island exposed in sun 12°12.04’S, 096°54.02’E.

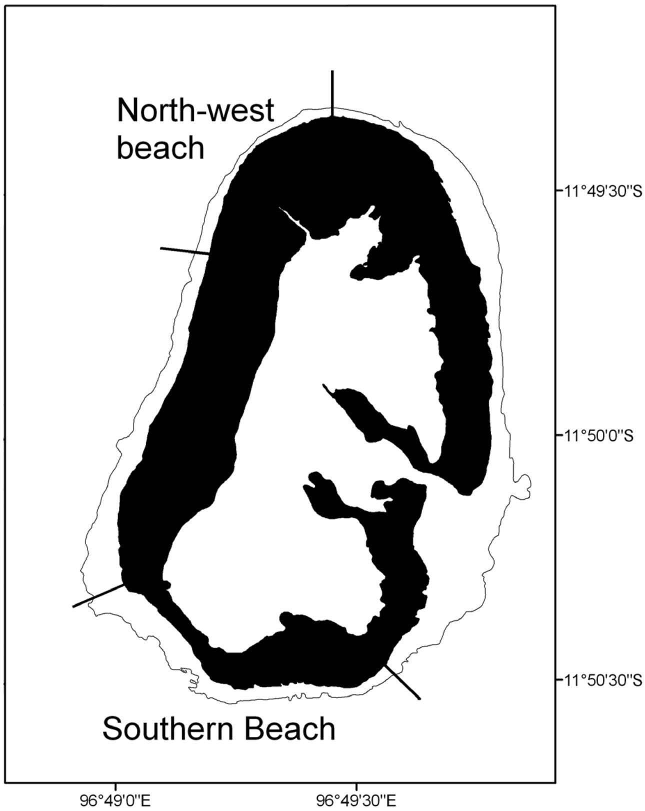

Fig. 4. Map of Pulu Keeling showing the main nesting area to the north and the lower density nesting beach to the south. The two sections mark out the two areas of accessible nesting beach on the island. The line around the atoll represents reef edge.

RESULTS

Foraging: species composition, size class structure and relative abundance. On the southern atoll, turtles were found in most sectors of the lagoon and also on or associated with

Table 2. Day time turtle densities and estimates of numbers in each strip transect survey zone.

Area	Species	Zone	Area (km^2)	Segment	2004		2005	
					Mean density /km^2	Pop. est for area ± SE	Mean density /km^2	Pop. est for area ± SE
West Island	Green	A	0.65	1 & 2	n/a	n/a	28	18 ± 15
		B	1.93	1 & 2	138.3	267 ± 42	90	173 ± 83
		C	4.52	1, 2, 3,4	115.4	521 ± 141	269	1215 ± 754
		D	3.67	1, 2, 3,4	7.5	28 ± 24	22	80 ± 37
	Hawksbill	A	0.65	1 & 2	n/a	n/a	0	0
		B	1.93	1 & 2	0	0	0	0
		C	4.52	1, 2, 3,4	10.5	47 ± 25	0	0
		D	3.67	1, 2, 3,4	0	0	0	0
South Island	Green	E	2.50	1 & 2	157	393 ± 244	58	145 ± 85
		F	2.32	1 & 2	7.2	17 ± 11.5	64	148 ± 42
	Hawksbill	E	2.50	1 & 2	11.7	29.3 ± 29.3	23	57 ± 30
		F	2.32	1 & 2	7.2	17 ± 10.6	42	97 ± 44

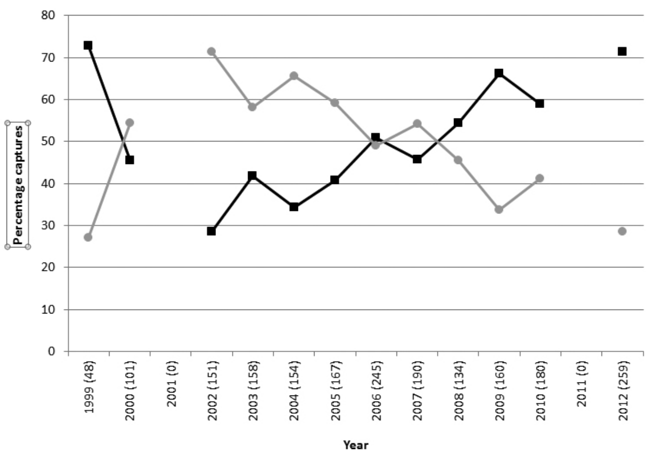

Fig. 5. Species composition over time. The number in brackets is the captured turtles for that period.

the fringing and subtidal reefs on the outer edge of the atoll. Total captures including recaptures between years was 1947 turtles, with 1109 of these turtles captured in Area 1 (West Island) (10.6 turtles/day), 799 captured in Area 2 (South Island) (15.4 turtles/day) and 39 captured in various other sectors in the lagoon (Table 1). Up to 45 turtles could be captured and processed in a 3-hour catch session. Catch numbers ranged from 35 greens and 13 hawksbills in 1999 to 185 greens and 74 hawksbills in 2012. Although the number of capture days in Area 1 was double that of Area 2, the relatively fewer numbers of captured turtles was a result of longer processing time for larger turtles. The species composition of green and hawksbill turtles was 51% and 49% respectively, but the composition was significantly different between areas with the composition of green and hawksbill turtles for Area 1 being 70.5% and 29.5% respectively and for Area 2 being 27% and 73% respectively. Using the combined catch from both catch areas each year, the catch composition moved towards a strong green turtle bias over time (Fig. 5). The size structure was dominated by juvenile turtles although this structure varied between catch areas (see Fig. 5). For green turtles, Area 1 contained both adult and juvenile sized turtles while Area 2 contained mostly immature sized turtles (see Fig. 6). For hawksbill turtles, both areas contained both adult and juvenile sized turtles although Area 1 contained a higher proportion of adults sized turtles (see Fig. 6).

The strip transect survey showed a different pattern of distribution than the capture data. Green turtles were dominant in all zones regardless of the adjacent island (Table 2; Fig. 7). Hawksbill turtles, in 2004 and 2005 made up between 0 and 5.5% respectively in the West Island Zones and 11 and 35% respectively in the South Island Zones. Green turtles comprised the reciprocal of these percentages. No hawksbill turtles were observed at night in either survey year. For green turtles, the West Island zones supported more adult sized turtles (79 and 86%) compared to the South Island zones (38–43%) (Fig. 8). No adult sized hawksbill turtles were sighted. Density estimates of green turtles were between 5 and 442 turtles km^{-1}. Density estimates for hawksbill turtles were between 0 and 10 turtles km^{-1}.

Additional daytime observations using SCUBA (2000 and 2003) and manta tows (2003) showed that the northern and western coast of West Island (Sector 1 extending around to offshore from North Beach and Quarantine Beach) and the sandy areas between West Island and Horsburgh Island supported green turtles. Only green turtles were sighted with up to 14 individuals sighted in a 60-minute dive. The behaviour commonly observed was resting. Green turtles were commonly seen from shore feeding on seagrass on the fringing reef on the western side of West Island.

From captured turtles, the size distribution was bimodal with modes of 45–50 cm ccl and 105–110 cm ccl (mean 64.7 cm ccl, sd = 20.0, range = 33.5–115.6, n = 984) and modal size hawksbill turtles was 50–60 cm ccl (mean = 57.6 cm ccl, sd = 13.0, range = 24.8–86.7, n = 952). The mean size of green turtles was larger in Area 1 than Area 2 (T = 11.6, df

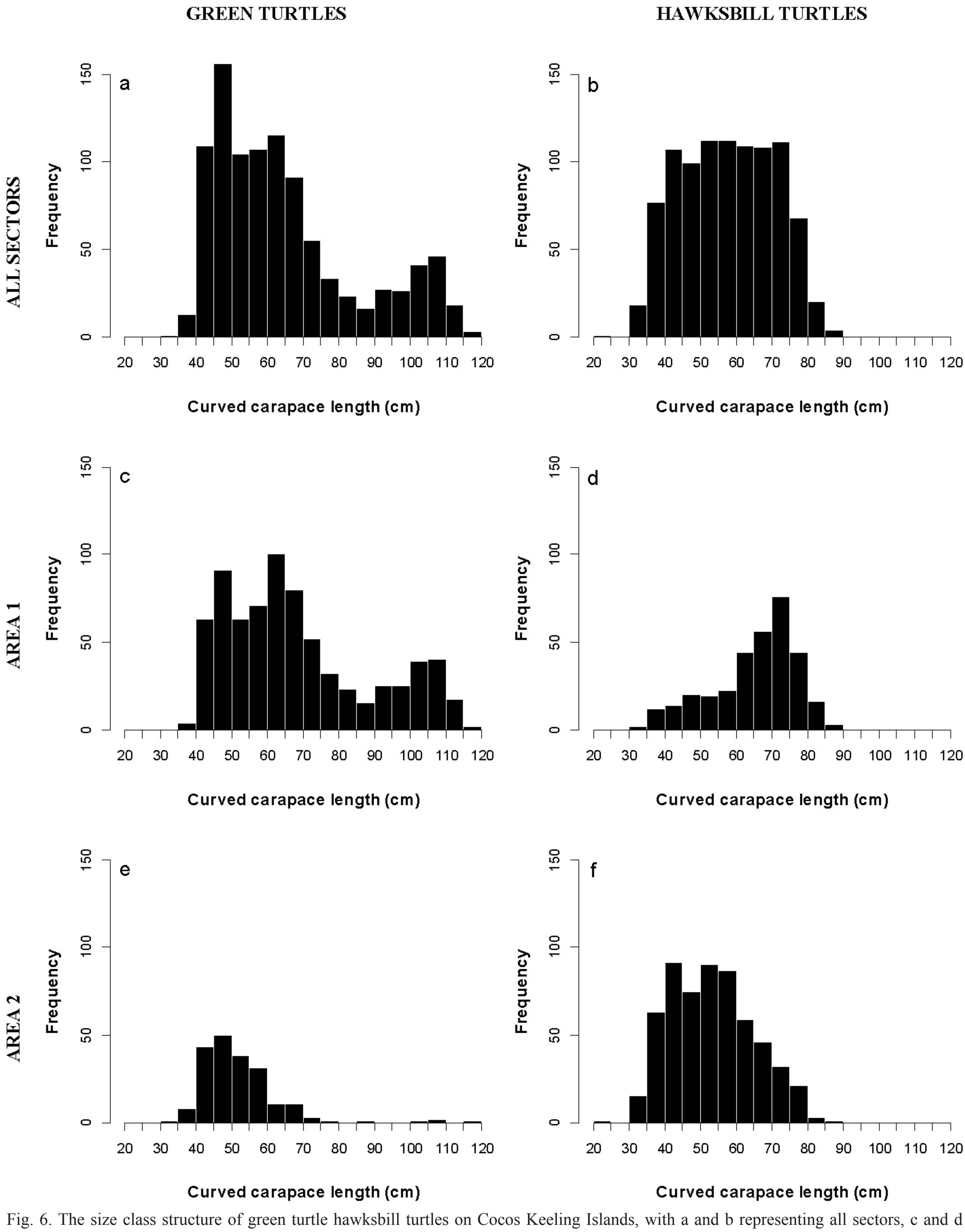

Fig. 6. The size class structure of green turtle hawksbill turtles on Cocos Keeling Islands, with a and b representing all sectors, c and d representing Area 1, and e and f representing Area 2.

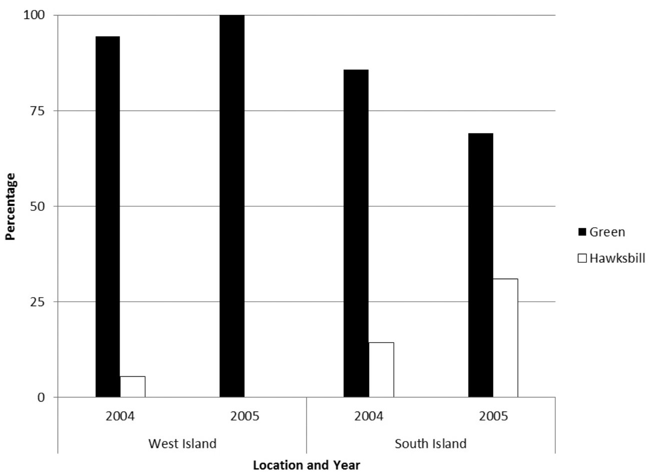

Fig. 7. Percentage of green and hawksbill turtles sighted using daytime strip transect surveys in each location by year (all segments).

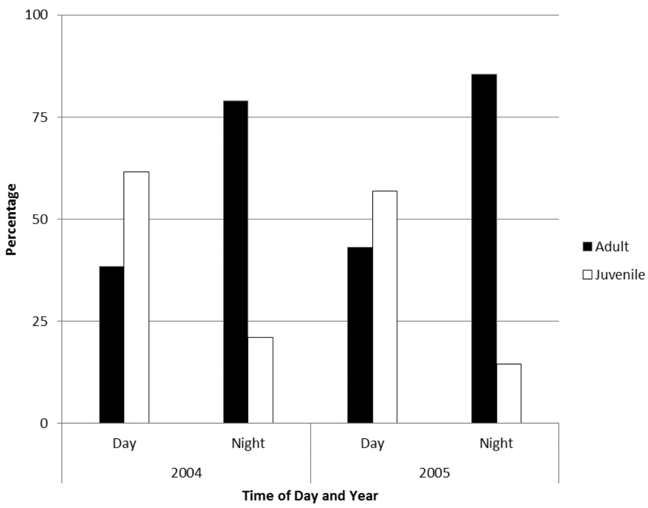

Fig. 8. Percentage of adult-sized and juvenile/immature green turtles sighted during day and night strip transect surveys in each year in the West Island survey area (inshore segments).

= 906) with means of 68.6 cm ccl (sd = 20.4, n = 757) and 51.4 cm ccl (sd = 9.8, n = 201) respectively. Green turtles in Area 1 were tri modal with modes at 45–50 cm ccl, 60–65 cm ccl, and 105–110 cm ccl, while Area 2 had a mode of 40–45 cm ccl). The proportion of green turtles below 85 cm ccl in Area 1 and Area 2 was 77.8% and 99.0% respectively.

Hawksbill turtles were also larger in Area 1 than Area 2 (T = 15.0, df = 906) with means of 65.0 cm ccl (sd = 11.9, n = 328) and 52.9 cm ccl (sd = 11.5, n = 580) respectively. Hawksbill turtles in Area 1 had a mode of 70–75 cm ccl and 40–45 cm ccl. The proportion of hawksbill turtles below 80 cm ccl in Areas 1 and 2 was 93.4% and 98.4% respectively.

Foraging: sex ratio and maturity. Laparoscopy was performed successfully on 34 green and 39 hawksbill turtles resulting in a male to female sex ratio of 1:1.1 and 1:13.0 respectively. Too few larger turtles were sampled to enable size at maturity to be determined using this method. Adult male green turtles were defined as those with tail lengths over 30 cm from the edge of the carapace to the tip. The size of male green turtles ranged from 85.7–110.6 cm ccl (mean = 95.7, sd = 5.0, n = 49).

Foraging: recruitment. Based on external examination, the mean size of green turtle new recruits was 42.9 cm ccl (sd = 4.2, range = 35.5–59.5, n= 35). Hawksbill turtles were more difficult to determine based on their appearance. The mean size for hawksbill turtle new recruits was 42.1 cm ccl (sd = 9.9, range = 24.8–56.7, n = 10). Because of the subjectiveness of external characteristics, especially for hawksbills, we investigated the proportion of captured turtles less than 45 cm for green turtles and less than 40 cm for hawksbill turtles. The recruitment rate based on this method has remained between around 5 and 20% for both species annually since 2001 when sample sizes increased (Fig. 9).

Foraging: site fidelity and movements. Most recaptured turtles were re-caught in the same catch location (same sector or adjacent sector) to where they were initially caught. From 52 recaptures of green turtles only one (0.2%) had changed catch areas from Area 2 (South Island) to Area 1 (West Island) while from 254 recaptures of hawksbill turtles, four (1.5%) had changed catch areas from Area 2 (South Island) to Area 1 (West Island). Some turtles have shown long term fidelity to the same catch area during multiple recaptures over many years of the study. One hawksbill turtle was captured on six occasions over eight years within sector 12.

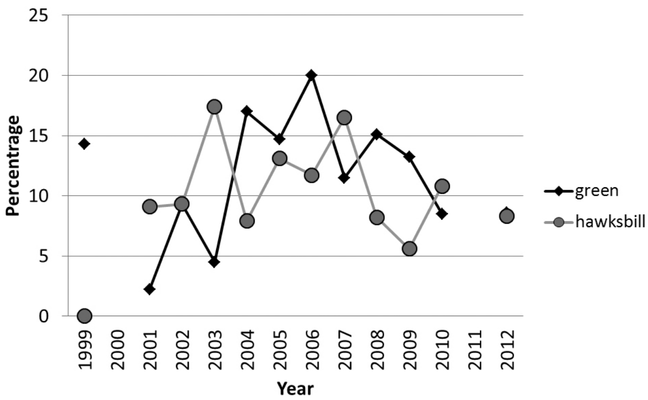

Fig. 9. The percentage of captured individuals less than 45 cm ccl for green turtles and less than 40 cm ccl for hawksbill turtles used as a surrogate for recruitment.

An immature green turtle (CA4253) (48.4 cm ccl) was originally tagged on the southern atoll in March 1999 and found stranded dead as an immature turtle (79.0 cm ccl) at Barrow Island, Western Australia in October 2011. An investigation of the stranded animal indicated that it had been recently feeding, which indicated that it had settled in Western Australia, a juvenile migration away from the Cocos (Keeling) Islands. Two resident hawksbill turtles made juvenile migrations in a westward direction away from Cocos (Keeling) Islands with one tracked using satellites travelling more than 1000 km before the transmission stopped (see Whiting & Koch, 2006), while the other was identified by flipper tags in a fishing net in Tanzania (Whiting et al., 2010).

Foraging: diet. Green turtle diet consisted mainly of the seagrass *Thalassia hemprichii* while the hawksbill turtles had a mixture of items dominated by algae and with some

Table 3. Day and night time comparison of green numbers counted during the strip transect surveys (segments 1 & 2 only).

	Zone	Area (km²)	Segment	2004		2005	
				Mean density /km²	Pop. est for area ± SE	Mean density /km²	Pop. est for area ± SE
Day	A	0.32	1	n/a	n/a	n/a	
	B	0.93	1	99.9	90 ± 46	28.1	26 ± 26
	C	2.63	1 & 2	97	226 ± 95	53.0	139 ± 107
	D	1.69	1 & 2	7.7	18 ± 18	7.2	12 ± 12
Night	A	0.32	1	240.4	118 ± 59	244	79 ± 41
	B	0.93	1	234.1	213 ± 122	284	264 ± 139
	C	2.63	1 & 2	428	998 ± 575	442	1043 ± 637
	D	1.69	1 & 2	5.4	12 ± 12	27	45 ± 28

Table 4. Mean percentage of food items found in lavage samples from individual turtles

	Taxa	Green	Subtotal	Hawksbill	Sub Total
Seagrass	*Thalassia hemprichii*	68.9	68.9	14.5	14.5
Algae	*Acanthophora spicifera*	8.4	29.4	–	69.3
	Euchema sp.	7.1		50.6	
	Unidentified algae	13.9		19.3	
Animal	Sponge	6.5	6.5	21.9	21.9
Total		105.8	105.8	106.3	106.3

*The Total will not sum to 100% because each taxa is taken as the mean of the individual samples and not a percentage of the pooled samples.

sponge (Table 4). One green turtle had 100% *T. hemprichii* while another green turtle had 100% algae.

Foraging: health assessment. In general the turtles at Cocos (Keeling) Islands appeared in healthy condition. For green turtles, sick, injured or deformed state represented less than 0.7% of the catch. Only one green turtle was found with fibropapilloma (0.1%) and no cases for hawksbill turtles. Fresh or healed injuries from boat strike represented 1.2% of the total sample. For hawksbill turtles, sick, deformed and injured turtles represented 1.0, 1.3, and 0.7% of the catch respectively. Fresh or healed boat strike injuries represented up to 8% in some years. The blood chemistry results (Table 5) were within published ranges. The carapace of one adult green turtle had injuries consistent with being harvested with the remains left high above the tide line. Other stranded turtles which occurred outside of the survey period were not recorded systematically.

Nesting: habitat, species composition and seasonality. Suitable nesting habitat was found on Pulu Keeling, Horsburgh Island, West Island, South Island and a minor section of Home Island (Table 6). All nesting sea turtles tracks and nesting turtles encountered were green turtles. Nesting seasonality could not be determined because surveys were limited to November, January, February and March. However, green turtles nested in all surveyed months. Mating pairs of green turtles were recorded in October, December, January and March through direct observation or confirmed reports.

Nesting: density, nesting success and size structure. In general, the southern atoll supported irregular low density nesting with higher density nesting occurring on Pulu Keeling. The north-western beach of Pulu Keeling supported 89.9% (sd = 10.0, range = 80–100) of green turtle nesting for the island (based on two circumnavigations) with the highest density of tracks recorded for both atolls (10.4 turtles km^{-1} $night^{-1}$) (Table 7). Clutches were laid between the high tide line to at least 10 m into the *Pisonia grandis* dominated forest which shaded most of the beach (other dominant plants include *Cocos nucifera* and *Argusia argentea*). The southern beach of Pulu Keeling had poor access from the sea and was comprised of coral rubble with exposed nesting locations and minimal shade from *Argusia argentea*. Emerged clutches were observed on the north-western beach of Pulu Keeling in late January. South Island nesting habitat was approximately 2 km along the southern shore. Body pits but no turtle tracks were observed by the authors on South Island during the survey period although tracks were reported to the authors by the public in November 2000. Horsburgh Island has several sandy beaches that could support sea turtle nesting, and although no turtle tracks were recorded on two visits in February 1999 and November 2000, nesting by green turtles was recorded in January 2014 (Ismail

Table 5. Blood chemistry reference values for green and hawksbill turtles of Cocos (Keeling) Islands. Variable is followed by the abbreviation used in subsequent tables and their units. The total reference range is given. Usually the middle 95 percentile (2.5–97.5) is reported, but in this case only a small number of samples were taken so the full range is shown. [5]also abbreviated to CPK. [6]According to the recommendations of the International Federation of Clinical Chemistry.

Variable	Measurement Method	Greens Turtles			Hawksbill Turtles		
		N	Mean ± sd	Range	N	Mean ± sd	Range
Curved Carapace Length (CCL) (cm)	Fibreglass tape	10	59.56 ± 5.57	50.3–67.5	6	52.7 ± 4.38	38.5–67.5
Sodium (Na) (mmol/L)	Direct Measurement ISE	9	149.44 ± 15.92	128–176	6	155.17 ± 17.43	127–172
Potassium (K) (mmol/L)	Direct Measurement ISE	9	5.52 ± 0.97	4.3–7.2	6	4.88 ± 1.47	3.2–7.0
Chloride (Cl) (mmol/L)	Direct Measurement ISE	9	111.56 ± 12.92	92–135	6	120.83 ± 13.99	99–136
Calcium (Ca) (mmol/L)	Arsenazo III	8	2.37 ± 0.42	1.69–3.13	6	22.25 ± 50.34	1.06–125
Phosphorus (P) (mmol/L)	Phosphomolybdate, UV	9	2.50 ± 0.45	1.84–3.11	6	2.17 ± 0.64	1.14–2.9
Total serum iron (Fe) (umol/L)	Ferrozine, no deproteinisation	9	8.44 ± 3.00	3–13	6	7.5 ± 2.59	1.0–11.0
Alanine aminotransferase ALT (U/L)	Kinetic UV	9	13.44 ± 9.43	2–30	6	16.33 ± 10.09	4–28
Aspartate aminotransferase(AST) (U/L)	Kinetic UV	9	254.78 ± 61.89	162–359	6	198.67 ± 123.06	102–437
Alkaline phosphatase (ALP) (U/L)	PNPP (AMP buffer)[6]	9	52.78 ± 21.98	22–88	6	59.17 ± 22.25	29–85
Total protein (g/L)	Biuret, reagent blank	10	46.10 ± 5.38	38–55	5	38.4 ± 12.36	29–58
Albumin (Alb) (g/L)	Bromocresol green	10	17.70 ± 3.09	13–22	5	13.6 ± 4.72	11–22
Globulin (Glob) (g/L)	Calculation	10	28.4 ± 4.33	18–33	5	24.8 ± 8.35	17–36
Albumin/globulin (alb/glob) (ratio)	Calculation	10	0.62 ± 0.53	0.5–0.9	5	0.56 ± 0.11	0.4–0.7
Urea (mmol/L)	Urease UV	9	3.66 ± 3.26	1.4–12.0	6	12.53 ± 7.08	3.1–21.7
Bilirubin (Bili) (umol/L)	Modified Malloye & Evelyn	9	5.00 ± 3.20	1–10	6	2.5 ± 1.22	1–4
Creatinine (Creat.)	Alkaline picrate - kinetic	9	25.89 ± 9.42	19–47	6	25.17 ± 36.93	2–99
Cholesterol (mmol/L) (Chol)	CHOD-PAP	9	2.86 ± 1.01	1.08–4.11	6	2.55 ± 1.81	0.94–6.08
Uric Acid (µmol/L)(Uric)	Uricase, colorimetric	9	153.33 ± 49.21	102–243	6	90.89 ± 56.53	1.34–153.00
Glucose (mmol/L) (Gluc)	GPO-PAP	9	6.57 ± 1.23	5.0–8.5	6	6.3 ± 1.40	4.6–8.6
Tryglcerides		9	1.59 ± 0.49	0.6–2.4	6	1.62 ± 1.78	0.40–5.20

Table 6. A summary of beaches and nesting activity at Cocos (Keeling) Islands from opportunistic surveys between 1999 and 2009.

Island	Beach	Latitude /Longitude (Start)	Latitude /Longitude (End)	Beach length (km)	Months surveyed	Month of fresh tracks	Body pits (no tracks)	Highest no. total tracks (Month)	Months of emerged clutches	Total days surveyed
West Island	Quarantine Beach	12°08.36'S 96°49.22'E	12°08.48S 96°49.12'E	1.2	Feb	Feb	0	0		1
	North Beach	12°06.61'S 96°49.00'E	12°09.71'S 96°49.26'E	0.8	Feb	Feb	0	0		1
South Island	SE Beach	12°08.36'S 96°49.20'E	12°08.48'S 96°49.12'E	2.8	Nov, Jan, Mar	0	Nov, Jan, Mar	6 *Nov		7
Home Island	North-east	12°06.47'S 96°53.34'E	12°06.93'S 96°53.85'E	0.9	Feb	0	0	0		1
	South-east	12°07.21'S 96°55.13'E	12°07.35'S 96°53.78'E	0.2	Feb	0	0	0		1
Horsburgh Island	All Beaches	12°12.03'S 96°49.22'E	circumnavigation	4.0	Nov, Feb,	0	0			2
Pulu Keeling	NW Beach	12°48.58'S 96°49.22'E	11°49.38'S 96°49.61'E	1.3	Nov, Jan, Mar	0	Nov, Jan, Mar	35 (Jan)	Jan	16
	South Beach			0.7	Nov, Jan	0	Nov	2 (Jan)		4

Table 7. Tracks, clutches and emerged clutch counts for north-west beach of Pulu Keeling from nightly surveys.

Dates	Tracks/night (sd, range, n)	Tracks/night/km (sd, range, n)	Percentage of clutches laid/track (%) (sd, range, n)	Emerged clutches
22–23 Nov 2000	2.5 (0.7, 2–3, 2)	2.8 (2.2, 2.2–3.3, 2)	42 (11.8, 33–50, 2)	0
18 Jan 2003 *	5	5.6	0	0
17–18 Jan 2005	3 (0, 3–3, 2)	3.3 (0, 3.3–3.3, 2)	0	0
16–18 Jan 2006	9.3 (4.0, 5–13, 3)	10.2 (4.5, 5.6–14.4, 3)	7.9 (0.4, 7.7–8.3, 3)	3
20–21 Jan 2009	3 (1.4, 2–4, 2)	3.3 (1.2, 2.2–4.4, 2)	0	1

Macrae, pers. comm.). West Island has several areas along the north-western shoreline that supported irregularly low density green turtle. Home Island has had anecdotal reports of nesting over the past decade estimated to account for one to two nesting attempts per year. Other islands on the southern atoll do not appear to support nesting because of lack of suitable habitat.

Nesting success at Pulu Keeling was low: 42% in November 2000, zero in January 2003, January 2005 and January 2009, and approximately 8% in January 2006. Some individuals dug as many as seven body pits during one night without completing a successful nest. Nesting was disturbed by the dense shoreline vegetation and roots and large amount of natural debris comprising coconuts and palms fronds.

The mean ccl of green turtles nesting at Pulu Keeling was 107.2 cm (sd = 3.7, range = 96.6–111.8, n = 16) (Fig. 10).

Nesting: adult and hatchling mortality. Two dead adult green turtles were recorded on Pulu Keeling during the survey period in 2003; one appeared to have flipped on to its back at the vegetation line while returning from a nesting attempt while the other adult-sized female turtle was washed ashore. Observations of two clutches of hatchlings that emerged during late afternoon revealed hatchlings were predated upon by night herons (*Nycticorax caledonicus*), ghost crabs (*Ocypode ceratophthalma*) and hermit crabs (*Coenobita perlata*).

Nesting: sand temperatures. Sand temperatures at 50 cm depth ranged between 25.0 and 29.1°C between January and April 2005. The shaded location on Pulu Keeling was cooler than both the shaded and exposed locations on South Island (Fig. 11). The shaded location at South Island remained about 0.5°C cooler than the exposed location.

Links between green turtle nesting and foraging areas. There is clear evidence linking the foraging resident population of green turtles of the Southern Atoll with the nesting population at Pulu Keeling. This has been confirmed through flipper tag recoveries from turtles tagged either while nesting at Pulu Keeling and subsequently captured on the southern atoll or vice versa. Two turtles tagged while at Pulu Keeling in 2006 were recaptured foraging around West Island; one in 2009 and one in both 2009 and 2012. Also, a turtle initially tagged while foraging was later recovered at Pulu Keeling. In addition, a green turtle (CA9710) tagged on the southern atoll in the foraging grounds in January 2006 was found nesting at North West Cape, Western Australia in March 2007.

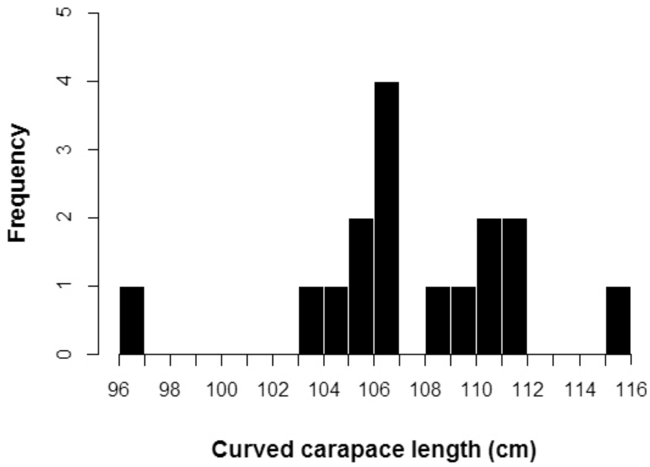

Fig. 10. The size of nesting green turtles at Pulu Keeling.

DISCUSSION

Foraging: species composition and size class structure. Green and hawksbill turtles were the only species captured or observed on the southern atoll during the survey periods. Olive Ridley turtles (*Lepidochelys olivacea*) are known in the region from being stranded in discarded nets and washed ashore at Cocos (Keeling) Islands (IM direct observations). No loggerhead turtles were sighted or captured during this study. Although uncommon, one loggerhead turtle was photographed in the lagoon on the southern atoll by a local photographer (Karen Wilshaw, www.underseareflections.com). Another loggerhead turtle depicted in Bunce (1988) is referred to in the text as a green turtle and is expected to be a wrongly inserted file photograph. There are no reports of leatherback turtles around Cocos (Keeling) Islands, but leatherback turtles tracked from the Andaman Islands indicate that at least some inhabit the adjacent waters (Namboothri et al., 2012).

The species composition of green and hawksbill turtles was almost one to one using direct capture while the composition was heavily biased towards green turtles using strip transect

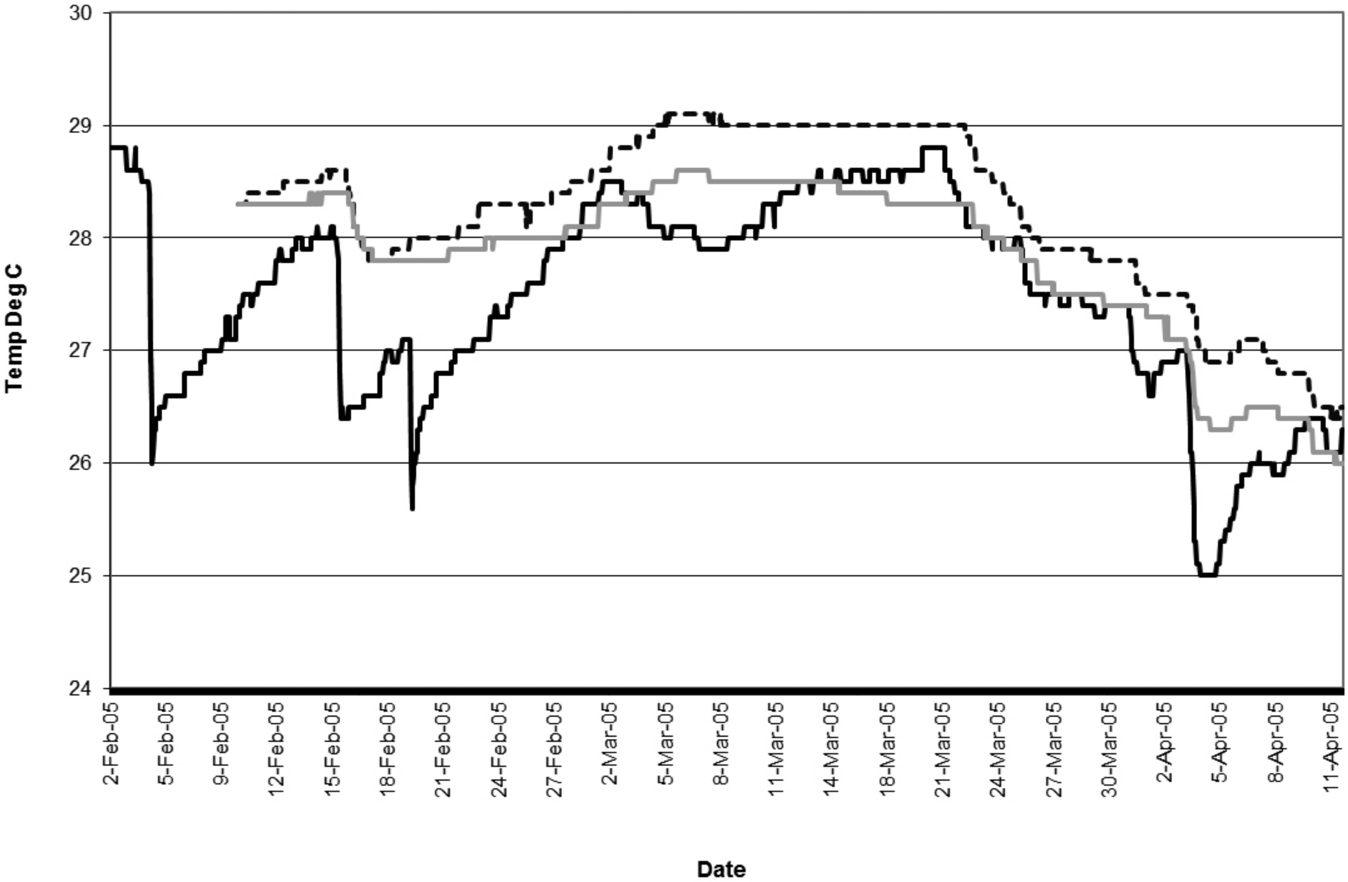

Fig. 11. Sand temperatures at South Island and Pulu Keeling between January and April 2005. North Keeling – shaded (solid black line), South Island – exposed (dashed black line), South island – shaded (grey line).

surveys. It is likely that both methods have inherent but different biases. Sightability biases would affect both methods while catchability bias is also present for the capture method. Capture bias is reduced by catching the next turtle sighted while sightability biases can alter with cloud cover and sea state. Biases such as unknown differences in "detection" and "flight distances" by each species could influence capture and strip transect results. Green turtles were captured across all sizes and many were of mature size. Adult males were identified from their tail length, and adult females were verified from laparoscopy and breeding records. Hawksbill turtles were captured across all size classes but no adult males were identified with extended tails.

High capture rates in Areas 1 and 2 at Cocos (Keeling) Islands indicate high density foraging habitat compared to other study sites (Collazo et al., 1992; Limpus, 1992a; Limpus et al., 1994, 2005; Shaver, 1994; Balazs, 2000; Diez, 2000; León, 2000; Phillips, 2000; Provancha, 2000; Bjorndal & Bolten, 2010; Eguchi et al., 2010). Alternative estimates of densities and numbers using mark recapture results will be provided in future publications. The high densities of green turtles can provide an understanding of the biology and ecology of local foraging aggregations at Cocos (Keeling) Islands important for local managers, but the site also provides a central location in the eastern Indian ocean to study a mixed stock foraging aggregation (Dethmers et al., 2010) to help understand the functioning of multiple breeding stocks in the region (Chagos, Indonesia, Malaysia, and mainland Australia).

Foraging: sex ratio. The sex ratio for green turtles of males to females is within the range of most studies (Bolten et al., 1992; Wibbels et al., 1993; Limpus et al., 1994, 2005; Chaloupka & Limpus, 2001), but with a more even ratio than others (1:4 in Pilcher, 2010). The hawksbill turtles, with a male to female ratio of 1:13.0 (n = 39), is heavily female-biased and is a much higher ratio than other studies (Great Barrier Reef 1:2.57 in Limpus, 1992a; and Puerto Rico 1:0.8 in Diez & van Dam, 2003). This highly female-biased ratio is of concern for the hawksbill population in the region as it raises the question of whether this could be influenced by climate change and how it may impact the long term viability of the breeding units given that a ratio this skewed has not been reported before. A bigger sample size is needed before any conclusive conclusions can be drawn. Genetic studies for hawksbill turtles have not yet been finalised for the Cocos (Keeling) Islands foraging population but when they are, management discussion should occur between Parks Australia and the managers of the linked rookeries to investigate sex ratios of hatchlings.

Foraging: recruitment. The surrogate estimate of recruitment using the percentage of captured individuals below 45 cm ccl for green turtles and 40 cm ccl for hawksbill turtles indicates continued recruitment from the pelagic life history stage, providing evidence of production from the linked rookeries. For hawksbill turtles, these rookeries are unknown. For green turtles, genetic evidence links Cocos foraging grounds to the rookeries of North West Shelf, Scott Reef and Cocos (Keeling), with distant links to The Great Barrier Reef and

Malaysia (Dethmers et al., 2010; Jensen, 2010), and satellite and flipper tag recovery evidence links to the rookeries of Pulu Keeling and North West Cape (North West Shelf management unit of Western Australia).

Foraging: fidelity and movements. Individuals of both hawksbill and green turtles showed strong site fidelity to catch sectors and catch areas between years and over longer periods. However, the size class differences between the West Island and South Island catch areas indicates that both species at South Island shift to other locations as they get larger but only a small proportion of shifts were detected to the West Island catch area. Shifts to other areas, maybe to deeper water adjacent to South Island, are also likely. Based on the different size class structure observed between night and day strip transect surveys at West Island, behavioural changes in larger turtles at both catch areas may also account for missing larger turtles.

Foraging: diet. The diet of green turtles was dominated by seagrass followed by algae, similar to other dietary studies across the globe (Limpus et al., 1994; Brand-Gardner et al., 1999; McDermid et al., 2007; Arthur & Balazs, 2008). The hawksbill diet was slightly different from other studies (Meylan, 1988; Leon & Bjorndal, 2002; Rincon-Diaz et al., 2011) as it contained more algae than sponge and even a large proportion of seagrass (20%). As the sample size was relatively low for both turtle species, limited interpretation will be made here, with an emphasis on more comprehensive dietary and habitat studies required for the future. Green turtles were found in most sectors in the inner lagoon on the southern atoll. They were also sighted on the exposed fringing reef and subtidal areas on the southern atoll through opportunistic observations, dedicated dives and manta tows, and reports from the public.

Foraging: health assessment. The turtles at Cocos (Keeling) Islands are in good health. Only one case of fibropapilloma for a green turtle was observed. Evidence of boat strike was observed on live turtles in most years and in some years reached 8% of the catch. The blood chemistry results were normal in comparison to other studies in this region (Hamann et al., 2006; Whiting et al., 2007, 2014; Flint et al., 2010).

Nesting: distribution and abundance. The Cocos (Keeling) Islands supported low density green turtle nesting with no evidence of nesting by other sea turtle species on either atoll either from this study or the literature. At the turn of the 20th century it was indicated that both green and hawksbill turtles commonly nested on Pulu Keeling but it is not known if nesting by hawksbill turtles was directly observed (Wood Jones, 1909). Again by 1950 it was stated that all nesting by hawksbill turtles had ceased on the southern atoll but nests are sometimes found on Pulu Keeling, but there is no evidence of nesting (Gibson-Hill, 1950). In the 1980s and early 1990s no hawksbill turtles were recorded on any island on Cocos (Keeling) Islands (J. Tranter, pers. comm. in Director of National Parks, 2004). Pulu Keeling supported most of the green turtle nesting, perhaps as high as 90% of all nesting. On Pulu Keeling, most nesting occurred on the north-western beach where turtles had good access from the sea during most tides. Nesting by green turtles on the southern atoll was incidental with the most consistent nesting activity occurring on South Island. Gibson Hill (1950) reported that green turtles occasionally nested on West Island (Pulu Panjang) and Horsburgh Island (Pulu Luar), with the presence of nesting on West Island supported by the two nesting attempts reported during this study. Nesting on Horsburgh was not reported during this study but body pits were recently (2013) observed on the beaches on the southern side. The green turtle nesting season at Cocos Keeling appears to be similar to other locations with nesting occurring between November and March although it is likely to have some nesting year round. Six turtles tracked from Pulu Keeling in January had all finished their nesting by end of March (Whiting et al., 2008) but mating observed as late as April indicates wider nesting seasonality than sub-tropical areas.

Nesting: nesting success. The nesting success was low. All outward facing shorelines of Pulu Keeling and the islands of the southern atolls have large amounts of natural and human-derived debris on the shoreline. Debris is composed on coconut palm fronds (*Cocos nucifera*), coconuts, plastic bottles and plastic pieces. On Pulu Keeling the natural debris impacted on the nesting success of turtles and on the movement of hatchlings. In addition the narrow beach between the high tide line and the vegetation line meant that turtles attempted to nest in a zone that comprised forest debris and the roots of Pisonia (*Pisonia grandis*), octopus bush (*Argusia argentea*) and cabbage bush (*Scaevola taccada*). The roots often interfered with nest construction and caused the turtles to abandon nests throughout the night.

Nesting: sand temperatures. The sand temperatures recorded were relatively low, although, temperatures were only recorded for the last half of the nesting season. The shaded location at Pulu Keeling was cooler than both the shaded and exposed locations on South Island, probably caused by the denser shading from the Pisonia and coconut forest. The sudden drop in temperatures at both islands was probably the result of rain squalls which are common during that time of year. These squalls can be quite isolated and Pulu Keeling appeared to get several in February that missed South Island. Sea turtles have temperature-dependent sex determination with the pivotal temperature being that at which 50% males and 50% females are produced. For all of the locations the temperature of the sand mostly remained below the pivotal temperature for the species (28.3°C in Ackerman, 1997), meaning that more males than females would be produced from nests on Cocos (Keeling) Islands during this period. However, this nesting aggregation is a separate genetic management unit and the pivotal temperature may be different than those reported in the literature.

The nesting green turtle population at Cocos (Keeling) is isolated from other suitable nesting habitat by over 900 km (Christmas Island 975 km, Java over 1000 km). This isolation, the small area of the islands and the relatively young age of the atolls (Woodroffe et al., 1994) may have led to recent colonisation by nesting turtles resulting in this rookery being relatively young. The isolation of any atoll in relation to other nesting beaches would be a dominant influence on the frequency and success of colonisation events. Raine Island is a shelf-edge island on the northern Great Barrier Reef in Queensland and is of similar age to the Cocos (Keeling) Island atolls (around 4000 years BP) and is the largest green turtle rookery in the world (Limpus et al., 2003). However, colonisation and recolonising events during sea level changes would have been achieved because of the close proximity to other islands and the Australian mainland. This study indicates that the Cocos (Keeling) Islands supports low density nesting by green turtles. Although, this size of the nesting population is not internationally significant, it is important because of its isolation and genetic distinctness (Dethmers et al., 2010).

There are few major anthropogenic threats to the foraging turtles at Cocos Keeling Islands. The most severe would be climate change and increased water temperatures altering the finite shallow water seagrass and algal beds in the lagoon of the southern atoll with regular heating events reducing the quantity and quality of shallow water seagrass in the lagoon (Director of National Parks, 2011). Similarly, habitat modification via recent dredging and a new port could result in long term reduction in foraging habitat. Other local anthropogenic threats include boat strike, disturbance to foraging behaviour by the increasing number of boats using the shallow water seagrass and algal beds. For nesting turtles, climate change, resulting in rising seas and increased incubation temperatures, poses the major threat (Director of National Parks, 2011). External pressures outside of Cocos (Keeling) Islands that impact both resident and nesting turtles include harvest in neighbouring countries (Shanker & Pilcher, 2003) and marine debris killing or injuring neonate size classes (Gunn et al., 2010).

The Cocos (Keeling) Islands represent an important stronghold for mixed stock foraging green and hawksbill turtles and a low density nesting by a distinct breeding management unit of green turtles.

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