Final Report

POPULATION STRUCTURE AND DYNAMICS OF MARINE TURTLES IN THE TUBBATAHA REEFS, CAGAYANCILLO, PALAWAN, PHILIPPINES

A project implemented by the

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1.0 Introduction

Marine turtles are integral components of the Sulu-Sulawesi marine ecosystems, and a priority conservation component of the Sulu-Sulawesi Seascape programme, and are similarly a priority under the IOSEA MoU, the CTI Regional Action Plan, and the ASEAN Sea Turtle MoU. At the National level sea turtles are completely protected in all three countries bordering the SSME. The Convention on International Trade in Endangered Species of Flora and Fauna (CITES) lists marine turtles occurring in the Sulu-Sulawesi on Appendix I, while the World Conservation Union (IUCN) lists the green turtle as Endangered, and the hawksbill as Critically Endangered. The turtles nesting in the Sulu-Sulawesi area were included in the top-ten priority listing for conservation by the IUCN Marine Turtle Specialist Group (MTSG, 2004), and as such are among priority focus areas of this conservation initiative.

The reefs at Tubbataha, Cagayancillo, Palawan, Philippines, are a developmental and nesting habitat for green turtles (*Chelonia mydas*), and a foraging habitat for hawksbill turtles (*Eretmochelys imbricata*). Green turtles nest on the two islands (South Islet and Bird Island) but hawksbills have not been recorded as nesters on the Tubbataha beaches (Cruz & Torres 2005, Pilcher 2010). These turtle species are considered endangered and critically endangered species, respectively, by the International Union for the Conservation of Nature and Natural Resources (IUCN).

Understanding the population dynamics in both breeding and foraging habitats is a vital part of assessing the long-term viability of any species, particularly those that are highly migratory, such as green turtles, *Chelonia mydas*. Monitoring of the populations at the foraging grounds may help detect early signs of population trends that would otherwise take decades to be seen at the nesting beach, and even then these trends might not be detected, or be misinterpreted. Recent studies on turtles in SE Asia have demonstrated declines in turtle populations due to increases in commercial fisheries, coastal development, illegal poaching and legal collection of turtle eggs. Management measures on nesting beaches where hatcheries are used are also implicated in these population declines (Pilcher 2010). This has been the case, for example, with green turtles in Sabah, Malaysia (Chan 1990), where populations have been steadily increasing, though nearly all eggs are moved to hatcheries, which have produced for many years 100% females due to warm development temperatures (Tiwol & Cabanban 2000) resulting in skewed population sex ratios.

Our understanding of the life-stage dynamics of stocks such as the ones at Tubbataha Reefs National Park will assist managers in the development and implementation of sound, effective conservation strategies which build on the biological characteristics of the turtles. Our understanding of the varied life-stage parameters will better enable scientists, managers and conservationists to protect these animals and ensure population stability or recovery.

1.1 General Marine Turtle Biology and Ecology

To fully understand the interconnectivity of the components of this proposal, it is necessary to take a step back and understand the underlying biology of the animals in question. All marine turtles share similar life histories, varying slightly among species: they migrate from distant feeding grounds to nesting areas and males and females mate during a period lasting one to two months. After mating, females take two to four weeks to emerge on the beach and lay the first clutch of eggs. After this first clutch, they may return four to eight more times to lay again in the same season. Each nest contains around 100 eggs, which take about 60 days to incubate and hatch after dark, only when the sand surface cools. The hatchlings excavate through the sand for two or three days before emerging, and then crawl down the beach and head directly offshore using light, wave direction and the earth's magnetic field for guidance. They swim for one day in what a 'swimming frenzy' to get as far offshore as possible, and after this they float as part of the ocean's plankton for several years until they migrate from oceanic waters onshore to shallow feeding areas. After five to ten years they may grow to juveniles 20 - 40 cm in length and settle down (recruit) in coastal feeding grounds. The turtles may have several feeding grounds between the first settling site and their adult feeding sites. They remain at their feeding grounds for five to ten or more years until they reach sexual maturity, and undertake their first migration to the mating and nesting areas, whereupon the cycle is repeated. Figure 1 provides a simplified diagram of this process.

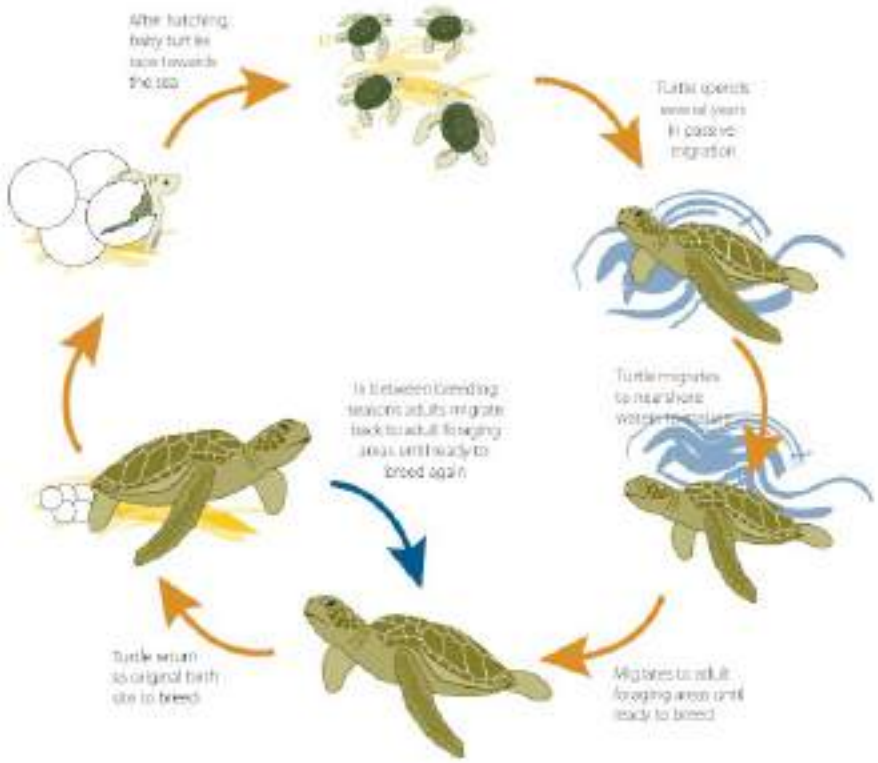

Figure 1: Diagram depicting generic sea turtle lifecycle.

The Tubbataha Reefs host nesting green turtles, and thus plays host to adult male and female turtles as they arrive from their foraging grounds and mate, following which the females emerge to lay eggs. After the hatchlings leave the reefs through, it is unknown where they go but this may be revealed via genetic studies. The reefs are also home to hundreds of juvenile and sub adult turtles, whose provenance is unknown at present, but could be resolved through the use of genetic studies. It is unknown if the developmental stage turtles remain at Tubbataha and become adults which lay eggs, of if these are two distinct population segments, possibly with differing origins.

1.2 Rationale for Population Assessments

While knowledge of absolute numbers of turtles is important for understanding turtle populations, it is the *trends* in these absolute numbers that have far more direct management implications. Are numbers increasing? Decreasing? Why may this be so? What distant or localized impacts might be causing changes in population structure? Several important aspects of turtle population management may be ascertained through periodic population assessments that document population structure, relative size and condition.

In the Sulu-Sulawesi region many cohorts of female-based hatchlings have been released to the sea from hatcheries at the Turtle Islands Park in Malaysia and the Turtle Islands Wildlife Refuge in the Philippines. Many other hatcheries operate with no knowledge of the sex ratios of emerging hatchlings. Will populations be impacted by lower proportions of males many years down the road? Unfortunately, impacts such as unnatural hatchery temperatures will only become apparent several decades later as turtles that have become adults now return to nest. By then it is likely management regimes will have changed, and personnel will have moved on, and cause-effect linkages will be hard to establish. More likely, managers at that time will look to other more-current impacts to explain any decreases in nesting activity: erosion, fisheries, illegal harvests, and the like. But the real causal effect, something which happened many years prior, will remain elusive.

For this reason periodic checks of the non-nesting populations and mark and recapture of individuals allow managers to track populations through their at-sea life components, from newly recruited juveniles through sub adult stages and into adulthood. They allow tracking of recruitment rates to each population age-class, they allow a determination of sex ratios in each, and they provide advance warnings of changes in population structure.

1.3 Objectives

The objectives of the present study were to conduct a population abundance estimate of marine turtles in the Tubbataha Reefs, to gather data on population structure and dynamics of marine turtles, and to analyse the first series of data from a long-term monitoring system for marine turtles which was implemented by marine park rangers. In addition to this, a training component was introduced to the 2014 surveys to build capacity amongst staff from the Tubbataha Marine Park, and various branches of the Philippines Department of Environment and Natural Resources. Training addressed genetic sampling, morphometric measurements, and laparoscopy.

2.0 Methods

The methods used in this assessment are based on those developed by the IUCN SSC Marine Turtle Specialist Group (Eckert et al. 1999) and are based on over 20 years of experience in designing and conducting marine turtle studies by the author. In-water captures and are based primarily on methods developed by Colin Limpus and colleagues in Australia, and used in the only other foraging ground study in SE Asia in Malaysia (Pilcher 2010). The methods used during this survey also used the findings and took note of recommendations of the initial survey conducted by Cruz & Torres (2005) and built on data sets derived during 2010 surveys, and data sets acquired by Marine Park Rangers in the intervening period. A record of daily activities is presented in Annex I.

2.1 In-Water Capture

Search techniques followed closely the methodology used by researchers in Queensland (Limpus & Reed 1985, Limpus et al. 1994a, Limpus et al. 1994b) and in Malaysia (Pilcher 2010). Rodeo-style captures were conducted from two fiberglass dinghies with rear steering and 25-30 hp outboard engines weaving in and out across sandy shallows at three key sites (Ranger Station, North Islet, South Islet). Two to three observers positioned at the front of the boat searched for turtles, and when a turtle was seen, it was chased until it was either captured or lost. Capture selections were made without regard to the size or location of the turtle. When the dinghies were full (10-20 turtles) they unloaded their catch at the Ranger Station or on the MV Navorca and continued catching.

2.4 SCUBA Capture

SCUBA dives were used to capture hawksbill turtles that were not encountered during the rodeo surveys. During the SCUBA captures divers carefully approached resting hawksbill turtles and held on to the nuchal and caudal scutes, then ascending slowly to the surface to avoid decompression sickness. The turtles were transferred to a waiting tender and the diver continued on the dive searching for more turtles.

2.3 Laparoscopy

Laparoscopy is a form of surgery that uses a miniature telescope to directly view the inside of the peritoneal cavity. The procedure results in important population structure data that can be used for effective marine turtle conservation in the SSME, where little is known about the complex population dynamics surrounding the turtle populations. Laparoscopy is more and more frequently being used as a tool to determine aspects of population dynamics in marine turtles (Dobbs et al 2007, Duronslet et al 1989, Limpus et al 2005, Wood et al 1983) and to validate data ascertained through other methods, such as blood radioimmunoassay to determine gender in Kemp's ridleys (Coyne 2000), and serum testosterone analysis (Diez & van Dam 2003). Laparoscopy can help identify varied aspects of an animal's reproductive history, such as activity over the preceding 2-3 years and evidence of historical nesting activity (in females), reproductive status (immature, pubescent, mature) and projected activity for the following season, over and above simple determination of gender (Miller & Limpus 2003). In this study laparoscopy provided information on gender, age class and reproductive status.

Turtles were checked for general appearance and obvious signs of damage or sickness, and photographs were taken of obvious defects. The turtles were then examined internally using a BAK (Germany) 30°, 5mm diameter × 30 cm long laparoscope. Care was taken each time to ensure the trocar had penetrated the peritoneal cavity prior to proceeding with the internal examination, and records were kept in instances where intestinal perforation resulted from the laparoscopy procedure. Turtles were scored for gender, and appearance of gonads (oviduct size and shape, colour of ovaries in females; testes size, shape and colour, and shape of epididimus in males) *sensu* Miller & Limpus (2003). Following laparoscopic examination, two sutures using self-dissolving catgut were used to seal the 0.8-1 cm incision. No tags were available to tag the turtles as they were returned to the water, so turtles were marked with a patch of bright rapid-drying orange spray pain to enable within-season observations and to avoid repeat captures and sampling. They were then carefully returned to the sea, and their behavior observed as they swam away from the base station / vessel.

2.4 Morphometric Measurements

Turtles were also carefully measured for curved carapace length (CCL) using a fiberglass tape measure (+/- 1mm) – measured over the curve of the carapace along the midline from the anterior point at the midline of the nuchal scute to the posterior tip of the surpacaudal scutes.

2.5 Training

Training was provided to staff from the Tubbataha Marine Park, the Turtle Islands Wildlife Sanctuary, the Palawan Council for Sustainable Development, and the veterinary office of the Biodiversity Management Bureau, department of Environment and Natural Resources. On the first day the training concentrated on collection of accurate data, maintenance of records, field procedures, and turtle measurements and genetic sampling. By the end of the first day the two veterinary staff were also learning the surgical procedures and interpretation of gonad status as part of the laparoscopy process. By the second day the veterinary staff were extremely adept at the surgical procedures required for the laparoscopy, and only routine checks of gonad interpretation were needed. By the end of the week, following more than 200 surgical procedures, the team were well-skilled and competent, and now possess the knowledge and skills to undertake their own programmes in the Philippines.

3.0 Research Results and Discussion

The findings during this marine turtle population assessment revealed a wealth of information on population structure, sex ratios, nesting activity, spatial distribution, residence times, growth rates and size structure. In many instances the data from past surveys allowed calculations of residence periods and growth rates. Rodeo-style activity resulted in the capture of 220 individual green turtles (*Chelonia mydas*). No hawksbills were seen nor captured during the rodeo outings. Timing of rodeo captures was not recorded in detail, but each outing by each boat typically lasted between one to two hours.

3.1 Population Structure and Male : Female Ratio – Green turtles

The vast majority of green turtles caught during the rodeo exercises were juveniles (88.4%). Two of these were identified as new recruits based on a white scratch-less plastron and small size. Sub-adults >65cm CCL comprised 9.3% of the captures, and adults only comprised 2.3% (**Figure 2, Table 1**). These findings are roughly consistent with the population structure detected in 2010. Substantially more females (69.8%) were captured than males (30.2%). This equates approximately to a 1M : 3F ratio. The female-biased juvenile population structure was significantly more female-biased than the 1M : 2F ratio recorded for juvenile and prepubescent turtles at Moreton Bay, Australia (Limpus et al. 1994a) but not as female-biased as the 1M : 4.5F gender structure at Mantanani, Malaysia (Pilcher 2010), and are possibly the norm for populations of turtles of this age-class structure in the Southeast Asia region.

Figure 2: Age class structure of nesting turtles, in-water sightings and rodeo captures at Tubbataha, May 2014.

Table 1: Sex and age class structure of rodeo-caught turtles at Tubbataha Reefs, Philippines, May 2014.

	Male	Female	Total
Juvenile	21.9%	66.5%	88.4%
Sub Adult	7.0%	2.3%	9.3%
Adult	0.9%	1.4%	2.3%
Total	30.2%	69.8%	

3.2 Population Structure and Male : Female Ratio – Hawksbill turtles

Only four hawksbill turtles were captured during the SCUBA surveys, comprising two males and two females. One of the males was a sub-adult and the other was an adult, while both females were juveniles. Unfortunately the small sample size precludes any further substantial analysis.

3.3 Size Distribution

Given the age-class structure, most turtles were in the smaller size ranges. As expected, given variation in growth rates, there was overlap in sizes amongst the differing age-classes (**Figure 3**). When broken down by age class, mean curved carapace length for juvenile turtles at Bird Island was 59.66cm (SD=8.571, range 38.8-75.4, n=122); mean juvenile CCL at the Ranger Station was 55.38cm (SD=6.439, range 62.0-69.0, n=31); and mean CCL at South Islet was 63.33cm (SD=8.245, range 37.6-76.6, n=40). There was a significant difference between mean juvenile carapace length sizes across all locations $ANOVA_{2,190}$ F=8.203, P=0.00038), with turtles at South Atoll being larger overall than juvenile turtles from the North Atoll. These findings are consistent with findings from 2010 and may be related to overall turtle density and carrying capacity. Further research into seagrass bed productivity and extent may corroborate these findings.

Although sample sizes were substantially smaller for the larger age classes, mean curved carapace length for sub-adult turtles at Bird Island was 65.75cm (SD=9.002, range 54.4-85.5, n=12); mean sub-adult CCL at the Ranger Station was 66.05cm (SD=3.489, range 62.0-69.0, n=4); and mean CCL at South Islet was 70.43cm (SD=7.058, range 63.7-82.2, n=5). Even accounting for slight variation, there was no major difference between mean sub-adult carapace length sizes across all locations $ANOVA_{2,18}$ F=0.647, P=0.5353). Samples sizes were insufficient for analysis of adult size classes.

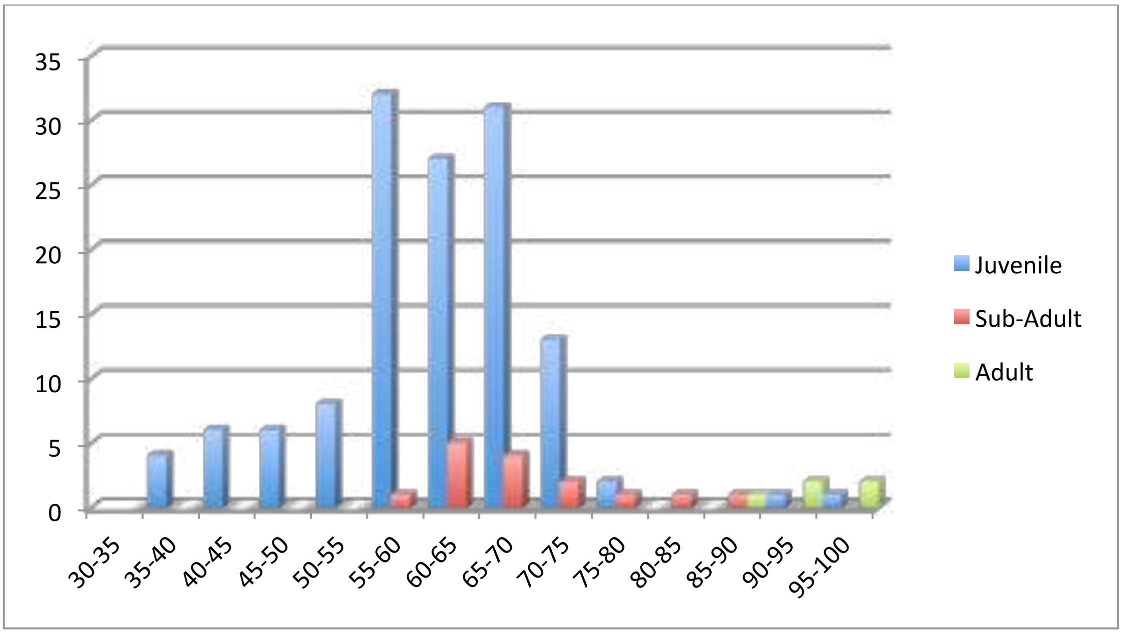

Figure 3: Size distribution of rodeo captures by site at Tubbataha Reefs, May 2014.

There was no significant difference (ANOVA$_{1,190}$ F=0.02, P=0.887; **Figure 4**) between juvenile female turtle CCL (average=59.89cm, SD=8.721, range 37.7-76.6, n=145) and male juvenile CCL (average=59.69cm, SD=7.537, range=44.25-72.2, n=47), although female turtles (145) were far more abundant than male turtles (47) for a effective gender distribution amongst juveniles of 1:3 females to males (**Figure 5**). Interestingly, by the time the age class progressed the ratio turned in favour of male turtles with a complete opposite ratio in sub-adults (1 female : 3 males) and a slightly male-biased adult population (3 males : 2 females). It is possible that the variations in sex ratios reflect a long-standing tradition of releasing predominantly-female cohorts from the two key rookeries in the region (see Jensen et al. in review) namely the Turtle islands Heritage Protected Area and the Sarawak Turtle Islands, and that the older age classes reflect pre-existing sex ratios in the wild (**Figure 5**).

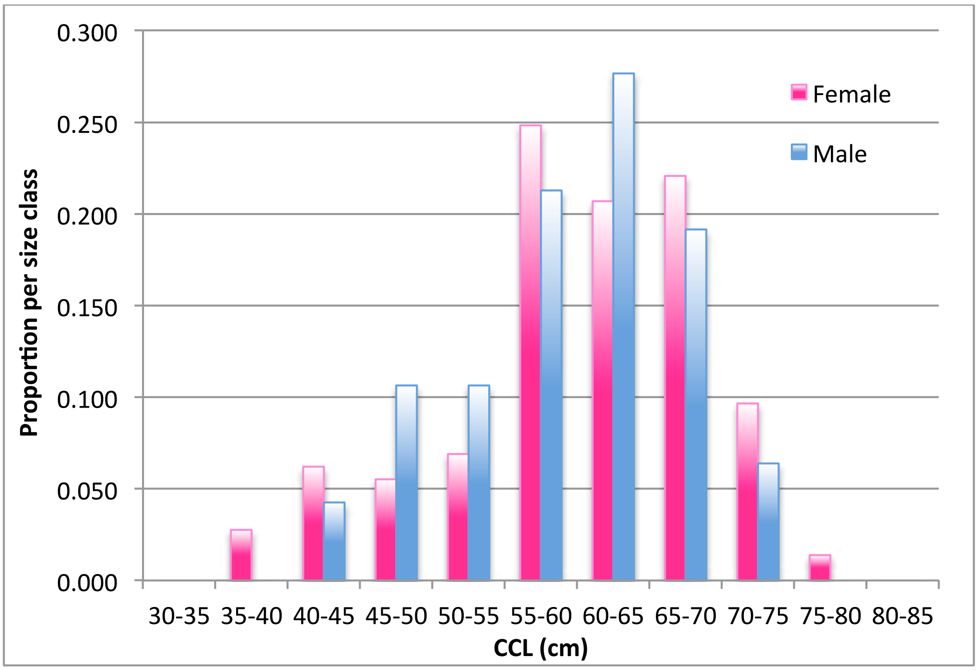

Figure 4: Size distribution of juvenile turtles by gender at Tubbataha Reefs, May 2014.

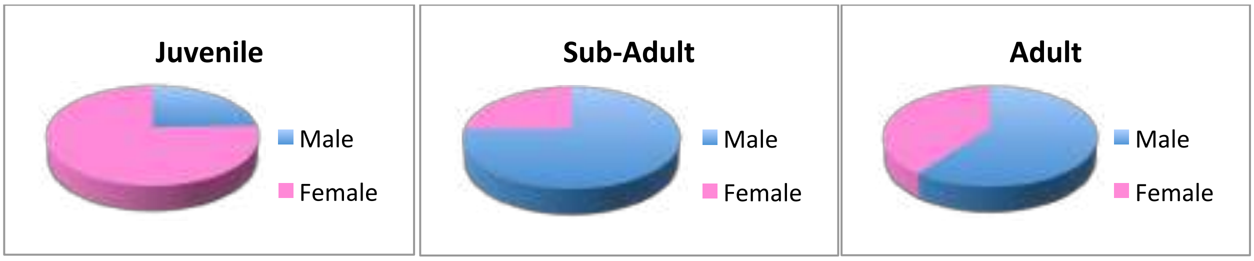

Figure 5: Gender distribution by age class of turtles at Tubbataha Reefs, May 2014.

3.4 Mark-Recapture, Growth & Residence Periods

Capture-mark-recapture studies allow assessments of growth rates, residence periods, migrations and age-specific mortality (**see Table 2**). This survey benefited from past efforts at the site by the Tubbataha Management Office personnel (unpublished data), by DENR (Cruz & Torres 2005), and TMO mark-recapture research since 2010.

In 2014, recaptures for which previous data was available accounted for 4.55% of all captures. Half of these were recaptured at North Islet while the balance was captured in the vicinity of the Ranger Station. No previously-marked turtles were caught at South Atoll, possibly as a result of lower tagging effort at this sight in previous years. In addition to the recaptures from 2014, an analysis was made of all previous data provided by TMO and DENR, from which a total 49 recaptures were identified (inclusive of the 2014 encounters). Of these, six had been recaptured twice (three total captures). Negative growth rates (as a consequence of measurement error) were encountered in 20% of the recaptures, and these were omitted from further calculations. It is important to note that the same measurement error may persist through the positive growth calculations, but in the absence of further empirical data these are used as the best estimates for growth of sea turtles at the site. All growth data is derived from green turtles, as the low number of hawksbill turtle captures precludes any further analysis. To standardise tagging records, a master tag field was added to the database, so that turtles can be tracked through time even if a tag is lost or replaced. In all cases this was selected as the lower value tag irrespective of side of application. In several instances where tags had been replaced the tracing back to a master tag number was done manually. The master tag field was then used to search among turtles for recapture records.

All curved carapace length calculations taken prior to 2010 and those in the interim between 2010 and 2014 were converted in order standardise measurements. Past measurements had always been made from the nuchal scute to the tip of the anteriormost (supracaudal) scute, while newer methods collected these data from the nuchal scute to the inside of the V-notch of the supracaudal scute. The conversions were made following double-measurements taken in 2010 of recaptured turtles based on the following formula:

$$CCL_{new}=(CCL_{old}-2.4815)/0.9648$$

Of all recaptures, 95% were amongst juvenile green turtles, with only two sub-adult turtles having been recaptured over the years (Note: these data are only pertinent to the period after 2010, when age-class data became available through laparoscopy). Of these, 75% were female turtles. The average recapture interval was 2.50 years, ranging from 0.27 to 5.1 years. None of the recaptures indicated any progression from juvenile to sub-adult age-classes, and none of the recaptures involved adult turtles. There was no significant difference between growth rates in female juvenile turtles and male juvenile turtles ($ANOVA_{1,39}$ F=0.0300, P=0.8633; **Figure 6**). Overall growth rates were 1.72 cm/yr (SD=1.766, range 0.06 to 9.03, n=39), which are on the low side globally for green turtles in these size ranges. Barring two outliers where growth was around 7-9 cm/yr, most growth rates fell between 0 and 4 cm/yr.

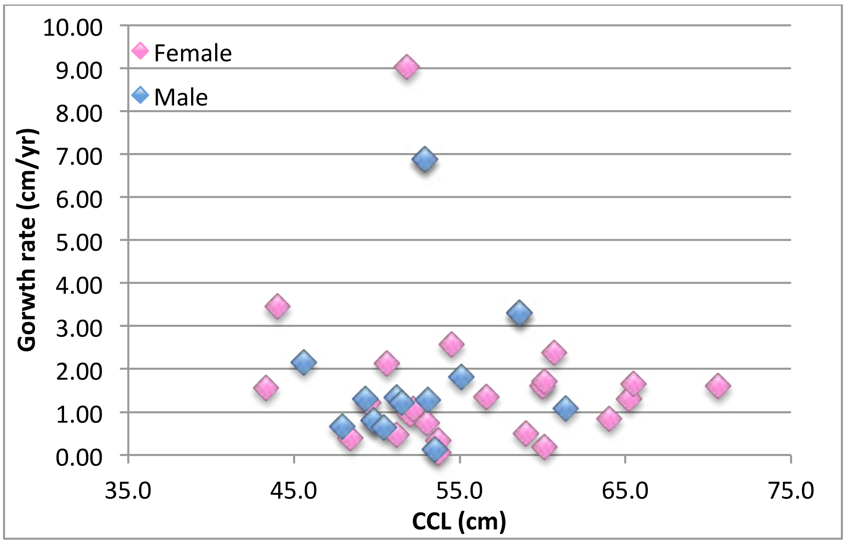

Figure 6: Growth rates of previously-tagged turtles at Tubbataha Reefs, 2005-2014.

Table 2: Recapture intervals and growth for turtles encountered at Tubbataha Reefs, Philippines, 2005-2014.

Master Tag	1st Sighting	Racapture Date	Age-Class	Sex	CCL	Growth (cm)	Interval (days)	Interval (years)	Groth Rate (cm/yr)
PH10102	11-May-05	16-Jun-10			47.6	1.2	1862	5.100	0.240
PH0121E	05-Mar-10	16-Jun-10	j	f	49.0		103	0.282	
PH0186C	17-Aug-09	18-Jun-10	j	f	49.2		305	0.836	
PH0196C	17-Aug-09	17-Jun-10	j	m	49.3	1.1	304	0.833	1.302
PH0198C	17-Aug-09	18-Jun-10	j	m	53.5	0.1	305	0.836	0.122
PH0201C	17-Aug-09	18-Jun-10	j	f	56.6	1.1	305	0.836	1.351
PH0203E	05-Mar-10	18-May-14	sa	m	69.0	19.7	1535	4.205	4.696
PH0205E	05-Mar-10	16-Jun-10	j	f	64.0	0.2	103	0.282	0.840
PH0211C	17-Aug-09	17-Jun-10	j	f	43.3	1.3	304	0.833	1.565
PH0213E	05-Mar-10	15-Jun-10	j	f	44.0	1.0	102	0.279	3.459
PH0215E	05-Mar-10	16-Jun-10	j	f	60.1	0.5	103	0.282	1.712
PH0215E	16-Jun-10	18-May-14	j	f	65.2	5.1	1432	3.923	1.300
PH0217C	17-Aug-09	18-Jun-10	j	f	51.2	0.4	305	0.836	0.470
PH0217E	05-Mar-10	16-Jun-10	j	f	51.8	2.5	103	0.282	9.029
PH0227E	10-Mar-10	18-Jun-10	j	f	62.7		100	0.274	
PH0231E	10-Mar-10	17-Jun-10	j	f	50.0		99	0.271	
PH0235E	10-Mar-10	17-May-14	j	f	65.5	6.9	1529	4.189	1.652
PH0237E	10-Mar-10	17-Jun-10	j	f	51.6		99	0.271	
PH0241E	10-Mar-10	18-Jun-10	sa	f	69.8		100	0.274	
PH0925A	23-Jan-10	16-Jun-10	j	f	39.1		144	0.395	
PH0941H	18-Jun-13	17-May-14	j	f	59.1		333	0.912	

PH0962H	26-Jun-13	17-May-14	j	f	60.7	2.1	325	0.890	2.380
PH0992H	26-Jun-13	19-May-14	j	f	60.1	0.2	327	0.896	0.192
PH6736	11-May-05	16-Jun-10			46.6	5.6	1862	5.1	1.1
PH6750	11-May-05	16-Jun-10			53.1	7.4	1862	5.1	1.45
PH6773	07-Jun-07	15-Jun-10	j	m	51.2	4.0	1104	3.025	1.329
PH6774	07-Feb-06	16-Jun-10	j	m	55.1	7.9	1590	4.356	1.818
PH6784	11-May-05	15-Jun-10	j	m	61.4	5.5	1861	5.099	1.082
PH6786	11-May-05	15-Jun-10	j	m	47.9	3.4	1861	5.099	0.670
PH6786	15-Jun-10	18-May-14	j	m	50.4	2.5	1433	3.926	0.637
PH6788	11-May-05	15-Jun-10	j	f	53.7	1.8	1861	5.099	0.344
PH6788	15-Jun-10	15-May-14	j	f	60.0	6.3	1430	3.918	1.608
PH6790	11-May-05	16-Jun-10	j	f	53.0	3.7	1862	5.101	0.735
PH6792	11-May-05	15-Jun-10	j	f	53.7	0.3	1861	5.099	0.059
PH7151	23-Mar-06	15-Jun-10	j	f	52.0	4.0	1545	4.233	0.943
PH7154	23-Mar-06	15-Jun-10	j	f	52.2	4.5	1545	4.233	1.064
PH7162	23-Mar-06	16-Jun-10	j	m	51.5	5.1	1546	4.236	1.216
PH7198	03-Nov-06	24-Jan-10			49.8	2.6	1178	3.227	0.803
PH7198	24-Jan-10	15-Jun-10	j	f	50.6	0.8	142	0.389	2.132
PH7804	03-Nov-06	16-Jun-10	j	f	49.5	4.4	1321	3.619	1.214
PH7806	07-Nov-06	15-Jun-10	j	m	45.6	7.7	1316	3.605	2.149
PH7816	07-Jun-07	15-Jun-10	j	f	44.4		1104	3.025	
PH7816	15-Jun-10	15-May-14	j	f	54.5	10.1	1430	3.918	2.578
PH7818	07-Jun-07	24-Jan-10			52.9	18.1	962	2.636	6.882
PH7824	07-Jun-07	17-Aug-09			58.6	7.3	802	2.197	3.302
PH7824	17-Aug-09	16-Jun-10	j	f	59.0	0.4	303	0.830	0.505
PH7829	07-Jun-07	16-Jun-10	j	m	53.1	3.8	1105	3.027	1.271
PH7853	08-Jun-07	17-Jun-10	j	f	64.3		1105	3.027	
PH7853	17-Jun-10	17-May-14	j	f	70.6	6.3	1430	3.918	1.608
PH7869	08-Jun-07	18-Jun-10	j	f	48.4	1.2	1106	3.030	0.403

As in 2010, residence periods were inferred from settlement sizes (new recruits at ~40 cm CCL) and growth rates (1.72 cm/yr), but accounting for all instances of recaptures to enhance statistical robustness of the findings. Overall residence periods for recaptured turtles tagged between 2005 and 2014 were calculated by subtracting the size at arrival from current size, and dividing by the average growth rate. There was a significant difference in both overall growth ($ANOVA_{1,41}$ F=0.752, P=0.3909) and residence times (a dependent factor on growth, given the estimation method) between male and female turtles whereby female turtles were resident for slightly over 13 years, while male turtles stayed at the reefs for a substantially shorter 7.8 years. It is unknown of this gender-residence period difference has any ecological significance (**Table 3**).

Table 3: Estimated average residence times for turtles at Tubbataha Reefs, Philippines, 2005-2014.

	Female Residence (years)	**Male Residence (years)**
Average	13.5	7.8
SD	6.60	3.84
Max	5.6	3.3
Min	29.0	16.9
n	11	11

3.5 Long Term Monitoring & Abundance Trends

Reliable abundance estimates are critical for management and conservation of sea turtles as turtle abundance is a key population dynamics parameter used in determining population trends. On nesting beaches this is invariably determined via proxy counts of nesting female turtles. While easy to implement, there lie a number of inherent problems with determining abundance trends via nesting numbers: the proportion of nesting females in any given year is primarily a reflection of the number of turtles ready to lay eggs that year, as opposed to an overall count of turtles; secondly, the nesting beach assessments do not take into account the number of male turtles, or the number of juvenile turtles. Thus determining changes in abundance at foraging grounds is far more informative than counts at nesting beaches, so long as the foraging turtles can be assigned to genetic stocks for management unit recognition.

Determining population abundance at foraging grounds requires long-term monitoring to detect changes in abundance, along with estimates of effort and detectability. A common way to conduct surveys over wide areas is to use line transects where repetitive surveys can be conducted at periodic intervals, or surveys over similar areas with standardized levels of effort. For instance, having one observer on one trip and two observers on the second trip increases the detection probability (more eyes looking for turtles) and unless accounted for, could lead to errors in abundance estimates. Many line-transect estimation methods use models to account for detection uncertainty.

Secondly, abundance estimates requires prior knowledge of the homogeneity of the area under survey, and assumptions about extrapolating to this area need to be clearly stated. For instance, at the Tubbataha reefs it would be erroneous to assume that density of turtles in the deeper portions of the lagoons would be similar to the reef flat, or on the outer reef edges, where forage material abounds. Similarly the differing water depth contours are likely to contain differing numbers of turtles, but there is little knowledge of turtle abundance in deeper waters as captures are only undertaken on the reef flat. Lastly, there are known 'hotspots' where turtles aggregate which are not similar to other parts of the reef. At the North Atoll, for instance, the shallow waters by the Ranger Station and surrounding Bird Island are known hotspots, but it remains unclear if there are other similar areas. Until some of these unknowns are resolved, any overall abundance estimates would only be representative of those hotspots where turtles were collected as part of the mark-recapture studies.

Given this, it is more practical to interrogate the existing straight line transect data (collected at varying intervals over nearly three years) and determine changes in abundance *along those transects*, and use these are indicative of overall changes at Tubbataha as a whole. Rangers from TMO conducted straight line transects along established routes between standardized waypoints during monsoon and non-monsoon periods since 2011 at three known hotspot areas, and the total number of turtles was extrapolated to density estimates per sq km based on a detection range of 10m to either side of the vessel.

Using the GPS unit to guide the boat along each transect line, surveys were conducted from a 9m fiberglass boat with two 115 hp outboard motors. Boat speed was kept constant at around 5-6 km/h and surveys were only conducted in Beaufort sea states of ≤3. Variables that could impact visibility (such as rain) or detectability (such as tide) were considered negligable as surveys were not conducted in poor weather and were always conducted at high tide when the boat could access the reef flat areas. Two observers continuously scanned for turtles by eye. When turtles were sighted, the time, GPS location, and number of turltes were recorded. In future these records should include angle from the boat and distance from the boat. For the current surveys, the maximum distance was arbitrarily set at 10m as an outer range for visibility. Trends in abundance per survey at each of the three sites are presented in **Figure 7**.

These are singular surveys along one transect line and thus there are not replicates for each survey. Using methods adapted from Dick & Hines (2011) for small marine mammals in similar reef conditions, and assuming a circular area of roughly 1 km in diameter per survey 'hotspot', abundance estimates were derived using the following formula:

$$N = A * \frac{n}{c * 2L * \mu}$$

Whereby N equals the abundance estimate, A is the Area being surveyed, *n* is the average number of sightings during each transect, *c* is the number of transects, *L* is the transect width, and μ is the effective transect half width. Calculations of overall abundance across all surveys at each site suggest that the number of turtle close to Bird Islet may be around 200.6 turtles and the number close to the Ranger Station at 150.4 turtle., The number of turtles at South Islet could not be accurately determined due to the high variance in the numbers of turtles reported.

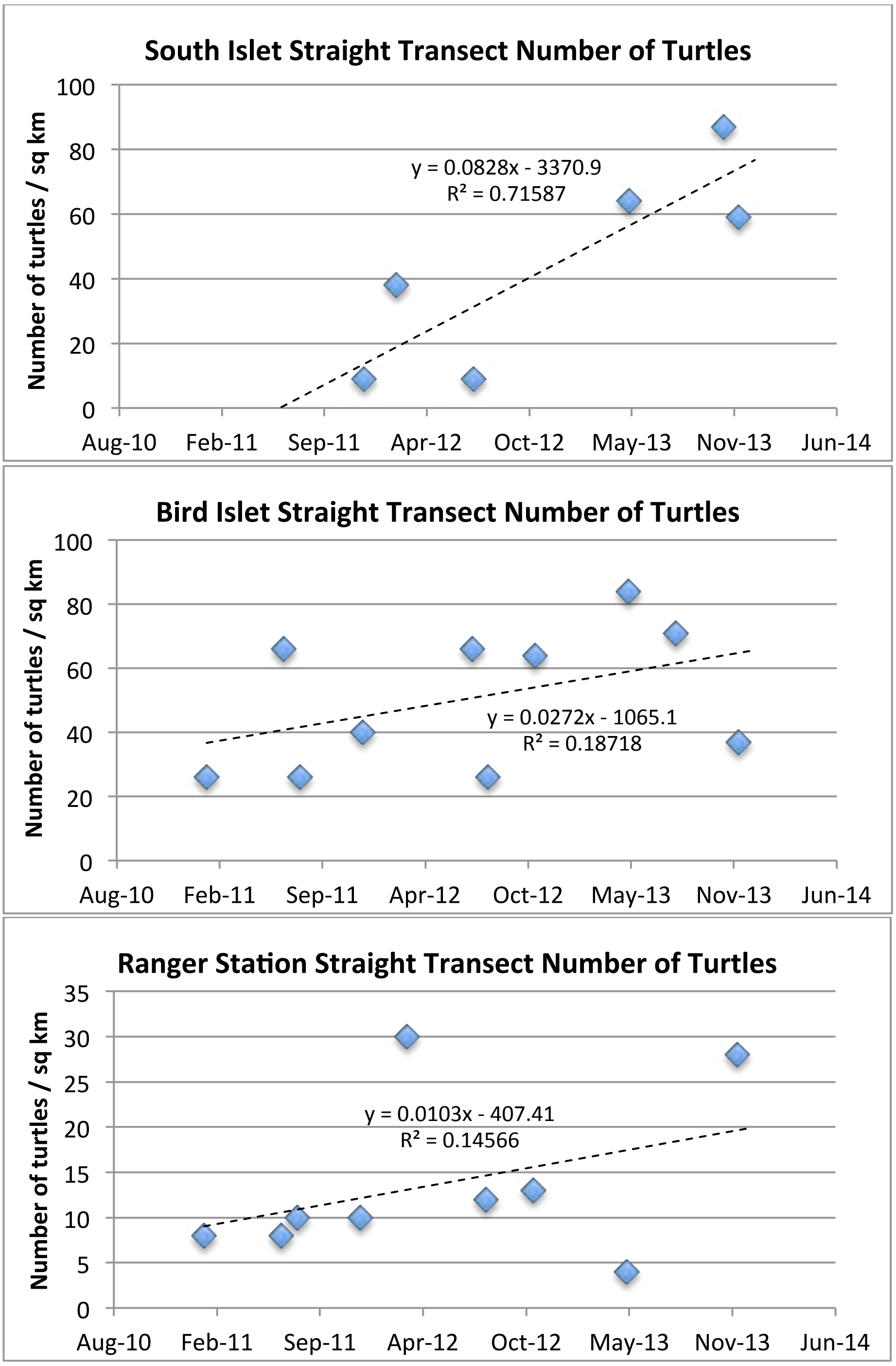

Figure 7: Trends in abundance estimates for green turtles at three known hotspots at Tubbataha, 2011-2014.

Given the transects were conducted across different weatehr seasons, the abundance estimates have been further broken down into (approximate) monsoon and non-monsoon periods, as this is likely more representative of weather-related activity patterns. At Bird Islet there were increasing trends for both monsoon and non-monsoon season (top panel, **Figure 8**) and similarly there were increasing trends during both seasons at South Islet (middle panel, **Figure 8**). This suggests these habitats are not advesely affected by changes in weatehr patterns, and that turtles are present and active year-round (with the caveat that the surveys during the monsoon season were only undertaken on calm days). At the ranger station there appeared to be a decreasing trend in turtles across summer (non-monsoon) surveys (lower panel, **Figure 8**), although it is unclear what (if any) ecological significance this has given the short duration of abundance monitoring and the lack of replicate surveys – that is, surveys over multiple days may 'balance out' single high or low counts.

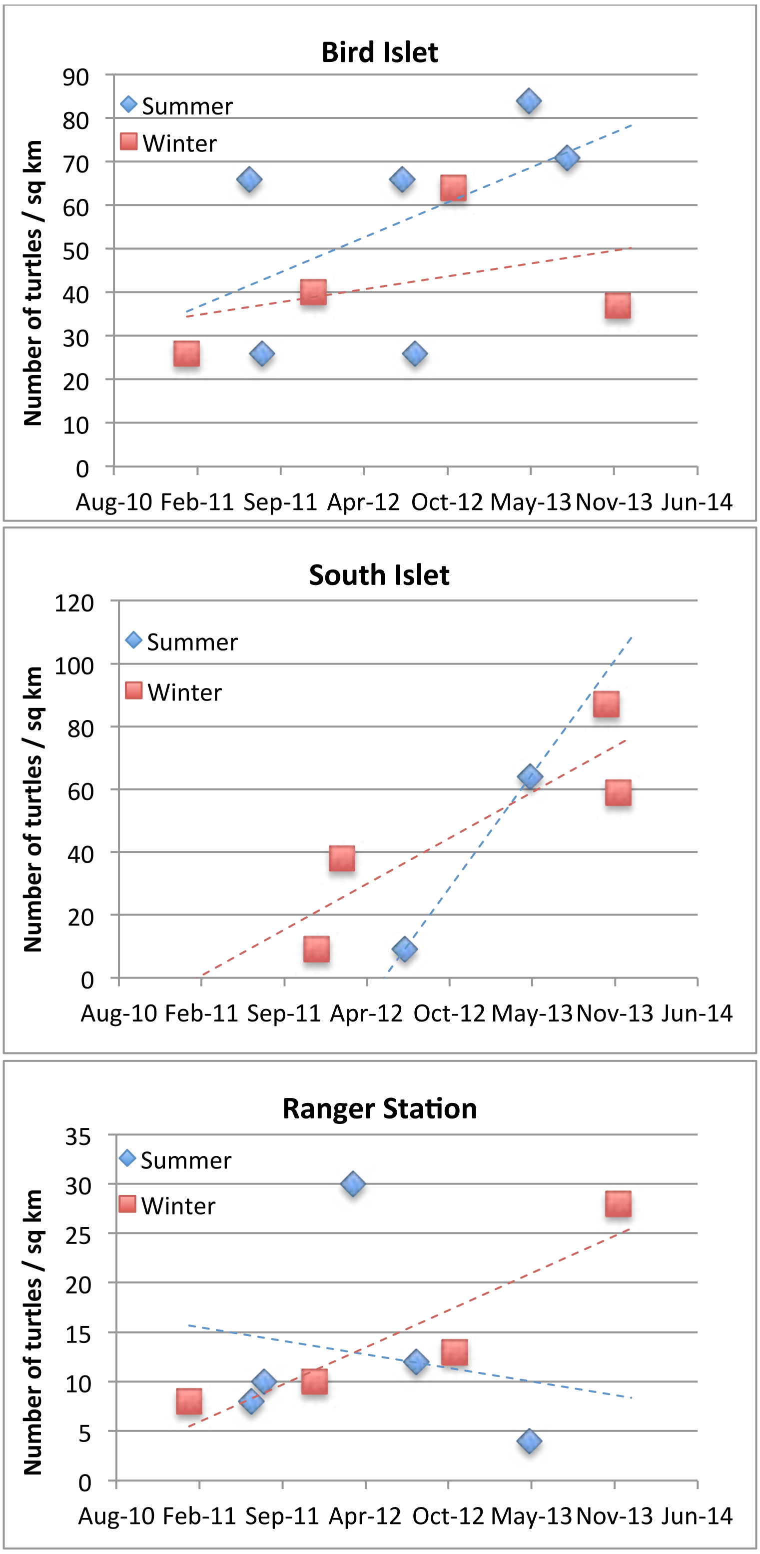

Figure 8: Trends in abundance estimates for green turtles at three known hotspots broken down by season, 2011-2014.

When considering overall abundance estimates and trends in numbers over time, all three sites demonstrated statistically robust and apparently growing numbers of turtles, but these data need to be interpreted with care: 1) the relatively short-term duration of the monitoring masks any natural variability; 2) the small number of new recruits identified during the 2014 sampling are not accounted for by a substantial influx of new juveniles on the reefs; and 3) there remain uncertainties in detection probability and effort expended on each survey.

However, at the same time, the data do not point to any decline in numbers, which is likely representative of a healthy ecosystem supporting large numbers of small juvenile green turtles, a handful of sub-adults and a few adult green turtles, alongside a much smaller proportion of hawksbills.

Detection probability and survey design are likely the two greatest issues to resolve for surveys at Tubbataha for the abundance estimates to become more robust in coming seasons. At present the surveys target known hotspots periodically, and conduct one large circle loop across the entire reef flat. The density variations in numbers of turtles during these two survey types preclude extrapolation of the findings into a total number of turtles for each reef. Detection probability is likely quite high, given the clear and shallow waters on the reef flat and experience of the observers, but surveys need standardising to periods when the weather is calm, waves are inconsequential, and when glare is minimal (clse to midday when the sun is overhead). Surveys at the three hotspot areas could continue with similar transects, but these transects need to be conducted more than once at each period (i.e. several days in a row so that there are multiple returns per transect survey).

For the surveys across the entire reef flat, given the low returns during transects conducted to date, these are likely to require slight modification in design to enhance their utility: It is likely a zig-zag pattern would yield higher returns as this would traverse 1) a greater reef area and 2) a more diverse reef area as the boat crosses from reef edge over the flat to the lagoon edge and back. A possible example of this design is presented in **Figure 9**. Note this is for illustrative purposes only.

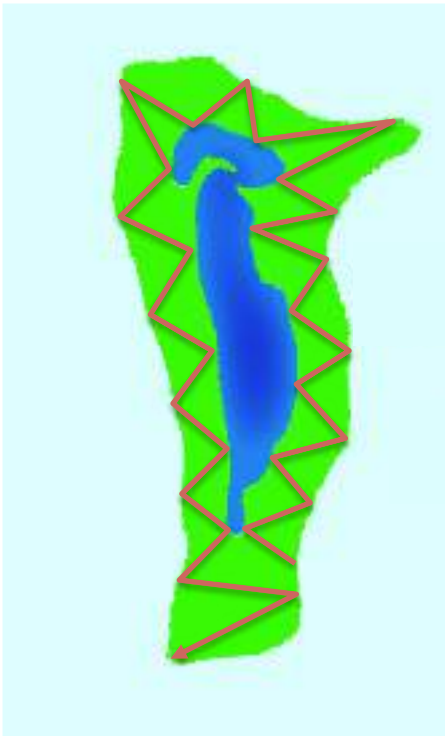

Figure 9: Possible alternative survey design for estimating turtle abundance across the entire reef flat (South Atoll in this example).

The actual pattern to be surveyed would need to be tested beforehand to ensure clear passage around shallow areas and major coral formations, and exact waypoints programmed into a GPS for easy and standardised replicability. These surveys would be longer than the previous single-circuit surveys, and may need to be broken down into shorter segments to become practical.

4.0 Data Accuracy and Precision

All measurements of sea turtles taken during the 2014 surveys were replicated by at least two personnel to ensure consistency in results. So long as measurements conformed to within 0.1 cm these were considered acceptable and within limits of normal error. These are standard practices among sea turtle researchers. Despite this however, measurement errors were still evident from the results and much of this was likely attributable to recorder error and data entry error. Average precision across all curved carapace readings was 0.2cm (SD=1.19, range 0 to 11.0 cm). Of these findings, it is important to note the high range limit on the error of 11.0 cm. This measure was over 15% greater than the total length of the turtle, and means that had this data been kept in the system and the turtle was recaptured and re-measured at a future date, all growth calculations would have been erroneous. Indeed, the turtle may have regressed in growth at a subsequent recapture. Indeed, 20% of all recaptured turtles also displayed 'negative growth' which is an impossibility in turtle biology (the hard carapaces do not 'shrink'). It is important to note just how important accuracy and precision are when it comes to measurements, and that measurement error needs to be kept to an absolute minimum for the data to be meaningful and useful in long-term monitoring programmes.

A second issue related to data collection concerns the 'from' and 'where to' measurements for carapace length. In 2010 the measurements were aligned with common practices for turtle research around the world whereby the measurement of CCL is made from the front edge of the nuchal scute (the one behind the neck) down along the midline of the carapace to the inside of the V-notch in the supracaudal scute. In the intervening years all measurements once again reverted to the 'old' style, potentially causing conflicts in data analysis – this was caught early on in the analysis process and correction factors were applied. It is important that rangers maintain one single measurement system so that data are compatible across years (all past data has been retroactively converted already).

Lastly is an issue related to database entry and maintenance. Databases can contain fields with numerical or alphanumeric data. Fields such as CCL, and distance, should only contain numbers and not a combination of numbers and text. For instance, a turtle carapace of 76.2 cm should simply be listed as 76.2, and not 76.2cm (as the latter can not be interpreted by the computer as a number). Similarly, dates need to be entered in a consistent format, as do times – so that these are comparable across sightings and data sets.

5.0 Conclusions

Laparoscopy is rapidly being recognized as one of the most valuable tools for understanding the dynamics of turtle populations in foraging grounds, and in a limited manner on nesting beaches. Laparoscopy provides information on the gender of immature and even mature turtles, and provides an opportunity to understand the reproductive history of the animal. Efforts at Tubbataha Reefs over subsequent seasons allow comparison amongst cohorts and provide management-oriented data that allows inferences to be drawn on hatchery management practices, and overall turtle survival. The collection of age-class and gender structure data for the turtles at Tubbataha is an important step in understanding population structure.

The 2014 study revealed that female juvenile green turtles outnumbered male juveniles by 3: 1, and that this trend was reversed in sub-adult turtle (1F : 3M). Adult turtles demonstrated a slight male-bias with a 3: 2

ratio of males to females. Given the predominance of juvenile turtles, the overall sex ratio approximated 3F ; 1M.

Juveniles accounted for ~88% of all turtles encountered during the surveys, with sub-adults comprising ~9% and adults the balance. Average juvenile turtle size was ~66cm, ranging from 54 to 86, reinforcing the notion of Tubbataha Reefs as primarily a juvenile development ground, with some nesting by adult green turtles. There was no difference in size between male and female juveniles. Sub-adults were slightly larger at ~67cm, ranging from 54 to 85 cm and overlapping the juvenile age class, further demonstrating the value of laparoscopy as a tool for determining in-water population demographics. The fewer adults were substantially larger at ~93cm ranging from 87 to 99cm, and no overlap with the younger age classes.

Following analysis of all data collected at Tubbataha since 2005, growth and residence period data were determined for 49 turtles, 95% of which were juvenile turtles. Average growth rates were ~1.7 cm / yr, with recapture intervals averaging ~2½ years, ranging from 0.3 to five years. These growth rates were low in comparison to other green turtle foraging grounds globally. There was no difference in growth rates amongst male or female turtles.

Residence periods were calculated for the recaptured turtles and suggested that female turtles may spend up to an average of 13-14 years at the reefs, while male turtles spend shorter periods of only 8 years. These figures were calculated based on an average arrival size of ~40cm CCL and with growth rates of 1.7cm / yr as noted above. These are minimum residence periods, given there is no reason the turtles would depart immediately, and continued monitoring of this parameter may further refine the residence periods for juvenile turtles at Tubbataha. However, the average size of sub-adults at Tubbataha is not much larger than that of juveniles (likely simply die to small sample sizes) and thus if the juvenile turtles are resident at Tubbataha until they are sub-adults (there is a notable size gap between the sub-adults and adults suggesting these may not be of the same genetic stock or may not be related, whereas there is a size continuum from juveniles to sub-adults), then these could possibly be expected to grow another 2-3 cm and be resident for another 1-2 years. At the outside, if turtles were to grow to the larger 85 cm sub-adult size, the turtles may be expected to remain on the reef an additional 12-13 years. These are long time-frames during which ongoing periodic population monitoring and research will further clarify the habitat role and importance of the reef complex among turtles of the region.

Finally, abundance estimates for the hotspot areas where turtles are more numerous suggest a density of some 150 to 200 turtles for areas of ~1km in diameter. These hotspot areas need further delineation to refine these assumptions. Additionally, some modified atoll-wide surveys are needed in order to extrapolate numbers across the entire reef complex.

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Annex 1: Detailed List of Activities during the 2014 Survey.

Day 1 (May 14)
1200 Office briefing, final logistics
1900 Departure from Puerto Princesa to Tubbataha
Day 2 (May 15)
0600 Arrival at Ranger Station
0800 Briefing on importance of turtles and value of laparoscopy as a tool to inform management
0900 to 1500 Demonstration and training in turtle rodeo, laparoscopy (identification of internal organs, determination of life stage and gender) – 20 turtles
Day 3 (May 16)
0700 Transfer to South Islet
0900 to 1500: Demonstration and training in turtle rodeo, laparoscopy (identification of internal organs, determination of life stage and gender) – 49 turtles
1600 Transfer to Ranger Station
Day 4: (May 17)
0630 Transfer to Bird Island
0830 to 1600: Laparoscopy guidance and supervision - 101 turtles
1630 to 1730: Scuba diving (one large green turtle; one marked green turtle)
1800 Transfer to Ranger Station
Day 5 (May 18)
0730 to 1500 : Laparoscopy guidance and supervision - 15 turtles
Day 6 (May 19)
0630: Scuba diving (caught one hawksbill, recorded one green)
0800: Scuba diving (caught three hawksbills)
1000: Transfer to Bird Island
1000 to 1300: Laparoscopy guidance and supervision - 35 turtles
1030: Scuba diving (recorded three green turtles)
1500: Transfer to Jessie Beazley reef
1530 Scuba diving (no turtles recorded or caught)
1700: Departure for Puerto Princesa