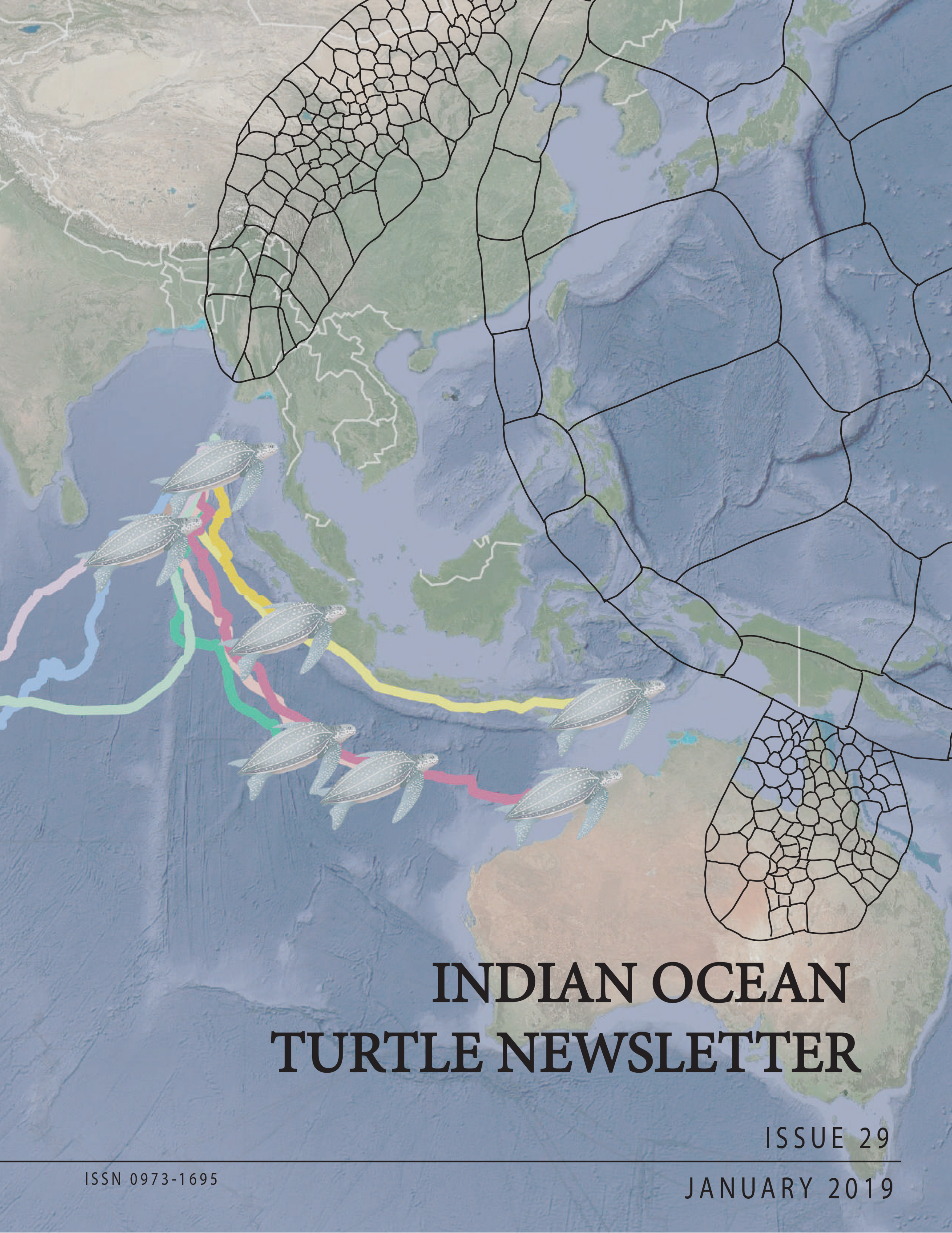

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The Indian Ocean Turtle Newsletter was initiated to provide a forum for exchange of information on sea turtle biology and conservation, management and education and awareness activities in the Indian subcontinent, Indian Ocean region, and south/southeast Asia. The newsletter also intends to cover related aspects such as coastal zone management, fisheries and marine biology.

The newsletter is distributed free of cost to a network of government and non-government organisations and individuals in the region. All articles are also freely available in PDF and HTML formats on the website. Readers can submit names and addresses of individuals, NGOs, research institutions, schools and colleges, etc. for inclusion in the mailing list.

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Cover photograph: Movements of leatherback turtles from their nesting beach at Little Andaman Island
Photo Courtesy: Swaminathan *et al*. (2019)

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EDITORIAL

WHERE TO NOW? BIASES AND KNOWLEDGE GAPS IN SEA TURTLE SATELLITE TELEMETRY STUDIES CONDUCTED THROUGHOUT THE INDIAN OCEAN AND SOUTH EAST ASIA

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To complement papers in Issue 28, which summarised satellite telemetry studies from the South West Indian Ocean north to the Red Sea, Arabian/Persian Gulf, and Arabian Seas, the current issue of IOTN includes reports from countries in South Asia, South East Asia, and the South East Indian Ocean. The combined contributed papers by Antonopoulou & Pilcher (2018), Hays *et al*. (2018), Mancini *et al*. (2018), Phillott & Jalihal (2019), Pilcher *et al*. (2019), Rees *et al*. (2018a,b) Richardson (2019), Robinson *et al*. (2018), Swaminathan *et al*. (2019), Tiwari *et al*. (2018) and Waayers *et al*. (2019) to the Indian Ocean Turtle Newsletter special issues (#28 and 29) summarise the contribution of satellite telemetry studies towards improving our understanding about sea turtle biology and conservation needs in the Indian Ocean and South East Asia.

As expected, most studies focus on the most prevalent species' in each sub-region (for example, leatherback turtles in the South West Indian Ocean and flatback turtles in the South East Indian Ocean; see Phillott & Jalihal, 2019). There is an additional study bias towards post-nesting, migrating females on the return to their foraging grounds- again, understandable as this is the most accessible life-stage in the sea turtle life cycle and can be most easily tracked.

Post-hatchlings, juveniles, sub-adults, adult males, and non-breeding adult females have been largely overlooked in tracking studies in the region. Although a similar gap also occurs in other regions worldwide, continuing to focus on nesting females will not help answer the important questions raised by Hamann *et al*. (2010), Rees *et al*. (2016), Hays & Hawkes (2018) and Wildermann *et al*. (2018).

Post-hatchling sea turtles

Post-hatchlings may be tracked if facilities are available in which turtles can be reared to an appropriate size, and suitably sized and powered tags are available. Tracking turtles in this age class can provide information on dispersal paths, rates and behaviour of small turtles from the nesting beach, information about developmental habitats, identify potential threats, and help determine the boundaries for Protected Areas (see Mansfield *et al*., 2012).

Immature turtles

Wildermann *et al*. (2018) recently consulted international sea turtle experts to identify priority areas for study on immature (including juvenile and sub-adult) turtles. The Indian Ocean was identified as the region with the greatest need for research on this cohort and their developmental habitats. Satellite telemetry studies on these life-stages will be most relevant if addressing any of the four priority areas identified by experts contributing to the study by Wildermann *et al*. (2018): population ecology, habitat use and behaviour, threat identification, and management of threats.

The rodeo style of capturing turtles (first described by Limpus & Reed (1985) and used in the region by Pilcher *et al*. (2015)) may be possible for researchers with access to a vessel. Challenges in encountering and capturing immature turtles may be overcome by working with small-scale and commercial fisheries vessels, ecotourism operators, offshore oil and gas platforms etc (see Wildermann *et al*., 2018).

Adult male turtles

In a similar manner to immature turtles, adult male turtles can be captured in neritic foraging grounds using the rodeo technique or through cooperation with local fishers in the areas that turtles frequent. Additionally, adult male green turtles occasionally come close to shore at their breeding areas for mating, where they may be opportunistically captured for tracking and other studies (e.g. Wright *et al*., 2012). Given that satellite tags often transmit for longer than 12 months, tagging adult males will allow researchers to test the hypothesis that male sea turtles maintain an annual breeding cycle, due to the smaller amount of resources a male is required to expend during a breeding season when compared to an adult female (e.g. Hays *et al*., 2010).

Non-breeding, adult female turtles

Capturing and tracking non-breeding adult females at their foraging and overwintering areas provides information on residency patterns and home ranges but lacks the important linkages to their breeding sites and nesting remigration interval, as the breeding remigration interval of adult female turtles in the region is often 2 years or more (e.g Bourjea *et al*., 2007; Ekanayake *et al*., 2010; Nishizawa *et al*., 2018) and, therefore, generally longer than the life of a satellite tag. It is possible to identify adult females captured in foraging grounds that are likely to undertake reproductive migrations in the near future using ultrasonography, or the more invasive laparoscopy, to identify the presence of mature ovarian follicles that indicate the turtle is in breeding condition (see Hamann *et al*., 2003). These turtles can then be the focus of satellite telemetry studies to determine the timing and pathways for breeding migrations.

How many satellite tracks are enough?

There is no simple answer to questions about the ideal sample size in satellite telemetry studies. Hays & Hawkes (2018) suggest that the number of required tags will depend on the location, species, population, focus of the research, and the variability in turtle behaviour. It is challenging (and expensive) for one individual person or group to accumulate enough data, and some studies only opportunistically apply satellite tags and delay publishing their results until a large number of tracks have been accumulated. However, Godley et al. (2008), Jeffers & Godley (2017) and Hays & Hawkes (2018) all emphasise that the greatest benefit of satellite tracking studies will be realised when data are widely shared (preferably through peer-reviewed publication) and data sets are combined in collaborative studies. We strongly encourage researchers to publish their small data sets or collaborate with other researchers in the region (or internationally) to ensure their efforts and the funding invested in the tracking work make the greatest contribution possible to improving our understanding of sea turtle biology and conservation needs.

Combining satellite tags with other research tools

The use of stable isotope analysis (SIA) to upscale findings from satellite tracking studies is becoming more widespread and can be used to varying degrees on different turtle species. The procedure is to identify stable isotope signatures for certain geographic locations from a number of tracked individuals and then the foraging area of a larger number of non-tracked individuals can be determined from their SIA signature (see Seminoff *et al*. (2013) for a topic overview). This combination of research tools can lead to population-level characterisation of foraging habitats and identify differing trajectories in turtle numbers contributing to a breeding population from widely separated source foraging sites, as eloquently described for green turtles in the Mediterranean in Bradshaw *et al*. (2017).

Flipper tagging

The value of traditional flipper tagging should not be forgotten. While satellite tags may provide more accurate data when answering some questions (e.g. the number of clutches laid by an individual per season; Tucker *et al*., 2018), well-applied flipper tags made of an appropriate material can allow individual turtles to be followed over decades (e.g. flatback turtle X23103 has been followed at Mon Repos, Australia, since first tagged in 1974; DES, 2016).

Far cheaper than satellite tags - hence larger sample sizes possible, more likely to receive permit approval, with a longer tag life, and accessible to anyone who is close enough to read the tag, flipper tagging has already proven its value in studies conducted throughout the region. A nesting olive ridley turtle tagged at Hawkesbay Beach, Pakistan, was captured 223 days later by a fisher off Bhaidar Island in the Gulf of Kachchh, India (Firdous, 1991), indicating potential foraging grounds and the need for international conservation efforts. Similarly, recoveries of metal flipper tags applied to olive ridley turtles at mass-nesting beaches in Odisha, India, indicated long-distance migrations to foraging grounds in the Gulf of Mannar and Sri Lanka. Some of the tag recoveries occurred at these distant locations during the known arribada period in the following year, suggesting females may utilise nesting beaches other than those in Odisha where they were tagged or not nest every year (Shanker & Pandav, 2001 in Pandav & Choudhury, 2006). Intra- and inter-seasonal shifts in nesting beaches were also directly observed via tag recoveries (Pandav, 2001 in Pandav & Choudhury, 2006). Because of their longevity flipper tags should also be used in conjunction with satellite tags. The flipper tag will often remain in place after a satellite tag has been shed from the turtle's carapace, so the identity and origin of the study animal is maintained for extended periods. Increasing the important individual-based dataset contributes greatly to our understanding of sea turtle life-history traits in different study locations.

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CALL FOR SUBMISSIONS

The Indian Ocean Turtle Newsletter was initiated to provide a forum for the exchange of information on sea turtle biology and conservation, management and education and awareness activities in the Indian subcontinent, Indian Ocean region, and south/southeast Asia. If you would like to submit a research article, project profile, note or announcement for Issue 30 of IOTN, please email material to iotn.editors@gmail.com before 1st April 2019. Guidelines for submission can be found on the last page of this newsletter or at http://www.iotn.org/submission.php.

WHERE DO THEY GO? SATELLITE TRACKING OF NESTING TURTLES IN SRI LANKA

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INTRODUCTION

Five species of turtle nest on Sri Lanka's beaches. Green (*Chelonia mydas*) and olive ridley turtles (*Lepidochelys olivacea*) are the most frequently encountered, with occasional nesting by hawksbill (*Eretmochelys imbricata*), leatherback (*Dermochelys coriacea*) and loggerhead (*Caretta caretta*) turtles also recorded (Kapurusinghe, 2006).

To date, two satellite telemetry studies on turtles have been conducted in Sri Lanka. The first involved a collaboration between the Marine Conservation Society (MCS), the Turtle Conservation Project, and the Government's Department of Wildlife Conservation (DWC) (Richardson *et al*., 2013). This study deployed satellite tags on ten nesting green turtles at the Rekawa Sanctuary, near Tangalle on the south coast, in 2006 and 2007.

The second study was a collaboration between the Wildlife Institute of India (WII) and DWC in 2010, and deployed satellite tags on four nesting olive ridley turtles and one nesting green turtle at Bundala, Rekawa, and Kosgoda turtle rookeries on the south and west coasts (Sivakumar *et al*., 2010). This study is yet to be fully published, and therefore this review only summarises the project tracking data as described in Sivakumar *et al*. (2010).

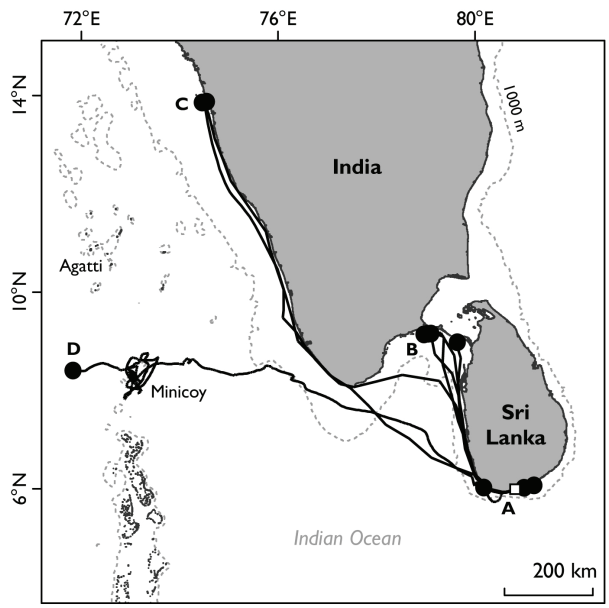

Figure 1. Migrations of 10 green turtles satellite tagged in the study by Richardson *et al*. (2013) at Rekawa Sanctuary (white square) to four geographic areas, A, Southern Sri Lanka (n = 3 turtles), B, Gulf of Mannar (n = 4 turtles), C, Karnataka (n = 2 turtles) and D, Lakshwadeep Islands (n = 1 turtle). Agatti Island is also shown.

SATELLITE TAGGING OF GREEN TURTLES NESTING AT REKAWA

Richardson *et al*. (2013) aimed to identify inter-nesting habitat, migration corridors and residence locations of a population of green turtles nesting within the Rekawa Sanctuary, the largest green turtle rookery on the southern coast of Sri Lanka (Figure 1). Sirtrack Kiwisat 101 satellite transmitters were attached to adult female green turtles (Table 1) after they had nested on Rekawa beach in July and August 2006 (n=6), and June 2007 (n=4), and the turtles' subsequent movements were tracked and mapped by STAT (Coyne & Godley, 2005). The turtles exhibited behavioural plasticity within the population.

Inter-nesting behaviour

While one green turtle started its post-nesting migration immediately after tagging, six turtles spent their inter-nesting periods proximate to Rekawa beach before nesting again at Rekawa (Figure 2). The other three turtles repeatedly travelled to respective and separate coastal locations at Usangoda, Bundala, and Habbaraduwa, all within 60km distance from Rekawa, to spend their inter-nesting periods before returning to Rekawa to lay subsequent clutches (Figure 2).

Table 1. Summary of biometric and tracking information for the 10 female green turtles fitted with satellite transmitters at the Rekawa Turtle Sanctuary (RS), Sri Lanka (Richardson *et al*., 2013).

Turtle ID #	CCL (cm)	Date tagged (dd.mm.yy)	Inter-nesting location(s)	Foraging site name and jurisdiction	Straight line distance between Rekawa and foraging centroid (km)	Days tracked (days at residence site)
Movement Pattern Type A1 (after Godley *et al*., 2008)						
1	117.5	30.07.06	Not known - turtle began post-nesting migration after tagging.	Gulf of Mannar, India	415	145 (136)
2	110.1	02.08.06	Proximate to RS	Gulf of Mannar, India	409	64 (46)
3	106.3	06.08.06	Proximate to RS	Gulf of Mannar, India	403	97 (51)
4	107.5	19.06.07	Proximate to RS	Gulf of Mannar, Sri Lanka	350	62 (32)
5	101.2	07.08.06	Proximate to RS	Karnataka, India	No centroid (last LC 'A' transmitted from Shirali Island, 1128 km from RS).	169 (56)
6	109.9	18.06.07	Proximate to RS	Karnataka, India	1128	126 (48)
Movement Pattern Type A3 (after Godley *et al*., 2008)						
7	95.0	03.08.06	Habbaraduwa	Habbaraduwa, Sri Lanka	60	61 (29)
8	97.1	16.06.07	Bundala	Bundala, Sri Lanka	38	172 (92)
9	90.1	17.06.07	Ussangoda	Ussangoda, Sri Lanka	16	69 (24)
Movement Pattern Type B (after Godley *et al*., 2008)						
10	92.8	08.08.06	Proximate to RS	Minicoy, India	898	140 (42)

Post-nesting migrations

After laying their last clutch of eggs at Rekawa, the green turtles exhibited multiple migration patterns as described by Godley *et al.* (2008) (Figure 1). The turtles that spent inter-nesting periods at the coastal locations away from Rekawa returned to their respective inter-nesting sites, where they remained until transmissions ceased. This relatively proximate residence to the nesting beach of these 'resident breeders' is described as movement pattern A3 by Godley *et al.* (2008).

The other green turtles exhibited two other movement patterns. Six turtles migrated away from Rekawa once they had laid their last clutch of eggs, travelling northwards in coastal waters, and corresponding with movement pattern A1 described by Godley *et al.* (2008) (Figure 1). Two of these turtles eventually settled at a site close to Shirali Island in coastal waters of Karnataka, India. Four of these turtles settled at sites in the Gulf of Mannar, with three of these turtles settling in the Gulf of Mannar National Park off the coast of Tamil Nadu. It is interesting to note that the only green turtle in the Sivakumar *et al.* (2010) study, tagged after nesting at Bundala in February 2010, also exhibited this movement pattern and also finally settled in the Gulf of Mannar National Park.

One green turtle exhibited movement pattern B described by Godley *et al.* (2008) when it migrated away

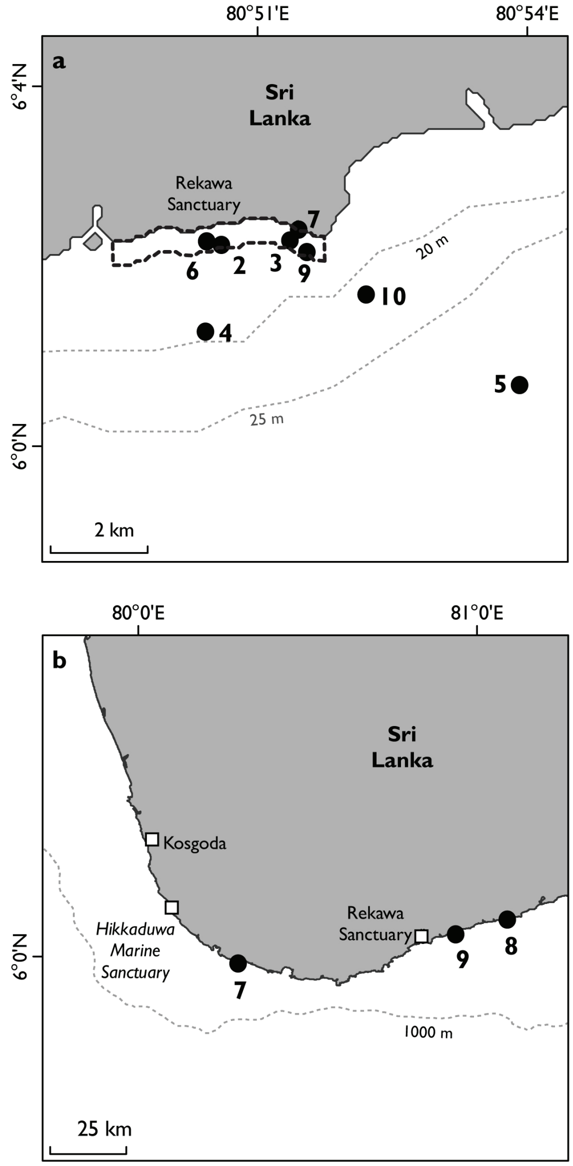

Figure 2. Inter-nesting centroids calculated for the nine turtles that nested at Rekawa after they were fitted with a satellite tag (numbers represent turtles in Table 1) in the study by Richardson *et al*. (2013), a, for turtles remaining proximate to Rekawa Sanctuary, b, inter-nesting and foraging site centroids calculated for the resident breeder turtles identified in this study.

from Sri Lanka through pelagic waters and travelled to Minicoy Atoll in the Lakshwadeep Islands (Figure 1). The turtle remained close to Minicoy for 39 days, constantly performing looping movements around the atoll, and up to 65km distance before returning back to the atoll. The tags transmissions ceased when the turtle was 135km away from Minicoy, after having travelled due west from the atoll for 3 days, perhaps migrating into the Arabian Sea.

SATELLITE TAGGING OF OLIVE RIDLEY TURTLES NESTING AT REKAWA AND BUNDALA

Sivakumar *et al.* (2010) describe the tracks of four female olive ridley turtles tagged after nesting in February 2010, and up to the 30th of June 2010 when the tags were still transmitting (tag make not specified). Two turtles were tagged at Bundala, one tagged at Kosgoda and one tagged at Rekawa. After nesting, two of these turtles (tagged in Bundala and Kosgoda) travelled to open oceanic habitats to the south west of Sri Lanka and were there in June 2010. One turtle (tagged in Bundala) migrated north-west to the Gulf of Mannar Park, where it appeared to settle in April 2010, and was still there in June 2010. The other turtle (tagged in Rekawa) travelled westwards to the Maldives, arriving in April 2010, before heading north and settling offshore of Kerala, India in May 2010. It was still there in June 2010.

DISCUSSION

The findings of these studies highlight the disparate nature of habitats that nesting green and olive ridley turtle populations in Sri Lanka depend on. The Rekawa green turtle population uses inter-nesting habitat proximate to Rekawa, as well as other inshore sites along Sri Lanka's southern coast. These sites also serve as resident foraging habitat for these turtles. The population uses important migration routes through the coastal waters of India and Sri Lanka, and some turtles share foraging sites far away from Sri Lanka in India's waters. Coastal fisheries incur turtle bycatch in both India and Sri Lanka (Kapurusinghe, 2006; Rajagopalan, 2006) and, therefore, more research is required to determine whether or not this bycatch poses a significant threat to Sri Lanka's nesting turtle populations. The study also highlighted the importance of protecting key foraging habitat for marine turtles, with the rich habitats in the Gulf of Mannar National Park being of particular significance to Sri Lanka's green turtle nesting population, and possibly olive ridley turtle populations. It is also of interest to note that Sri Lanka and the Lakshwadeep Islands share a green turtle population, and this has been corroborated through flipper tag return data from Agatti Island, another Lakshawdeep Island (see Richardson *et al.*, 2013). Atolls in the Lakshwadeep Islands have experienced increases in the number of foraging juvenile green turtles aggregating in atoll lagoons in the recent years causing conflict with local fishers (Lal *et al.*, 2010). Further research is required to determine whether turtle conservation efforts in Sri Lanka over the last 20 years (Ekanayake, 2002) may be linked to this phenomenon.

These studies represent the first ever satellite telemetry studies on Sri Lanka's turtles, but should not be the last. The results pose more questions than they answer. Researchers in Sri Lanka, India and elsewhere are encouraged to develop partnerships and share resources to develop more telemetry and genetics studies on the countries' turtle populations. These should aim to fully determine the ecology, range and behaviours of these populations with a view to better informing future conservation efforts.

ACKNOWLEDGEMENTS

These figures are from Richardson *et al*. (2013) and I encourage anyone interested in a better understanding of this paper to visit www.seaturtle.org/mtrg/pubs/. I thank my co-authors for their invaluable contributions to that paper, and for the numerous Turtle Conservation Project staff and volunteers for supporting the tracking project. I also thank Dr BC Choudhury for sending me a copy of the note by Sivakumar *et al*. (2010).

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TRACKING LEATHERBACK TURTLES FROM LITTLE ANDAMAN ISLAND

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INTRODUCTION

Leatherback nesting in India is currently restricted to the Andaman and Nicobar Islands (Andrews *et al*., 2006). A long-term monitoring programme was established in 2008 at Little Andaman Island, and two index beaches, South and West Bay (Figure 1) were chosen to study the recovery of leatherback turtles after the earthquake and tsunami of December 2004 (Swaminathan *et al*., 2011, 2017). Over the years, the objectives evolved to include monitoring of leatherback nesting at the index beaches through a capture-recapture programme. The data indicate that leatherback nesting on Little Andaman Island has recovered substantially after the 2004 tsunami and seems stable with some fluctuations (Swaminathan *et al*., 2017). One of the components of the project was to identify the post-nesting migratory routes of leatherback turtles nesting in this region. For the first time in India, leatherback turtles were tagged with satellite transmitters to understand their migratory routes and foraging sites (Namboothri *et al*., 2012).

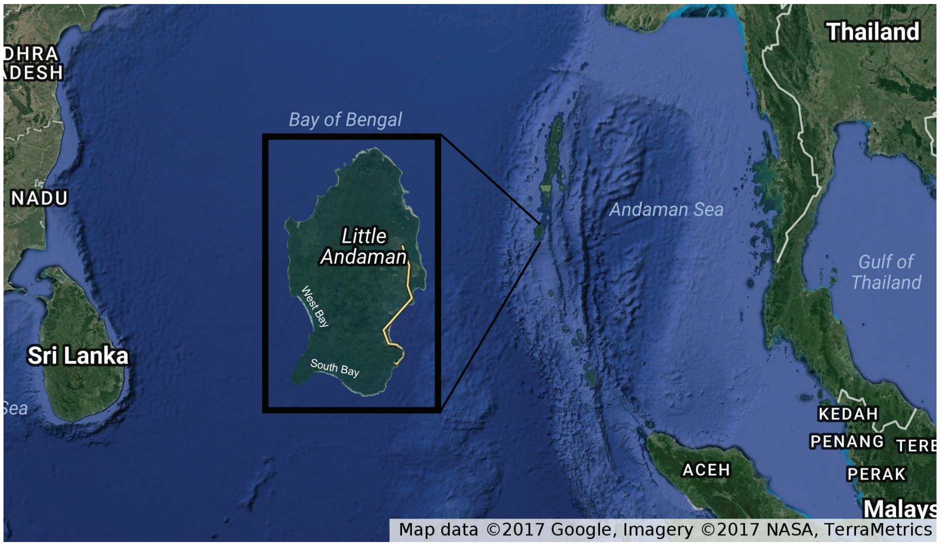

Figure 1. Map of Little Andaman.

METHODS

Between 2011 and 2014, ten nesting leatherback turtles were tagged with Platform Transmitter Terminals (PTT), model Kiwisat 202 (specially designed for leatherback turtles by Sirtrack Wildlife Tracking Solutions Ltd.), on West Bay beach. All satellite transmitters were equipped with a saltwater switch, programmed to transmit continuously for the first three months and every alternate day for the rest of the period. The PTTs were attached surgically onto the carapace of nesting females using the direct attachment method (Fossette *et al.*, 2008; Byrne *et al.*, 2009).

All tagged turtles were monitored regularly based on the data received through ARGOS and the data were analysed using the Satellite Tracking Analysis Tool (STAT; Coyne & Godley, 2005; www.seaturtle.org/STAT).

RESULTS

All the turtles tagged on West Bay, Little Andaman, initially travelled south and then predominantly in two directions: South East (five turtles) towards the western coast of Australia, and South West (four turtles) towards the eastern coast of Africa (Figure 2). Data about one turtle was not transmitted.

One of the tracked turtles (PTT ID No. 113335 tagged on 3rd February 2013) travelled southeast to the coast of Western Australia (6,713km) before transmission stopped (Figure 2). Another turtle (PTT ID No. 113336, tagged on 5th January 2014) travelled southwest to the Northeastern coast of Madagascar in 395 days, swimming 12,328km. Similarly, PTT ID No. 113337 (tagged on 8th January 2014) travelled close to the western coast of Mozambique in 266 days, covering 13,237km; this turtle also travelled to the north-west coast of the Andaman and Nicobar Islands during the inter-nesting period and remained in the Andaman Sea for several weeks (post-nesting) before heading southwest. Turtle No. 113337 travelled an average distance of 49.8km per day (Figure 2; Table 1).

DISCUSSION

The patterns of movements demonstrated by adult female turtles tagged in 2013 and 2014 was consistent with those previously tagged in 2011 and 2012 (Namboothri *et al.*, 2012). They traverse much of the Indian Ocean during their foraging migrations, ranging as far east as Western Australia, and as far west as Mozambique and Madagascar. The migration strategy appears to be direct with open ocean crossing or indirect with movements along the coastal shelf. The average distance covered in a day by the nine turtles was 43.5±13.8km (StDev; Range 15.6-60.2km).

While we now have some insight into the migratory patterns of leatherbacks in the Indian Ocean, more satellite telemetry studies need to be carried out in subsequent years to assess if there are other migratory routes taken by the turtles nesting at Little Andaman. Additional data on dive behaviour and oceanography will help us better understand their migratory behavior and identify 'hot spots' where leatherbacks are vulnerable to fishing activities.

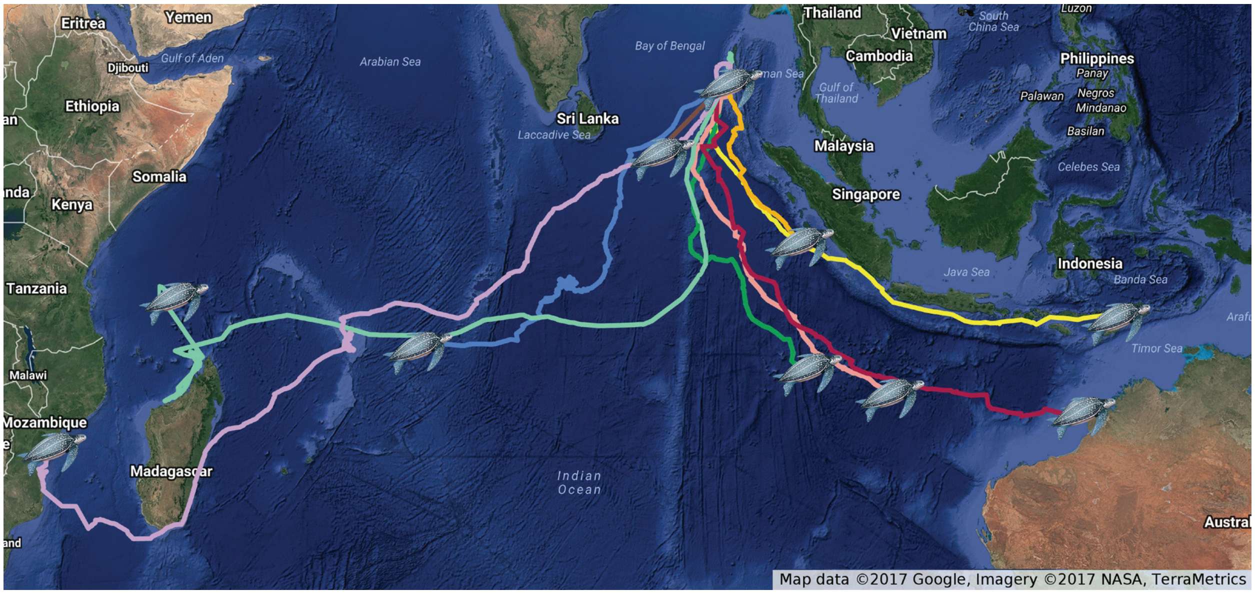

Figure 2. Post-nesting migratory routes of leatherback turtles nesting at Little Andaman. Turtle icons represent the tagging location and the last known locations for each individual turtle. For coloured tracks, see the pdf version, available on-line.

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Table 1. Satellite telemetry data of 10 female leatherback turtles tagged in West Bay, Little Andaman, from 2011-2014.

Turtle ID	Release Date yyyy-mm-dd	# Days Transmitted	Total Distance Travelled (km)	Average Distance Per Day (km)
103333	2011-01-04	179	7,312	40.85
103334	2011-01-04	69	1,077	15.60
103335	2011-01-05	92	4,600	50.00
103402	2012-02-13	77	4,634	60.20
113332	2012-01-23	183	6,998	38.24
113333	2012-01-23	51	2,690	52.75
113334	2012-01-23	-	-	-
113335	2013-02-03	125	6,713	53.70
113336	2014-01-05	395	12,328	31.20
113337	2014-01-08	266	13,237	49.80

AN OVERVIEW OF SEA TURTLE SATELLITE TRACKING IN MALAYSIA

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INTRODUCTION

Malaysian beaches support nesting green turtles *Chelonia mydas* which nest in large numbers (1,000s) and the hawksbill *Eretmochelys imbricata* with more moderate nesting numbers (low 100s; deSilva, 1982; Siow & Moll, 1982; Chan, 1991). Malaysia used to host one of southeast Asia's largest leatherback *Dermochelys coriacea* populations with upwards of 10,000 nests deposited in the 1950s at Rantau Abang, Terengganu (Chan & Liew, 1996). These numbers declined to some 10 per year by 2000 (Chan & Liew, 1996) and the population went functionally extinct in Terengganu in 2010 (DOFM, unpubl. data). Solitary nesting olive ridley turtles *Lepidochelys olivacea* now nest extremely infrequently in Malaysia (Chan, 1991, 2006), with occasional nesting events occurring on Penang Island, the Turtle Islands Park in Sabah and the Talang-Satang National Park in Sarawak (see Figure 1 for locations).

Green turtles nest predominantly at the Turtle Islands Park and on Sipadan Island off Sabah; at the Talang-Satang National Park in Sarawak; and at numerous beaches in peninsular Malaysia including Ma'Daerah, Redang Island

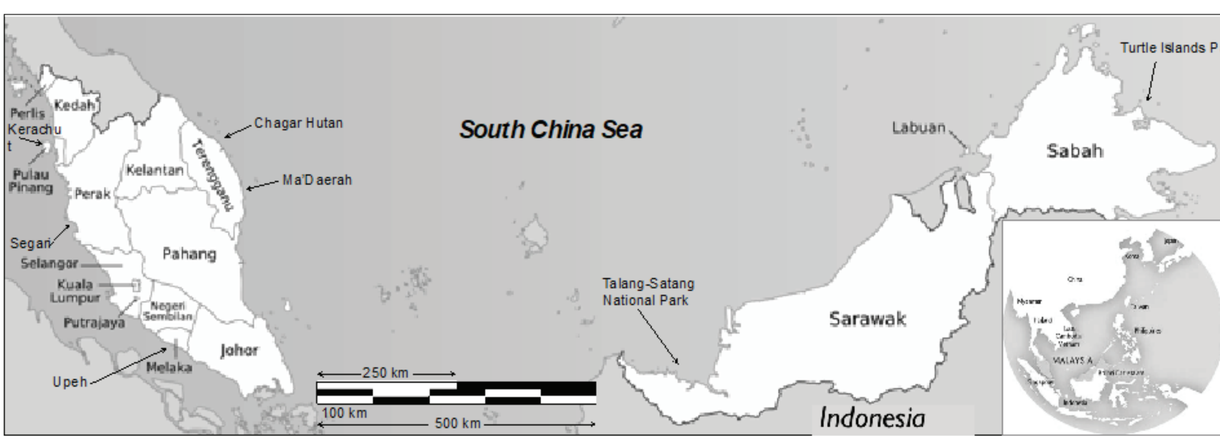

Figure 1. Map of Malaysia highlighting the States and geographical separation of Sabah and Sarawak, along with deployment sites of satellite-tracked sea turtles.

and Setiu in Terengganu, and Segari in Perak (see Figure 1 for locations). Hawksbills nest predominantly at Gulisaan Island (Turtle Islands Park) in Sabah and on Upeh Island and several mainland sites in Malacca. Chagar Hutang also hosts a small number of hawksbills that frequently breed each 2-3 years (Chan & Liew, 1999; Chan, 2013; see Figure 1 for locations). Hawksbill nesting elsewhere in the country is only occasional and widely distributed.

Malaysia is geographically divided by the South China Sea, with peninsular Malaysia States comprising the peninsular extending south of Thailand and ending at the Singapore border, with the two Borneo States of Sarawak and Sabah lying to the east, some 580km at the nearest point between Johor and Sarawak, and some 1600km at the furthest point between Kelantan and Sabah (Figure 1). The physical separation has resulted in marked and often intriguing differences in migration paths by some of the tracked turtles. Particularly, the narrow Malacca Straits separating peninsular Malaysia from Indonesia becomes a physical barrier to widespread oceanic dispersal, and interestingly the narrow Balabac Straits separating Sabah from the western reaches of the Philippines, which may have otherwise been an impediment to widespread movement, are a conservation bottleneck with green turtles regularly traversing the straits in each direction.

The State of Sarawak in Malaysia holds a prominent place in the history of tracking turtles, dating back 65 years when in 1952 John Hendrickson undertook some of the world's very first efforts at tracking green turtles using copper tags drilled on to the rear edge of the carapace off the Talang Talang and Satang Islands (Hendrickson, 1958). Subsequent to these (mostly failed) efforts, Hendrickson moved on to using 'Hasco' Monel cattle ear tags (Hendrickson, 1958), in what later developed into the most common flipper tagging method in use across the world today. Those same flipper tagging techniques are now commonplace at key rookeries in Malaysia, including the Turtle Islands Park in Sabah (Basintal & Lakim, 1993), the Sarawak Turtle Islands (Tisen & Bali, 2000), at Redang Island in Terengganu (Chan & Liew, 1999), and across all major nesting sites in peninsular Malaysia (Sukarno *et al.*, 2007).

Despite multiple decades of flipper tagging involving thousands of sea turtles, little has been revealed about the long-distance migrations and linkages between nesting and foraging grounds with conventional flipper tags. Tag returns from the Turtle Islands Park and from

Figure 2. Map of area surrounding deployment sites of satellite-tracked sea turtles in Malaysia.

the Philippines Turtle Islands Heritage Sanctuary, jointly designated as the Turtle Islands Heritage Protected Area (TIHPA; MoU TIHPA, 1996) have been recovered from Tawi Tawi, Negros Occidental and Mindoro in the Philippines and from the Berau area in Indonesia (Ramirez de Veyra, 1994; Sagun, 2004). But recoveries are rare. Some 5,000 turtles are tagged annually on nesting beaches in Malaysia and several hundred are tagged as foraging turtles (Basintal & Lakim, 1993; Bali & Ganyai, 2007; Isnain, 2008; Pilcher, 2010), but other than the occasional tag returns and encounters of a handful of tagged Malaysian turtles, flipper tagging has not demonstrated the ability to provide robust information on post-nesting migrations and movements of foraging turtles.

Information on location, spatial extent and condition of feeding grounds, along with linkages between nesting and feeding grounds, population demographics at feeding grounds and spatial and temporal habitat use are all considered among the top research priorities for sea turtles at present (Hamann *et al.*, 2010, NRC, 2010). The advent of rapidly developing technology, satellite tracking is now able to respond to many of these information needs (Godley *et al.*, 2008). The international linkages that are determined using satellite tracking can highlight the need for international cooperation (Blumenthal *et al.*, 2006) although caution should be exercised in the deployment of small numbers of tags and over short periods that are unlikely to lead to management and conservation results. Satellite tracking efforts often work best as large collaborations where tracks are coalesced into larger data sets, and that results of satellite tracking need widespread dissemination (Jeffers & Godley, 2016). Satellite tracking can be a useful tool in determining Important Turtle Areas (ITAs; Pilcher *et al.*, 2014) to assist in streamlining conservation efforts for marine turtles (Gredzens *et al.*, 2014; Pilcher *et al.*, 2014; Boudouin *et al.*, 2015).

Malaysia also has a substantial history of working with satellite transmitters starting in 1991, although earlier efforts (which were far more expensive relative to today's costs) largely precluded significant sample sizes - in many cases only one to four turtles were tracked at a time. In recent years there has been a substantially greater investment to use satellite tracking to determine linkages between nesting and foraging grounds in an attempt to better inform management and conservation agencies.

Herein we present a summary of the initial findings of 15 satellite tracking projects by various government agencies and Non Profit Organisations (NGOs) in Malaysia, most of which were carried out as collaborative efforts amongst Malaysian institutions and in some cases with external agencies and Universities (Table I). We do not have access to data for one olive ridley and one leatherback tracked by the department of Fisheries Malaysia. The 15 deployments we summarise here spanned 23 years from 1993 to 2016 and collectively they provide indications of the types of migrations and in many cases the locations of foraging grounds for the two most abundant marine turtle species in Malaysia (greens and hawksbills), and inform management agencies of the need for several close bilateral conservation approaches, and additional protection of habitats in Malaysian waters.

METHODS

Deployment of tags generally occurred with small numbers of turtles (one to five) at Chagar Hutang (Pulau Redang) and Ma' Daerah, Terengganu, Kerachut Beach on Penang Island, TIHPA (Sabah / Philippines), on Tioman Island in Pahang and on Segari Beach, Perak. Somewhat larger samples (10-15) were deployed subsequently from the Talang-Satang National Park in Sarawak and from Upeh Island in Malacca, and the largest samples (24-27) were deployed more recently from Terengganu and the Turtle Islands Park in Sabah (Table 1; see Figure 1 for locations).

Data analysis methods varied across projects, but all satellite signals were sourced from Argos, and data from tags deployed after 2008 were processed by ARGOS using Kalman filtering (www.argos-system.com). WWF-Malaysia and MRF data were automatically downloaded by the Satellite Tracking and Analysis Tool (Coyne & Godley, 2005), filtered to exclude locations over land and selected for location fix qualities 3, 2, 1, A, and B. No additional post-processing or filtering of the data has been performed on these data sets as yet, and they are provided herein to complete the summary of all Malaysian tracking efforts. For turtles deployed by DOFM, SEATRU and Sarawak Forestry Corporation, data were sourced and filtered in a similar manner directly from the Argos service, and mapped independently. We recognise that the lack of filtering and modeling of data could represent errors up to ~1,000m, but for the purposes of tracking general migration routes we suggest that these potential errors are tolerable and that the findings provide a general orientation of tracks and final destinations for many of the turtles.

To develop graphics of all tracks deployed in Malaysia, particularly as some of the older data sets were not available, data were traced in Google Earth™ and plotted using ArcGIS 10.2 (www.esri.com). Where actual data were available, tracks were visually analysed and all points prior to the departure point from the nesting site were categorised as internesting (the period post-deployment until departure from the nesting site). Following an

Table 1. Meta-data for 102 transmitter deployments in Malaysia. Note: There is no data available for the single olive ridley and the single leatherback tracking efforts.

Year Started	Location	State	Species	Number	Life Stage	Capture Method	PTT Type	Partners	Citation
1993	Chagar Hutang	Terengganu	Green	4	Adult	Post-nesting	Telonics ST-3	SEATRU; DOFM	Liew *et al.*, 1995; Papi *et al.*, 1995
1998	Turtle Islands Park	Sabah	Green	4	Adult	Post-nesting	Telonics ST-14	Sabah Parks; OneOcean	Sabah Parks, unpubl. data
1999	Talang-Satang NP	Sarawak	Green	9	Adult	Post-nesting	Telonics ST-14	Sarawak Forestry Corporation; SEATRU	Bali *et al.*, 2002
1999	Talang-Satang NP	Sarawak	Hawksbill	1	Adult	Post-nesting	Telonics ST-14	Sarawak Forestry Corporation; SEATRU	Bali *et al.*, 2002
2000	Turtle Islands Park	Sabah	Hawksbill	3	Adult	Post-nesting	Telonics ST-14	Sabah Parks; US National Marine Fisheries Service	NMFS & Sabah Parks, unpubl. data
2001	Chagar Hutang	Terengganu	Hawksbill	1	Adult	Post-nesting	KiwiSat 101	SEATRU; DOFM	SEATRU, unpubl. data
2005	Ma'Daerah	Terengganu	Green	4	Adult	Post-nesting	KiwiSat 101	Griffith University; DOFM	van de Merwe *et al.*, 2009
2007	Mantanani	Sabah	Green	5	Juvenile	Rodeo	Kiwisat 101	MRF	MRF, unpubl. data
2008	Upeh Island; Terendak Camp	Malacca	Green	15	Adult	Post-nesting	KiwiSat 101	WWF Malaysia; DOFM	Lau *et al.*, 2009
2008	Tioman	Pahang	Green	1	Adult	Post-nesting	Kiwisat 101	DOFM; Japanese Trust Fund IV Program	DOFM, unpubl. data
2008	Ma'Daerah; Setiu; Chagar Hutang	Terengganu	Green	24	Adult	Post-nesting	KiwiSat 101	WWF Malaysia; DOFM; Terengganu State Department of Fisheries	Lau *et al.*, 2009
2011	Chagar Hutang	Terengganu	Hawksbill	2	Juvenile	Head-started	Telonics TGM4325	SEATRU; KLCC Aquaria; Body Shop Foundation	Liew *et al.*, 2012
2013	Segari	Perak	Green	1	Adult	Post-nesting	Kiwisat 101	DOFM; Malakoff Corporation	DOFM, unpubl. data
2015	Kerenchut	Penang	Green	1	Juvenile	Head-started	Kiwisat 101	DOFM; Malakoff Corporation	DOFM, unpubl. data
2015	Turtle Islands Park	Sabah	Green	27	Adult	Post-nesting	SPOT-293A	MRF; Sabah Parks	MRF, unpubl. data

increase in travel speeds and assumption of direct purposeful travel from the nesting site with minimal deviation from a straight path, subsequent location fixes until the commencement of foraging were categorised as migration paths (see Pilcher *et al.*, 2014 for methods). For data sets which were only available as graphics, we determined if the turtle had reached a conclusive foraging ground by an accumulation of location fixes at that location. Unless this was clearly observed, this data set was not used in the determination of final foraging ground locations.

RESULTS & DISCUSSION

A total of 104 satellite transmitters have been deployed on sea turtles in Malaysia since 1993, comprising 79 green turtles (76%), 23 hawksbills (22%), one olive ridley (1%) and one leatherback (1%). Data is available for 102 of these (excluding the solitary olive ridley and leatherback tracks), and among these the track durations ranged from 10 to 625 days with a median of 77 days (Figure 3). Of the 64 post-nesting greens that were tracked, 35 (55%) reached foraging grounds, as determined by a reduction in travel rates and a shift from purposeful migration direction and unidirectional orientation to short distance movements with random heading changes (Schofield *et al.*, 2010; Foley *et al.*, 2013), or by an accumulation of location fixes at the terminal location as depicted by the original track graphic. In contrast, a total of 19 of the 22 hawksbills (86%) also reached foraging grounds. The following sections describe species- or topic-specific implications of turtle movements; a map depicting regions and locations identified in the coming sections is presented in Annex I to maintain clarity of the migration maps.

Green Turtles

Green turtle migrations took on two major forms: (i) coastal movements, whereby turtles remained in waters generally shallower than 100m; and (ii) oceanic movements, whereby turtles migrated out into deeper

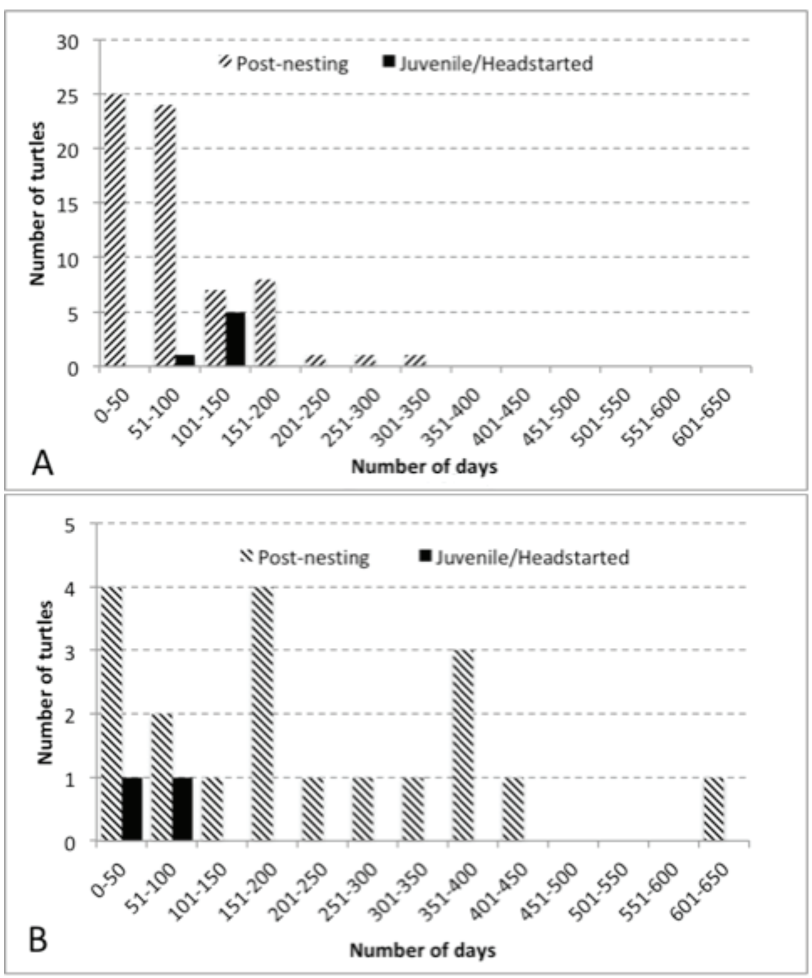

Figure 3. Transmission durations of satellite transmitters deployed on green (A) and hawksbill (B) sea turtles in Malaysia.

waters typically deeper than 3,000m and crossed either the South China Sea or the Sulu and Sulawesi Seas (Figure 4). This differentiation in behaviour patterns was also noted by Papi *et al.* (1995) for the five green turtles tracked in the 1990s. Turtles departing from Terengganu, on the east coast of peninsular Malaysia were far more likely to undertake oceanic migrations (13 out of 29 turtles; ~52%), while only two of 27 (~7%) turtles deployed in Sabah or Sarawak did likewise (one cutting diagonally in a NE direction from the Turtle Islands Park towards the middle of Palawan, and the second swimming due south from the easternmost tip of Sabah to reach Sulawesi. All of the nine turtles deployed from Sarawak remained close to shore for the majority of their migrations, and 25 of 27 turtles (~93%) from the TIP also remained close to shore during their migrations (Figure 4).

The coastal migration behaviour is of note given the prevalence of fishery-based mortality in both peninsular Malaysia (Chan *et al.*, 1988; Chan & Liew, 1996; DOFM, unpubl. data) and the Borneo states (Tisen & Bali, 2000; Jaaman *et al.*, 2009; Pilcher *et al.*, 2009). Tracking efforts by van de Merwe *et al.* (2009) also highlighted how male and female turtles remained within 30km of the nesting beach during the breeding and inter-nesting periods, which includes habitat beyond the 'no trawl zone' designed to protect turtles in this area.

Shrimp fishing in shallow nearshore waters is one of the world's leading causes of sea turtle mortality (NRC, 2010), and in Malaysia there are thousands of registered shrimp trawl vessels. In peninsular Malaysia alone there are some 200 vessels operating along the east coast where most turtles occur. In Sabah there are some 1,500 registered vessels (although not all of these are active, and not all are shrimp trawlers), and in Sarawak another 500 (DOFM, 2015). In recent years Malaysia has moved toward a legal requirement for Turtle Excluder Devices in shrimp trawl nets, with peninsular Malaysia online in October 2017, and full national implementation expected by 2022, in a joint project between the Department of Fisheries Malaysia and the Marine Research Foundation. It is expected that several thousand sea turtles will be saved each year through these efforts.

In terms of overall movements, tracking efforts to date have revealed some interesting findings: Many green turtles deployed in peninsular Malaysia remained quite close to the deployment sites, and given that many of the tag durations were not long, it is possible the turtles had not yet commenced their migration and were still in internesting areas (Figure 4). Among the longer migrations however, there are clear linkages between West and East Malaysia (~1,600km), and between Malaysia and Indonesia (700km to the Riau Islands, ~1,100km to Belitung Island and 1,300km to just north of Jakarta), the Philippines (~1,700km) and one example of a link between Malaysia and Vietnam, some 1,500km distant.

Turtles deployed from Sarawak all stayed extremely close to shore as they moved northeast towards Sabah. Several of these turtles stopped in Labuan/Lawas Bay (a known seagrass habitat) for a period before continuing on with their journeys (Bali *et al.*, 2000), and it is possible that they were feeding and replenishing energy supplies following a lengthy nesting season. Interestingly, all turtles headed northwest out through the narrow Balabac Straits to enter the Sulu Sea and then dispersed in various southwest directions, reaching foraging grounds in Tawi Tawi, southern Palawan, southeast Sabah and as far south as the Berau district in East Kalimantan, Indonesia (a minimum displacement of >2,000km). While these were all coastal movement types, the Sarawak migrations represent long migrations of ~1,200km to ~2,000km (Figure 4, northern-most reaching track).

Turtles deployed from Sabah mostly stayed coastal, with the longest track being one turtle that moved north to Palawan, continuing in a northeast direction up and around the north of Panay Island then southeast, settling eventually around Talong Island in the Visayan Sea, some 1,800km afar. Two Sabah turtles went counterclockwise out of the Sulu Sea and into the South China Sea, counter to the movements of Sarawak turtles, with turtles taking up residence close to the Klias peninsula in southwest Sabah, some 800km away. The balance of migrations headed to three main areas: southern Palawan Island and Balabac Island, at the western extent of the Philippines and just northwest of Sabah; south into Indonesia to the Berau District of East Kalimantan (Borneo) and Sulawesi; and south to other coastal sites in Sabah.

Some of the turtles from the Turtle Islands Park headed to southeast to an area just outside (in deeper waters) of the Sun Sakaran Marine Park, and one headed north to the Tun Mustafa Park, highlighting the value of Marine Protected Areas (MPAs) in safeguarding sea turtle habitat (Figure 5). These areas are all protected by Sabah Parks via State legislation. Recent work at a global level highlights how MPAs are important for safeguarding sea turtle habitat at various stages of their life cycle (Scott *et al.*, 2012), who demonstrated that turtles aggregate in designated MPAs far more than would be expected by chance when considered globally (35% of all turtles were located within MPAs) or separately by ocean basin (Atlantic 67%, Indian 34%, Mediterranean 19%, Pacific 16%). In addition, Scott *et al.* (2012) also showed that the size, level of protection and time of establishment

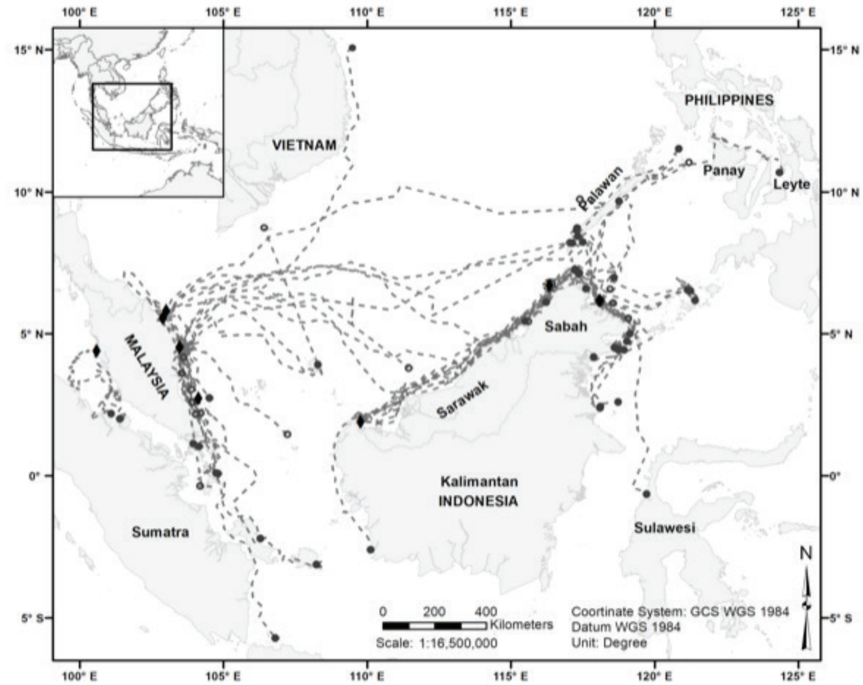

Figure 4. Post-nesting migration routes of all satellite-tracked green sea turtles deployed at key Malaysian nesting beaches (open circles represent track end points that did not reach foraging grounds; filled circles represent track end points that did reach foraging grounds; black diamonds are release points). Graphics based on the original work by Papi *et al.* (1995), Bali *et al.* (2002), DOFM (unpublished and unfiltered data), Lau *et al.* (2009), van de Merwe *et al.* (2009), MRF and Sabah Parks (unpublished and unfiltered data).

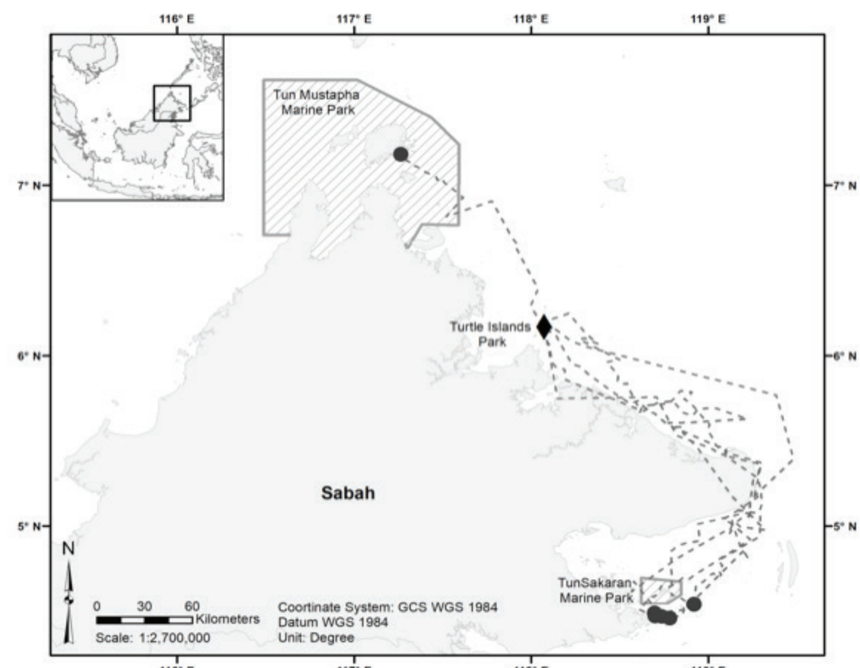

Figure 5. Movements of nesting green sea turtles in Sabah from one marine protected area (Turtle Islands Park) to the Tun Mustafa and Tun Sakaran Marine Parks (Black diamond is the release site, black filled circled final foraging ground locations). Graphics based on original work by MRF (unpublished and unfiltered data).

of MPAs affects the likelihood of MPAs containing foraging turtles, highlighting the importance of large, well-established reserves. Tracking results from Sabah reinforce these results and highlight how important these protected areas are for green turtles, but also demonstrate how (at least in the case of the Tun Sakaran Marine Park) the area is not extensive enough to protect the majority of important turtle foraging habitats, and that an eastward and southward expansion of the MPA boundaries might more effectively safeguard the species.

An additional note related to the coastal migration behaviour lies in the interpretation of conventional tag return information. Sagun (2004) reported on recoveries of tags from the Turtle Islands Heritage Protected Area, providing information on 17 turtles. Ramirez de Veyra (1994) similarly reported on recapture locations of another two turtles moving from the Turtle Islands Park in Malaysia to Puerto Princesa in Palawan and to Bacolod in Negros Occidental. But given the lack of any movement data for the intervening period between last nesting records and subsequent recapture, migration assumptions acquire a 'straight-line' form as the turtles disperse (Figure 6, left). However, satellite tracking of the same species of sea turtles, often to similar locations, paints a very different picture, with turtles studiously avoiding the deep water trenches of the Sulu Sea and preferring instead to take more circuitous and *coastal* movements (Figure 6, right).

One last note on the movements of green turtles relates to the one tag deployed from Terengganu which moved southeast to reach the Riau Islands in Indonesia (sitting between Terengganu and Sarawak, a site that was a known turtle destination. However, in this particular case, the next time the tag was active the turtle had moved all the way to the Con Dao Islands in Vietnam. The cessation of signals, and subsequent reception of signals for a brief period in the vicinity of Vietnam is suggestive of fisheries bycatch or purposeful capture. There is a substantial problem with sea turtle poaching in Southeast Asia (MIMA, 2009), and this particular turtle's data could indicate it was part of that trade. When the signals ended the turtle could have been kept in the hold of the vessel where signal reception was not possible, and the short subsequent reappearance of data from Con Dao might be suggestive of someone noting that the transmitter might provide location

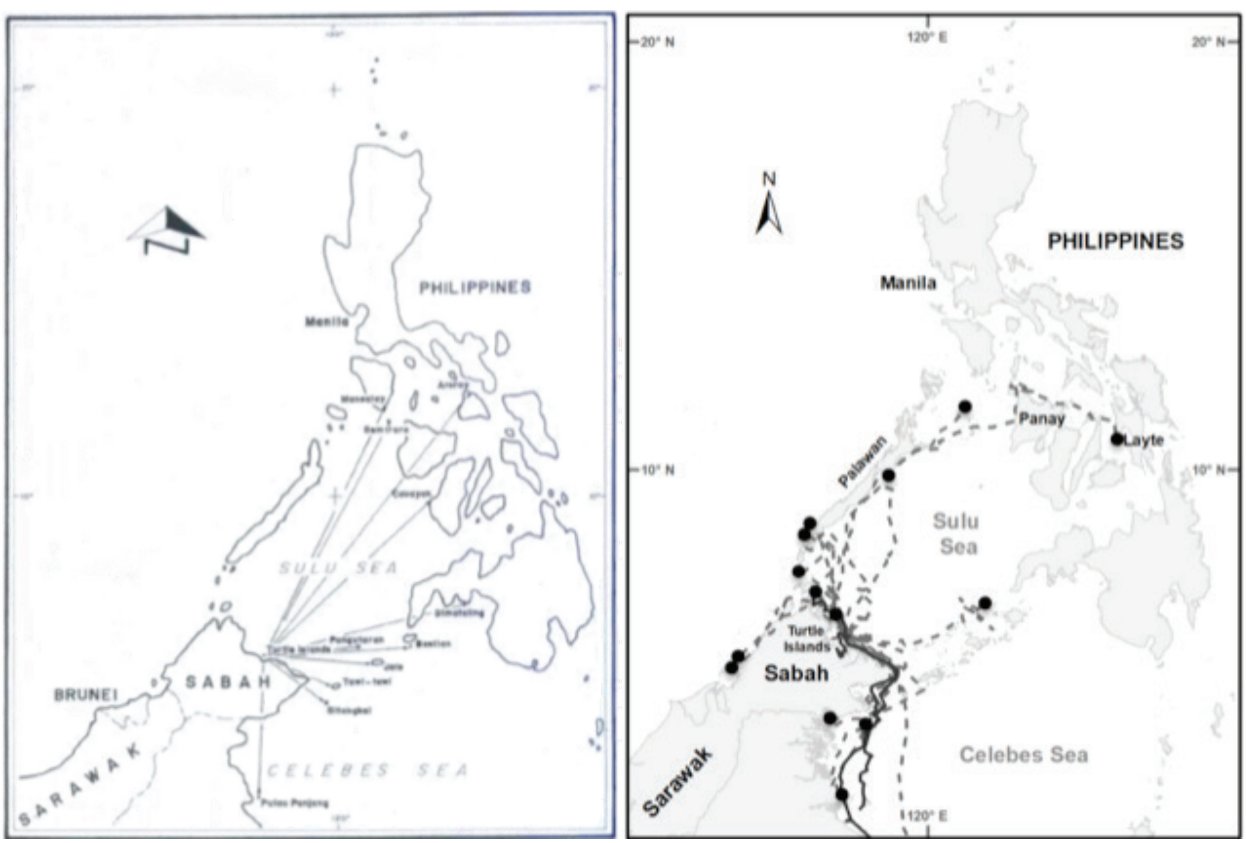

Figure 6. Inferred post-nesting migration routes green sea turtles from the Turtle Islands Heritage Protected Area from flipper tag recoveries (left; Sagun, 2004), alongside actual migration trajectories determined via satellite tracking (right; MRF, unpublished and unfiltered data). Black circles indicate end-points of the satellite tracks.

data and the transmitter being disarmed or discarded.

Hawksbill Turtles

Comparatively fewer hawksbills have been tracked in Malaysia (Figure 7), with the most intensive effort that of WWF Malaysia in partnership with the Department of Fisheries Malacca between 2008 and 2013 (Lau *et al.*, 2009). This project tracked 15 turtles from both the only remaining island rookery and from two sites on the mainland of Malacca state, and found that nearly without exception the sea turtles migrated southeast towards the Riau archipelago in Indonesia, south of Singapore (inset, Figure 7), where they remained for substantially longer periods than all other turtles tracked in Malaysia (an average of 227 days, range 16-625 days, SD=173.89). These turtles were confined geographically by the narrow Straits of Malacca, with the large island of Sumatra to the west. However, unlike some of the green turtles that migrated far further south (see lower left, Figure 4), none of the Malacca hawksbills moved beyond Riau. This confined migration opens up a well-defined and small-scale bilateral cooperation opportunity for hawksbill turtle conservation between Malaysia and Indonesia. Although a track is not available for the adult hawksbill studied in 1995, this turtle also swam south and settled in the Riau archipelago, further strengthening that link. Of the two head-started turtles from Chagar Hutang, one did not move from the waters close to the island, while the second headed northeast towards the southern shores of Vietnam (Liew *et al.*, 2012). Unfortunately, this turtle did not take up residence at a foraging ground, with the transmitter ceasing before the turtle reached

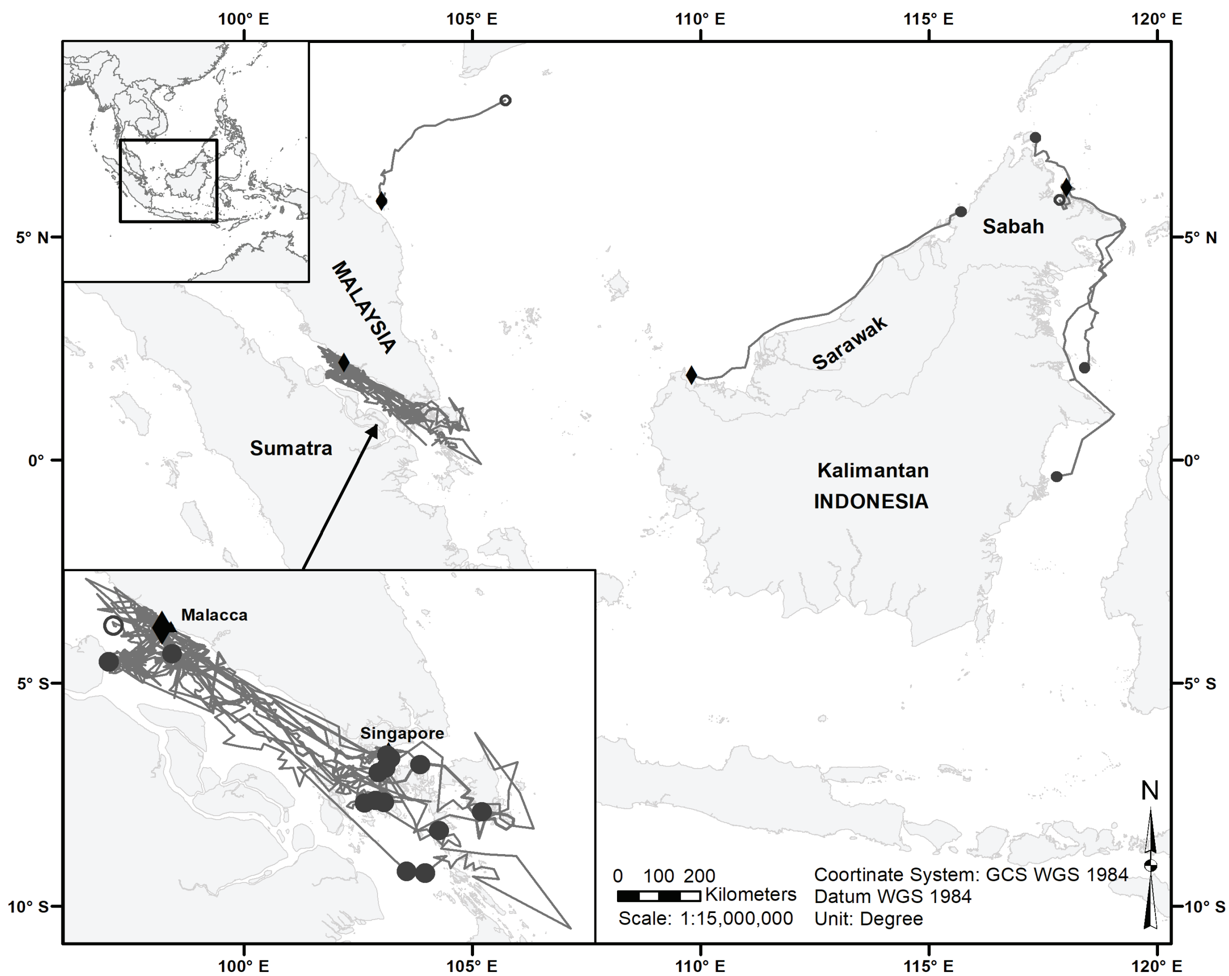

Figure 7. Routes of all satellite-tracked hawksbill sea turtles deployed at key Malaysian nesting beaches (open circles represent track end points that did not reach foraging grounds; filled circles represent track end points that did reach foraging grounds; black diamonds are release points). Northernmost track from Terengganu was a head-started turtle. All others were post-nesting migrations. Graphics based on the original work by Bali *et al.* (2002), Lau *et al.* (2009), Liew *et al.* (2012) and Sabah Parks (unpubl. data).

the Con Dao archipelago (upper track, Figure 7).

Hawksbills tracked from Sarawak and Sabah all adopted the coastal movement behaviour, rarely moving off the coastal shelf and staying within the confines of the island of Borneo (Bali *et al.*, 2002, Sabah Parks, unpubl. data). Unfortunately sample sizes are low, and further work is needed to elucidate the true nature of habitat use for hawksbills leaving rookeries in Sabah and Sarawak. However, while the turtles did not move off the Borneo shelf, movements were substantial for three of the turtles: One moved some 830km from Sarawak to Membakut in Sabah, another moved 1,050km from the Turtle Islands to an area near Samarinda in Indonesia, and a final one moved 520km from the Turtle Islands Park to Kakaban Island in Indonesia. These long distance movements suggest that the notion of hawksbills being more sedentary than other species (e.g. Chung, 2009) may be less applicable to many of the Borneo hawksbills. This is also supported by recent tracking of hawksbills in the Seychelles where turtles have undertaken long migrations, with one of them moving nearly 4,000km (Hays *et al.*, 2014).

Regional Significance

Notwithstanding the local extinction of the leatherback and the virtual cessation of olive ridley nesting, Malaysia remains home to some of the more robust populations of green and hawksbill sea turtles in Southeast Asia (Shanker & Pilcher, 2003). These turtles are a shared resource given the extensive movements and the genetic linkages amongst foraging and nesting stocks (see Joseph, 2006; Joseph *et al.*, 2014, 2016), and understanding movements and interlinkages between nesting populations and foraging stocks is becoming increasingly more important with rising pressures on the marine environment. At the regional level the various populations combine to form Regional Management Units (RMUs; Wallace *et al.*, 2010) based on shared genetic backgrounds, distribution of foraging grounds, and known migrations. The tracking efforts in Malaysia go a long way to contributing to refining the boundaries of green and hawksbill sea turtle RMUs, and provide substance to status assessments undertaken by entities such as the IUCN SSC Marine Turtle Specialist Group. The differentiation between coastal and oceanic migrations, and the selection of identifiable foraging habitats provide regional and Malaysian management agencies with a wealth of information on which to build conservation agendas for these species. Bycatch reduction on coastal waters remains a key priority, but so do bilateral agreements and on-the-ground programmes to protect turtles at the various life stages and in the varied locations identified by this work. We believe there is still a lot more to be done as relates to tracking sea turtles from Malaysian rookeries to safeguard sea turtles, but we also believe the foundations of much of this work have already been laid by the legacy of the work we summarise herein.

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SATELLITE TRACKING OF MARINE TURTLES IN THE SOUTH-EASTERN INDIAN OCEAN: A REVIEW OF DEPLOYMENTS SPANNING 1990-2016

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INTRODUCTION

Satellite telemetry is an indispensable technology for obtaining quantitative information about distribution, behaviour, movements and habitat use by many marine fauna species (Cooke, 2008; Hussey *et al*., 2015). For marine turtles, there remains a recognised bias in species and age class of turtles being tagged (Godley *et al*., 2008). Identifying these biases and regional knowledge gaps is a first step in making informed decisions about future conservation strategies for the protection of marine turtle species (Hays *et al*., 2016).

Six species of marine turtle occur in the south-eastern Indian Ocean region (Figure 1): green turtles (*Chelonia mydas*), flatback turtles (*Natator depressus*), loggerhead turtles (*Caretta caretta*), hawksbill turtles (*Eretmochelys imbricata*), olive ridley turtles (*Lepidochelys olivacea*) and leatherback turtles (*Dermochelys coriacea*). The region supports some of the largest marine turtle populations in the world (Dethmers *et al*., 2006; Limpus, 2009), with green and flatback turtles being the most abundant species (Limpus, 2009; Waayers *et al*., 2015; Commonwealth of Australia, 2017).

Satellite telemetry studies on marine turtles in the south-eastern Indian Ocean region have led to a better understanding of their inter-nesting areas (Sperling, 2007; Waayers, 2011; Whittock *et al*., 2014; Thums *et al*., 2017; Whittock *et al*., 2017), migratory pathways (Kennett *et al*., 2004; Whiting *et al*., 2007, 2008; Pendoley *et al*., 2014; Thums *et al*., 2017, 2018) and the location of key foraging areas (Pendoley, 2005; McMahon *et al*., 2007; Waayers *et al*., 2015; Hoenner *et al*., 2016; Whittock *et al*., 2016a; Thums *et al*., 2017). However, these publications report only a fraction of tags that can be found on seaturtle.org or other public web portals. Furthermore, many of the unpublished studies undertaken on behalf of industry (as part of environmental approval processes) and by conservation groups are not always reported in the peer-reviewed literature.

The key objective of this paper is to provide an exhaustive list of satellite tag deployments across species, Management Units (MUs), age classes and geographic scales to identify key ecological and regional gaps. Identifying these gaps should help to guide future satellite tag deployments and inform management priorities in the South-Eastern Indian Ocean (SEIO).

METHODS

Study area

The south-eastern Indian Ocean region covers a large portion of the Australian coastline (Figure 1). For this review, we used the formal definition of the Indian Ocean boundary (International Hydrographic Organisation, 1953), and included the marginal Timor and Arafura Seas to define a deployment envelope bounded by the Australian Economic Exclusion Zone (EEZ), which extends up to 200nm from the Australian territorial sea baseline. This area covers the coastline of Western Australia, Northern Territory, Gulf of Carpentaria, Northwest Cape York and offshore islands including Cocos (Keeling) Islands and Christmas Island (Figure 1).

The recently updated Recovery Plan for Marine Turtles in Australia (RPMTA) (Commonwealth of Australia, 2017) provides specific locations of nesting sites and MUs in Australia. Due to the spatial limitations of the study area, two of the MUs were split along the Cape York Peninsula, including the northern Queensland hawksbill turtle MU, and the Arafura flatback turtle MU.

Data collection

We collated and analysed the metadata on the deployment of satellite tags from peer-reviewed literature, conference proceedings, Environmental Impact Assessment (EIA) technical reports, University theses, Non-Government Organisation (NGO) reports, seaturtle.org and personal communication from researchers throughout the region and included what we believe to be all satellite tag deployments between the first release in 1990 through to December 2016. Online searches of known nesting locations within the region were undertaken in seaturtle.org and compared with information extracted from published and grey literature to avoid replication of tag numbers. Permission was obtained from the project owner (as listed on seaturtle.org) to use the location and year of deployment metadata for this paper. Partners and sponsors of the projects were also identified to recognise their contribution.

The metadata included species, life stage (adult, sub-adult and juvenile), deployment type (e.g. nesting, in-water or rehabilitation release), gender, primary owner, type of institution (government, resource industry, private business, NGO, university), location of deployment and associated MU and year of deployment. The number of tags was tallied for each location, with details of the primary owner and any publicly available peer-viewed papers, conference proceedings and reports resulting.

Data analysis

To illustrate the extent of satellite telemetry studies on turtles in the SEIO region, we computed the number of tags deployed on each species per year, organisation and MUs between 1990 and 2016. Additionally we

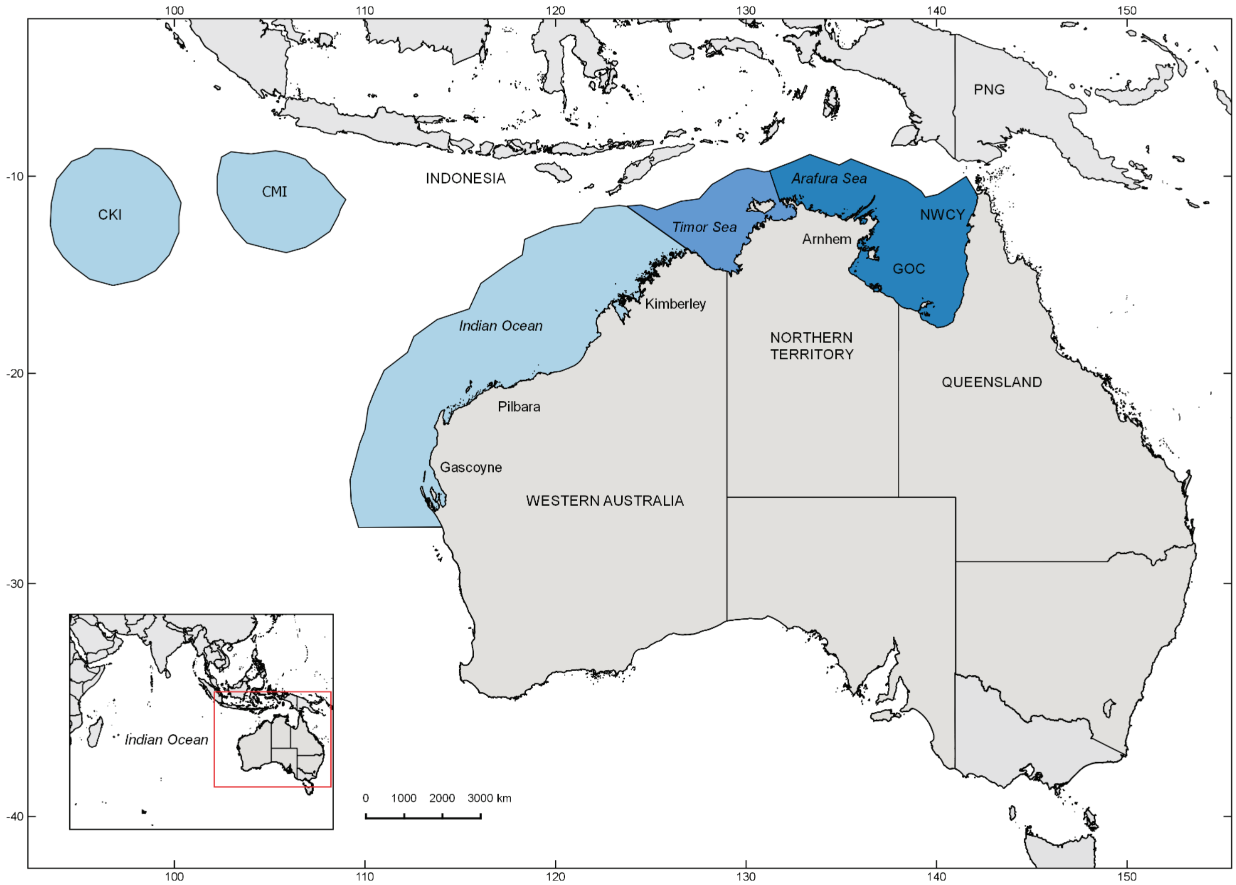

Figure 1. Location map of the south-eastern Indian Ocean including the marginal seas and offshore islands. For colour, see pdf version available online.

compared the spatial distribution and abundance of satellite tag deployments to known nesting locations within MUs in QGIS (QGIS Development Team, 2017).

RESULTS

Satellite tag deployments

Deployment metadata gathered from multiple sources identified a total of 622 satellite tags were deployed on marine turtles in the SEIO region spanning 1990 to December 2016. Of these deployments, 540 tags (87 %) were deployed on nesting female turtles (Table 1), 67 (11 %) on free-swimming wild turtles (including 13 female adults, 14 male adults, 17 sub-adults and 23 juveniles) and 15 (2%) on rehabilitated turtles released at designated locations (Table 2).

A total of 28 project owners and 61 associated partners and sponsors were involved in the deployment of satellite tags in the SEIO region. Most satellite tags were deployed by government agencies (247 tags; 40%) and resource industry (237 tags; 38%), with lesser contributions by NGOs (71 tags; 11%), private business (39 tags; 6%) and universities (28 tags; 5%) (Table 2). The owners that have deployed the most tags were the Department of Biodiversity Conservation and Attractions (150 tags; 24%) and Chevron (119 tags; 19%), with fewer deployments from Pendoley Environmental (39 tags; 6%), Rio Tinto (36 tags; 6%), Woodside (34 tags; 5%) and Conservation Volunteers Australia (31 tags; 5%). Over half of all deployments were made on flatback turtles (341 tags; 55%), with fewer tags deployed on other species including green turtles (165; 26%), loggerhead turtles (51 tags; 8%), hawksbill turtles (37 tags; 6%), and olive ridley turtles (28 tags; 5%) (Figure 2). No leatherback turtles have been tagged in this region to-date.

Given that many of the projects identified in this study presented the same data in multiple sources (e.g. peer reviewed journals, conference proceedings, technical reports (e.g. EIA reports, NGO annual reports) and on seaturtle.org), we have presented the highest level of publication for each project. Of the 66 projects identified in this study, 18 projects (27%) published their data in peer reviewed journals, six projects (9%) presented at conferences and were published in the proceedings, one

Table 1. Satellite tags deployed on adult female turtles in the southeast Indian Ocean. (To follow links to seaturtle.org data use http://www.seaturtle.org/tracking/index.shtml?project_id="*add number given in table*"). Note that multiple owners have deployed tags in the same location.

Management Unit	Deployment Location	No. of tags	Owner & Partners	Data Sources (seaturtle.org Project ID and/or Publication)
Flatback turtles				
Arafura	Crocodile Is. (CDI)	2	NAMRA	802
	Cobourg Pen. (CP)	4	CVA	894
	Field Is. (FI)	4	KNP, DEE	1033
	Sir Edward Pellew (SEP)	6	LSR, WWF, PWNT	49, 99
	Jardine River (JR)	2	ALT, EHP	1046
	Bare Sand Is. (BSI)	13	CDU, ATI, Cardno, Inpex	1145, Sperling (2007, 2008, 2010)
	C. Domett (CD)	15	DBCA, MGR, DNRETAS	417, 1120
Cape Domett	West Governor Is. (WGI)	1	DBCA, BR	1232
Unknown	Maret Is. (MI)	8	Inpex, DBCA, WGR	1232, Waayers (2014), Waayers & Fitzpatrick (2012)
	Lacepede Is. (LPI)	11	WEL, RPS	611, Waayers *et al*. (2011), Thums *et al*. (2015, 2017)
Southwest Kimberley	C. Villaret (CVL)	21	CVA, WEL	462, 567, 670, 689, 803, 951, McFarlane & Mueller (2012)
	Eighty Mile Beach (EMB)	29	DBCA, NYTO, KTO, NGTO, BHP	689, 1053
	Ashburton Is. (ABI)	4	Pendoley	RPS (2010), Whittock *et al*. (2016b)
Pilbara	Delambre Is. (DLI)	5	RIO	Metadata supplied by Rio Tinto, Waayers *et al*. (2015)
	Locker Is. (LI)	8	DBCA	1168
	Mundabullangana (MBG)	8	CVX, Pendoley	112, 195, Pendoley *et al*. (2014), Whittock *et al*. (2014, 2016a, b), Waayers *et al*. (2015)
	Montebello Is. (MBI)	15	DBCA	1175
	Thevenard Is. (TVI)	20	DBCA, Pendoley	1181, Pendoley *et al*. (2014), Whittock *et al*. (2014, 2016a, b), Waayers *et al*. (2015)
	Port Hedland (PHL)	30	BHP, Pendoley	685, Whittock & Pendoley (2012), Waayers *et al*. (2015)
	C. Lambert (CLB)	31	RIO, DBCA	579, 795, Waayers *et al*. (2015)
	Barrow Is. (BWI)	89	CVX, Pendoley	108, 194, 264, 354, 457, 575, 695, 941, Pendoley (2005), Pendoley *et al*. (2014), Whittock *et al*. (2014, 2016a, b), Waayers *et al*. (2015)
Green turtles				
Unknown	Crocodile Is. (CDI)	1	NAMRA	802
Gulf of Carpentaria	Cobourg Pen. (CP)	2	NTG, CVA	319
	Djulpan Bch. Arnhem (DBA)	20	NTU, DLMAC	802, Kennett *et al*. (2004)
	Ashmore Reef (AMR)	1	GBRPA, DEE	Spring & Pike (1998)
Ashmore	Cocos (Keeling) Is. (CKI)	6	BI, CDU, PA	Whiting *et al*. (2008)
Cocos Keeling	Scott Reef (SR)	17	CDU, WEL, SKM, MU, BHP, Pendoley	17, 478, Pendoley (2005)
Scott - Browse	North West Cape (NWC)	3	DBCA	Mau *et al*. (2012), Waayers *et al*. (2015)
Northwest shelf	Montebello Is. (MBI)	6	DBCA	Metadata supplied by DBCA
	Lacepede Is. (LPI)	11	WEL, RPS	Waayers *et al*. (2011, 2015)
	Barrow Is. (BWI)	33	Pendoley, CVX, MU	40, 197, 956, Waayers *et al*. (2015)
	Maret Is. (MI)	21	Inpex, RPS	Waayers (2014), Waayers & Fitzpatrick (2012), Waayers *et al*. (2015)

Table 1 cont.

Management Unit	Deployment Location	No. of tags	Owner & Partners	Data Sources (seaturtle.org Project ID and/or Publication)
Loggerhead turtles				
Western Australia	Montebello Is. (MBI)	1	DBCA	Metadata supplied by DBCA
	Dirk Hartog (DH)	5	DBCA, Aubrey Strydom	Metadata supplied by DBCA
	Muiron Is. (MRI)	5	DBCA, Aubrey Strydom	1176
	North West Cape (NWC)	9	DBCA, NTP, DEE	265, Mau *et al*. (2012), Waayers *et al*. (2015)
	Gnaraloo (GNL)	10	GTCP, Aubrey Strydom	1149, Strydom *et al*. (2017)
Hawksbill turtles				
Northeast Arnhem Land	Groote Eylandt (GEI)	12	WWF, ALC, DRETAS	94, 320, 341, Whiting *et al*. (2006), Hoenner *et al*. (2015), Lambert *et al*. (2015)
	Evans Shoal (ES)	1	DLRM, Inpex, Cardno	983
North Queensland	Woody Wallis Is. (WWI)	1	JCU	Hoenner *et al*. (2015)
Unknown	Montebello Is. (MBI)	5	DBCA	Metadata supplied by DBCA
Western Australia	Varanus Is. (VNI)	6	Pendoley	Pendoley (2005); Waayers *et al*. (2015)
	Rosemary Is. (RMI)	10	DBCA, MR, Pendoley	1136, Pendoley (2005), Waayers *et al*. (2015)
Olive Ridley turtles				
Northern Territory	Crocodile Is. (CDI)	3	NAMRA	802, Metadata supplied by NAMRA
	Wessel Is. (WSL)	4	WWF, TLC, CCA	McMahon *et al*. (2007); Hamel *et al*. (2008)
	Tiwi Is. (TI)	8	CDU, UWS, GMR	19, 78, Whiting *et al*. (2007)
	Marpoon (MPN)	9	EHP	Metadata supplied by EHP
	Aurukun (AKN)	1	EHP	Metadata supplied by EHP

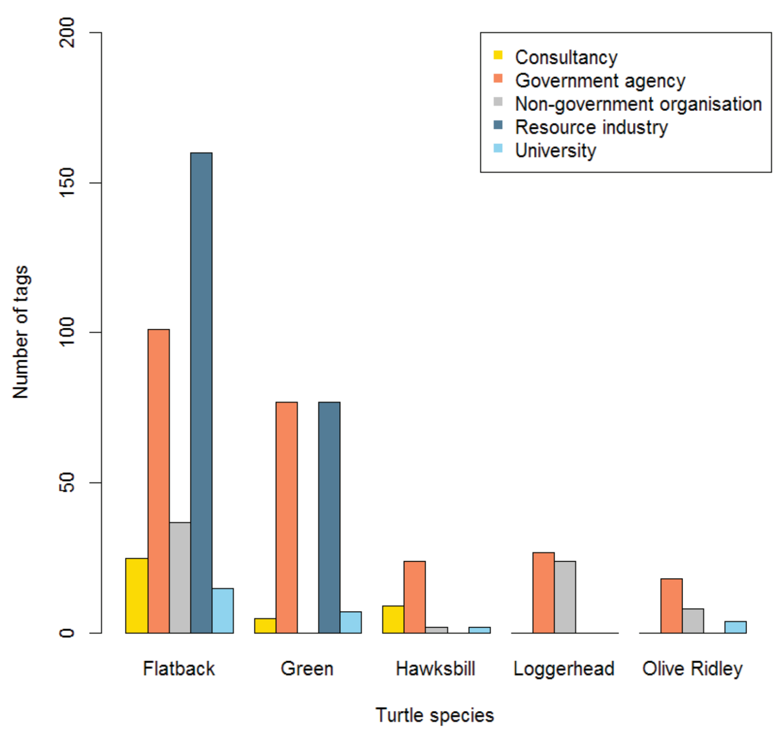

Figure 2. Number of tags deployed on each species by project owner. For colour, see pdf version available online.

Table 2. Satellite tags deployed on wild and rehabilitated juvenile and sub-adult sea turtles in the southeast Indian Ocean. (To follow links to seaturtle.org data use http://www.seaturtle.org/tracking/index.shtml?project_id= "*add number given in table*"). Note that multiple owners have deployed tags in the same location.

Management Unit	Deployment Location	Deployment Type: Juvenile		Sub-adult female	Adult female		Adult male	Owner & Partners	Data Sources (seaturtle.org Project ID and/or Publication)
		wild	rehab.	wild	wild	rehab.	wild		
Flatback turtles									
Arafura	Bare Sand Is. (BSI)	2						NAMRA	Metadata supplied by NAMRA
Unknown	Darwin (DWN)					2		NAMRA	Metadata supplied by NAMRA
SW Kimberley	Eighty Mile Beach (EMB)		2					FAU, DBCA, AQWA	1053
	Eighty Mile Beach (EMB)	8						DBCA	1074
Unknown	Cable Beach (CB)	1						DBCA, AQWA, DDC, NREC, OP, PZ	Metadata supplied by DBCA
Green turtles									
Cocos Keeling Is.	Cocos Keeling Is. (CKI)	2					1	DEE, BI	pers.comm. to S. Whiting
Northwest shelf	North West Cape (NWC)	4			12			CSIRO, BHP, DBCA, WAPF	814, 1101
	One Arm Pt. (OAP)			10	2			CSIRO, BJR, DBCA	1091
	Shark Bay (SB)	2			3			DU, DBCA	Metadata supplied by DBCA
	Roebuck Bay (RBB)	2						DBCA, YR	1157
Unknown	Bare Sand Is. (BSI)	2						CDU, ATI	1148
Arafura	Wanuwuy beach (WB)	1						NAMRA	Metadata supplied by NAMRA
Loggerhead turtles									
Western Australia	North West Cape (NWC)		5					DBCA, AWA, DDC, NREC, OP, PZ	879
	Montebello Is. (MBI)			1	1			DBCA	Metadata supplied by DBCA
	Shark Bay (SB)				3		11	FIU, DBCA, YTO	Olson *et al*. (2012), Wirsing *et al*. (2004)
Hawksbill turtles									
Unknown	Fog Bay (FGB)	1						CDU, ATI	Whiting *et al*. (2010)
	Cocos Keeling Is. (CKI)	2						DE, BI	Whiting & Koch (2006)
Olive Ridley turtles									
Northern Territory	Wanuwuy beach (WB)	1						NAMRA	Metadata supplied by NAMRA, Dethmers (2016)
	Bare Sand Is. (BSI)	1						NAMRA	Metadata supplied by NAMRA
Unknown	Roebuck Bay (RBB)					1		DBCA	Metadata supplied by DBCA

Acronyms in Tables 1 and 2 represent the following institutions:

AIMS=Australian Institute of Marine Science, ALC=Anindilyakwa Land Council, ANU= Australian National University, ALT=Apudthama Land Trust, AS=Aubrey Strydom, ATI=AusTurtle Inc, AWA=Aquarium of Western Australia, BHP=BHP Billiton, BI=Biomarine International, BJR=Bardi Jawi Rangers, BR=Balanggarra Rangers, BTO=Bunidj Traditional Owners; Cardno=Cardno Ecology Lab, CCA= Coast Care Australia, CDU=Charles Darwin University, CFHA=Care for Hedland Association, CSIRO=Commonwealth Scientific and Industrial Research Organization, CVA=Conservation Volunteers Australia, CVX=Chevron Australia, DBCA=Department of Biodiversity, Conservation and Attractions, DDC=Dolphin Discovery Centre, DEE=Department of Environment and Energy, DLMAC=Dimurru Land Management Aboriginal Corporation, DLRM=Department of Land Resource Management, DNRETAS=Department of Natural Resources, Environment, the Arts and Sport, DU=Deakin University, DEHP=Department of Environment and Heritage Protection; FAU=Florida Atlantic University, FIU=Florida International University, GBRMPA=Great Barrier Reef Marine Park Authority, GMR=Gumurr-Marthakal Rangers, GTCP=Gnaraloo Turtle Conservation Program, Inpex=Inpex Ichthys Project, JCU=James Cook University, KNP=Kakadu National Park staff, KTO=Karajarri Traditional Owners, LSR=Lianthawarriyarra Sea Rangers, MGR=Miriuwung - Gajerrong rangers, MR=Murujuga Rangers, MU=Murdoch University, NAMRA=Northern Australian Marine Research Alliance (alliance between AIMS, CDU, ANU and NTG), NGTO=Ngarla Traditional Owners, NREC=Naragebup Regional Environment Centre, NTG=Northern Territory Government, NTP=Ningaloo Turtles Program, NTU=Northern Territory University, NYTO=Nyangumarta Traditional Owners, OP=Ocean Park, PA=Parks Australia, Pendoley=Pendoley Environmental, PWNT=Parks and Wildlife of the Northern Territory, PZ=Perth Zoo, RIO=Rio Tinto, RPS=RPS Environment and Planning, SFU=Simon Fraser University, SKM=Sinclair Knight Merz, TLC=Tiwi Land Council, UWS=University of Wales Swansea, WAPF=Western Australian Department of Fisheries, WEL=Woodside Energy Ltd, WGR=Wunambal Gaambera Rangers, WWF=World Wildlife Fund for Nature (Australia), YTO=Yajgalah Traditional Owners, YR=Yawuru Rangers.

project was published in a PhD thesis, and 41 projects (62%) have not been published. Of the projects that have not published their data, metadata was only available from seaturtle.org (25 projects), directly sourced from the owner (10 projects), or found in technical reports (6 projects). The majority of projects (62%) uploaded their data on seaturtle.org. Data from tags deployed by the resource industry were available through publications in peer reviewed journals, proceedings, online technical reports or seaturtle.org. The majority of the unpublished data was from tags deployed by government agencies, however many of these tags were deployed in the past few years.

The first satellite tag in the region was released on a green turtle at Ashmore Reef in 1990 with no other tags deployed until 1998. Satellite tags were deployed sporadically between 1998 and 2008, with a dramatic increase in deployments by industry in 2009 (Figure 3). Many of the tags deployed in 1998 were on flatback and green turtles (Figure 3). There was a steady distribution of tags deployed between 2010 and 2014, with another increase in deployments in 2015 and 2016 (Figure 3). The deployments in the last two years appear to target multiple species more evenly.

Spatial distribution of satellite tags

Of the tags deployed on flatback turtles, the greatest proportion were deployed in the Pilbara (210 tags; 62%), followed by the southwest Kimberley (71 tags; 21%) and Arafura Sea (33 tags; 9%) (Figure 4). Of the larger nesting rookeries of flatback turtles in the Pilbara, Barrow Island is well represented (89 tags; 26%), with fewer deployments from Mundabullangana (8 tags; 2%) and Cape Domett (15 tags; 4%) (Figure 5). Other key rookeries where deployments occurred included Eighty Mile Beach, Cape Lambert, Port Hedland, Cape Villaret and Thevenard Island. Nesting beaches where no tags have been deployed included the northwest Kimberley region, north Cobourg Peninsula, northeast Arnhem Land, Groote Eylandt Islands, Wellesley Islands and northwest Cape York (Figure 5).

The greatest proportion of tags deployed on green turtles was within the Northwest Shelf (109 tags; 67%) (Figure 5). Other MUs with substantial sampling included the Gulf of Carpentaria (24 tags; 15%), Scott Reef (17 tags; 10%) and Cocos Keeling (9 tags; 6%) (Figure 6). Rookeries with >20 tags within the Northwest Shelf MU included Barrow Island, the Maret Islands and

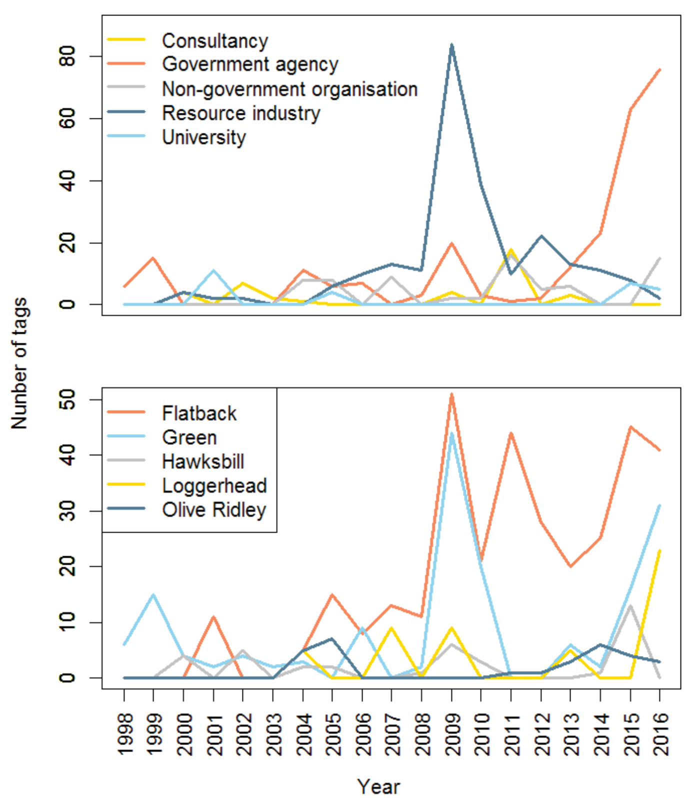

Figure 3. Number of tags deployed by organisation type (top) and on each species (bottom) over time between 1998 and 2016. The only deployment prior to 1998, not represented here, was on a green turtle by a government body. For colour, see pdf version available online.

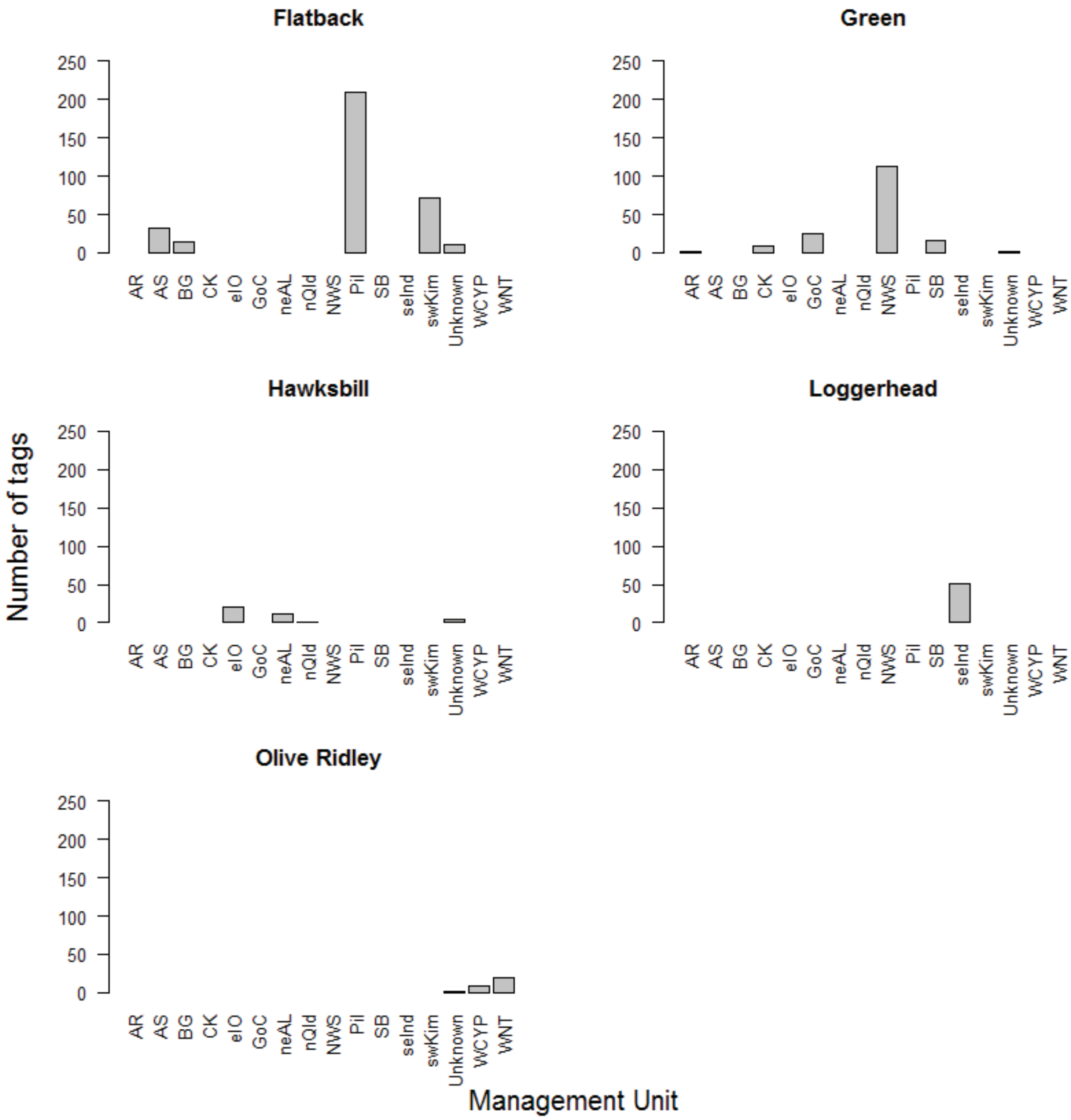

Figure 4. Number of tags deployed on each species by management unit.

Northwest Cape (Figure 6). Wild juvenile and adult green turtles were recently (2013-onwards) tagged in waters off the Northwest Cape and One Arm Point (28 tags).

In the Gulf of Carpentaria, most tags were deployed on nesting turtles at Djulpan Beach (20 tags), with one tag deployed at Djulpan beach, Wanuwuy beach, Crocodile Islands and Cobourg Peninsula. Green turtles at different life stages have been tagged at Cocos Keeling Island, with six on nesting females, two on wild juveniles and one on a male adult turtle. No tags have been deployed in the southern Ningaloo region, northwest Pilbara region, Browse Island, northwest Kimberley region, northwest Arnhem Land, Groote Eylandt Islands, Sir Edward Pellew Islands and Wellesley Islands (Figure 6).

The distribution of loggerhead turtle rookeries in the region is limited to Western Australia, with some nesting recorded at Ashmore Reef (Figure 7). Studies in Western Australia have focused on deploying tags at Northwest Cape (14 tags), Shark Bay (14 tags) and Gnaraloo (10 tags) (Figure 7). These tags have been deployed on turtles in different life stages including rehabilitated juvenile turtles on the Northwest Cape, adult female and male turtles at Shark Bay. The focus at Gnaraloo has been on post-nesting loggerhead turtles. No tags have been deployed from Bernie and Dorre Islands and Ashmore Reef (Figure 7).

Most tags deployed on hawksbill turtles were within the eastern Indian Ocean MU (21 tags; 57%), northeast Arnhem Land (11 tags; 32%) at Groote Eylandt and

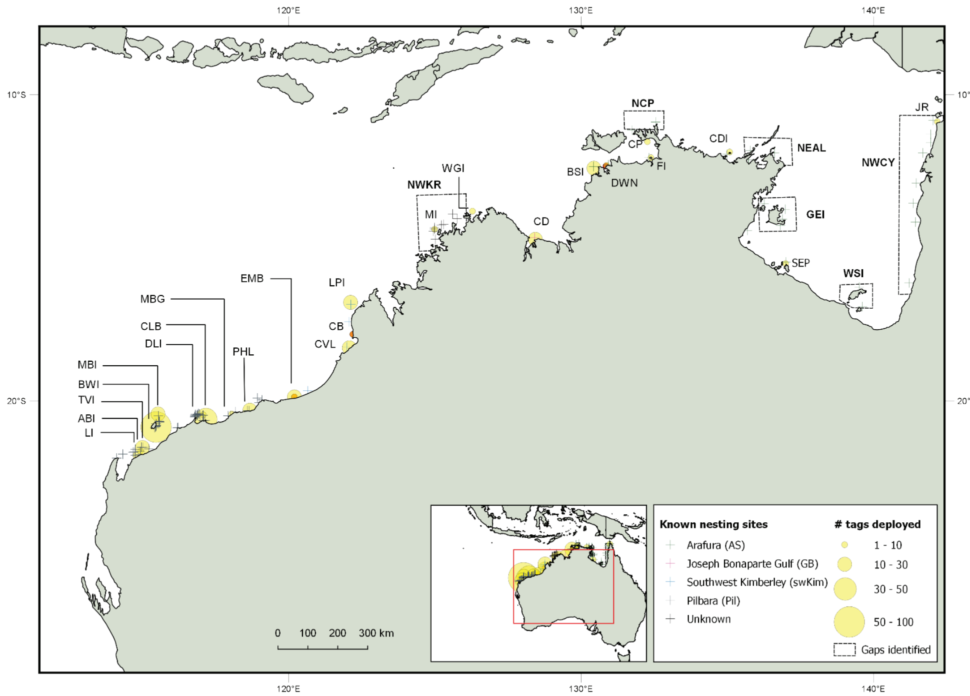

Figure 5. Number of satellite tags deployed on flatback turtles at known nesting sites (yellow circles), in water (orange) or on rehabilitated animals (red circles) within each management unit. Refer to Table 1 and 2 for acronyms used for deployment locations. Gap locations in bold include NWKR: Northwest Kimberley region; NCP: North Cobourg Peninsula; NWAL: Northwest Arnhem Land; GEI: Groote Eylandt; WSI: Wesley Islands and NWCY: Northwest Cape York. For colour, see pdf version available online.

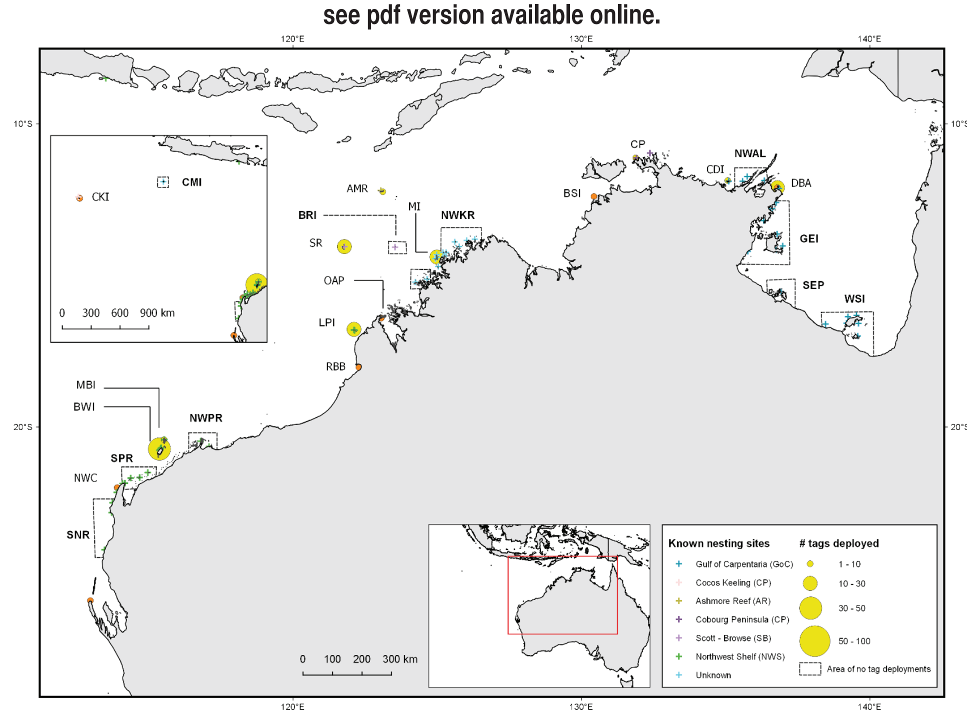

Figure 6. Number of satellite tags deployed on green turtles at known nesting sites (yellow circles) and in-water (orange) within each management unit. Refer to Table 1 and 2 for acronyms used for deployment locations. Gap locations in bold include SNR: south Ningaloo region; SPR: south Pilbara region; NWPR: northwest Pilbara region; BRI: Browse Is.; CMI: Christmas Is.; NWKR: Northwest Kimberley region; NWAL: Northwest Arnhem Land; GE: Groote Eylandt; SEP: Sir Edward Pellew Is.; WSI: Wellesley Islands. For colour, see pdf version available online.

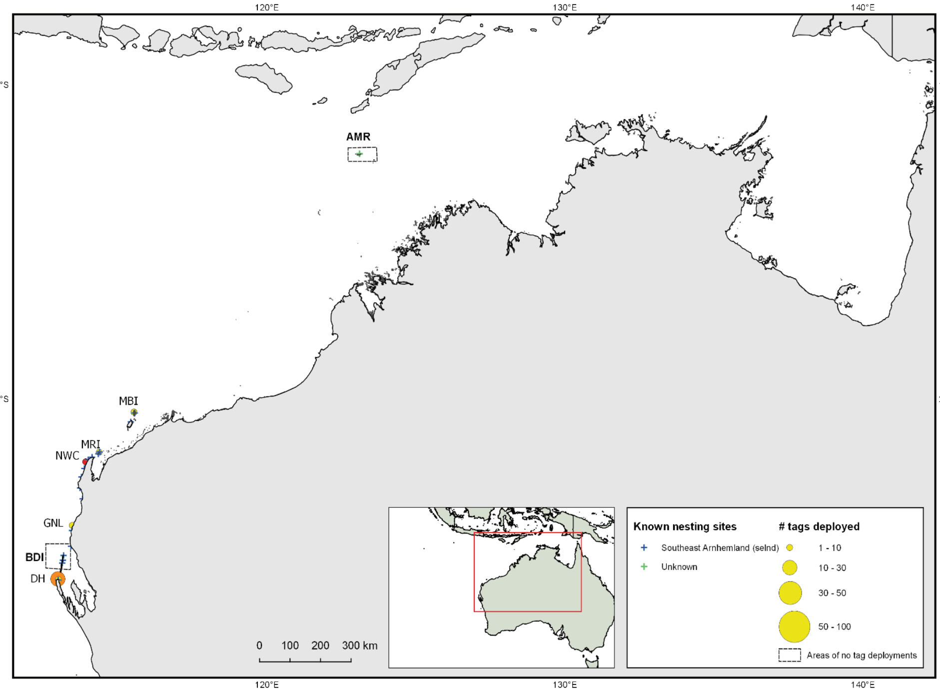

Figure 7. Number of satellite tags deployed on loggerhead turtles at known nesting sites (yellow circles), in water (orange) or on rehabilitated animals (red circles) within each management unit. Refer to Table 1 and 2 for acronyms used for deployment locations. Gap locations in bold include BDI: Bernie and Dorre Islands; AMR: Ashmore Reef. For colour, see pdf version available online.

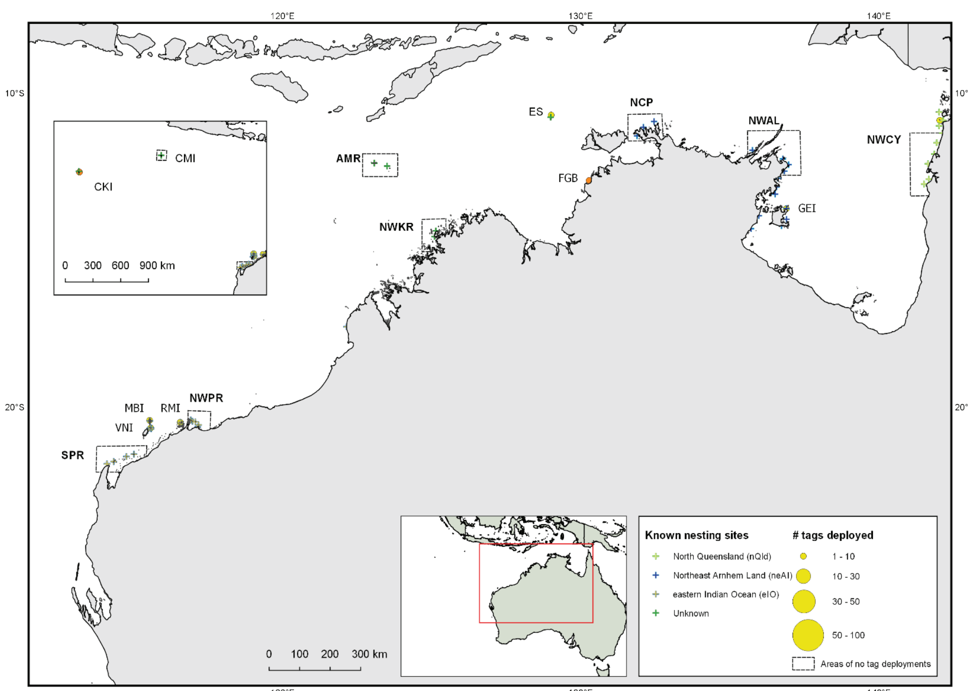

Figure 8. Number of satellite tags deployed on hawksbill turtles at known nesting sites (yellow circles) and in-water (orange) within each management unit. Refer to Table 1 and 2 for acronyms used for deployment locations. Gap locations in bold include SPR: south Pilbara region; NWPR: northwest Pilbara region; NWKR: Northwest Kimberley region; CMI: Christmas Island; AMR: Ashmore Reef; NCP: north Cobourg Peninsula; NWAL: Northwest Arnhem Land; NWCY: Northwest Cape York. For colour, see pdf version available online.

one at Woody Wallis Island in Torres Strait, with the remaining in undefined genetic populations (4 tags; 11%) (Figure 8). In Western Australia, the bulk of satellite tags were deployed at Rosemary Island, Montebello and Varanus Islands (Figure 8). No tags have been deployed from known nesting sites in the southern Pilbara region, northwest Pilbara region, Maret Islands, Ashmore Reef, north Cobourg Peninsula, northwest Arnhem Land and the northwest Cape York (Figure 8).

Most satellite tag deployments for olive ridleys were carried at nesting sites in the Northern Territory (19 tags; 63%) and Northwest Cape York (9 tags; 30%) (Figure 9). Most of the tags released in Northern Territory were deployed from the Tiwi Islands (8 tags), with few tags deployed at other nesting sites. Recently, tags have been deployed at Marpoon and Aurukun within the northwest Cape York MU. One rehabilitated olive ridley was released at Roebuck Bay in Western Australia. No tags have been deployed in the mid-Kimberley region, north Cobourg Peninsula, Wellesley Islands and southwest Cape York in the Gulf of Carpentaria (Figure 9).

Review of available publications

Our literature review of satellite tag deployments on marine turtles identified 21 peer-viewed papers, five abstracts in conference proceedings, three technical reports and two theses (Tables 1 and 2). Of these publications, 25 presented single species deployments, with six publications describing multiple species. Flatback turtles were represented in 19 of the 30 publications, with the majority of these from deployments in the Pilbara region. Some of the publications in the Pilbara region represent the same individual flatback turtles tagged at Barrow Island, Mundabullangana, Thevenard Island and Port Hedland, but with different spatial overlap with marine parks, oil and gas developments and environmental factors. Two papers presented data on adult male and female loggerhead turtles in Shark Bay (Wirsing *et al*., 2004; Olson *et al*., 2012) and one paper described the initial transit of a hawksbill turtle from Cocos (Keeling) Islands (Whiting *et al*., 2010) (Table 2).

DISCUSSION

The review highlights two common biases of satellite tag deployment identified by Godley *et al*. (2008), including the bias towards deploying tags on adult females at nesting sites and a disproportionate number of tags deployed on specific species. This finding is unsurprising as most research has been species-driven, or with specific impact questions (Whittock *et al*. 2014, 2016a, 2016b). Historically, there appears to have been multiple purposes for the deployment of transmitters to turtles. Some are

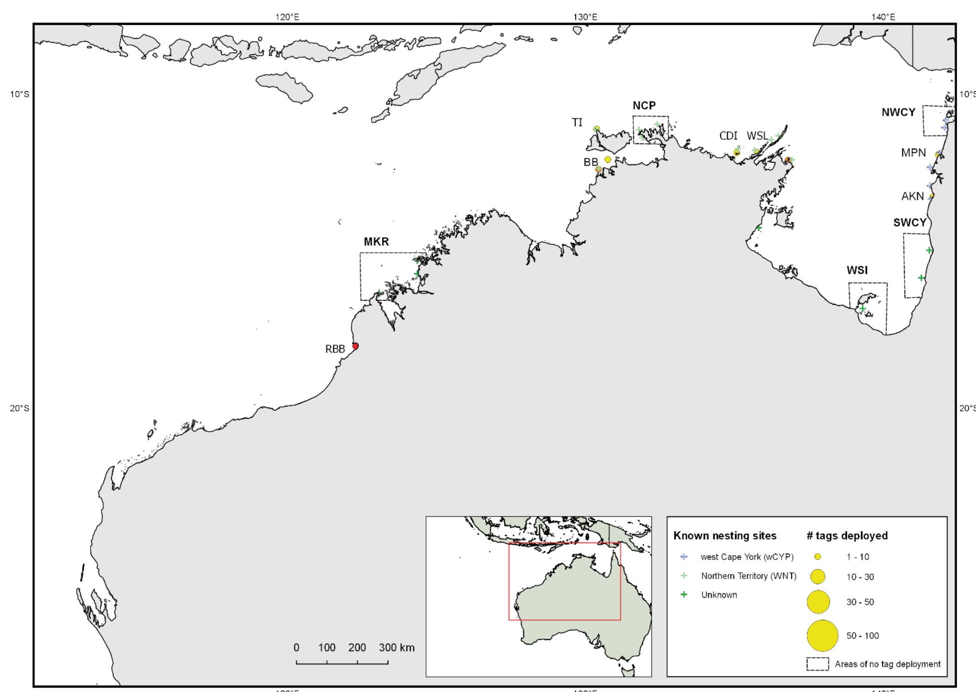

Figure 9. Number of satellite tags deployed on olive ridley turtles at known nesting sites (yellow circles), in water (orange) or on rehabilitated animals (red circles) within each management unit. Refer to Table 1 and 2 for acronyms used for deployment locations. Gap locations in bold include MKR: Mid-Kimberley region; NCP: north Cobourg Peninsula; WSI: Wesley Islands: SWCY: southwest Cape York; NWCY: northwest Cape York. For colour, see pdf version available online.

related to increasing general knowledge (e.g. DBCA tagging programs), while others are related to specific questions (e.g. NMRA ghost net project) (Dethmers *et al*., 2016) or potential impacts from developments (e.g. Gorgon Turtle Program) (Whittock *et al*., 2014). Some projects have had local interests while others have had regional scale questions. Science may not always be the driver, with community engagement or education as one of the main objectives. It is important to consider from scientific point of view that future deployments should be conducted with specific research questions in mind and these should be formed prior to deployment. This will assist studies to select the correct type of transmitter, consider sample size and expected analyses.

The bulk of tags were deployed on nesting turtles, with a shift in recent years toward research objectives that focus on in-water deployments on juveniles, adult females and adult male turtles. It is intrinsic for the initial focus to be on nesting turtles, as they provide the easiest location to attached transmitters to understand inter-nesting movements, migration routes and identify foraging grounds. NMRA tagged 13 turtles in Northern Territory to predict where turtles will be most likely to come into contact with ghost nets (Dethmers *et al*., 2016). Despite the recent efforts in the field by CSIRO, NMRA and universities to tag male turtles, there are only a few publications that present data on male turtles from Shark Bay (Wirsing *et al*., 2004; Olson *et al*., 2012) and a juvenile turtle from Cocos Keeling (Whiting and Koch, 2006). These publications represented 19% (15 of 79 tags) of the total number of tags deployed on non-nesting turtles, indicating a need to publish the remaining tracking datasets.

Most satellite tag deployments on nesting flatback turtles occurred within the Pilbara MU, which are associated with port developments near rookeries and a requirement to monitor the potential impacts to these populations (Waayers, 2014; Whittock *et al*. 2014, 2016b). While it is usually not ideal to have species bias, in this case the focus on flatback turtles was not entirely negative given that this species is listed as data deficient by the IUCN. It is encouraging to see that recent work has expanded to focus on tracking other species (Figure 3). By targeting species other than flatback turtles, we can begin to understand the linkages between species distribution, identify shared migratory pathways and foraging habitats, and assist in developing a comprehensive management strategy for all turtle species. Increases in the deployment of tags were primary linked to baseline data requirements for industry projects and funding opportunities in the mid-2000s. However, a decline in the deployment of industry-funded tags occurred since 2013, as many projects either deferred developments (e.g. Woodside Browse Project and BHP Billiton Outer Harbour Project) or the project has progressed from post-production baseline studies to operational monitoring. Following this shift in industry projects, there was an increase in tag deployment by government agencies, largely facilitated by environmental offset or similar funding. The most significant offset package in recent years was the Gorgon Gas Northwest Shelf Flatback Turtle Conservation Program (NWSFTCP) (Whiting and Tucker, 2015), which is dedicated to improving the conservation status of flatback turtles in Western Australia. Since 2015, satellite tags have been deployed on multiple species over a broader area. In some cases, surplus tags from EIA projects were donated to indigenous and local conservation groups, which also contributed to an increase in deployments by NGOs.

Our review identified several key areas supporting major nesting sites that are under-represented in terms of tag deployments and contain multiple species (e.g. northwest Kimberley, north Cobourg Peninsula, northwest Arnhem Land, Groote Eylandt Islands, Wesley Islands and Northwest Cape York) which may be explained by the remoteness of those areas. Targeted telemetry studies need to consider the resources required to access remote nesting sites and whether the size of the nesting population is worth the effort and resources.

An integrated approach to field planning could help reduce these expenses and provide an opportunity to deploy tags over several locations. For instance, the Northwest Kimberley supports multiple nesting sites for green and flatback turtles (Waayers, 2014; Commonwealth of Australia, 2017). Whereas satellite tags have been deployed from the Maret Islands, there are hundreds of offshore islands in the Bonaparte Archipelago that support green and flatback turtle nesting (Waayers, 2014). Satellite tracking data from southern nesting sites have identified this area as a foraging area for flatback (Pendoley *et al*., 2014; Thums *et al*., 2017), loggerhead (Mau *et al*., 2013; Waayers *et al*., 2015) and olive ridley turtles (Whiting *et al*., 2007), providing additional opportunities to tag foraging turtles in this area. There were also satellite tags deployed at several nesting sites that have not yet been defined within a MU (17 tags deployed across all species in undefined genetic areas). Determining the genetic affiliation of these areas will provide a better understanding of the broader ecology of turtles throughout the region (FitzSimmons & Limpus, 2014).

FURTHER RESEARCH

This exhaustive review of satellite telemetry studies in the south-eastern Indian Ocean region highlights further opportunities to advance our current understanding of ecological processes across sea turtle populations. Recommendations for further research in the field of bio-telemetry on marine turtles within the south-eastern Indian Ocean and abroad include:

- Increase efficiencies by integrating fieldwork with other organisations/companies to undertake multiple scopes.
- The need for satellite tagging data and metadata to be compiled into an Australian database that would include an inventory of tags deployed, along with some commitment by the owners to contribute to an Australia-wide mapping system. This would facilitate similar reviews in the future and make identifying gaps in deployments for each species easier.
- Develop a national metadata system for all tag deployments would set the framework for providing updated information as well as identify gaps in deployments for each species.
- Make data available to those researchers who can analyse and publish data. This might involve integrating tracking data with complementary datasets, including dive profiles, CTD measurements, habitat associations, genetic and stable isotope analyses to understand better how species respond to their physical environment.
- Prioritise gaps in knowledge presented in this paper using key questions and key impacts to assist in focusing future deployment efforts.
- Publish datasets with the paper and/or make it freely available on online data repositories such as Zoatrack (https://zoatrack.org/) or the Australian Ocean Data Network (AODN, https://portal.aodn.org.au/)
- Synthesise data from the deployments identified in this paper to highlight migration pathways and foraging areas. The results would provide the basis for further investigations at foraging hotspots and information relevant to the development of protected areas.

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AN ANNOTATED BIBLIOGRAPHY AND SUMMARY OF SEA TURTLE SATELLITE TELEMETRY STUDIES CONDUCTED THROUGHOUT THE INDIAN OCEAN AND SOUTH EAST ASIA

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To supplement the study descriptions, findings and analyses published in the satellite telemetry special issues of the Indian Ocean Turtle Newsletter (Issue 28 and 29), we compiled the bibliography below of all published studies for the Indian Ocean and South East Asia. Studies not discussed in a broader context by the contributed papers of Antonopoulou & Pilcher (2018), Hays *et al.* (2018), Mancini *et al.* (2018), Pilcher *et al.* (2019), Rees *et al.* (2018a,b) Richardson (2019), Robinson *et al.* (2018), Swaminathan *et al.* (2019), Tiwari *et al.* (2018) and Waayers *et al.* (2019) have been annotated. Table 1 presents the species and life stage tracked in each study, and Table 2 a summary of the proportion of tracking studies by region, species, and life stage and activity.

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Attum, O., A. Kramer, T. Mahmoud & M. Fouda. 2014. Post-nesting migration patterns of green turtles (*Chelonia mydas*) from the Egyptian Red Sea. *Zoology in the Middle East* 60: 299-305.

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Bali, J., H.C. Liew, E.H. Chan & O.B. Tisen. 2002. Long distance migration of green turtles from the

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Behera, S., B. Tripathy, B.C. Choudhury & K. Sivakumar. 2018. Movements of olive ridley turtles (*Lepidochelys olivacea*) in the Bay of Bengal, India, determined by satellite telemetry. *Chelonian Conservation and Biology* 17: 44-53.

Satellite transmitters were applied to 11 female and three male olive ridley turtles at Gahirmatha during the mating and nesting season. Resulting tracks did not indicate common migratory corridors or feeding grounds, and turtles passed through both inshore and oceanic waters. Ten of the tracked turtles appeared to use multiple foraging grounds in the open ocean rather than consistently feeding in the same area. The authors conclude that the entire Bay of Bengal may be an important area to protect for olive ridley turtles. Some of the tracks described in this paper may also be reported in Sivakumar *et al.* (2010).

Bourjea, J., J.A. Mortimer, J. Garnier, G. Okema, B.J. Godley, G. Hughes, M. Dalleau, C. Jean, S. Ciccione & D. Muths. 2015. Population structure enhances perspectives on regional management of the western Indian Ocean green turtle. *Conservation Genetics* 16: 1069-1083.

Post-nesting tracks of four green turtles in the Amirantes Islands revealed limited distribution and supported genetic data indicating limited links with other green turtle stocks in the South West Indian Ocean.

Christiansen, F., N. Esteban, J.A. Mortimer, A.M. Dujon & G.C. Hays. 2017. Diel and seasonal patterns in activity and home range size of green turtles on their foraging grounds revealed by extended Fastloc GPS tracking. *Marine Biology* 164: 10.

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Dalleau, M., S. Benhamou, J. Sudre, S. Ciccione & J. Bourjea. 2014. The spatial ecology of juvenile loggerhead turtles (*Caretta caretta*) in the Indian Ocean sheds light on the "lost years" mystery. *Marine Biology* 161: 1835-1849.

Eighteen juvenile loggerhead turtles, caught as bycatch and released after rehabilitation, were tracked from Reunion Island to determine oceanic movements. Trans-oceanic and trans-equatorial migrations were recorded. Links to foraging areas used by turtles nesting in Oman were confirmed.

Esteban, N., J.A. Mortimer & G.C. Hays. 2017. How numbers of nesting sea turtles can be over-estimated by nearly a factor of two. *Proceedings of the Royal Society B: Biological Sciences*. 284: 20162581.

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Esteban, N., R.K.F. Unsworth, J.B.Q. Gourlay & G.C. Hays. 2018. The discovery of deep-water seagrass meadows in a pristine Indian Ocean wilderness revealed by tracking green turtles. *Marine Pollution Biology* 134: 99-105.

To locate seagrass meadows anecdotally reported from the Great Chagos Bank, nesting green sea turtles (n=18) at Diego Garcia in the Chagos Archipelago were equipped with satellite transmitters at the end of the nesting season and tracked as they migrated to their foraging grounds. Four such animals travelled to the Great Chagos Bank, from where their repeat locations were surveyed to describe seagrass assemblages. See also Hays *et al.* (2014).

Garnier, J., N. Hill, A. Guissamulo, I. Silva, M. Witt & B. Godley. 2012. Status and community-based conservation of marine turtles in the northern Querimbas Islands (Mozambique). *Oryx* 46: 359-367.

To study nesting and migration patterns, four nesting green turtles were tracked to their foraging grounds in Tanzania, Kenya and Madagascar. Migration paths passed through coastal and oceanic waters in up to seven marine conservation areas across the four countries.

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Hitipeuw, C., P.H. Dutton, S. Benson, J. Thebu & J. Bakarbessy. 2007. Population status and interesting movement of leatherback turtles, *Dermochelys coariacea*, nesting on the northwest coast of Papua, Indonesia. *Chelonian Conservation and Biology* 6: 28-36.

The inter-nesting tracks of 10 leatherback turtles revealed use of nearshore waters adjacent to the nesting beach and within the archipelago. Some tracked turtles nested at other beaches during the study, and the authors recommended this be taken into consideration when planning protected marine areas.

Hoenner, X., S.D. Whiting, M. Hamann, C.J. Limpus, M.A. Hindell & C.R. McMahon. 2015. High-resolution movements of critically endangered hawksbill turtles help elucidate conservation requirements in northern Australia. *Marine and Freshwater Research* 67: 1263-1278.

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Hughes, G.R., P. Luschi, R. Mencacci & F. Papi. 1998. The 7000-km oceanic journey of a leatherback turtle tracked by satellite. *Journal of Experimental Marine Biology and Ecology* 229: 209-217.

See Robinson *et al*. (2018) for overview

Khan, A. 2013. Pakistan Wetlands Programme's marine turtle conservation efforts on Daran Beach, Jiwani, Pakistan. *Indian Ocean Turtle Newsletter* 17: 26-30.

Post-nesting green turtles (n=15) were tracked from Daran Beach, Pakistan. Three turtles were presumed to have been picked up by boats (as indicated by straight track lines for several days to arrive in Gulf States), but natural movements of the remaining twelve turtles were recorded. Turtles were tracked within Pakistani waters as well as to India, Iran, Qatar and the United Arab Emirates.

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Papi, F., P. Luschi, E. Crosio & G.R. Hughes. 1997. Satellite tracking experiments on the navigational ability and migratory behaviour of the loggerhead turtle *Caretta caretta*. *Marine Biology* 129: 215-220.

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Pelletier, D., D. Roos & S. Ciccione. 2003. Oceanic survival and movements of wild and captive-reared immature green turtles (*Chelonia mydas*) in the Indian Ocean. *Aquatic Living Resources* 16: 35-41.

Captive-reared and rehabilitated, wild green turtles were tracked from different islands in the South West Indian Ocean to investigate oceanic movements of juvenile turtles. Wild turtles remained close to the release site, while captive-reared turtles demonstrated long-distance migrations. The authors infer that differences in behaviour between the groups may represent stage-specific habitat requirements.

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Rees A.F., A. Al-Kiyumi, A.C. Broderick, N. Papathanasopoulou & B.J. Godley. 2012a. Conservation related insights into the behaviour of the olive ridley sea turtle ***Lepidochelys olivacea*** **nesting in Oman.** ***Marine Ecology Progress Series*** **450: 195-205.**

See Rees *et al.* (2018a) for overview

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Rees, A.F., A. Al Kiyumi, N. Papathanasopoulou & B.J. Godley. 2018a. The ***Masirah Turtle Conservation Project*****: The first turtle tracking on Masirah Island, Oman.** ***Indian Ocean Turtle Newsletter*** **28: 12-15..**

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See Rees *et al.* (2018a) for overview

Rees, A.F., N. Papathanasopoulou & B.J. Godley. 2018b. Tracking hawksbill and green sea turtles in Kuwait reveals variability in migratory and residency strategies. ***Indian Ocean Turtle Newsletter*** **28: 23-26.**

Richardson, P.B. 2019. Where do they go? Satellite tracking of nesting turtles in Sri Lanka. ***Indian Ocean Turtle Newsletter*** **29: 5-8.**

Richardson, P.B., A.C. Broderick, M.S. Coyne, L. Ekanayake, T. Kapurusinghe, C. Premakumara, S. Ranger, M.M. Saman, M.J. Witt & B.J. Godley. 2013. Satellite telemetry reveals behavioural plasticity in a green turtle population nesting in Sri Lanka. ***Marine Biology*** **160: 1415-1426.**

See Richardson (2019) for overview

Robinson, D.P., R.W. Jabado, C.A. Rohner, S.J. Pierce, K.P. Hyland & W.R. Baverstock. 2017a. Satellite tagging of rehabilitated green sea turtles ***Chelonia mydas*** **from the United Arab Emirates, including the longest tracked journey for the species. PLoS ONE 12: e0184286.**

Green sea turtles, rehabilitated and released off the coast of the United Arab Emirates, utilised shallow water habitats in the same general vicinity of where they had stranded. One adult female swam to the Andaman Sea, in what is believed to be the longest published track for the species of >8,000km.

Robinson, N.J., D. Anders, S. Bachoo, L. Harris, G.R. Hughes, D. Kotzke, S. Maduray, S. McCue, M. Meyer, H. Oosthuizen, F.V. Paladino & P. Luschi. 2018. Satellite tracking of leatherback and loggerhead sea turtles on the southeast African coastline. ***Indian Ocean Turtle Newsletter*** **28: 3-7.**

Robinson, N.J., S.J. Morreale, R. Nel & F.V. Paladino. 2016. Coastal leatherback turtles reveal conservation hotspot. ***Scientific Reports*** **6: 37851.**

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Robinson. N.J., S.J. Morreale, R. Nel & F.V. Paladino. 2017b. Movements and diving behaviour of inter-nesting leatherback turtles in an oceanographically dynamic habitat in South Africa. ***Marine Ecology***

***Progress Series* 571: 221-232.**

See Robinson *et al.* (2019) for overview

Sale, A., P. Luschi, R. Mencacci, P. Lambardi, G.R. Hughes, G.C. Hays, S. Benvenuti & F. Papi. 2006. Long-term monitoring of leatherback turtle diving behaviour during oceanic movements. *Journal of Experimental Marine Biology and Ecology* 328: 197-210.

See Robinson *et al.* (2018) for overview

Sasimal, S.K. & R.C. Panigraphy. 2006. Influence of eddies on the migratory routes of the sea turtles in the Bay of Bengal. *International Journal of Remote Sensing* 27: 3115-3122.

This study examines the olive ridley turtle tracks originally described by Shanker *et al.* (2003) with reference to sea surface temperature, chlorophyll-*a* and mean sea level anomaly. Eddies were determined to influence the migration of olive ridley turtles in the western Bay of Bengal.

Shanker, K., B.C. Choudhury, B. Pandav, B. Tripathy, C.S. Kar, S.K. Car. N.K. Gupta & J.G. Frazier. 2002. Tracking olive ridley turtles from Orissa. In: *Proceedings of the Twenty-Second Annual Symposium on Sea Turtle Biology and Conservation* (comp. Seminoff, J.A.) NOAA Technical Memorandum NMFS-SEFSC-503. Pp. 50-51.

Of four olive ridley turtles tracked from their *arribada* nesting beach south of Devi River mouth, three moved into waters off the coast of Orissa and Andhra Pradesh and one migrated south to Sri Lanka. End points for the turtles could not be confirmed, as the sudden stop in transmissions suggested fishery-related mortality. (See also Pandav & Choudhury, 2006.)

Sivakumar, K., B.C. Choudhury & S.R.B. Dissanayake. 2010. Joint turtle conservation programme of Sri Lanka and India: Sea turtles of Sri Lanka, also breeds in India and Maldives. *Wildlife (Journal of Department of Wildlife Conservation, Sri Lanka)* 2010: 18-24.

See Richardson *et al.* (2019) for overview

Sivakumar, K., B.C. Choudhury, R.S. Kumar, B. Tripathy, S.K. Behera, S. Behera, S. John & V.P. Ola. 2010. Application of satellite telemetry technique in sea turtle research in India. In: *Telemetry in Wildlife Science* (eds. Sivakumar, K. & B. Habib). ENVIS Bulletin: Wildlife and Protected Areas Vo. 13. Pp 139-144. Wildlife Institute of India: Dehradun, India.

In their post-nesting migrations, 30 olive ridley turtles tagged in 2007 at the mass nesting beaches of Gahirmatha, Devi River mouth, Rushikulya used common migratory waters ~200-400km offshore. Turtles originally moved towards the Andaman Sea then shifted south towards Sri Lanka. All tags ceased transmission within 6mo, suggesting fishing-related mortality or tag malfunction or detachment. Reinforcing the tags with additional fibreglass in 2009 resulting in longer transmission times for 32 tagged animals, with the study ongoing at the time of publication. Sivakumar *et al.* (2010) also tracked four olive ridley turtles during their post-nesting migration from beaches in Sri Lanka west towards the Arabian Sea. (Some tracks reported by Sivakumar *et al.* (2010) may also be described in Behera *et al.* (2018).)

Spring, S. & D. Pike. 1998. Tag recovery supports satellite tracking of a green turtle. *Marine Turtle Newsletter* 82: 8.

See Waayers *et al.* (2019) for overview

Swaminathan, A., N. Namboothri & K. Shanker. 2019. Tracking leatherback turtles from Little Andaman Island. *Indian Ocean Turtle Newsletter* 29: 8-10.

Thums, M., D. Waayers, Z. Huang, C. Pattiaratchi, J. Bernus & M. Meekan. 2017. Environmental predictors of foraging and transit behaviour in flatback turtles *Natator depressus*. *Endangered Species Research* 32: 333-349.

See Waayers *et al.* (2019) for overview

Thums, M., J. Rossendell, M. Guinea & L.C. Ferreira. 2018. Horizontal and vertical movement behaviour of adult flatback turtles during the key phases of their life history and overlap with industrial development. *Marine Ecology Progress Series* 602: 237-253.

See Waayers *et al.* (2019) for overview

Tiwari, M., R. Baldwin, A.A. Kiyumi, M.S. Willson, A. Willson & E. Possardt. 2018. Satellite telemetry studies on nesting loggerhead turtles in Oman. *Indian Ocean Turtle Newsletter* 28: 20-22.

***Tucker, A.D., R. Baldwin, A. Willson, A. Al Kiyumi, S. Al Harthi, B. Schroeder, E. Possardt & B. Witherington. 2018.* Revised clutch frequency estimates for Masirah Island loggerhead turtles (*Caretta caretta*). *Herpetological Conservation and Biology* 13: 158-166.**

See Tiwari *et al.* (2018) for overview

van de Merwe, J.P., K. Ibrahim, Y.S. Lee & J.M. Whittier. 2009. Habitat use by green turtles (*Chelonia mydas*) nesting in Peninsular Malaysia: Local and regional conservation implications. *Wildlife Research* 36: 637-645.

See Pilcher *et al.* (2019) for overview

Waayers, D. 2014. Marine turtles. In: *Ecological Studies of the Bonaparte Archipelago and Browse Basin* (eds. Comrie-Greig, J. & L.J. Abdo). Pp 213-272. INPEX Operations Australia Pty Ltd, Perth WA, Australia.

See Waayers *et al.* (2019) for overview

Waayers, D. & J. Fitzpatrick. 2012. Genetic affiliations and key habitats of marine turtles in the Kimberley region, Western Australia. In: *Proceedings of the First Western Australian Marine Turtle Symposium, 28-29th August 2012*. (eds. Prince, R., S. Whiting, H. Raudino, A. Vitenbergs & K.L. Pendoley). Science Division, Department of Parks and Wildlife, Perth WA, Australia. Pp 34-36.

See Waayers *et al.* (2019) for overview

Waayers, D., R. Mau, A. Mueller, J. Smith & L. Pet-Soede. 2015. A review of the spatial distribution of marine turtle nesting and foraging areas in Western Australia. In: *Proceedings of the Second Australian and Second Western Australian Marine Turtle Symposia, Perth, 25-27 August 2014*. (eds. Whiting, S.D. & T. Tucker). Department of Environment and Conservation, Perth WA, Australia. Pp 83-86.

See Waayers *et al.* (2019) for overview

Waayers, D., L.M. Smith & B.E. Malseed. 2011. Inter-nesting distribution of green *Chelonia mydas* and flatback *Natator depressus* turtles at the Lacepede Islands, Western Australia. *Journal of the Royal Society of Western Australia* 94: 59-64.

See Waayers *et al.* (2019) for overview

Waayers, D., T. Tucker, S. Whiting, R. Groom, M. Vanderklift, R. Pillans, J. Rossendell, K. Pendoley, X. Hoenner, M. Thums, K. Dethmers, C.J. Limpus, A. Wirsing, C. McMahon, A. Strydom, P. Whittock, K. Howlett, D. Oades, G. McFarlane, T. Duke, M. Guinea, A. Whiting, M. Speirs, J. King, K. Hattingh, M. Heithaus, R. Mau & D. Holley. 2019. Satellite tracking of marine turtles in the South-Eastern Indian Ocean. A review of deployments spanning 1990-2016. *Indian Ocean Turtle Newsletter* 29: 23-37.

West, L. 2014. The first documented case of foraging ground philopatry in a female green turtle *(Chelonia mydas)* in Tanzania. African Turtle Newsletter 2: 34-36.

A green turtle was tracked for two consecutive nesting seasons from her nesting beach at Juani Island to foraging grounds adjacent to Buyuni, both in Tanzania. The short distance migration (5 days of travel) followed a similar path in both years, suggesting strong fidelity to both migratory route and feeding grounds. Prior to the tracking results, Buyuni had not been recognised as a foraging area for green sea turtles.

Whiting, S.D. & A.U. Koch. 2006. Oceanic movement of a benthic foraging juvenile hawksbill turtle from the Cocos (Keeling) Islands. *Marine Turtle Newsletter* 112: 15.

See Waayers *et al.* (2019) for overview

Whiting, S.D., S. Hartley, S. Lalara, D. White, T. Bara, C. Maminyamunja & L. Wurramarrba. 2006. Hawksbill turtle tracking as part of initial sea turtle research and conservation at Groote Eylandt, Northern Australia. *Marine Turtle Newsletter* 114: 14-15.

See Waayers *et al.* (2019) for overview

Whiting, S.D., J.L. Long & M. Coyne. 2007. Migration routes and foraging behaviour of olive ridley turtles *Lepidochelys olivacea* in northern Australia. *Endangered Species Research* 3: 1-9.

See Waayers *et al.* (2019) for overview

Whiting, S.D., W. Murray, I. Macrae, R. Thorn, M. Chongkin & A.U. Koch. 2008. Non-migratory breeding by isolated green sea turtles (*Chelonia mydas*) in the Indian Ocean: Biological and conservation implications. *Die Naturwissenschaften* 95: 355-360.

See Waayers *et al.* (2019) for overview

Whiting, S.D., I. Macrae, W. Murray, R. Thorn, T. Flores, C. Joyson-Hicks & S. Hashim. 2010. Indian Ocean crossing by a juvenile hawksbill turtle. *Marine Turtle Newsletter* 129: 16-17.

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Whittock, P.A. & K.L. Pendoley. 2012. It starts with one: Delineation of foraging and mating habitats used by a flatback turtle in Western Australia. In: *Proceedings of the First Western Australian Marine Turtle Symposium, 28-29th August 2012*. (eds. Prince, R., S. Whiting, H. Raudino, A. Vitenbergs & K.L. Pendoley). Science Division, Department of Parks and Wildlife, Perth WA, Australia. Pp 40.

See Waayers *et al*. (2019) for overview

Whittock, P.A., K.L. Pendoley & M. Hamann. 2014. Inter-nesting distribution of flatback turtles *Natator depressus* and industrial development in Western Australia. *Endangered Species Research* 26: 25-38.

See Waayers *et al*. (2019) for overview

Whittock, P.A., K.L. Pendoley & M. Hamann. 2016a. Flexible foraging: Post-nesting flatback turtles on the Australian continental shelf. *Journal of Experimental Marine Biology and Ecology* 477: 112-119.

See Waayers *et al*. (2019) for overview

Whittock, P.A., K.L. Pendoley & M. Hamann. 2016b. Using habitat suitability models in an industrial setting: The case for internesting flatback turtles. *Ecosphere* 7: e01551.

See Waayers *et al*. (2019) for overview

Whittock, P.A., K.L. Pendoley, R. Larsen & M. Hamann. 2017. Effects of a dredging operation on the movement and dive behaviour of marine turtles during breeding. *Biological Conservation* 206: 190-200.

See Waayers *et al*. (2019) for overview

Table 1. Numbers of satellite transmitters applied during studies of sea turtles in the Indian Ocean and South East Asia.
Species: Cc- *Caretta caretta* (loggerhead turtle); Cm- *Chelonia mydas* (green turtle); Dc- *Dermochelys coriacea* (leatherback turtle); Ei- *Eretmochelys imbricata* (hawksbill turtle); Nd- *Natator depressus* (flatback turtle); Lo- *Lepidochelys olivacea* (olive ridley turtle)

Life stage: PH- post-hatchling; J- juvenile; SA- sub-adult (male or female); A-M- adult (male); F- foraging; B- breeding; A-F- adult (female); PrN- pre-nesting; IN- inter-nesting; PoN- post-nesting

Other: C- captive reared before tracking; R- rescued/rehabilitated before tracking; D- displaced for study purpose

		Species						Life Stage and Activity										Other	
											A-M		A-F						
Region/Citation	Country	Cc	Cm	Dc	Ei	Nd	Lo	PH	J	SA	F	B	F	PrN	IN	PoN	C	R	D
South West Indian Ocean																			
Bourjea *et al*. (2015)	Amirantes Islands		4													x			
Christiansen *et al*. (2017)	Chagos Archipelago		8										x						
Dalleau *et al*. (2014)	Reunion Island	18							x										
Esteban *et al*. (2017)	Chagos Archipelago		10												x				
Esteban *et al*. (2018)	Chagos Archipelago		4													x			
Galli *et al*. (2012)	South Africa			4												x			
Garnier *et al*. (2012)	Mozambique		4										x		x	x			
Harris *et al*. (2015)	South Africa														x				
Harris *et al*. (2017)	South Africa	20		14												x			
Hays *et al*. (2014)	Chagos Archipelago		8										x			x			
Hughes *et al*. (1998)	South Africa															x			
Lambardi *et al*. (2008)	South Africa															x			
Luschi *et al*. (2003a)	South Africa	5														x			x
Luschi *et al*. (2003b)	South Africa			3												x			
Papi *et al*. (1997)	South Africa	5														x			x
Pelletier *et al*. (2003)	Reunion, Glorioso, Tromelin & Moheli Is		8						x				x				x	x	
Robinson *et al*. (2016)	South Africa			16												x			
Robinson *et al*. (2017b)	South Africa			10											x				
Sale *et al*. (2006)	South Africa			4												x			
West *et al*. (2014)	Tanzania		4										x		x	x			

Table 1 cont.

Region/Citation	Country	Species									Life Stage and Activity						Other		
											A-M		A-F						
		Cc	Cm	Dc	Ei	Nd	Lo	PH	J	SA	F	B	F	PrN	IN	PoN	C	R	D
North West Indian Ocean																			
Attum *et al*. (2018)	Egypt		4												x	x			
Pilcher *et al*. (2014b)	Iran				10								x	x	x	x			
Pilcher *et al*. (2014b)	Oman				25								x	x	x	x			
Pilcher *et al*. (2014b)	Qatar				27								x	x	x	x			
Pilcher *et al*. (2014b)	UAE				28								x	x	x	x			
Rees *et al*. (2010)	Oman	10													x	x			
Rees *et al*. (2012a)	Oman						9						x		x	x			
Rees *et al*. (2012b)	Oman		2													x			
Rees *et al*. (2013)	Kuwait		3										x		x	x			
Rees *et al*. (2018)	Kuwait		4										x					x	
Robinson *et al*. (2017a)	UAE		8							x			x					x	
Tucker *et al*. (2018)	Oman	34													x				
South Asia																			
Behera *et al*. (2018)	India						14					x				x			
Khan (2013)	Pakistan		15													x			
Namboothri *et al*. (2012)	Andaman Archipelago			7											x	X			
Pandav & Choudhury (2006)	India						4									x			
Richardson *et al*. (2013)	Sri Lanka		9										x		x	x			
Sivakumar *et al*. (2010)	India						62									x			
Sivakumar *et al*. (2010)	Sri Lanka		1				4									x			
Swaminathan *et al*. (2019)	Andaman Archipelago			3											x	X			

Table 1 cont.

Region/Citation	Country	Species						Life Stage and Activity									Other		
											A-M		A-F						
		Cc	Cm	Dc	Ei	Nd	Lo	PH	J	SA	F	B	F	PrN	IN	PoN	C	R	D
South East Asia																			
Bali *et al*. (2002)	Malaysia		4													x			
Hitipeuw *et al*. (2007)	Indonesia			10											x				
Lau *et al*. (2009)	Malaysia		39													x			
Liew *et al*. (2012)	Malaysia				2				x								x		
Pilcher *et al*. (2019)	Malaysia		39		4				x				x			x	x		
van de Merwe *et al*. (2009)	Malaysia		4									x	x		X	x			

Table 2.
Species: Cc- *Caretta caretta* (loggerhead turtle); Cm- *Chelonia mydas* (green turtle); Dc- *Dermochelys coriacea* (leatherback turtle); Ei- *Eretmochelys imbricata* (hawksbill turtle); Nd- *Natator depressus* (flatback turtle); Lo- *Lepidochelys olivacea* (olive ridley turtle)

Life stage: PH- post-hatchling; J- juvenile; SA- sub-adult (male or female); A-M- adult (male); F- foraging; B- breeding; A-F- adult (female); PrN- pre-nesting; IN- inter-nesting; PoN- post-nesting

Region	Total Studies	Total Tracks	Proportion of Tracks in Region						Proportion of Studies in Region									
			Species						Life Stage and Activity									
												A-M		A-F				
			Cc	Cm	Dc	Ei	Nd	Lo	PH	J	SA	F	B	F	PrN	IN	PoN
South West Indian Ocean	20	177	27.1	28.8	44.1	0.0	0.0	0.0	0.0	10.0	0.0	0.0	0.0	25.0	0.0	25.0	70.0
North West Indian Ocean	9	164	26.8	12.8	0.0	54.9	0.0	5.5	0.0	0.0	11.1	0.0	0.0	55.6	11.1	66.7	66.7
South Asia	8	123	0.0	20.3	8.1	0.0	0.0	71.5	0.0	0.0	0.0	0.0	14.3	14.3	0.0	14.3	100.0
South East Indian Ocean	23	478	1.9	14.6	0.0	4.8	75.3	3.3	0.0	8.7	0.0	0.0	0.0	52.2	4.3	60.9	65.2
South East Asia	6	102	0.0	84.3	9.8	5.9	0.0	0.0	0.0	16.7	0.0	0.0	16.7	33.3	0.0	33.3	66.7

REPORT

SYMPOSIUM ON SEA TURTLE CONSERVATION IN SOUTHEAST ASIA AT THE 5th INTERNATIONAL MARINE CONSERVATION CONGRESS, KUCHING, SARAWAK, MALAYSIA, 27th JUNE 2018

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During the 5th International Marine Conservation Congress (IMCC5) from 24-29th June 2018, Seh Ling Long, a postgraduate student from Universiti Malaysia Terengganu (UMT) and Pelf Nyok Chen, co-founder of Turtle Conservation Society of Malaysia, organised a symposium titled 'Sea Turtle Conservation in Southeast Asia: Where we are and how do we move forward?' The symposium was held on 27th June 2018 at the Waterfront Hotel in Kuching, Sarawak, Malaysia, and brought together sea turtle researchers, conservationists, academics and non-academics in the Southeast Asia region to promote their research, share their findings, and identify common threats and legislation loopholes. It also provided a platform to discuss how these findings can be translated into advances in conservation policies and legislation, and communicated to the public. Seven speakers presented, followed by a discussion period at the end of the symposium.

Presentation 1: Illegal sea turtle trade in Sabah, Malaysia: New mode of operation with national and regional linkages

Gavin Jolis, a Senior Marine Conservation Officer under the Marine Programme of the World Wide Fund for Nature Malaysia (WWF-Malaysia), highlighted a new mode of sea turtle poaching operation in the state of Sabah in East Malaysia with national and regional linkages. Between 2004 and 2016, there were at least 23 poaching cases amounting to more than 835 turtles. From 2004 to 2009, poaching occurred in the west coast waters of Sabah but the areas of poaching had extended to Kudat in the north and Semporna and Sandakan in the southeast of Sabah since 2014. In 2004, the state's Marine Police found more than 130 dead turtles onboard a Chinese fishing trawler from Hainan in the west coast of Sabah. The confiscated turtles were already preserved in formaldehyde, indicating that these fishers were also skillful taxidermist. Between 2014 and 2015, decomposing turtles were discovered on a secluded island north of Sabah. Meanwhile between 2014 and 2017, turtle carcasses with missing plastron and marginal scutes were found lying on beaches and floating on the water surface in the southeast of Sabah. The enforcement authorities investigated and gathered intelligence information on the reported cases, leading to discoveries of hotspot poaching areas, type of gears used for capture, mode of transportation, and further information. In earlier years, foreign fishers were catching turtles around the waters in Sabah. Recently, local fishers and communities have been involved in the operation, using nets to catch turtles at foraging grounds, for example in Kudat and Semporna, but the mode of operation differed between sites. They either stockpiled live turtles, took only parts of turtles and left the rest behind, or processed the turtles on secluded islands first before trading to foreign fishers who then transported the turtles to countries in East Asia such as China to fulfill the demand of turtle meat for consumption and shell for ornamental purposes. The operation from capturing to trading turtles is well-organised and planned, involving various individuals from poachers to local middlemen to foreign fishermen. The authorities carry out various efforts at the district and state levels including advocacy, establishment of a taskforce unit, revision of the existing laws and improved prosecution and conviction of cases with high penalty and sentencing. Nonetheless, poaching of sea turtles is one of the biggest threats and goes beyond the state boundary, hence requiring regional efforts. Equally important is community engagement as part of the solutions to address this threat.

Presentation 2: Local to global sharing: Lessons learnt on human-sea turtle interactions of coastal communities in South China Sea

Jarina Mohd Jani from UMT shared insights on human-sea turtle interactions as her team embarked on a journey following the turtle's trail from Terengganu to Lawas in

Sarawak and Natuna Island in Indonesia. In Terengganu, there is a long history of turtle egg trade and the Terengganu Turtle Enactment was first promulgated in 1951 to regulate turtle egg collection. The enactment was amended twice, in 1987 and 1989, to include provisions that provided more legal protection including the creating of turtle sanctuaries as well as the ban of sale and consumption of leatherback turtle eggs. Today the law allows for concession (except for leatherback turtle eggs) to co-exist with conservation, which ideally balances the livelihood and conservation interests if optimally used. The trade is a thriving economy but opportunistic in nature since major nesting beaches are already protected as turtle sanctuaries and reserve beaches. In marine park islands, there is a transformative nature of sea turtles as natural capital from consumptive to non-consumptive use. Collecting turtle eggs was one their main economic activities but now conservation and tourism development provide for other turtle-related livelihood activities such as work opportunities in conservation (i.e. rangers) and turtle-based tourism (i.e. turtle watch tour providers). In Kuala Lawas, turtles only forage but do not nest. The locals wished that the turtles had also nested there as they wanted turtle eggs. Meanwhile, in Natuna Island, community-based conservation co-exists with community-based trade. They trade 50% of the eggs and incubate the remaining 50%. When the hatchlings hatch, they were headstarted before they were released into the wild. These findings provide important insights towards improved protection and conservation measures, ensuring the sustainability of both people's livelihoods and sea turtle populations at local, national and regional levels. The way forward is to invest in people through (1) more engagement with local stakeholders and acknowledge them as worthy and knowlegeable potential partners in conservation, (2) collaborative enforcement of existing laws, (3) more inter-state understanding on the complex human-sea turtle dimensions, and (4) more effective international research and engagement in understanding transboundary nature of sea turtle conservation.

Presentation 3: Preliminary study on geomorphology of Terengganu turtle nesting beaches and its vulnerability to climate change

Noor Azariyah Mohtar, a Marine Conservation Officer for Terengganu Turtle Project under the Marine Programme of WWF-Malaysia, discussed her current project in collaboration with Universiti Malaysia Sarawak (UNIMAS) to create a baseline database to monitor the impact of climate change towards sea turtles in Terengganu. Four species of sea turtles are known to nest along the coastline of Terengganu but only the nesting of green turtles is increasing. Climate change is affecting turtles in multiple ways and at all life stages, including the loss of nesting beaches resulting from sea level rise and increased erosion. Terengganu has distinct monsoon seasons, namely the post-monsoon (April - May), pre-monsoon (September - November) and the Northeast monsoon (December - March) which dynamically shape the shoreline and beaches. Nesting activities occur between March and September every year, and decreases rapidly during the monsoon seasons due to rough seas. To monitor the vulnerability of nesting beaches to monsoon conditions, they carried out beach profiling, shoreline tracing and Coastal Integrity Vulnerability Assessment Toolkit (CIVAT) at six main nesting beaches in Terengganu (i.e. Kuala Baharu Selatan and Telaga Papan in Setiu as well as Kerteh, Ma'Daerah, Chakar Hutang and Paka in Kemaman) before and after the monsoon seasons in 2016 and 2017. The Northeast monsoon severely impacts the coastline as the beach profile showed great changes of beach slopes. Not only that, there are a lot of anthropogenic activities on these nesting beaches. The creation of a new river mouth at Kuala Baharu Selatan, Setiu, has caused sediment deposition where the shoreline has shifted. The government has since invested in sand dredging to remove the sand as the river mouth is getting too shallow and the boats cannot pass through. In Paka, the local community has to build a new jetty and the state government has to put revetment along the beaches to prevent further erosion that is already encroaching the village settlement. All these have an impact on nesting activities such as shifting of nesting areas. Of all six nesting sites, Ma'Daearah (also a turtle sanctuary) and Chakar Hutan are highly vulnerable and need immediate mitigation intervention. On-going monitoring of the shoreline is not only needed to measure the changes and potential loss of nesting areas for green turtles but also how it impacts the coastal communities living there. WWF-Malaysia is currently conducting a series of workshops to introduce Local Early Action Plan (LEAP) to include adaptation planning with a focus on ecosystem-based actions in the existing local state plans.

Presentation 4: Turtle Watch Camp - Batu-Batu, Pulau Tengah - Findings and recommendations from a turtle conservation project in Johor, Malaysia

Tanya Leibrick, the Conservation and Sustainability Manager for Turtle Watch Camp and Batu-Batu Resort, reported on their turtle conservation work at Pulau Tengah and other marine parks islands in Johor since 2015. Turtle Watch Camp is a privately operated conservation programme founded by Batu-Batu Resort which aims to protect green and hawksbill turtles. One of the main threats to these species is the collection of turtle eggs by licensed and unlicensed egg collectors who subsequently sell the eggs in the markets. Boat strikes in the area are also frequent, and they recorded 10 stranded turtles with fatal lacerations in 2016 and 2017. Since 2015, they have incubated 21,961 eggs from 149 hawksbill and 42 green turtle nests in the hatchery, collected by egg collectors from 12 islands, resulting in the release of 11,743 hatchlings. In the beginning, they had relatively low hatching success. By providing training for egg collectors in eggs handling and hiring experienced staff in hatchery management, the hatching success has increased. As turtle egg collection is sporadic, they have also increased boat patrol to monitor seven other islands to protect more nests. They engage various stakeholders in outreach activities to educate and raise awareness on conservation issues affecting sea turtle populations, which includes presentations and hachery tours to resort guests, beach clean-ups, nest adoptions, school programmes, collaborative training with government agencies. Tanya highlighted the need to assess the efficacy of current legislation and enforcement, increase community-level education and engagement programmes and assess the current population status of sea turtles throughout the state of Johor.

Presentation 5: Finding the balance: Sea turtle tourism interaction in Apo Island, Phipillines

Sue Andrey Ong, the Co-Project Leader of Apo Island Sea Turtle Research and Conservation Project under the Large Marine Vertebrates Research Institute Philippines, described various ways to study in-water sea turtle population and assess sea turtle tourism interaction in Apo Islands, Philippines. Apo Island Protected Landscape and Seascape (AIPLS) is a marine protected area and a popular holiday destination for diving and turtle watching activity, drawing approximately 17,000 tourists (51% Filipino) in 2015. Despite the growing diving-related tourism and snorkelling interactions with turtles, there has never been dedicated work to assess the green turtle population and tourism interactions with the species in this area. To do so, they conducted behavioural observation, habitat surveys and photographic identification (photo-ID) in June-July 2017 and daily since November 2017. They have also deployed temperature-depth recorder archival tags on two resident turtles to further understand the habitat use and complement visual observation data. Using I^3S Pattern Software, they have identified 158 individual turtles from 5,621 encounters, with an average of 32 individuals identified per day (range 5–72). They identified eight algae species and by categorising a feeding area into four sites, preliminary results show that sea turtles demonstrate habitat preference to one site. To also understand the presence and site fidelity of the resident turtles, the project integrated the photographic catalogue with systematic but opportunistic photo-ID data collected since 2013 by a resident dive operator and online citizen science searches. The longest photographic match dated back to 2007. They also monitored the presence and distribution of tourists and counted the highest number/density of tourists between 10-11 am. They undertook a tourist compliance assessment and administered over 500 questionnaires to tourists and local stakeholders to assess their perception on the interaction and areas for improvement. AIPLS is an important hotspot for green turtles and the local community heavily rely on their economic value for tourism, therefore finding a balance is of utmost importance.

Presentation 6: Understanding the movement of green turtles in Terengganu, Malaysia through a shared photographic identification database

Kok Lynn Chew, Camp and Field Project Manager of Lang Tengah Turtle Watch, shared the the potential of a shared photo-ID database in understanding the movement of green turtles between nesting and foraging sites. Photo-ID of individual sea turtles through facial scale patterns has been increasingly used for in-water population and behavioural studies. The Perhentian Turtle Project (PTP) and Lang Tengah Turtle Watch (LTTW) have been collecting sighting photographs of sea turtles from dedicated turtle surveys and citizen scientists at Perhentian Islands and Lang Tengah Island in Terengganu since 2014. The database consisting of photographs of the left and right facial scale patterns of green turtles from PTP (181 nesting and 66 in-water individuals) and LTTW (12 nesting individuals) were consolidated in 2017. They ran all photographs through an automated pattern matching software called Interactive Individual Identification System Pattern (I^3S), which produced a list of matches based on a match score starting from 0 (perfect match) to over 100, or "No Match". They then visually checked the list for any correct matches and found a match between an in-water green turtle from PTP database and a nesting green turtle from LTTW database, suggesting movements between foraging and nesting sites that are approximately 20km apart. The turtle has been sighted 44 times at the same foraging site at Perhentian Islands from 2013-2016, and was found nesting once at Lang Tengah Island on 2nd June 2017. This study shows the efficacy of I^3S in matching individuals within a shared database, provided that the photographs are of high resolution and the facial scales are visible. The matches found demonstrate the potential of a shared photo-ID database in having a greater understanding of the movements of sea turtles between nesting and foraging grounds in a wide geographical area.

Presentation 7: Measuring success of the uptake of Turtle Excluder Device (TEDs) in Malaysia

Nicolas Pilcher, founder of the Marine Research Foundation (MRF), discussed MRF's flagship project to introduce Turtle Excluder Devices (TEDs) to Malaysian trawl fisheries. Bycatch of sea turtles is of grave concern in Sabah. Due to the overlapping turtle and shrimp habitats, shrimp fishing is one the leading causes of sea turtle mortality today. More than 2,000 turtles are killed each year in trawl fisheries. The ecotourism value of a turtle is approximately USD 10,000 (equivalent to MYR 40,000), which means the state loses a possible annual contribution of MYR 20,000,000 from ecotourism when they lose 2,000 turtles to fisheries per year. Fortunately the solution to mitigate this is through the use of TEDs. The MRF works closely with the Department of Fisheries Malaysia (DOFM) and the Department of Fisheries Sabah (DOFS) to successfully introduce TEDs in Malaysia, starting in 2007 with a volunteer trial programme in Sabah, and culminating with legal requirement for TEDs in 2017 with staged implementation until 2022. However, TED uptake requires buy-in from fishers and needs to be demonstrated to be effective. To boost buy-in, MRF commissioned a professional video in three languages, conducted site visits to the US with fishermen and DOFM and DOFS officers, developed a portable fuel-flow meter to measure fuel savings, and developed a real-time video system (TEDsCam) using GoPro cameras and drone technology to deliver live video feeds to boat captains. To measure impact, MRF calculated fuel savings and translated these into CO_2 emissions savings, and used fishing effort and past statistics to determine number of turtles potentially saved by the fishery. TEDs work as they save turtles and reduce fuel consumption so less CO_2 enters the atmosphere. MRF estimated saving up to 1,000 turtles per year and 150,000 kg of CO_2 emissions per year at the current implementation stage, and for this to quadruple once full national adoption is reached. In addition, the product value increases as shrimps in better condition (present in nets equipped with TEDs) can sell at a higher price and fishermen spend less downtime repairing their nets. Together with the buy-in from the government and fishing communities across Malaysia, the adoption of TEDs enhances the conservation of sea turtles and reduces the national carbon footprint, while ensuring preservation of fisher livelihoods.

During the discussion period, IMCC5 participants asked several questions on the mode of transportation of the illegal trade happening in Sabah, the use of automated matching software to photo-ID sea turtles, the engagement of local communities in mitigating loss of nesting beaches due to climate change and other humans factors, the tourist briefing in Apo Island and others, the implementation of TEDs, etc. The symposium ended with a thank-you note from the symsposium chair to all presenters, participants and IMCC organisers.

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