

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; McMahan *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 Furthermore, many of the unpublished studies undertaken on behalf of industry (as part of environmental approval processes) and by conservation groups are not always reported in the peer-reviewed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

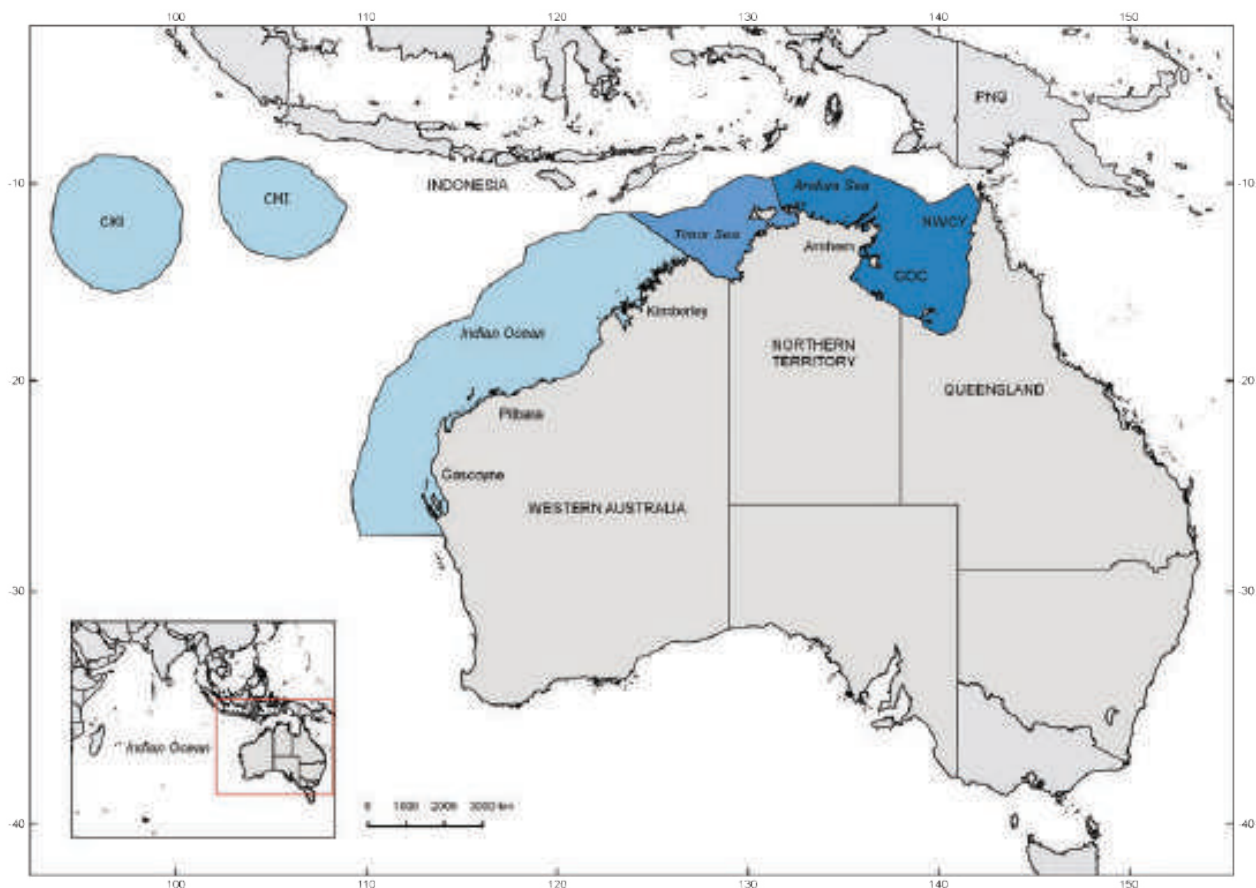


Figure 1. Location map of the south-eastern Indian Ocean including the marginal seas and offshore islands. For colour, see pdf version available online.

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 <i>et al.</i> (2011), Thums <i>et al.</i> (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 <i>et al.</i> (2016b)
Pilbara	Delambre Is. (DLI)	5	RIO	Metadata supplied by Rio Tinto, Waayers <i>et al.</i> (2015)
	Locker Is. (LI)	8	DBCA	1168
	Mundabullangana (MBG)	8	CVX, Pendoley	112, 195, Pendoley <i>et al.</i> (2014), Whittock <i>et al.</i> (2014, 2016a, b), Waayers <i>et al.</i> (2015)
	Montebello Is. (MBI)	15	DBCA	1175
	Thevenard Is. (TVI)	20	DBCA, Pendoley	1181, Pendoley <i>et al.</i> (2014), Whittock <i>et al.</i> (2014, 2016a, b), Waayers <i>et al.</i> (2015)
	Port Hedland (PHL)	30	BHP, Pendoley	685, Whittock & Pendoley (2012), Waayers <i>et al.</i> (2015)
	C. Lambert (CLB)	31	RIO, DBCA	579, 795, Waayers <i>et al.</i> (2015)
	Barrow Is. (BWI)	89	CVX, Pendoley	108, 194, 264, 354, 457, 575, 695, 941, Pendoley (2005), Pendoley <i>et al.</i> (2014), Whittock <i>et al.</i> (2014, 2016a, b), Waayers <i>et al.</i> (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 <i>et al.</i> (2004)
	Ashmore Reef (AMR)	1	GBRPA, DEE	Spring & Pike (1998)
Ashmore	Cocos (Keeling) Is. (CKI)	6	BI, CDU, PA	Whiting <i>et al.</i> (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 <i>et al.</i> (2012), Waayers <i>et al.</i> (2015)
Northwest shelf	Montebello Is. (MBI)	6	DBCA	Metadata supplied by DBCA
	Lacepede Is. (LPI)	11	WEL, RPS	Waayers <i>et al.</i> (2011, 2015)
	Barrow Is. (BWI)	33	Pendoley, CVX, MU	40, 197, 956, Waayers <i>et al.</i> (2015)
	Maret Is. (MI)	21	Inpex, RPS	Waayers (2014), Waayers & Fitzpatrick (2012), Waayers <i>et al.</i> (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 <i>et al.</i> (2012), Waayers <i>et al.</i> (2015)
	Gnaraloo (GNL)	10	GTCP, Aubrey Strydom	1149, Strydom <i>et al.</i> (2017)
Hawksbill turtles				
Northeast Arnhem Land	Groote Eylandt (GEI)	12	WWF, ALC, DRETAS	94, 320, 341, Whiting <i>et al.</i> (2006), Hoenner <i>et al.</i> (2015), Lambert <i>et al.</i> (2015)
	Evans Shoal (ES)	1	DLRM, Inpex, Cardno	983
North Queensland	Woody Wallis Is. (WWI)	1	JCU	Hoenner <i>et al.</i> (2015)
Unknown	Montebello Is. (MBI)	5	DBCA	Metadata supplied by DBCA
Western Australia	Varanus Is. (VNI)	6	Pendoley	Pendoley (2005); Waayers <i>et al.</i> (2015)
	Rosemary Is. (RMI)	10	DBCA, MR, Pendoley	1136, Pendoley (2005), Waayers <i>et al.</i> (2015)
Olive Ridley turtles				
Northern Territory	Crocodile Is. (CDI)	3	NAMRA	802, Metadata supplied by NAMRA
	Wessel Is. (WSL)	4	WWF, TLC, CCA	McMahon <i>et al.</i> (2007); Hamel <i>et al.</i> (2008)
	Tiwi Is. (TI)	8	CDU, UWS, GMR	19, 78, Whiting <i>et al.</i> (2007)
	Marpoon (MPN)	9	EHP	Metadata supplied by EHP
	Aurukun (AKN)	1	EHP	Metadata supplied by EHP

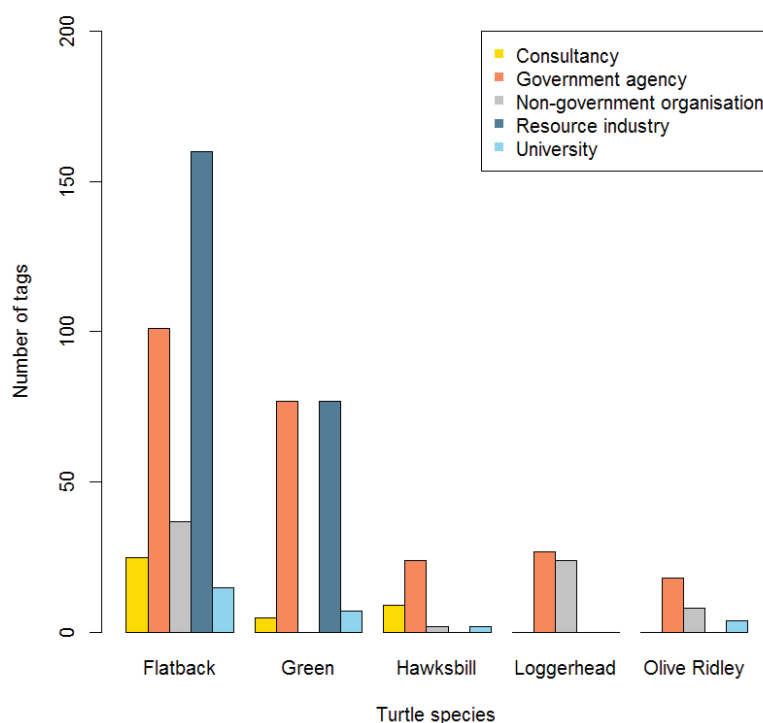


Figure 2. Number of tags deployed on each species by project owner. For colour, see pdf version available online.

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](http://www.seaturtle.org) data use [http://www.seaturtle.org/tracking/index.shtml?project_id= "add number given in table"](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				Owner & Partners	Data Sources (seaturtle.org Project ID and/or Publication)
		Juvenile		Sub-adult			
		wild	rehab.	wild	rehab.		
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
Unknown	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
Unknown	One Arm Pt. (OAP)		10	2		CSIRO, BJR, DBCA	1091
Unknown	Shark Bay (SB)	2		3		DU, DBCA	Metadata supplied by DBCA
Unknown	Roebuck Bay (RBB)	2				DBCA, YR	1157
Arafura	Bare Sand Is. (BSI)	2				CDU, ATI	1148
Unknown	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
Unknown	Montebello Is. (MBI)	1		1		DBCA	Metadata supplied by DBCA
Unknown	Shark Bay (SB)			3	11	FIU, DBCA, YTO	Olson <i>et al.</i> (2012), Wirising <i>et al.</i> (2004)
Hawksbill turtles							
Unknown	Fog Bay (FGB)	1				CDU, ATI	Whiting <i>et al.</i> (2010)
Unknown	Cocos Keeling Is. (CKI)	2				DE, BI	Whiting & Koch (2006)
Olive Ridley turtles							
Northern Territory	Wanuwuy beach (WB)	1				NAMRA	Metadata supplied by NAMRA, Deihmers (2016)
Unknown	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=Apuudhama Land Trust, AS=Aubrey Stydrom, ATI=AusTurtle Inc, AWA=Aquarium of Western Australia, BHP=BHP Billiton, BI=Biomarine International, BJR=Bardi Jawi Rangers, BR=Balanggarra Rangers, BTO=Bunji 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=Dimuru 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 Ichthyos Project, JCU=James Cook University, KNP=Kakadu National Park staff, KTO=Karajarri Traditional Owners, LSR=Lianthawariyara Sea Rangers, MGR=Mitiuwung - 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, PWN1=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=Yaigalah 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

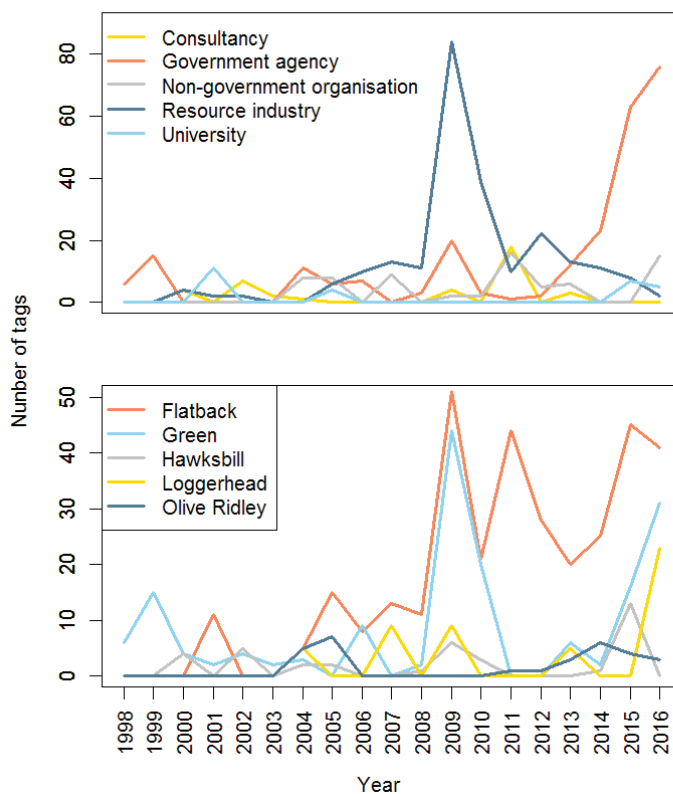


Figure 3. Number of tags deployed by organisation type (top) and on each species (bottom) over time between 1998 and 2016. The only deployment prior to 1998, not represented here, was on a green turtle by a government body. For colour, see pdf version available online.

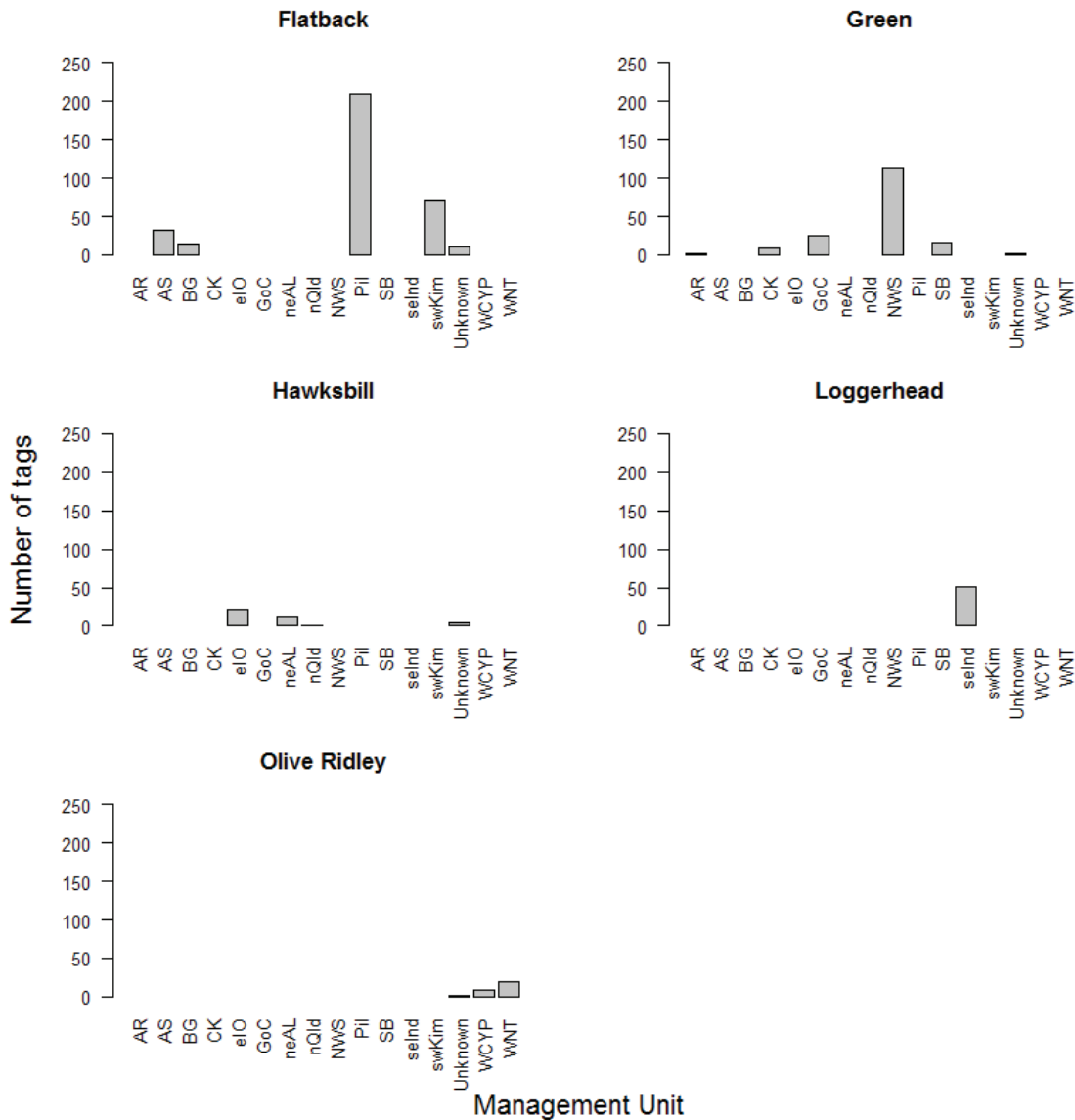


Figure 4. Number of tags deployed on each species by management unit.

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

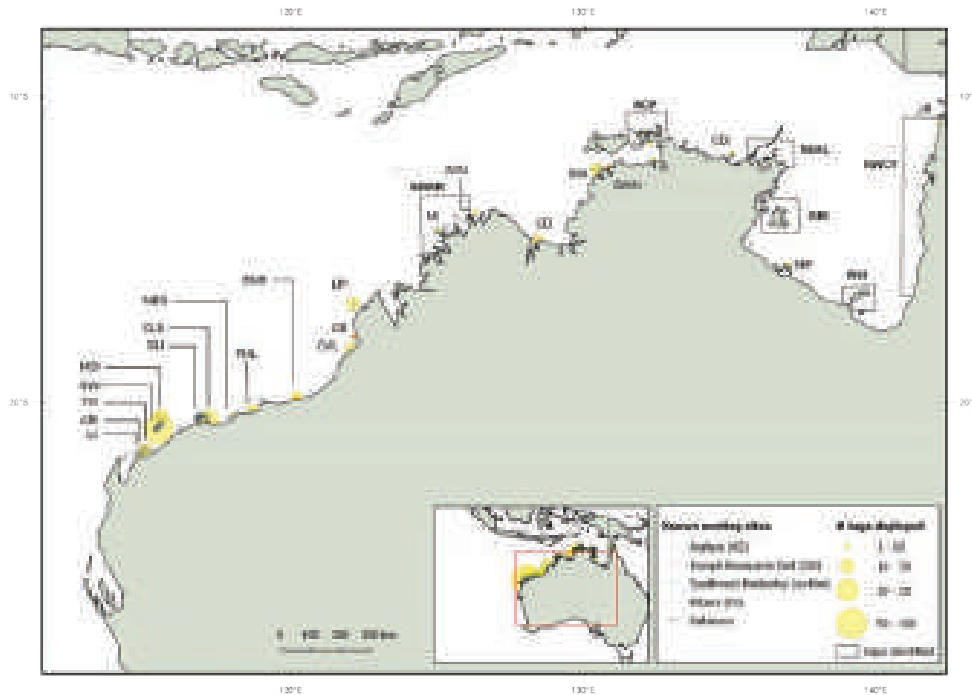


Figure 5. Number of satellite tags deployed on flatback turtles at known nesting sites (yellow circles), in water (orange) or on rehabilitated animals (red circles) within each management unit. Refer to Table 1 and 2 for acronyms used for deployment locations. Gap locations in bold include NWKR: Northwest 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.

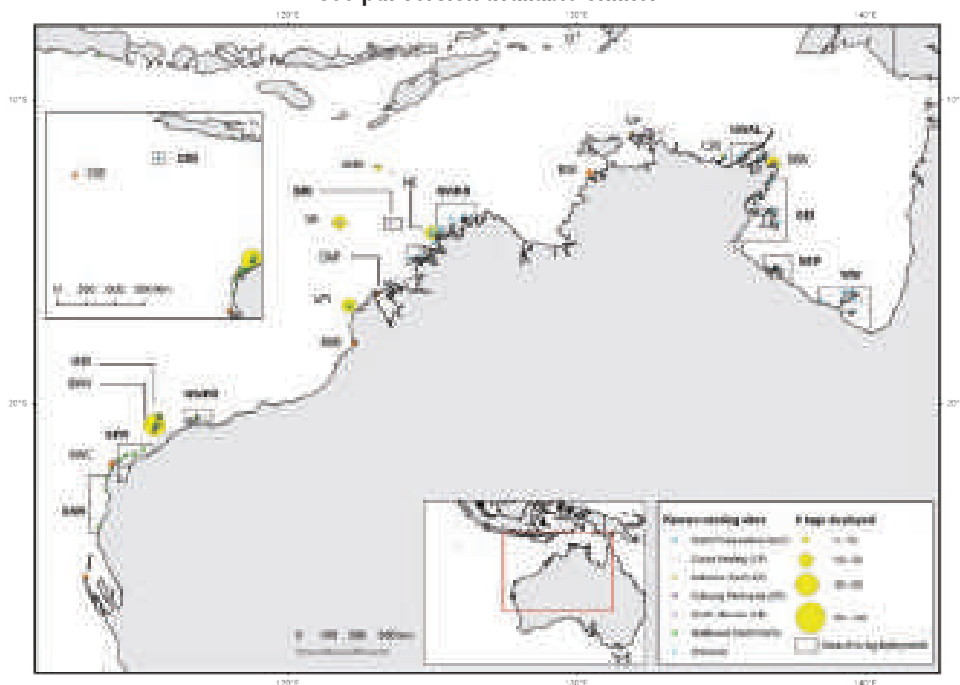


Figure 6. Number of satellite tags deployed on green turtles at known nesting sites (yellow circles) and in-water (orange) within each management unit. Refer to Table 1 and 2 for acronyms used for deployment locations. Gap locations in bold include SNR: south Ningaloo region; SPR: south Pilbara region; 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.

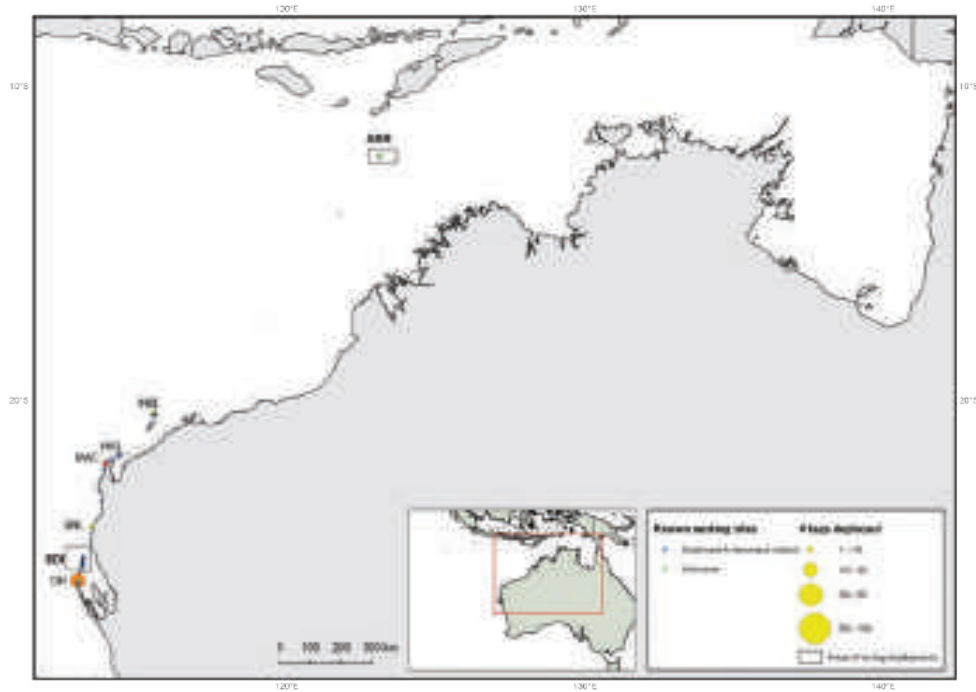


Figure 7. Number of satellite tags deployed on loggerhead turtles at known nesting sites (yellow circles), in water (orange) or on rehabilitated animals (red circles) within each management unit. Refer to Table 1 and 2 for acronyms used for deployment locations. Gap locations in bold include BDI: Bernie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

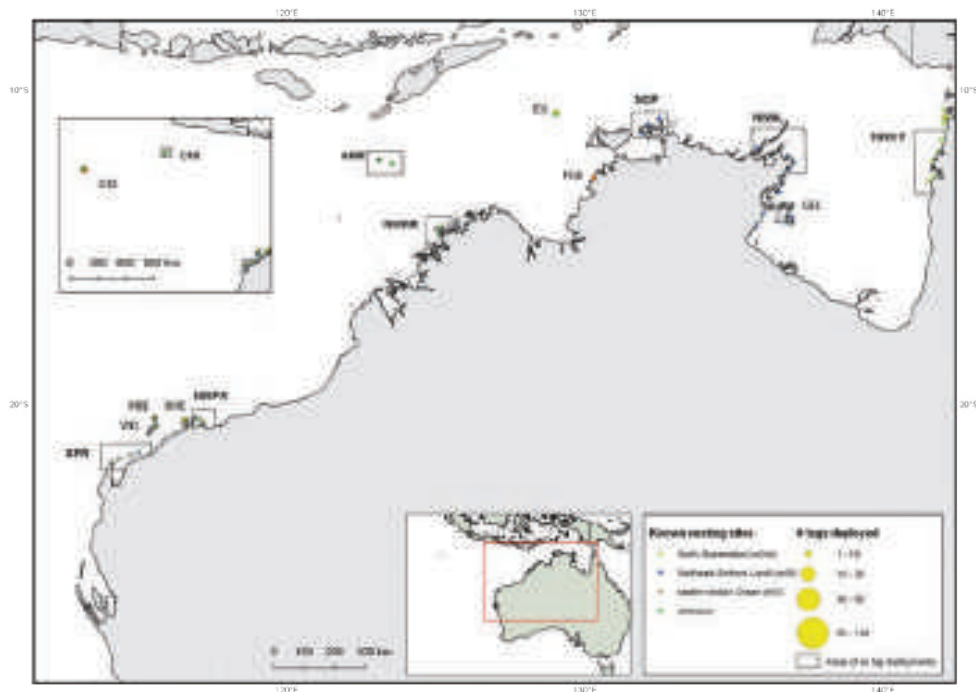


Figure 8. Number of satellite tags deployed on hawksbill turtles at known nesting sites (yellow circles) and in-water (orange) within each management unit. Refer to Table 1 and 2 for acronyms used for deployment locations. Gap locations in bold include SPR: south Pilbara region; NWPR: northwest Pilbara 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 (Whitlock *et al.* 2014, 2016a, 2016b). Historically, there appears to have been multiple purposes for the deployment of transmitters to turtles. Some are

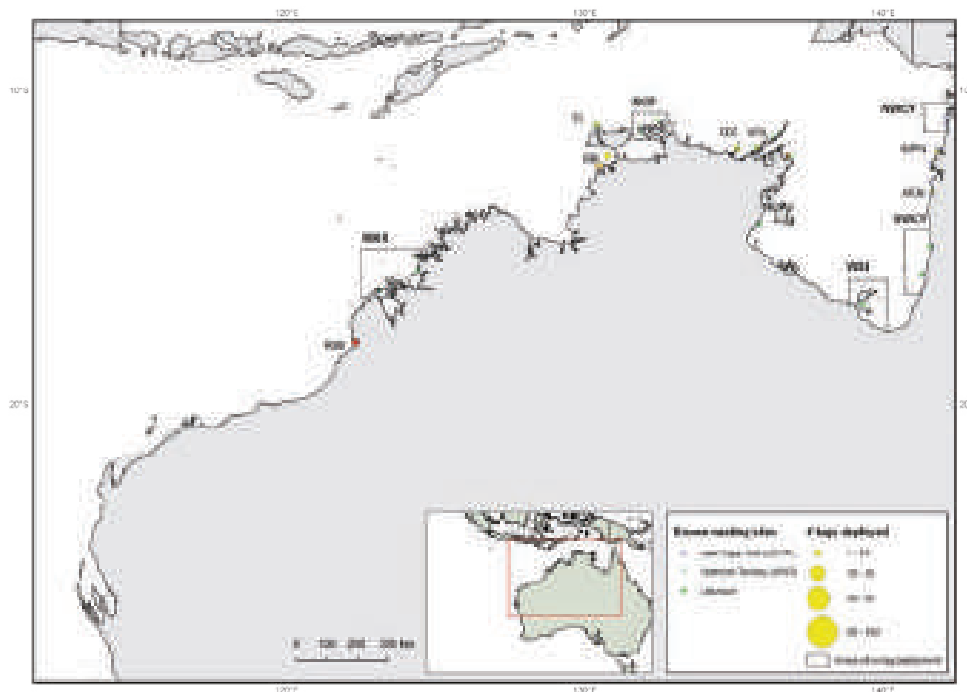


Figure 9. Number of satellite tags deployed on olive ridley turtles at known nesting sites (yellow circles), in water (orange) or on rehabilitated animals (red circles) within each management unit. Refer to Table 1 and 2 for acronyms used for deployment locations. Gap locations in bold include MKR: Mid-Kimberley region; NCP: north Cobourg Peninsula; WSI: Wellesley 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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See Mancini *et al.* (2018) for overview

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