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Understanding the risk to flatback turtles (*Natator depressus*) from expanding industrial development in Western Australia

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Table showing the contribution of co-authors for each publication

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2	**Whittock, P.A.**, Pendoley, K.L. and Hamann, M. (2014) Inter-nesting distribution of flatback turtles (*Natator depressus*) and industrial development in Western Australia. *Endangered Species Research* **26**, 25-38.	The authors co-developed the research question. Whittock and Pendoley collected the data. Whittock performed the data analyses. Whittock wrote the paper with editorial input from Hamann and Pendoley. Whittock developed the figures and tables.
3	**Whittock, P.A.**, Pendoley, K.L. and Hamann, M. (2016) Flexible foraging: Post-nesting flatback turtles on the Australian continental shelf. *Journal of Experimental Marine Biology and Ecology* **477**, 112-119.	The authors co-developed the research question. Whittock and Pendoley collected the data. Whittock performed the data analyses. Whittock wrote the paper with editorial input from Hamann and Pendoley. Whittock developed the figures and tables.
4	**Whittock, P.A.**, Pendoley, K.L. and Hamann, M. (2016) Using habitat suitability models in an industrial setting: the case for inter-nesting flatback turtles. *Ecosphere* **7(11)**, e01551.	Whittock and Hamann co-developed the research question. Whittock and Pendoley collected the data. Whittock performed the data analyses. Whittock wrote the paper with editorial input from Hamann. Whittock developed the figures and tables.
5	**Whittock, P.A.**, Pendoley, K.L., Larsen, R. and Hamann, M. (2017) Effects of a dredging operation on the movement and dive behaviour of marine turtles during breeding. *Biological Conservation* **206**, 190-200.	Whittock, Pendoley and Hamann co-developed the research question. Whittock collected the data, with input of Marine Fauna Observer data by Larsen. Whittock performed the data analyses. Whittock wrote the paper which with editorial input from Hamann and Larsen. Whittock developed the figures and tables.

Outputs during candidature

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Whittock, P.A., Pendoley, K.L., Larsen, R. and Hamann, M. (2017) Effects of a dredging operation on the movement and dive behaviour of marine turtles during breeding. *Biological Conservation* **206**, 190-200 (Chapter 5).

Other publications

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Pendoley, K.L., Schofield, G., **Whittock, P.A.**, Ierodiaconou, D. and Hays, G.C. (2014) Multi-species use of a coastal migratory corridor connecting Marine Protected Areas. *Marine Biology* **161(6)**, 1455-1466.

Pendoley, K.L., **Whittock, P.A.**, Vitenbergs, A. and Bell, C.D. (2016) Twenty years of turtle tracks: marine turtle nesting activity at remote locations in the Pilbara, Western Australia. *Australian Journal of Zoology* **64**, 217-226.

Conference presentations

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Abstract

An increased global demand for natural resources has driven a recent expansion in Western Australia’s industry resource sector, notably within the North West Shelf (NWS) region. This demand has increased industry resource activities both offshore e.g. exploration, drilling, production, and nearshore of the NWS’s coastal boundary e.g. dredging, construction, underwater blasting. Elsewhere, these activities are known to present a threat to marine turtles and there is a potential for the expanding NWS industry resource sector to present a threat and risk of impact to flatback turtles that are known to occur within the same region.

Threats posed to flatback turtles by developments and activities associated with the industry resource sector are managed through the Environmental Impact Assessment (EIA) process. The process includes two important phases: a screening/referral exercise that considers the potential presence of protected species within the development’s footprint and determines the subsequent scale of the EIA; and an Environmental Scoping Document (ESD) which includes a risk-assessment process that helps inform the need and design of control measures required to remove or reduce the risk of impact to a species from a particular activity. To be effective, both phases require baseline species information and prior knowledge gained from follow-up case studies involving the species and a similar activity.

For flatback turtles and proposed industry resource sector developments/activities on the NWS, there are knowledge gaps that may prevent effective screening/referral and ESD phases, potentially resulting in an insufficient level of protection during construction or operation. This thesis has therefore been applied in nature to address these gaps and contribute information and knowledge that can be applied during the different EIA phases outlined above and ultimately to contribute to the conservation of flatback turtles within the region.

My first objective was to identify the baseline spatial movement and distribution of flatback turtles on the NWS and determine the extent of the industry resource sector threat by investigating their potential for interaction during different life phases. To achieve this objective, I used data from satellite tracking units that were attached to nesting flatback turtles at multiple rookeries on the NWS to investigate their movements and behaviour during their inter-nesting (Chapter 2) and subsequent post-nesting foraging (Chapter 3) life phases. I undertook a broad scale assessment of the potential likelihood for interaction and threat from the industry resource sector by identifying their overlap with areas that have the potential to host activities associated with the industry resource sector in the region.

I found differences between rookeries with regards to the extent of the threat from the industry resource sector. Flatback turtles tracked from offshore islands (Thevenard and Barrow)

demonstrated the largest overlap of their inter-nesting home range and time with areas that have the potential to host industry resource sector activities. Extended inter-nesting movements from these offshore islands to the coastline close to the mainland also increased their exposure to current and planned major resource developments. I found no overlap of inter-nesting home range areas and time with areas that have the potential to host industry resource sector activities for turtles tracked from mainland rookeries (Mundabullangana and Port Hedland).

Following the completion of their inter-nesting phase, I further investigated their movements, behaviour and likelihood of interaction with the industry resource sector during their foraging life phase (Chapter 3). I found that foraging areas were broadly dispersed across the region, with the furthest foraging area situated 2511 km from the original nesting site (Port Hedland) within the Gulf of Carpentaria in Queensland state waters. I delineated five main areas of concentrated foraging use. I recorded an overlap of habitat use by flatback turtles from multiple rookeries within the same RMU for the first time, with some individual foraging areas utilised by flatback turtles tracked from rookeries of different origin.

I considered that during the flatback turtle foraging life phase, the extent of the threat from the industry resource sector was lower compared to their inter-nesting life phase. Nearly half of their foraging areas were situated within an existing protected area and there was a smaller overlap of their home range areas with petroleum title areas when foraging. Their behaviour appeared more flexible when foraging compared to inter-nesting, showing low site fidelity and moving between multiple areas distributed across a broad area.

My second objective involved investigating the environmental variables that influenced flatback turtle distribution during their inter-nesting life phase and generating a habitat suitability model to identify areas of the NWS where flatback turtles may be present and specific areas where they have the highest likelihood of impact from industry resource sector activities.

I used an ensemble ecological niche-modelling approach to identify the environmental variables that influenced inter-nesting flatback turtle distribution across the NWS study area (Chapter 4). Inputs into the model included selected environmental variables and flatback turtle presence data based on inter-nesting tracking positions from multiple rookeries in the region. Outputs of the model included the importance of each variable and a regional flatback turtle inter-nesting habitat suitability map. I compared the inter-nesting habitat suitability map with a cumulative resource sector impact layer to produce a regional risk map and identify specific inter-nesting areas with the highest likelihood of interaction across the region.

I found the primary environmental variables that influenced flatback turtle inter-nesting distribution were bathymetry, distance from coastline and sea surface temperature. The habitat suitability map demonstrated areas of inter-nesting habitat in close proximity to many known flatback turtle rookeries across the region. I found areas of suitable inter-nesting habitat overlapped spatially with resource sector impact areas in close proximity to nearly all known flatback rookeries within the NWS study area, with notable overlaps of highly suitable habitat with areas of high cumulative impact in areas offshore from the Gorgon Liquefied Natural Gas (LNG) development at Barrow Island and the existing port at Port Hedland.

My third objective was to contribute an EIA follow-up case study by evaluating the predicted vs. actual consequence of the Gorgon LNG dredging operation at Barrow Island to inter-nesting flatback turtles. I also considered the suitability of implemented control measures by comparing flatback turtle movement and behaviour at different phases of the dredging operation and combining this with actual survivorship data as represented by injury/mortality observations recorded by onboard Marine Fauna Observers (MFOs).

To achieve this objective, I attached satellite tracking units and time-depth recorders to nesting flatback turtles at different phases of the Gorgon LNG dredging operation: before (baseline), during (dredging) and after (post-dredging). I compared specific inter-nesting movement and behavioural characteristics recorded during each of these dredging phases and reviewed the observation records of onboard MFOs.

I found that during the active dredging operation, flatback turtles had a substantially higher use of the dredging areas compared to the baseline and post-dredging phases (Chapter 5). During the dredging operation, they used the areas being dredged to undertake longer and deeper dives compared to baseline and post-dredging phases, utilising the now deeper and highly turbid waters of the dredging areas. Despite their increase in time spent within the active dredging areas and subsequent increase in potential exposure to entrainment or vessel strike, no events of injury or mortality were detected by the onboard MFOs.

I considered that the implemented control measures may have been effective in preventing their injury or mortality, however, based on the results showing that turtles remained within the active dredging areas, the spatial scale of the control measures' effectiveness in deterring turtles from the area may be smaller and less effective than first anticipated. I further reviewed the potential drivers behind their increased use of the dredging areas during the active dredging operation. The most likely driver was considered to be a combination of the increase in turbidity and acoustic noise within the dredging area; potentially resulting in an area that was predator-free and reduced the likelihood of predator detection.

This thesis demonstrates that the expanding industry resource sector provides a risk of impact to NWS flatback turtles when inter-nesting and foraging offshore, though any realised impact from this threat is likely dependent on the scale that it is assessed at. At a project-by-project scale, the potential for an individual development or activity to provide a population wide impact to flatback turtles situated offshore is limited due to the existing regulated EIA process and variations in flatback turtle spatio-temporal movement and behaviour characteristics demonstrated at multiple rookeries in this study. However, at a regional scale, the movement and behaviour characteristics, spatial extent of the industry resource sector and limitations within the EIA process for assessing cumulative impact, provides potential for population wide impacts to NWS flatback turtle rookeries from the industry resource sector.

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Chapter 1

General Introduction

1.1 Industrial Activities as a Threat to Biodiversity

The development of an industry sector is driven by its potential contribution to economic growth and resulting benefits such as a reduction in the level of poverty, unemployment, technological innovation and environmental research (United Nations 2007; Chen & Ravallion 2004). Some of the recent growth in the primary or extractive industry sector (referred to herein as industry resource sector) has been attributed to an increase in global population and associated demand for energy, minerals and metals (UNEP 2012). Consequently, the industry resource sector is expanding into new, previously ‘untouched’ remote areas, much of it within coastal and offshore regions (Pinder 2001; Gill 2005; IEA 2013; Merrie et al. 2014).

There are a number of threats to biodiversity within the coastal zone and many can be related to human population growth (Gray 1997). Indeed, it is estimated that nearly 50% of the world’s coasts are threatened by development-related activities, with much of this attributed to the estimated 37% of the world’s population living within 100 km of the coast at a population density twice the global average (UNEP 2012). Furthermore, population pressure is driving the need for additional development, particularly within the industry resource sector as it is reliant on the coastal zone for port sites, offshore gas pipelines, shipbuilding, and the import and export of raw minerals and metals. This has led to an increase in industry resource sector-related activities offshore within the coastal zone, including dredging, underwater blasting, construction, land reclamation and seismic surveys (Gill 2005; UNEP 2012).

In addition to activities within the coastal zone, advances in technology are facilitating further expansion of industry exploration activities into increasingly deeper offshore areas (Pinder 2001). This expanding exploration led to nearly 70% of all global oil and gas discoveries between 2000 and 2009 being made in offshore areas (Sandrea & Sandrea 2010), with many of these areas within previously unreachable deep-sea deposits (Ahlbrandt et al. 2005). As a result, since 2009 nearly one-third of global oil production and one-quarter of natural gas production has originated from offshore platforms (Maddahi & Mortazavi 2011). Considering the expected future global population growth and advances in technology, the industry resource sector, along with related offshore activities, is predicted to experience ongoing growth, expansion and increased capital expenditure over the next century (IEA 2013).

Globally, industry resource sector activities within coastal and offshore regions have caused environmental harm and increased pressure on natural environments and biodiversity (Bellamy et al. 2013; Halpern et al. 2008; Gill 2005). Activities have led to direct impact including habitat destruction from beach or shoreline alteration (e.g. Bilkovic & Roggero 2008) and species mortality through vessel collision (e.g. Neilson et al. 2012), underwater blasting (e.g. Keevin & Hempen 1997), entrainment (e.g. Goldberg et al. 2015), seismic activity (e.g. Nelms et al. 2016), fisheries bycatch (e.g. Žydelis et al. 2009) and contamination from an oil spill event (e.g. Munilla et al. 2011; Helm et al. 2006). Activities have also resulted in indirect impacts to habitats and species through increased underwater noise (e.g. Merchant et al. 2014), artificial light (e.g. Harewood & Horrocks 2008), sedimentation (e.g. Erftemeijer et al. 2012), contaminant/effluent discharge (e.g. Primavera 2006) and oil spill events (e.g. Peterson et al. 2003).

1.2 Industry Resource Sector Activities as a Threat to Adult Marine Turtles

All seven species of marine turtle are internationally protected and are listed by the International Union for the Conservation of Nature (IUCN) as Vulnerable (olive ridley, *Lepidochelys olivacea*; leatherback, *Dermochelys coriacea*; loggerhead, *Caretta caretta*), Endangered (green, *Chelonia mydas*), Critically Endangered (Kemp's ridley, *Lepidochelys kempii*; hawksbill, *Eretmochelys imbricata*) and Data Deficient (flatback, *Natator depressus*). Marine turtles are circumglobally distributed, inhabit nearly all oceans and their life cycle involves long time spans and long-distance migration between breeding and foraging locations (Wallace et al. 2010). Interactions with industry resource sector activities can negatively affect their distribution (e.g. Carstensen et al. 2006; Harewood & Horrocks 2008), health (e.g. Madsen et al. 2006; Stewart et al. 2007) and alter their behaviour (e.g. Leung Ng & Leung 2003; Thompson et al. 2010).

Industry resource sector activities can directly alter marine turtle nesting habitat through erosion or accretion following beach nourishment, sand mining or dredge spoil disposal, or indirectly following beach armouring or artificial impediments to longshore drift (such as groynes, seawalls or jetties; Witherington 1999). These alterations can influence an adult turtles nest site selection or reduce the habitat area suitable for nesting, potentially resulting in nests being laid closer to the water and subsequent loss following a high tide or storm surge event (Matsushita et al. 1993). Alterations to beach characteristics can also negatively influence the nest’s incubation environment, potentially influencing the hatching and/or emergence success (Mota & Peterson 2003; Peters et al. 1994; Pilcher 1999).

Noise and vibration generated by activities associated with exploration and construction is another potential threat to marine turtles (Lenhardt et al. 1996; O’Hara 1990). The actual threat of persistent noise in the marine environment to turtle behaviour and physiology is inconclusive and poorly understood, as is the role hearing plays in their capacity for survival (Lenhardt 1994). Noise generating activities situated offshore include seismic surveys, dredging, underwater blasting and the construction and operation of offshore infrastructure.

Offshore seismic surveys are used to search for oil and gas deposits beneath the seabed and involve firing airguns suspended within the water column to generate high intensity pressure (shock) waves. The exact threat of seismic activities to marine turtles is poorly understood (Nelms et al. 2016) but the disturbance has the potential to influence their foraging or breeding behaviour

(McCauley et al. 2000), affect their hearing, cause injury or death (Samuel et al. 2005) or cause a depressed immune function (Anderson et al. 2011). In addition, there is a risk of entanglement with the towing setup of the airgun array (Nelms et al. 2016).

Vessels involved in activities associated with the industry resource sector can strike marine turtles leading to their injury or mortality (Hazel & Gyuris 2006). Within US waters, 9 – 18% of stranded turtles displayed injuries consistent with a boat strike (Lutcavage et al. 1997) and in Queensland, Australia, 56% of 139 marine turtle stranding records showed injuries consistent with a vessel strike (Haines & Limpus 2000). Clearly, any increase in vessel use as a result of industrial development is of concern.

Offshore dredging is often required to facilitate coastal development and involves excavation, transportation and disposal of benthic substrate. In addition to habitat destruction, direct impacts of dredging activities to marine turtles includes: entrainment (Dickerson et al. 1991; Goldberg et al. 2015), noise disturbance (Thomsen et al. 2009) and increased turbidity (Weiffen et al. 2006). Yet despite the potential impact, studies examining dredge impacts on marine turtles are rare.

One consequence of industry activities that can threaten marine turtles and all utilised habitat (including when breeding/nesting/foraging) is an oil spill event (Jernelöv 2010). The routine activities of tankers, oil refineries and offshore drilling and production platforms are a potential source of oil spills in the nearshore coastal zone and offshore waters. Major oil spill events that are known to have threatened or impacted marine turtles include the 2009 Montara well blowout in the Timor Sea near Australia (Burns & Jones 2016) and the 2010 BP Deepwater Horizon oil spill in the Gulf of Mexico (Wallace et al. 2015). However, at present, there are few data from these events to indicate whether population scale impacts occurred.

1.3 Thesis Study Area: The Australian North West Shelf

The Australian North West Shelf (NWS) is situated in Western Australia and extends from the North West Cape in the west to the De Grey River in the east, and offshore to the 100 m isobath (as defined by the North West Shelf Joint Environmental Management Study; CSIRO 2007; Figure 1.1). The NWS is host to both an offshore industry resource sector and multiple flatback turtle rookeries.

1.3.1 NWS Offshore Industry Resource Sector

Since 2003/04, Australia’s industry resource sector has been growing substantially, with the growth largely attributed to the strong demand for petroleum and iron ore resources from emerging markets in China and India (Figure 1.2).

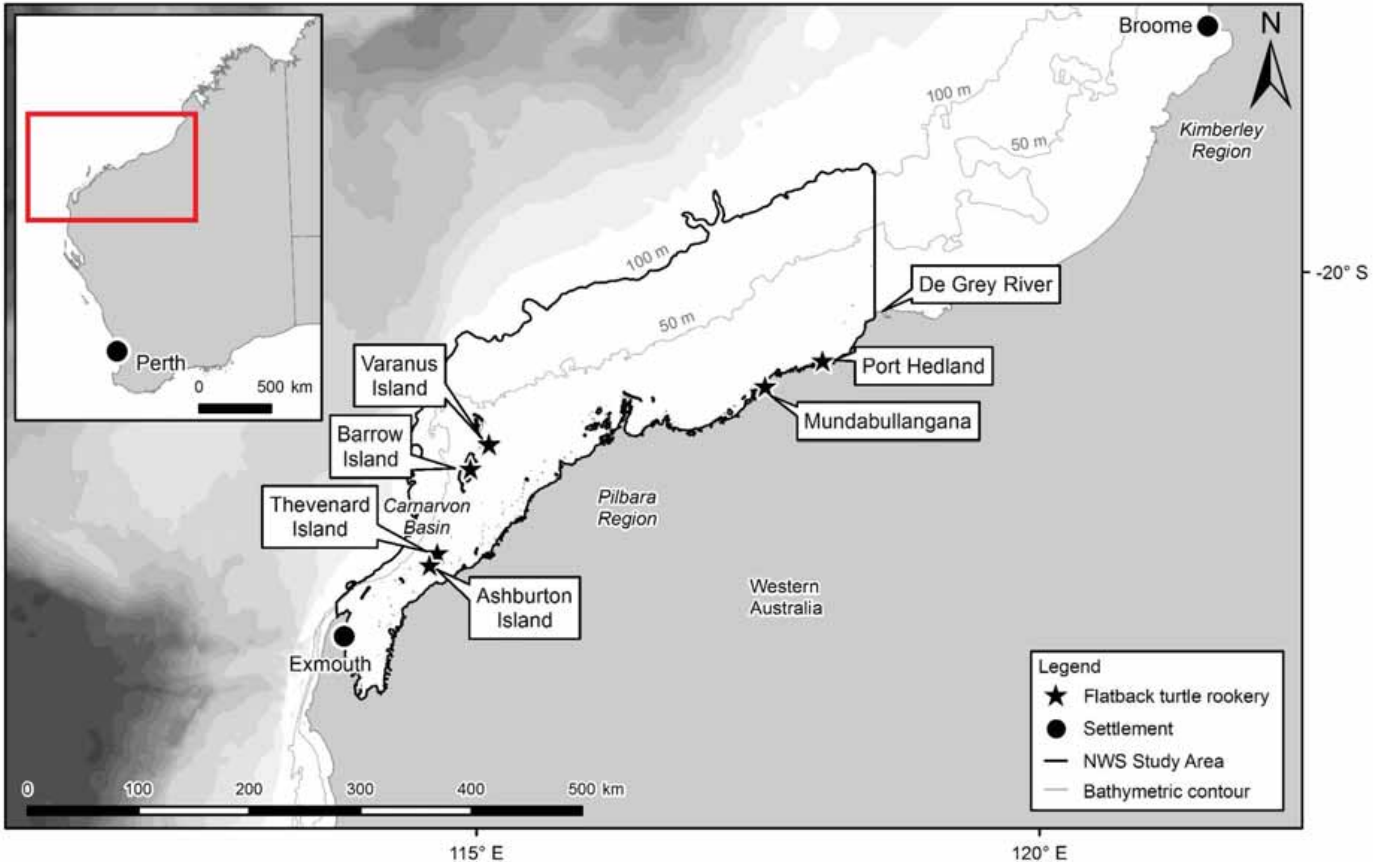

Figure 1.1 The boundary of the Australian North West Shelf.

The majority of this growth has occurred within the state of Western Australia where a large proportion of Australia's existing petroleum resource reserves are found: 64% of crude oil; 75% of condensate (light oil); and 57% of liquefied natural gas (LNG) (ABARE 2010). Notably, many of these reserves are found offshore in the Carnarvon Basin within the boundary of the NWS (Figure 1.3).

The global demand for resources has resulted in the value of Australia's iron ore exports increasing from A$5.3 billion in 2003/04 to A$34.2 billion in 2008/09 (Figure 1.2; ABARE 2010). A high proportion of this iron ore is mined and processed within Western Australia, with regional ports situated within the NWS boundary carrying 95% of Australia's total iron ore export (Figure 1.3; CSIRO 2007).

The NWS also hosts a number of other important industries including salt production, commercial fisheries and a rapidly expanding tourism industry. This, combined with the recent expansion of the petroleum and iron ore resource sectors, has seen the NWS become one of the most economically significant coastal and offshore regions in Australia (Human & McDonald 2009).

The growth of the NWS industry resource sector has coincided with an increased need for storage, processing and transport facilities and an increased regional population, which itself requires additional infrastructure and services (Figure 1.3). This has led to a surge in offshore activities on the NWS, including dredging, exploration involving drilling and seismic surveys, and construction. For example, in Western Australia alone, more than 200 million cubic metres of dredge spoil (sediments and materials removed from the seabed during dredging) from new coastal developments has recently been approved for ocean and coastal disposal (DSEWPaC 2011).

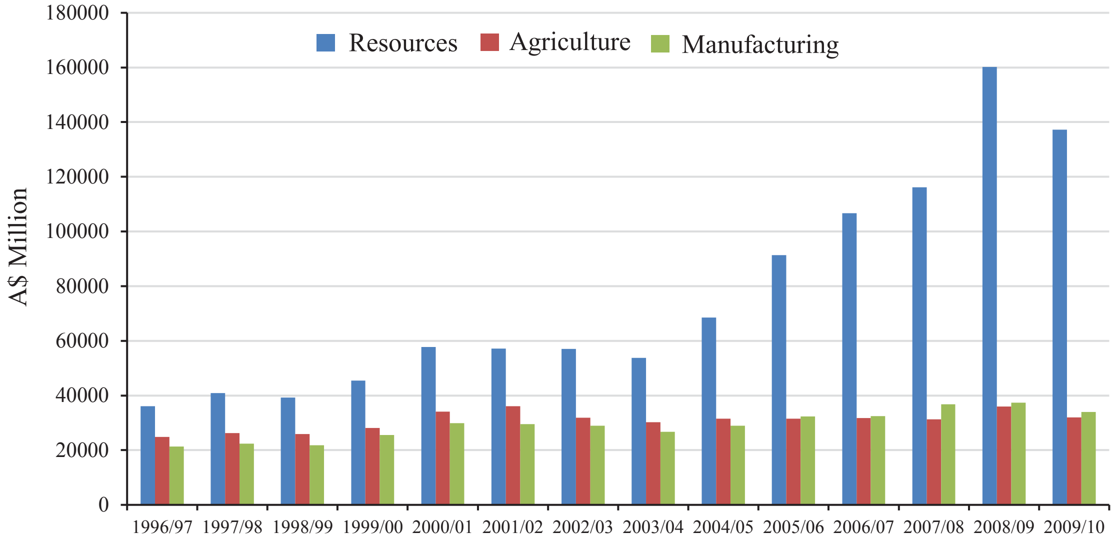

Figure 1.2 Australia's annual export earnings from industry resources, agriculture and manufacturing sectors (ABARE 2010).

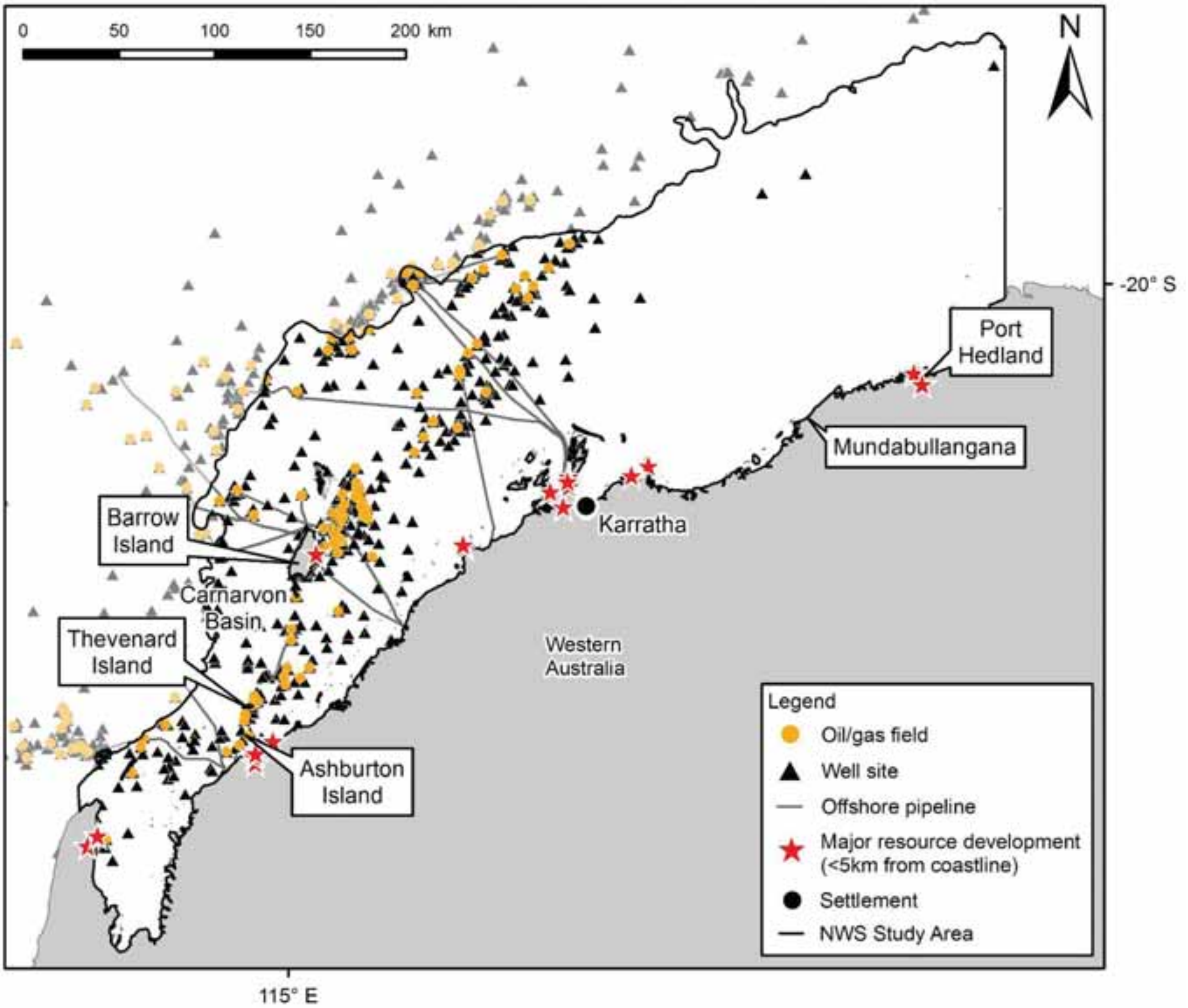

Figure 1.3 Location of existing NWS industry resource sector infrastructure and known oil/gas fields.

1.3.2 Flatback Turtles on the NWS

Of all the marine turtle species globally, flatback turtles are considered the least studied and are the only marine turtle species to be listed by the IUCN as Data Deficient (Red List Standards & Petitions Subcommittee 1996). This listing is given to species when there is inadequate information to make a direct, or indirect, assessment of its risk of extinction based on its distribution and/or population status and indicates that more information is required. The absence of adequate long-term information on flatback turtle populations is likely due to the location of their nesting sites in remote, often inaccessible, parts of northern Australia. In addition to their international protection, under Australian legislation they are listed as a threatened species making the species a "Matter of National Environmental Significance (MNES)" under the *Environment Protection and Biodiversity Conservation (EPBC) Act (1999)* (Environment Australia 2003).

1.3.2.1 Breeding

Flatback turtles are endemic to the Australian continental shelf meaning the species does not have an open ocean pelagic oceanic phase in its life cycle (Pritchard 1997; Walker & Parmenter 1990). Their global distribution extends from the Pilbara region of Western Australia, northwards around the Northern Territory and into Queensland waters (Bustard et al. 1975; Limpus 1971, 2009; Limpus et al. 1981, 1983, 1988; Parmenter & Limpus 1995). Five genetic stocks are currently recognised: Pilbara Coast, Arafura Sea, Joseph Bonaparte Gulf, South West Kimberley and Eastern Australia (Pittard 2010).

The range of flatback turtle breeding in Western Australia extends eastwards from Cape Range in the Pilbara region to Cape Domett in the Kimberley Region, with Cape Domett hosting the largest rookery in the state (Whiting et al. 2008). In the NWS study area, the highest concentration of significant rookeries is found in the Pilbara region (see Figure 1.1; Limpus 2007) and the largest known rookeries are Barrow Island, Mundabullangana and collectively, the Mackerel Islands offshore from Onslow (Pendoley et al. 2014a; Pendoley et al. 2016). Flatback turtle rookeries within the NWS are part of the same Pilbara Coast genetic stock and are within the South East Indian Ocean Regional Management Unit (RMU) boundary, one of two RMU's recognised by the IUCN Marine Turtle Specialist Group for flatback turtles (Wallace et al. 2010).

All species of marine turtles are oviparous, meaning females lay eggs on their natal beach. Female flatbacks lay multiple clutches of eggs during each nesting season (Hamann et al. 2003; Limpus 2009; Pendoley et al. 2014a). Between each nesting event, the female moves to an area situated offshore while they form their next clutch of eggs. This period is known as the inter-nesting period. The drivers behind their movement during this period remains unknown (Plotkin 2003). It is thought that during this period, flatback turtles remain in near shore waters close to their nesting beaches, however this has not been confirmed in published studies and there is little information within grey literature on the extent of their movements during this time (Plotkin 2003; Waayers et al. 2011). Analysis of six inter-nesting flatback turtles satellite tracked from a flatback rookery on the NWS (Barrow Island) as part of the environmental approval process for a development showed that between nesting events, they either spent time in nearshore waters <10 km from their nesting beaches or in an area situated ~50 km away off the adjacent mainland coast (Chevron Australia 2009). The dive behaviour of inter-nesting flatback turtles from rookeries within the NWS also remains unknown, including duration, frequency and maximum depth.

1.3.2.2 Foraging

Following the completion of breeding activities, flatback turtles will commence their post-nesting migration to reach their foraging habitat. The migratory range of post-nesting flatback turtles is restricted to the tropical waters of the Australian continental shelf (Limpus et al. 1981) to as far north as the Gulf of Papua in Papua New Guinea (Spring 1982) and coastal waters of Papua in Indonesia (Samertian & Noija 1994). Satellite tracking of flatback turtles from multiple rookeries within the NWS indicated their migratory movement was in a NE direction towards foraging habitat situated outside of the NWS within the Kimberley region, though the locations of the foraging habitat remains unknown (Pendoley et al. 2014b; Figure 1.1). Once at their foraging habitat, adult females will prepare for their next breeding migration, typically returning to nest after an interval of around two years (Barrow Island: 1.9 years; Mundabullangana: 2.2 years; Pendoley et al. 2014a).

Observations of adult flatback turtles at the surface indicates they are commonly found in areas with a bathymetric depth of 40 – 45 m and occasionally at depths of 60 m (Walker 1991; Poiner & Harris 1996; Robins & Mayer 1998). In the Northern Territory, Sperling et al. (2010) recorded inter-nesting flatback turtles diving to a maximum depth of 44 m using time-depth recorder (TDR) technology, indicating that the species may be shallower divers than other marine turtle species.

1.4 Assessing the Environmental Impact of the Industry Resource Sector to Flatback Turtles

Environmental Impact Assessment (EIA) is a process of identifying and evaluating the consequences of human actions on the environment and, where appropriate, mitigating those consequences (Erickson 1994). The process involves a systematic and orderly evaluation of a development proposal and its impact on the environment.

Within Western Australia, industry resource sector proponents take primary responsibility for the protection of the environment relating to their development proposals. Under the EPBC Act (1999), a proponent who considers that their development may have a significant impact on a MNES species (e.g. flatback turtles) must undertake a screening exercise by referring their development proposal to the Environmental Protection Authority (EPA) i.e. the competent authority (regulator), for consideration of the need to undergo the process of EIA. The EPA will determine whether the proposal is likely to have a significant impact using professional judgement and will consider a number of factors when making its decision, including:

- values, sensitivity and quality of the environment which is likely to be impacted;
- extent (intensity, duration, magnitude and geographic footprint) of the likely impacts;
- consequence of the likely impacts (or change);
- resilience of the environment to cope with the impacts or change;
- cumulative impact with other projects; and

- level of confidence in the prediction of impacts and the success of proposed mitigation.

If it is decided that an EIA is required, the EPA may request a Public Environmental Review (PER) level of assessment, with the decision based on whether the proponent's development proposal meets any of the following criteria:

- the proposal is of regional and/or State-wide significance;
- the proposal has several key environmental factors or issues, of which some are complex or of a strategic nature;
- how environmental issues could be managed; or
- the level of public concern about the likely impact of the proposal, if implemented, on the environment, warrants a public review period.

One fundamental component of the PER assessment is the scoping phase which involves the preparation of an environmental scoping document (ESD). The ESD includes an assessment of the potential risk an operation's activity may have on MNES species (e.g. flatback turtles) or their habitats that may be present in proximity to the activity or within the development's footprint. The ESD includes details of any offsets that are needed for any significant residual impact(s) or risks and, if required, identifies the need for an environmental management plan (EMP) and proposed mitigation measures to manage adverse environmental impacts.

The process of assessing risk within an ESD typically involves the use of a matrix combining both the likelihood of an activity causing an impact and the potential consequence of the activities impact on the identified species population or habitat. The combination of likelihood and consequence scores identifies the overall inherent risk of impact. Once the risk score has been established, management actions are identified that can be implemented to prevent, reduce or offset the likelihood or consequence of the activity and a new residual risk of impact identified.

Applying the ESD's risk-assessment process to determine likelihood and consequence scores for the impact to flatback turtles is particularly challenging for an operation's activity when situated offshore. To conduct an accurate assessment of likelihood, sufficient baseline information outlining the flatback turtles offshore spatial and temporal distribution is required so that any overlap with the activity and potential interaction can be determined. Difficulties arise when identifying this baseline information as it is logistically and/or technically challenging. As a result, gathering this information can be overlooked in the EIA process or instead inferred from other baseline information such as terrestrial nesting beach surveys. This can lead to inaccuracies in the assigned scores within the ESD's risk matrix, potentially resulting in an absence of protection measures or, due to the low confidence in assigned scores, the precautionary principle approach may be applied, potentially leading to a multitude of inefficient or poorly designed protection measures being implemented. Regardless, the outcomes of both approaches may not provide adequate protection and may come at additional cost to the proponent.

In addition to the use of baseline data to inform risk matrix scores within the ESD, proponents or regulators may also use lessons learned and/or past experience highlighted within follow-up exercises of other EIA's involving similar activities and/or species from developments situated elsewhere. EIA follow-up is defined as the monitoring and evaluation of the impacts of a project (that has been subject to EIA) for management of, and communication about, the environmental performance of that project (Morrison-Saunders & Arts 2004). EIA follow-up comprises four elements (Arts et al. 2001):

1. Monitoring: the collection of activity and environmental data both before (baseline monitoring) and after activity implementation (compliance and impact monitoring).
2. Evaluation: the appraisal of the predictions as well as the environmental performance of the activity.
3. Management: making decisions and taking appropriate action in response to issues arising from monitoring and evaluation activities.
4. Communication: informing the stakeholders about the results of EIA follow-up in order to provide feedback on project/plan implementation as well as feedback on EIA processes.

In Western Australia, if a proposal is acceptable, the regulator may impose certain legally binding Ministerial approval conditions on the proponent which may include the need to conduct a follow-up. However, there are currently no known reviews or EIA follow-up exercises involving any of the four components listed above for flatback turtles and any industry resource sector activity on the NWS.

1.5 Offshore Flatback Turtles and Industry Resource Sector Activities within the NWS

Offshore waters within the NWS provide inter-nesting and foraging areas for globally significant populations of flatback turtles (Limpus 2009). Many of these areas are likely to be situated in proximity to their remote nesting sites, away from coastal development. However, the recent growth of the industry resource sector into previously untouched offshore and coastal areas (see Section 1.3.2) may now pose a threat to flatback turtles when they utilise their habitats in these same areas.

Since it is known how industry activities have impacted marine turtles elsewhere (see Section 1.2) there is a high likelihood of an interaction and subsequent impact occurring to flatback turtles situated offshore due to the expanding industrial resource sector on the NWS. However, despite this potential impact, there is no information relating to any overlap or interaction between any phases of the flatback turtle life cycle with industry activities on the NWS, nor are there any reviews or EIA follow-up exercises of the actual realised impacts to flatback turtles following the completion of an industry resource activity. This is largely due to significant knowledge gaps that remain in the spatial distribution of flatback turtles situated offshore, an understanding of the factors that influence their movement and behaviour on the NWS and the absence of imposed conditions for proponents to conduct EIA follow-up.

These identified knowledge gaps have the potential to impede the process of undertaking a comprehensive EIA and result in inefficient or poorly designed protection measures being implemented: at the screening/referral phase, the proponent and EPA are hindered when considering the presence of flatback turtles in proximity to an activity or a development's footprint; and when completing the ESD (if required), the assessment of initial likelihood and consequence scores within the risk matrix for a particular activity may be inaccurate or low in confidence due to the absence of baseline data or EIA follow-up involving the evaluation and communication of lessons learned from past experiences.

The consequence of the NWS's growing industry resource sector and a deficiency of data on the potential impact to flatback turtles means that any management solution is based solely on ecological knowledge gained elsewhere in Australia or potentially overseas and based on other species. An empirical study focused on understanding the relationship between offshore industry activities and flatback turtle distribution within the NWS is therefore well-timed and valuable in regards to managing the current and future growth of industry resource activities to ensure adequate protection is provided for flatback turtles.

1.6 Thesis Design and Objectives

This thesis is applied in nature and its primary aim is to provide new insights into species biology and behaviour and a new science approach that can inform the screening/referral and scoping phases of an EIA to help identify the need and design of control measures implemented to protect flatback turtles from industry resource sector activities (Figure 1.4). More specifically, the following objectives for this thesis are proposed:

Objective 1: To identify the offshore spatial movement and distribution of flatback turtles from rookeries on the NWS during their inter-nesting and foraging life phases and determine their overlap and likelihood of interaction with industry resource sector activities (Chapters 2 and 3).

Objective 2: For the life phase considered to have the highest likelihood of interaction with industry resource sector activities (based on Objective 1 outcomes): (a) Investigate the environmental variables that influence flatback turtle distribution; and (b) Generate a habitat suitability model to identify areas of the NWS where flatback turtles may be present and specific areas where they have the highest likelihood of impact from industry resource sector activities (Chapter 4).

Objective 3: Assess the consequence of an industry resource sector activity (dredging) to flatback turtles in an area with a high likelihood of interaction (based on Objective 2 outcomes) and consider the suitability of implemented control measures by: (a) reviewing flatback turtle movement and behaviour during the resource sector activity; and (b) combining this movement and behavioural information with actual survivorship data (Chapter 5).

1.7 Thesis Outline

This thesis is made up of six chapters, with four data chapters (Chapters 2 – 5) written with the intention of publication in internationally recognised journals.

At thesis submission, all four data chapters have been published in peer-reviewed journals (Chapters 2 - 5). As such, all chapters are presented as independent papers, albeit with minor adjustments to ensure they are consistent in written style and linked together to improve flow and clarity. The thesis structure, where each chapter is intended as a standalone paper, results in some information being repeated in the introduction and methods sections.

Chapter 1: Provides a general introduction to the industry resource sector and the global threat it poses to biodiversity and marine turtles. The spatial scale of the NWS is defined and the current knowledge of the offshore movements and behaviour of flatback turtles within the area is presented together with the current status of the region’s industry resource sector. Key knowledge gaps are highlighted and the project framework and objectives outlined.

Chapter 2: This chapter presents the spatial distribution of flatback turtles from multiple rookeries with the NWS during their inter-nesting life phase. The likelihood of interaction with industry resource sector activities is investigated for each rookery by quantifying their overlap with areas potentially occupied by industry. The patterns and movements of flatback turtles during each inter-nesting period are compared across rookeries in order to identify any potential opportunities for effective regional conservation management.

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

Chapter 3: This chapter identifies the location and characteristics of foraging areas for flatback turtles from multiple rookeries within the NWS, quantifies their exposure to the industry resource sector, identifies their need for protection and investigates those ecological variables that influence their vulnerability to identified threats e.g. site fidelity, size of foraging habitat, range of areas.

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

Chapter 4: This chapter combines the inter-nesting spatial position data generated in Chapter 2 with a habitat suitability model to: (a) identify the environmental variables that influence inter-nesting flatback turtle distribution across the NWS; and (b) generate an inter-nesting habitat suitability map. The map, which represents the potential geographic distribution of inter-nesting flatback turtles across the NWS, is integrated with the location of resource sector activities (as indicated by the position of vessels used for resource sector activities) to contextualise and quantify the likelihood of an interaction with industry activities across the entire area.

- **Whittock, P.A.**, Pendoley, K.L. and Hamann, M. (2016) Using habitat suitability models in an industrial setting: the case for inter-nesting flatback turtles. *Ecosphere* **7(11)**, e01551

Chapter 5: This chapter uses a case study to conduct an EIA follow-up by evaluating the consequence of an industry resource sector activity (dredging) to inter-nesting flatback turtles at Barrow Island, an area identified in Chapter 4 as having a high likelihood of interaction with industry activities. A comparison of the initial dredge-related impact predictions stated in the development's ESD, with the actual dredge-related impact to marine turtles is completed by investigating marine fauna observer (MFO) injury/mortality records. Movement and behaviour characteristics of flatback turtles are compared between each stage of the dredging program (before, during and after) to investigate behavioural changes as a result of dredging. The effectiveness of implemented dredging-related control measures are investigated by considering any behavioural changes concurrently with actual survivorship data i.e. injury/mortality observations recorded by onboard MFOs.

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

Chapter 6: Summarises and discusses the outcomes from the four data chapters (Chapters 2 – 5) and considers implications to the conservation and management of flatback turtles on the NWS and elsewhere. The chapter highlights management outcomes and provides recommendations for future research directions.

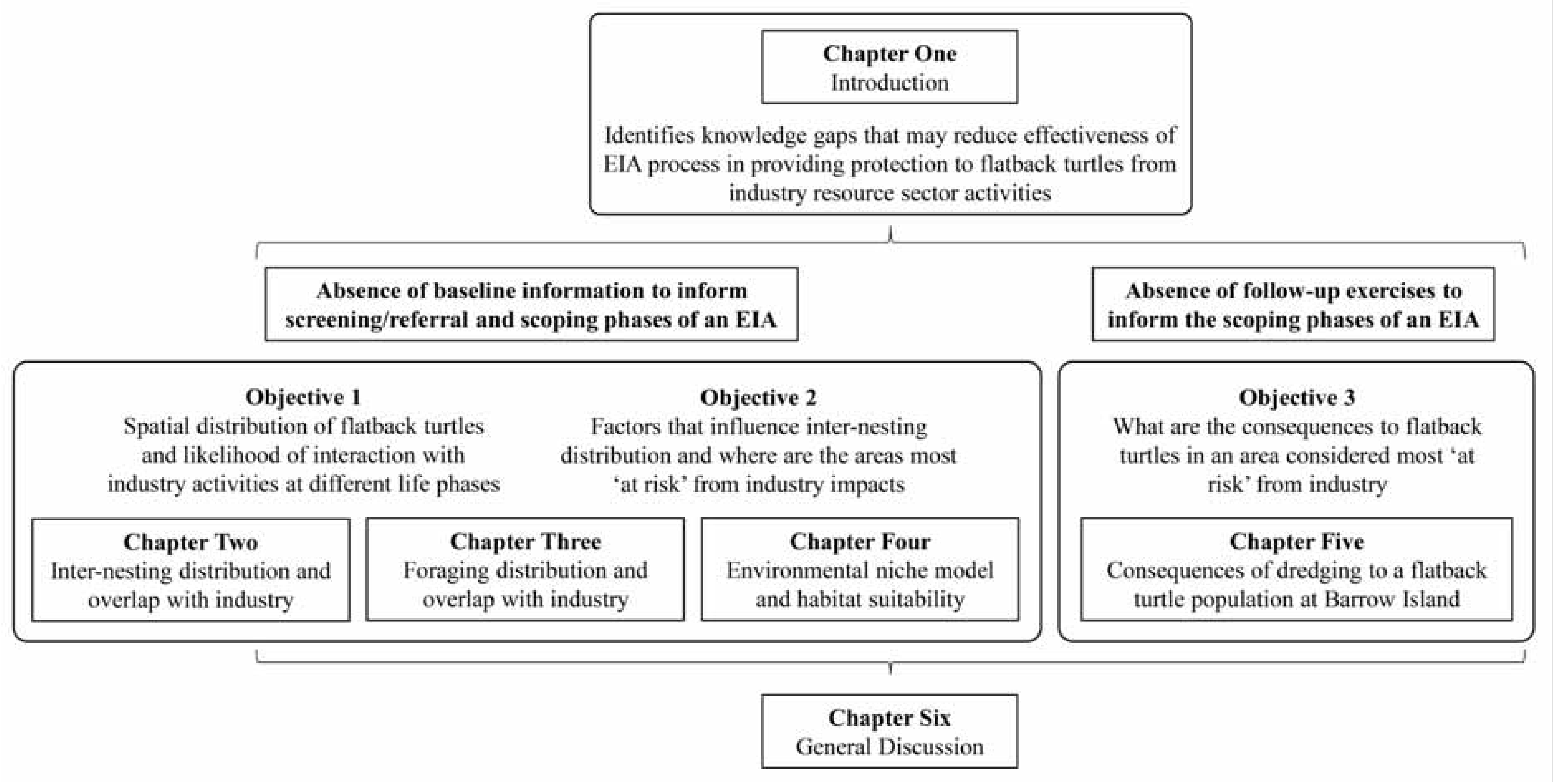

Figure 1.4 Schematic diagram of thesis structure.

Chapter 2

Industry resource sector and inter-nesting flatback turtles

Chapter 1 highlighted existing knowledge gaps that may hinder the screening/referral and scoping phases of an EIA for industry resource sector activities and potentially result in inadequate protection of flatback turtles situated offshore. The gaps related to an absence of offshore baseline spatial data for flatback turtles on the NWS that limits the consideration made by the proponent and regulator of the potential presence of flatback turtles within the development's footprint (screening/referral) and the accuracy and confidence of the assessment in determining the likelihood of an impact occurring from a particular activity (scoping).

This chapter uses satellite tracking technology to address the knowledge gap of offshore baseline spatial data for flatback turtles during their inter-nesting life phase. Their movement patterns and distribution extent from multiple flatback turtle rookeries on the NWS are described. Movement data is overlaid with areas that currently host, or have the potential to host, industry resource sector activities to provide an indication of the likelihood of interaction and potential threat.

Published manuscript:

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

www.int-res.com/articles/esr2015/26/n026p025.pdf

2.1 Abstract

Offshore interactions of inter-nesting flatback turtles with industry resource sector activities are potentially frequent, yet the associated impact is largely unquantified. Consequently, there is a need to understand the degree of interaction and to provide data that can assist with effective conservation and management within an EIA. This chapter therefore highlights the potential interaction of inter-nesting flatback turtles (*n* = 56) from four rookeries (Thevenard, Barrow Island, Mundabullangana and Port Hedland) on the NWS, with industry resource sector activities, using satellite tracking.

Flatback turtles demonstrated varying inter-nesting movements, with displacement distances from their nesting sites ranging from 3.4 to 62.1 km. Some turtles at all four rookeries remained <10 km from the nesting beach. Core home range areas for inter-nesting flatback turtles ranged from 1.4 – 601.1 km^2. The proportion of core home range areas for Thevenard and Barrow Island turtles that overlapped areas where industry resource sector activities may occur (as indicated by petroleum title areas) was 85.7% and 88.6%, respectively. The proportion of median daily positions that overlapped petroleum title areas was also high; 80.8% (Thevenard) and 87.3% (Barrow). There was no overlap of home range areas and median daily positions with petroleum title areas for Mundabullangana and Port Hedland turtles, though some inter-nesting movements of Port Hedland turtles were in close proximity to a proposed port expansion.

The wide ranging inter-nesting movement patterns from all four rookeries highlights a need for regulators and proponents to expand the scope of the EIA screening/referral phase, ensuring flatback turtles are considered within the proponents proposal and adequate protection is provided to inter-nesting flatback turtles. The similar nearshore inter-nesting movement pattern recorded by some flatback turtles at each rookery provides an opportunity to establish boundaries for small scale spatial and temporal protection measures.

2.2 Introduction

Interaction between industrial development activities and protected fauna species is of worldwide concern (Gill 2005; Halpern et al. 2008). Interactions can negatively affect distribution (Carstensen et al. 2006; Harewood & Horrocks 2008), behaviour (Leung Ng & Leung 2003; Thompson et al. 2010) and health (Madsen et al. 2006; Stewart et al. 2007) of terrestrial and marine species during different phases of their life cycle. Expansion of traditional industrial development activities (e.g. mineral extraction processes) and, more recently, activities related to renewable energy developments (e.g. wind farms, tidal barriers), into ‘untouched’ remote coastal and offshore regions, provides further opportunity for interaction between breeding and migration life phases of marine species (Gill 2005). While the potential impact of interactions have been documented for some migrating marine species (Bailey et al. 2010; Maxwell et al. 2013), for breeding and migratory marine turtles, the potential overlap (and associated consequences) with industrial activities remains of concern.

Marine turtles lay multiple clutches of eggs, spend several months in proximity to the nesting beach between successive clutches (Miller 1997; Hamann et al. 2002) and typically demonstrate strong site fidelity, laying each of their clutches on the same beach or island. As capital breeders, marine turtle behaviour during the inter-nesting period (the period between a successful clutch and the next nesting attempt) is understood to be inactive (Hays et al. 1999; Fossette et al. 2012), presumably to conserve energy for successive reproductive events (see Hays et al. 1999). However, little is known about the behaviour of females offshore during this period compared to during nesting and post-nesting migration periods (Hamann et al. 2010). Research on female behaviour during the inter-nesting period is important as offshore inter-nesting habitat adjacent to nesting beaches is typically afforded fewer protection measures than nesting beaches (see Dryden et al. 2008).

The movement of turtles during the inter-nesting period varies considerably between and within populations. Turtles from some populations remain in close proximity to the nesting beach (loggerhead turtles: e.g. Stoneburner 1982; Godley et al. 2003; green turtles: e.g. Hays et al. 1999; Craig et al. 2004; Troëng et al. 2005a; Fuller et al. 2008; hawksbill turtles: e.g. Troëng et al. 2005b; Whiting et al. 2006; Kemp's ridley turtles: e.g. Seney & Landry 2008; Shaver & Rubio 2008; olive ridley turtles: e.g. Maxwell et al. 2011), while turtles from other populations undertake long distance migrations (loggerhead: e.g. Blumenthal et al. 2006; Schofield et al. 2013; leatherback: e.g. Eckert 2006; Shillinger et al. 2010; olive ridley: e.g. Hamel et al. 2008). Similarly, the degree to which inter-nesting habitats are anthropogenically used and managed also varies considerably (see Zbinden et al. 2007; Maxwell et al. 2011).

The flatback turtle offers a useful case study in this regard. As highlighted in Chapter 1 (Section 1.3.2), its nesting is endemic to the Australian continental shelf and is widespread and abundant in northern Australia (see Limpus 2007). Nesting sites and patterns of site-fidelity are well known (Figure 2.1; Limpus 2007). The Pilbara region and NWS is also rich in hydrocarbon and mineral resources, making it an area of great economic importance for the State and Commonwealth governments (Human & McDonald 2009). As a result, the area hosts a substantial and rapidly expanding industry resource sector, with dredging, coastal development and infrastructure for mineral storage, processing and transport facilities, located on, or near to, several flatback rookeries (Limpus 2007). Fatal interactions of inter-nesting flatback turtles with resource sector activities can potentially occur (e.g. Dickerson et al. 1991; Lutcavage et al. 1995), yet the associated impact remains understudied and unquantified (Limpus 2007), outside that presented in EIA. There is only one published account of offshore habitat use by flatback turtles in Western

Australia (Waayers et al. 2011), with the account providing no consideration for offshore interaction with resource sector activities. Consequently there is a clear need to understand the degree of interaction between industry resource sector development and flatback turtles and to provide data that can assist with effective management through EIAs and development orientated EMPs.

Inter-nesting habitats and interconnected migratory pathways host dense aggregations of adult marine turtles (Godley et al. 2008; Pendoley et al. 2014b). The paucity of data regarding flatback turtle habitat use, abundance and distribution among habitats during key life stages, when considered together with the scale of marine and coastal development, inhibits effective conservation and management planning from further potential threats of the industry resource sector.

The aim of this chapter was therefore to identify the distribution of inter-nesting turtles using satellite tracking and to gain a better understanding of how flatback turtle inter-nesting movement patterns vary between rookeries. In addition, flatback turtle distribution and the location of core home range areas is related to industry resource sector developments and petroleum title areas to identify the extent of overlap. This overlap is used as an indication for a likelihood of interaction and the potential threat, and support development and implementation of improved and effective EIAs and regional conservation management.

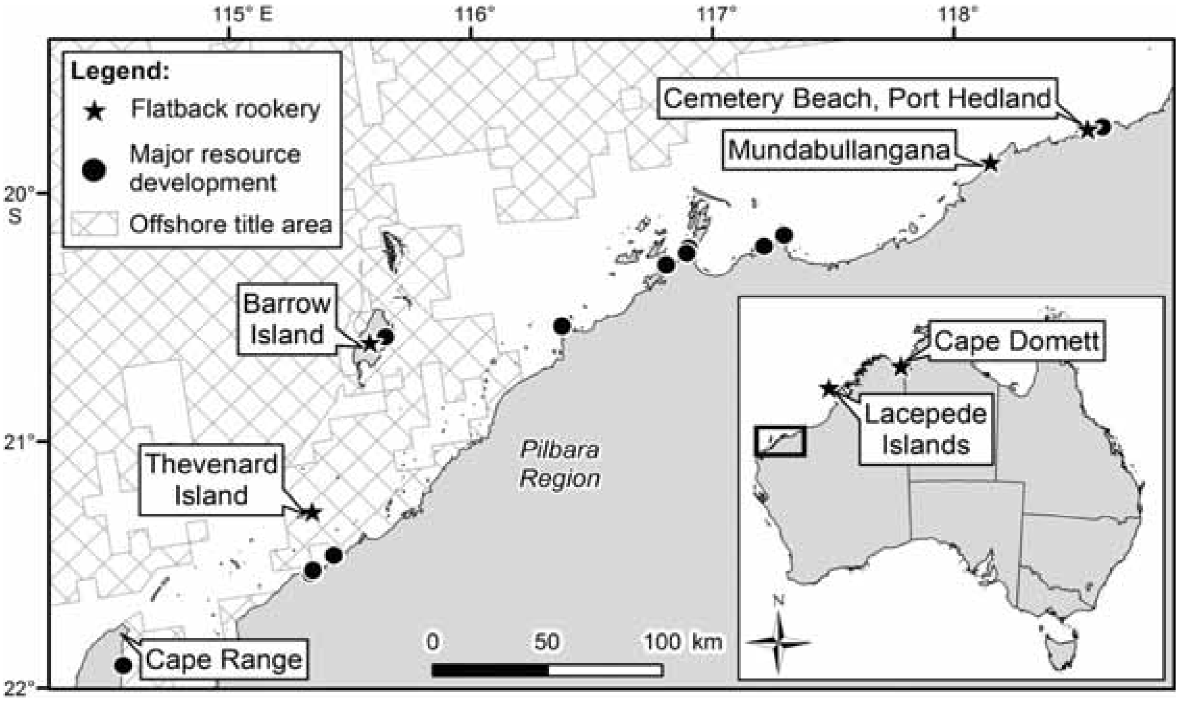

Figure 2.1 Location of Thevenard Island, Barrow Island, Mundabullangana and Cemetery beach, Port Hedland flatback turtle rookeries in relation to major resource developments and offshore petroleum title areas in Western Australia.

2.3 Methodology

2.3.1 Study Sites

Female flatback turtles were tracked from four flatback rookeries within the Pilbara Coast genetic stock on the NWS of Western Australia; Thevenard Island (Thevenard), Barrow Island (Barrow), Mundabullangana and Cemetery beach, Port Hedland (Port Hedland). The four rookeries are separated by a maximum distance of ~350 km (Figure 2.1).

Thevenard is situated 20 km off the mainland coast and flatback nesting occurs on the island's south coast (Figure 2.1). The beach ranges in width from 5 – 30 m (Pendoley 1991). Thevenard Island is a production hub for six oil and gas fields located within a 17 km radius. It has an oil and gas processing and storage facility located on the eastern end of the island immediately adjacent to the flatback nesting beach. Barrow is situated 60 km off the mainland coast and has six flatback nesting beaches on the east coast. The beaches range from 500 m to 1100 m in length and 10 – 15 m in width and are bounded by rocky headlands at each end (Pendoley 2005). A large-scale LNG processing plant is being constructed on the central east coast of the island (Gorgon LNG development) and includes construction of substantial offshore infrastructure and vessel activity (Figure 2.1). Mundabullangana is 60 km west of Port Hedland on the mainland coast and is isolated from coastal development. The main nesting site at Mundabullangana is Cowrie beach, a 3.3 km long beach bounded by a mangrove creek to the north-east and a rocky headland to the south-west. Cemetery beach is the main town beach for Port Hedland, which is home to the largest bulk minerals export port in the world and the site of a planned large port expansion project (Figure 2.1). Cemetery beach is 1 km long and 10 – 15 m wide and has been substantially modified by the creation of a dredge spoil spit located to the west of the beach.

2.3.2 Data Collection

Fifty-six adult female flatback turtles (curved carapace length range: 85 – 99 cm) were tracked between 2005 and 2010; Thevenard (n = 6), Barrow (n = 33), Mundabullangana (n = 2) and Port Hedland (n = 15) (Table 2.1). To ensure inter-nesting data was gathered, tracking units were deployed on nesting turtles at the beginning of the nesting season. It was unknown if the selected turtles were nesting for the first time in the season at the time of attachment, therefore data presented in this chapter may not represent the overall season's inter-nesting distribution for each tracked turtle.

Four different models of tracking unit were used, two models (KiwiSat101, (n = 9); Sirtrack Ltd. and MK-10 (n = 6); Wildlife Computers) provided Argos only locations and two models (Fastloc GPS-Argos tracking units (n = 12); Sirtrack Ltd. and Satellite Relayed Data Loggers (SRDL; n = 29); St Andrews Mammal Research Unit) provided Fastloc GPS locations.

Table 2.1 Summary of tracking unit deployment (2005 – 2011) at Thevenard Island (THV), Barrow Island (BWI), Mundabullangana (MDA) and Cemetery beach, Port Hedland (PH).

Year	**Turtle #**	**CCL (cm)**	**Attachment location**	**Tag type**	**Attachment date**	**End of inter-nesting**	**Number of tracked days (*n*)**	**Number of inter-nesting periods (*n*)**	**FKD 50% UD area (km^2)**	**Proportion of FKD 50% UD in titles area (50%)**
2005/06	1	90	BWI	Argos	29/11/2005	28/12/2005	29	2	-	-
2005/06	2	94	BWI	Argos	06/12/2005	06/01/2006	31	2	-	-
2005/06	3	90	BWI	Argos	02/12/2005	01/01/2006	30	2	-	-
2005/06	4	88	BWI	Argos	01/12/2005	30/12/2005	29	2	-	-
2006/07	5	85	BWI	Argos	18/12/2006	14/01/2007	27	2	-	-
2006/07	6	86	BWI	Argos	09/01/2007	19/01/2007	10	1	-	-
2006/07	7	88	BWI	GPS	15/12/2006	03/01/2007	19	1	158.5	82.5
2006/07	8	87	BWI	GPS	18/01/2007	13/02/2007	26	2	182.5	81.9
2007/08	9	91	BWI	Argos	15/12/2007	30/12/2007	15	1	-	-
2007/08	10	89	BWI	GPS	16/12/2007	05/01/2008	20	1	6.3	100
2007/08	11	92	BWI	GPS	13/12/2007	11/01/2008	29	2	11.8	100
2008/09	12	86	BWI	GPS	18/12/2008	03/01/2009	16	1	141.7	100
2008/09	13	90	BWI	GPS	18/12/2008	31/12/2008	13	1	5.3	100
2008/09	14	90	BWI	GPS	17/12/2008	24/01/2009	38	3	244.4	47.1
2008/09	15	90	BWI	GPS	17/12/2008	13/01/2009	27	2	497	92.9
2009/10	16	90	BWI	GPS	29/11/2009	13/12/2009	14	1	39.6	100
2009/10	17	88	BWI	GPS	02/12/2009	15/12/2009	13	1	490.7	70.9
2009/10	18	91	BWI	GPS	01/12/2009	11/01/2010	41	3	7.5	100
2009/10	19	89	BWI	GPS	03/12/2009	09/01/2010	37	3	90.2	88.2
2009/10	20	91	BWI	GPS	27/11/2009	08/01/2010	42	3	28.9	100
2009/10	21	96	BWI	GPS	28/11/2009	28/12/2009	30	2	318.3	96.8
2009/10	22	90	BWI	GPS	29/11/2009	09/01/2010	41	3	97.4	100
2009/10	23	87	BWI	GPS	28/11/2009	07/01/2010	40	3	1.4	100
2009/10	24	91	BWI	GPS	02/01/2010	19/01/2010	17	1	601.1	74.4
2009/10	25	90	BWI	GPS	03/12/2009	14/01/2010	42	3	3.1	100

Year	Turtle #	CCL (cm)	Attachment location	Tag type	Attachment date	End of inter-nesting	Number of tracked days (*n*)	Number of inter-nesting periods (*n*)	FKD 50% UD area (km^2)	Proportion of FKD 50% UD in titles area (50%)
2009/10	26	93	BWI	GPS	28/11/2009	26/12/2009	28	2	3.3	100
2009/10	27	96	BWI	GPS	01/12/2009	11/01/2010	41	3	20.3	100
2009/10	28	90	BWI	GPS	29/11/2009	10/01/2010	42	3	18.5	100
2009/10	29	88	BWI	GPS	01/12/2009	29/12/2009	28	2	176.7	27.6
2009/10	30	88	BWI	GPS	27/11/2009	20/01/2010	54	4	49	100
2009/10	31	87	BWI	GPS	29/11/2009	14/12/2009	15	1	269.8	46.6
2009/10	32	91	BWI	GPS	30/11/2009	08/01/2010	39	3	209.7	93.7
2009/10	33	88	BWI	GPS	01/12/2009	20/01/2010	50	4	47.8	100
2005/06	34	85	MDA	Argos	09/12/2005	20/12/2005	11	1	-	-
2005/06	35	90	MDA	Argos	10/12/2005	01/01/2006	22	2	-	-
2008/09	36	87	PH	GPS	08/12/2008	04/01/2009	27	2	64.5	0
2008/09	37	85	PH	GPS	07/12/2008	25/12/2008	18	1	49.1	0
2008/09	38	89	PH	GPS	06/12/2008	30/12/2008	24	2	166.9	0
2008/09	39	89	PH	GPS	06/12/2008	19/12/2008	13	1	132.6	0
2009/10	40	92	PH	Argos	12/12/2009	15/01/2010	34	3	-	-
2009/10	41	85	PH	Argos	09/12/2009	02/01/2010	24	2	-	-
2009/10	42	86	PH	Argos	12/12/2009	22/12/2009	10	1	-	-
2009/10	43	87	PH	Argos	10/12/2009	22/12/2009	12	1	-	-
2009/10	44	86	PH	Argos	12/12/2009	05/01/2010	24	2	-	-
2009/10	45	94	PH	Argos	11/12/2009	24/12/2009	13	1	-	-
2010/11	46	88	PH	GPS	30/11/2010	27/12/2010	27	2	5.5	0
2010/11	47	91	PH	GPS	27/11/2010	08/12/2010	11	1	21.9	0
2010/11	48	90	PH	GPS	30/11/2010	21/12/2010	21	2	89.7	0
2010/11	49	90	PH	GPS	01/12/2010	06/01/2011	36	3	146.1	0
2010/11	50	88	PH	GPS	26/11/2010	30/12/2010	34	3	4.6	0

Year	**Turtle #**	**CCL (cm)**	**Attachment location**	**Tag type**	**Attachment date**	**End of inter-nesting**	**Number of tracked days (*n*)**	**Number of inter-nesting periods (*n*)**	**FKD 50% UD area (km^2)**	**Proportion of FKD 50% UD in titles area (50%)**
2010/11	51	99	THV	GPS	14/12/2010	18/01/2011	35	3	138.5	87.5
2010/11	52	92	THV	GPS	12/12/2010	05/01/2011	24	2	256.7	88.2
2010/11	53	89	THV	GPS	12/12/2010	11/01/2011	30	3	337.1	86.1
2010/11	54	98	THV	GPS	11/12/2010	05/01/2011	25	2	137.2	87.2
2010/11	55	92	THV	GPS	11/12/2010	27/12/2010	16	1	191.3	75.2
2010/11	56	89	THV	GPS	17/12/2010	29/12/2010	12	1	89	89.9

The standard method of attaching tracking units to hard-shelled turtles using epoxy resin is unsuitable for flatback turtles as they have a carapace covered by a soft and easily abraded skin (Sperling & Guinea 2004). Tracking units were therefore attached using a harness as outlined in the protocol described by Sperling & Guinea (2004) for eastern Australian flatback turtles (Figure 2.2).

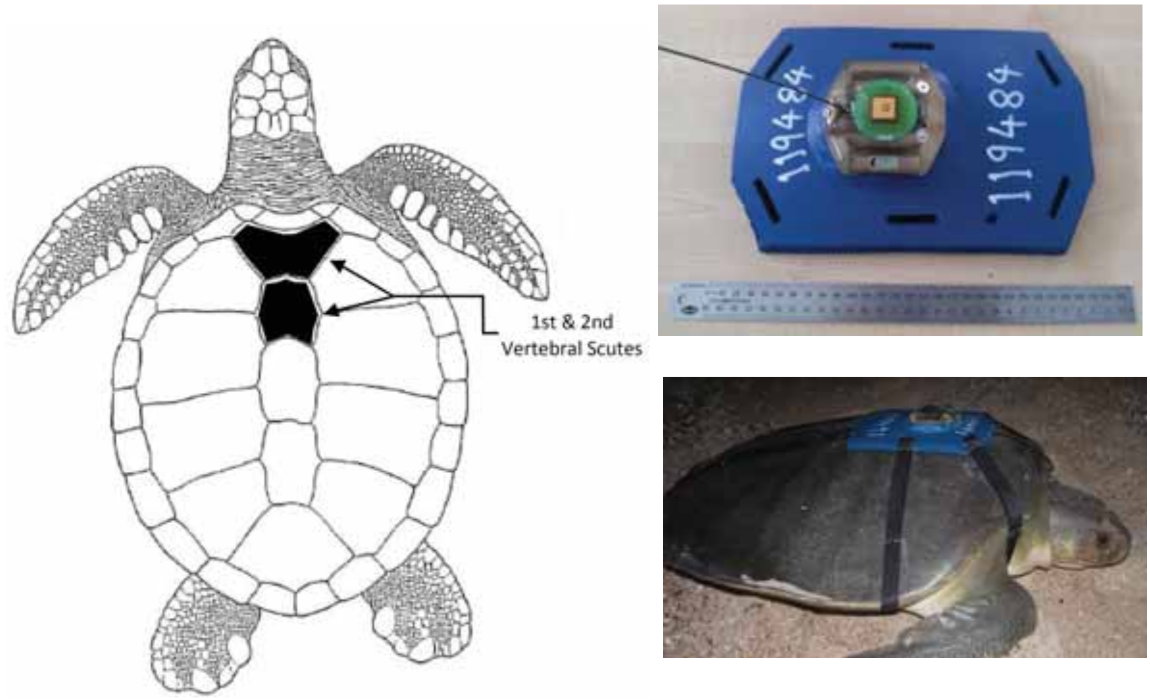

Figure 2.2 Location of tracking unit attachment on a flatback turtle (outline image from Eckert et al. 1999) and a close-up of the polycarbonate plate and neoprene padding.

Selected turtles were allowed to complete their nesting activity prior to tracking unit attachment. In summary, each unit was attached to a polycarbonate plate lined with grooved neoprene padding that allowed water flow beneath the plate. The unit was positioned on the flatback turtle using a harness threaded through six slots present on the polycarbonate plate. Each unit was positioned on the central anterior portion of the flatback turtle carapace, covering approximately the first and second vertebral scutes (Figure 2.2). The harness had six straps made from nylon seatbelt webbing, which were secured using Velcro. Zinc staples held the straps in place and served as a deliberate ‘weak link’ that gradually corroded, releasing the harness and polycarbonate plate from the turtle. The harness attachment method was proved viable by the return of females between one and three years after unit attachment in 2005; however, some individuals had evidence of carapace wear (see Pendoley et al. 2014b).

Each tracking unit was programmed to transmit data when at the surface, as indicated by a saltwater switch present on each tracking unit. Transmitted data from both types of Argos tags (KiwiSat101 and MK-10) were collected using the Argos satellite system (CLS 2011) and downloaded and managed using the Satellite Tracking and Analysis Tool (STAT; Coyne & Godley 2005). The Argos satellite system calculates the position of a tracking unit by doppler shift of the transmission frequency as the satellite passes overhead and the accuracy of the ‘fix’ (location class) is determined by the number of uplinks received by the satellite in a single overpass. The standard Argos unit accuracy is categorised by location classes (LC): LC 3, LC 2, LC 1 or LC 0 locations, which are classified as within 150, >150 to 350, >350 to 1000 or >1000 m respectively. Locations classified as Classes A and B indicate fixes of poor accuracy (Hays et al. 2001a) and only Argos locations LC 3, 2, 1 and 0 were used for analysis. To exclude implausible locations, the Argos dataset was filtered using the following criteria: (1) a minimum speed of travel was calculated between successive locations and only those indicating travel speeds of <5 km hr^{-1} from the previous location were included (Hays et al. 2004a; Shimada et al. 2012); and (2) successive fixes with turning angles >25º were also removed because acute turning angles are often indicative of erroneous ‘off-track’ locations (Hawkes et al. 2007).

The SRDL and Fastloc GPS-Argos tags incorporated both a Fastloc GPS receiver and an Argos Platform Terminal Transmitter (PTT). The Fastloc receiver captures GPS constellation data over a very short time period (<100 ms^{-1}) allowing GPS data to be yielded from very brief surface intervals (Hazel 2009). This rapid acquisition method removed a number of transmission difficulties associated with recording GPS data from diving marine animals (Hays 2008). The GPS constellation data was saved onboard the tag and subsequently transmitted via the Argos satellite network. The accuracy of Fastloc GPS location estimates vary, locations generated using a higher number of satellites are known to be more accurate (eight satellites: 26 ± 19.2 m; four satellites: 172 ± 372.5 m; Hazel 2009; Witt et al. 2010; Shimada et al. 2012). Therefore Fastloc GPS positions generated from <6 satellites were excluded.

2.3.3 Determination of Inter-nesting Periods

Subsequent successful nesting events following tracking unit deployment for each turtle were identified to enable determination of individual inter-nesting periods. Exact dates and times of re-nesting events were identified for those turtles equipped with SRDL tags that transmitted ‘haul-out’ events, with the start of a haul-out event triggered once the tag was continuously dry for >6 minutes and ending once the tag was continuously wet for >40 seconds. Successful nesting was defined by a haul-out event of >40 minutes, recorded on or near land (<200 m), with no subsequent haul-out event recorded for the following ten days. For all other tag types, re-nesting events were inferred based on: (a) directed nearshore movement; and (b) the position data, indicating that the turtle was not on, or adjacent to, the beach for the following ten days. A period of ten days was selected, as nine days is regarded as the physiological limit for the development of a new clutch of eggs (Miller 1985; Hamann et al. 2003). The nearshore bathymetry at all four rookeries is consistently shallow and it was not suitable to use a sudden change in depth use as an indication of a nesting event, as used in other published studies (Schofield et al. 2007). On occasion, turtles were also observed on the beach by staff, confirming the exact time and date of the occurrence of a nesting event. These direct observations were used to validate the process of using tracking data to infer re-nesting events.

The absolute end of inter-nesting was indicated by the commencement of post-nesting migration, which was deemed to have begun once movement away from the nesting beach was directional and protracted (Zbinden et al. 2008).

2.3.4 Data Analysis

Location data (both Argos and Fastloc) were filtered to calculate a median daily position for each turtle (as per Schofield et al. 2010a). Median daily positions were used to determine total distance travelled and maximum displacement distance from the previous nesting site providing a representation of movement during the inter-nesting period.

ArcGIS 10 (Environmental Systems Research Institute (ESRI); Redlands, CA, USA) was used to plot turtle movements from the filtered Argos and Fastloc GPS location datasets. Patterns of inter-nesting movement were determined based on the maximum displacement distance of the turtle between nesting sites and the general direction the turtle moved away from the nesting beach.

2.3.5 Home Range

Home range was estimated by the fixed kernel density method (Worton 1989) for each turtle tracked using Fastloc GPS. The filtered location data (Fastloc only) was used to calculate a median position for each 6 hr period of tracking. This period was selected to ensure the sample size was large enough for kernel home range analysis (i.e. n >30 locations; Seaman et al. 1999). Turtles tracked using Argos tracking units were not considered for home range analysis due to the lower quantity of suitable locations received. Geospatial Modelling Environment (GME) v0.7.2.1 software (Spatial Ecology; Beyer 2012), an extension to ArcGIS, was used to calculate fixed kernel density estimates (FKD) using the *kde* function (R Development Core Team 2013; Beyer 2012). The FKD for each inter-nesting period was calculated with least square cross validation as a band width to calculate the smoothing parameter. This approach has been used to delineate home ranges for several other species of marine turtles (see Seminoff et al. 2002; Schofield et al. 2010a). A 50% utilisation distribution (UD) was used to establish the core home range area of use (Worton 1989; Hart & Fujisaki 2010).

The density distribution of filtered location data across a grid was calculated for each rookery. There is no standard methodology for choosing the grid cell size, however in this chapter I felt that the appropriate grid cell size should be as fine as possible to best define small-scale movements, but large enough to produce smooth contours as an individual turtle moved from one grid cell to the next (i.e. reducing gaps between successively used cells). Using this reasoning, I chose a grid cell size of 3 km^2 for the analysis.

2.3.6 Potential Interaction with the Industry Resource Sector

GIS shapefiles of the location of proposed and operational major resource developments in the Pilbara region, were provided by the Western Australian Department of Mines and Petroleum (DMP). A proposed development is considered major if it has a capital expenditure >$A20 million, and an operational development is considered major if it has an actual value or anticipated value of production >$A10 million. Major resource developments not involving offshore construction or dredging were removed from the dataset; these were all terrestrial based with no likely direct impact on flatback turtles situated offshore. Interactions were considered to potentially occur between a tracked turtle during its inter-nesting period and a major resource development if the inter-nesting track extended to <5 km from the development. The 5 km threshold was considered the potential distance that vessel activities might occur away from the major resource development.

In Western Australia, offshore petroleum exploration and development is regulated by a title system. Petroleum activities can only occur if a company holds a valid title, which in itself provides holders with an exclusive right to apply for further approvals to conduct safe petroleum operations in the area. The title areas provide boundaries within which petroleum related activities currently occur or can potentially occur in the future.

The type and location of currently active offshore titles released for petroleum industry activities were also provided by the DMP. Title areas are divided into graticular sections. Each section is five minutes of latitude by five minutes of longitude, with sections to the north of Western Australia having an area of ~84 km^2. Five relevant title types exist: exploration permits (for the purpose of seismic surveys and oil/gas well drilling); retention leases (a five year exploration lease); production licence (for the purpose of extracting or producing oil/gas from the ground); infrastructure licence (for the construction of offshore facilities for the storage and processing of oil/gas); and a pipeline licence (for subsea pipelines).

Two metrics were used to determine which rookeries have inter-nesting turtles that are potentially exposed to current or future offshore activities associated with the petroleum resource industry within the title areas: (1) the proportion of daily median positions for inter-nesting turtles that occurred within the relevant offshore title areas; and (2) proportion of the core 50% UD home range area for each inter-nesting turtle that overlapped offshore title areas. These metrics aim to provide a broad indication of the likelihood of an impact based on the overall extent of spatial overlap between areas released for petroleum activities and inter-nesting habitat for each rookery and are not to be considered as a direct indication of impact i.e. the consequence.

2.3.7 Statistical Analysis

All data were tested for distribution normality. A generalized linear mixed effects modelling approach was used to test for differences between rookeries with individual turtles as random effect and rookery as a fixed effect. The modelling approach used individual turtles as a random effect to account for pseudoreplication and was fitted in R (R Development Core Team 2013) using the *lme4* contributed package (Bates et al. 2008). Data used in the linear mixed models were tested for distribution normality and checked for homogeneity of variance. P values were based on likelihood ratio tests conducted using the *lmerTest* package for R (Kuznetsova et al. 2014). A non-parametric Mann-Whitney test was used to test for differences between home range areas for turtles tracked from offshore island rookeries (i.e. Barrow and Thevenard) and mainland coastal rookeries (i.e. Mundabullangana and Port Hedland).

The relationship between home range size and body size for each individual turtle was tested using a Spearman's correlation test.

2.4 Results

A total of 112 individual inter-nesting periods (Thevenard *n* = 12; Barrow *n* = 70; Mundabullangana *n* = 3; Port Hedland *n* = 27) were determined from 56 flatback turtles (Thevenard *n* = 6; Barrow *n* = 33; Mundabullangana *n* = 2; Port Hedland *n* = 15). Twenty-five inter-nesting periods were recorded using Argos tags (*n* = 15) and 87 using Fastloc GPS tags (*n* = 41). Each tracked turtle recorded 2.0 ± 0.9 inter-nesting periods (range = 1 – 4, *n* = 56) prior to the commencement of its post-nesting migration. Individual inter-nesting periods were determined by direct observation on the beach (*n* = 16), by haulout data (*n* = 52) and from recorded positions (*n* = 44). All inter-nesting periods determined by direct observation on the beach were validated by the process of determining inter-nesting periods from recorded positions. Mean inter-nesting period duration was 13.0 ± 2.0 days (range = 8 – 20, *n* = 112).

Argos tags recorded a mean of 30.0 ± 18.7 positions per inter-nesting period (range = 6 – 75, *n* = 25) at a mean of 3.0 ± 1.6 positions per day (0.7 – 6.3, *n* = 25) and Fastloc GPS tags recorded a mean of 115.0 ± 48.4 positions per inter-nesting period (range = 15 – 217, *n* = 87) at a mean of 9.0 ± 3.6 positions per day (1.1 – 17.1, *n* = 87).

2.4.1 Thevenard Island

Flatback turtles tracked from Thevenard (*n* = 6) provided 12 inter-nesting tracks. The turtles travelled a mean total distance of 78.4 ± 31.6 km (range = 15.6 – 126.1, *n* = 12) and had a mean maximum displacement distance away from the nesting beach of 25.7 ± 11.9 km (range = 6.2 – 42.5, *n* = 12) during the inter-nesting period (Figure 2.3). The mean duration of the inter-nesting period was 11.8 ± 1.8 days (range = 8 – 16, *n* = 12). Turtles showed a high level of nest site fidelity, returning to the same beach where the tracking unit was applied for their subsequent clutch.

Four patterns of inter-nesting movement were identified (Figure 2.4a – d); three inter-nesting periods (turtles *n* = 3) were spent entirely within 10 km of the prior nesting site, with all tracks circling the island (Figure 2.4a). One turtle spent an inter-nesting period moving in an anti-clockwise loop to the north of the island reaching a maximum displacement of 24.4 km from its prior nesting site (Figure 2.4b); five inter-nesting periods (turtles *n* = 5) were spent moving south towards the mainland and then swimming in a westerly direction, reaching a maximum displacement distance of 42.5 km (Figure 2.4c); and three inter-nesting periods (turtles *n* = 3) moving south towards the mainland, before migrating in an easterly direction, reaching a maximum displacement of 32.0 km from the prior nesting site (Figure 2.4d).

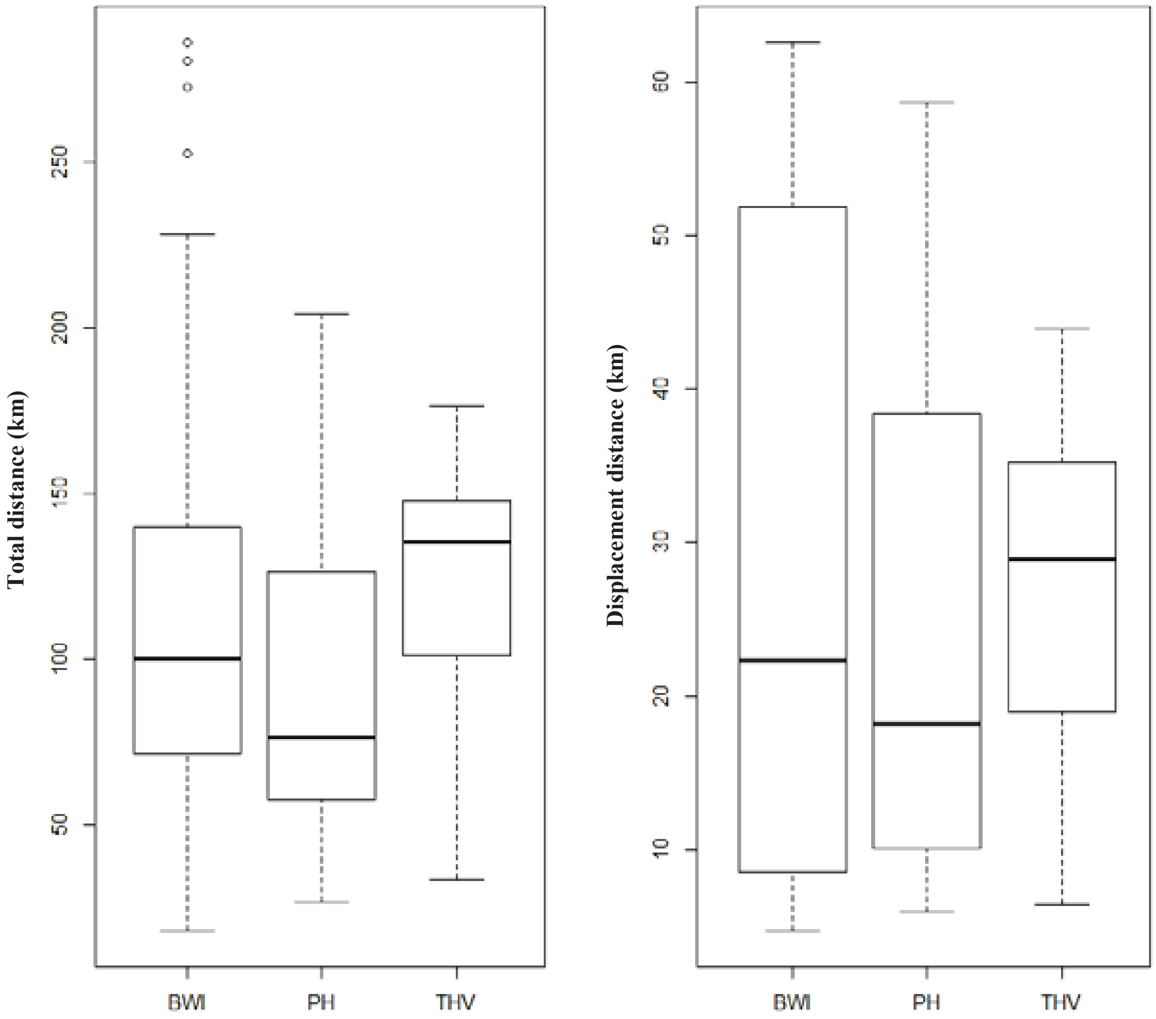

Figure 2.3 Box-and-whisker plots of total distance and maximum displacement distance travelled for turtles tracked from Barrow Island (BWI), Port Hedland (PH) and Thevenard Island (THV).

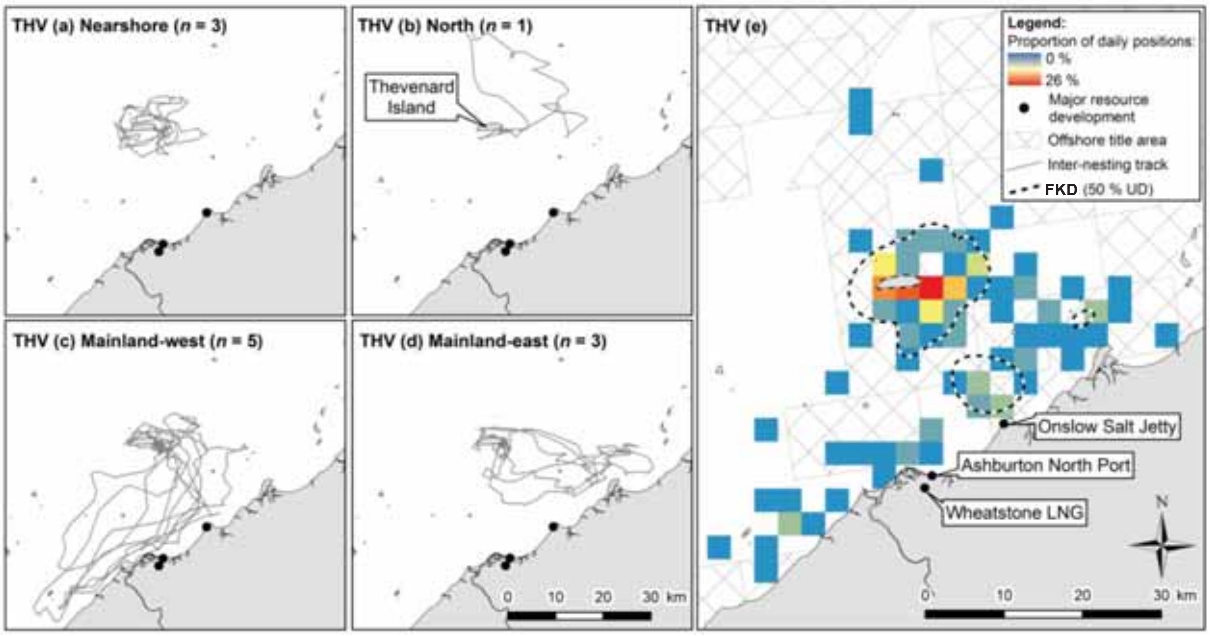

Figure 2.4 (a) – (d) Thevenard Island inter-nesting track distribution and potential interaction with major resource projects (e) Density distribution of all median daily positions (3 km^2 grid) and merged boundaries of core home range areas (FKD 50% UD) for all turtles tracked from Thevenard Island in relation to offshore title areas.

2.4.2 Barrow Island

Flatback turtles tracked from Barrow (*n* = 33) provided 70 inter-nesting period tracks. Turtles travelled a mean total distance of 68.7 ± 48.5 km (range = 12.5 – 221.8, *n* = 70) and had a mean maximum displacement distance away from the nesting beach of 27.2 ± 20.9 km (range = 4.0 – 62.1, *n* = 70; Figure 2.3). There was no statistically significant difference in distance travelled and displacement distance compared to turtles tracked from Thevenard (df = 1, p >0.05). The mean duration of the inter-nesting period was 13.7 ± 1.8 days (range = 10 – 20, *n* = 70). The turtles always returned to Barrow to nest but once on the island showed a low level of nest site fidelity to a specific beach, with 21 of the 33 turtles returning to nest on a different beach to the one where the tracking unit was deployed.

Four patterns of inter-nesting movement from the Barrow flatback turtles were identified (Figure 2.5a – d); 26 inter-nesting periods (turtles *n* = 13) were spent within 10 km of the prior nesting site to the east of Barrow, with turtles spending time within a deep water channel formed between two nearshore reefs (Figure 2.5a); six inter-nesting periods (turtles *n* = 4) were spent moving in an easterly direction >10 km away from Barrow, with none of the tracks extending to within 10 km of the mainland coast (Figure 2.5b); 14 inter-nesting periods (turtles *n* = 9) were spent moving >10 km away from Barrow in a south-east direction, with none of the tracks extending to within 10 km of the mainland coast (Figure 2.5c); and 12 inter-nesting periods (turtles *n* = 9) were spent moving away from Barrow in a south-east direction, spending part of their inter-nesting period within 10 km of the mainland coast (Figure 2.5d).

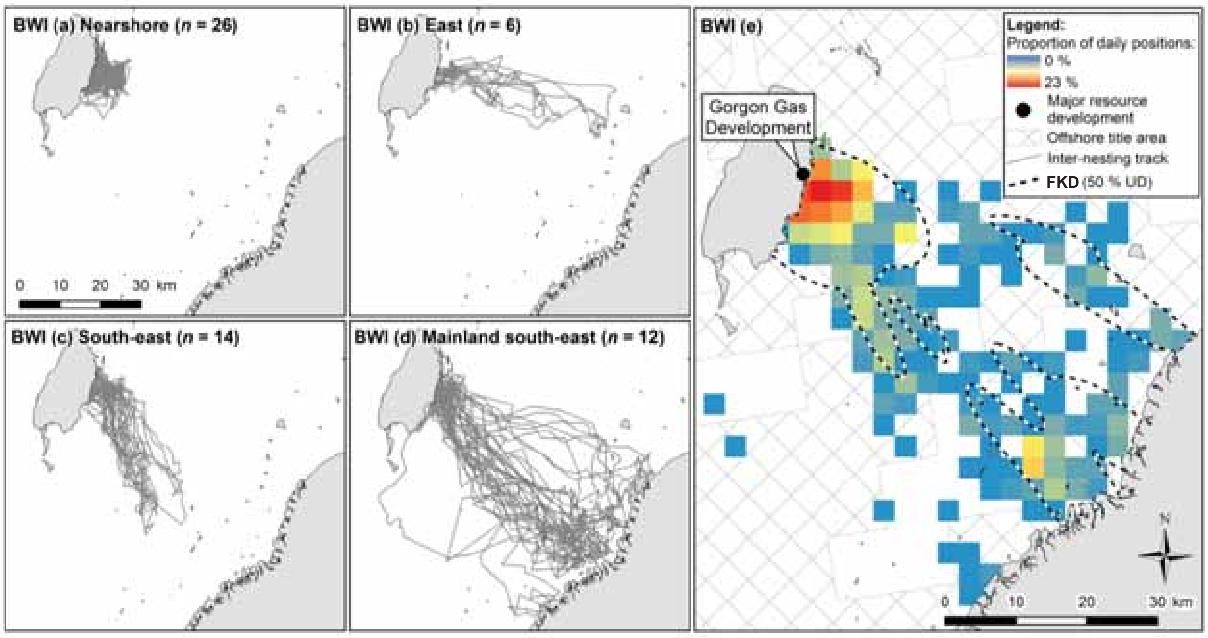

Figure 2.5 (a) – (d) Barrow Island inter-nesting track distribution and potential interaction with major resource projects (e) Density distribution of all median daily positions (3 km^2 grid) and merged boundaries of core home range areas (FKD 50% UD) for all turtles tracked from Barrow Island in relation to offshore title areas.

2.4.3 Mundabullangana

The tracked flatback turtles (*n* = 2) provided three inter-nesting period tracks. Turtles travelled a mean total distance of 38.7 ± 8.6 km (range = 31.9 – 48.4, *n* = 3) and had a mean maximum displacement distance away from the nesting beach of 11.7 ± 4.0 km (range = 8.5 – 16.2, *n* = 3). The distance travelled was statistically similar to turtles tracked from Thevenard (df = 1, $p > 0.05$) and Barrow (df = 1, $p > 0.05$). The mean duration of the inter-nesting period was 11.0 ± 1.0 days (range = 10 – 12, *n* = 3). Turtles showed a high level of nest site fidelity, returning to the same beach where the tracking unit was applied for subsequent clutches.

Two patterns of inter-nesting movement were identified (Figure 2.6a – b); one turtle spent two inter-nesting periods within 10 km of the prior nesting site adjacent to the nesting beach (Figure 2.6a); and one turtle spent an inter-nesting period moving to the west of the nesting beach, extending up to a maximum displacement of 16.2 km away from the previous nesting site (Figure 2.6b).

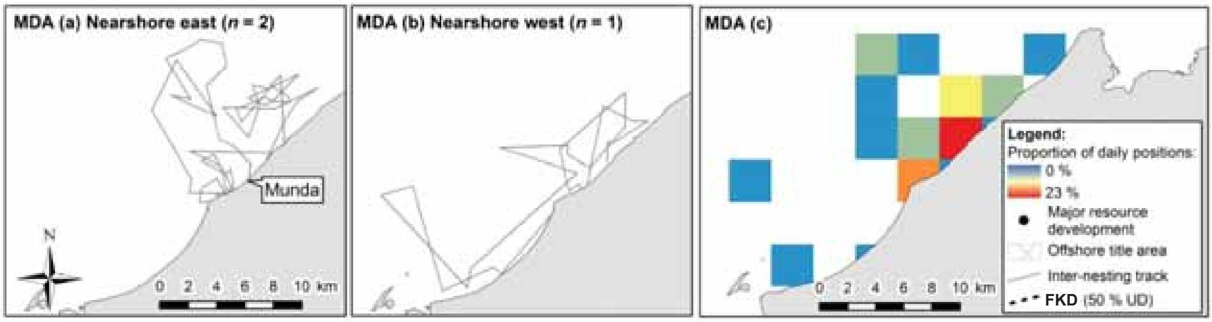

Figure 2.6 (a) – (b) Mundabullangana inter-nesting track distribution and potential interaction with major resource projects (c) Density distribution of all median daily positions (3 km^2 grid) in relation to offshore title areas.

2.4.4 Port Hedland

The flatback turtles tracked from Port Hedland (*n* = 15) were tracked for 27 inter-nesting periods. Turtles travelled a mean total distance of 57.6 ± 37.2 km (range = 14.4 – 145.8, *n* = 27) during each inter-nesting period and had a mean maximum displacement distance of 22.9 ± 16.4 km (range = 3.4 – 56.6, *n* = 27; Figure 2.3). The distance travelled was similar to turtles tracked from Thevenard (df = 1, p >0.05), Barrow (df = 1, p >0.05) and Mundabullangana (df = 1, p >0.05). The mean duration of the inter-nesting period was 12.0 ± 1.9 days (range = 10 – 18, *n* = 27). With one exception the turtles showed a high level of nest site fidelity, always returning to Port Hedland to nest. The exception was a turtle which moved approximately 60 km away from Port Hedland to nest at Mundabullangana.

Four patterns of inter-nesting movement were identified (Figure 2.7a – d); eight inter-nesting periods (turtles *n* = 6) were spent within 10 km of the prior nesting site in a near shore area north of Port Hedland (Figure 2.7a); six inter-nesting periods (turtles *n* = 6) migrated to an area >10 km but <30 km to the east of Port Hedland (Figure 2.7b); six inter-nesting periods (turtles *n* = 4) migrated >10 km from Port Hedland in a north-westerly direction (Figure 2.7c); and seven inter-nesting periods (turtles *n* = 6) migrated in a easterly direction to an area >30 km from Port Hedland (Figure 2.7d).

2.4.5 Home range

The size of inter-nesting core-use areas (50% UD) for each tracked turtle ranged from 1.4 – 601.1 km^2 at Barrow (mean = 143.1 ± 170.9 km^2, *n* = 26), 4.6 – 166.9 km^2 at Port Hedland (mean = 75.7 ± 61.7 km^2, *n* = 9) and 89.0 – 337.1 km^2 at Thevenard (mean = 191.6 ± 91.3 km^2, *n* = 6). Body size (CCL) did not correlate with size of core-use areas (*n* = 41, rs = 0.022, p = 0.892; Figure 2.8). There was no significant difference in home range area for turtles tracked from offshore islands (Barrow and Thevenard), compared to turtles tracked from the mainland coast (Port Hedland) (U = 177, p >0.05).

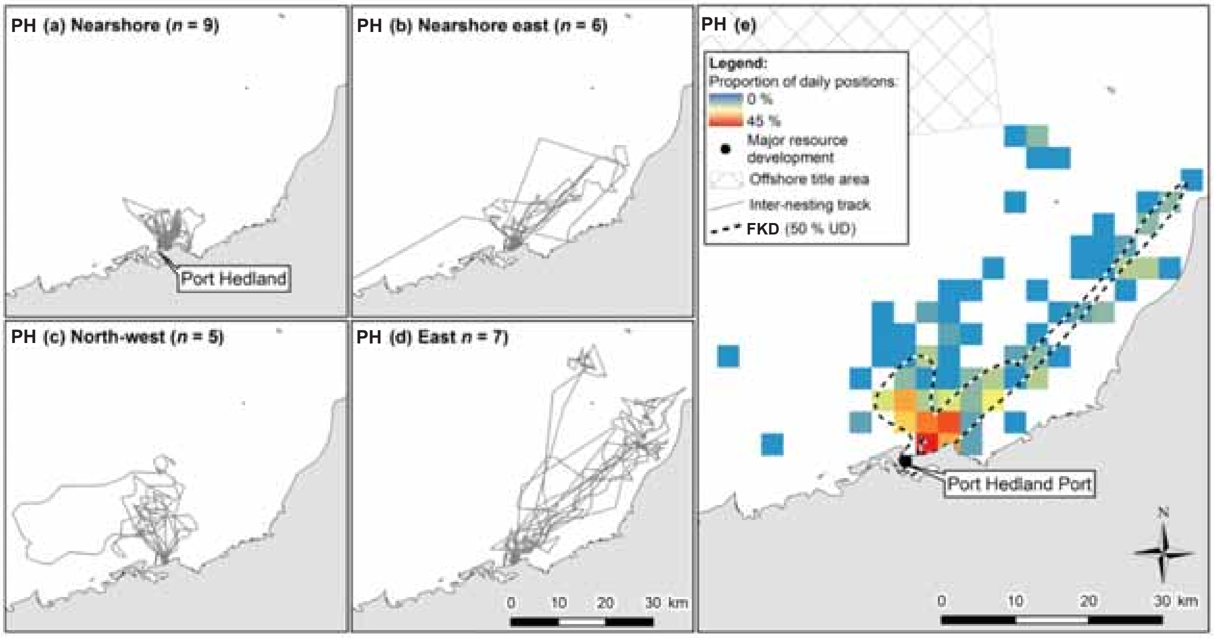

Figure 2.7 (a) – (d) Port Hedland inter-nesting track distribution and potential interaction with major resource projects (e) Density distribution of all median daily positions (3 km^2 grid) and merged boundaries of core home range areas (FKD 50% UD) for all turtles tracked from Port Hedland in relation to offshore title areas.

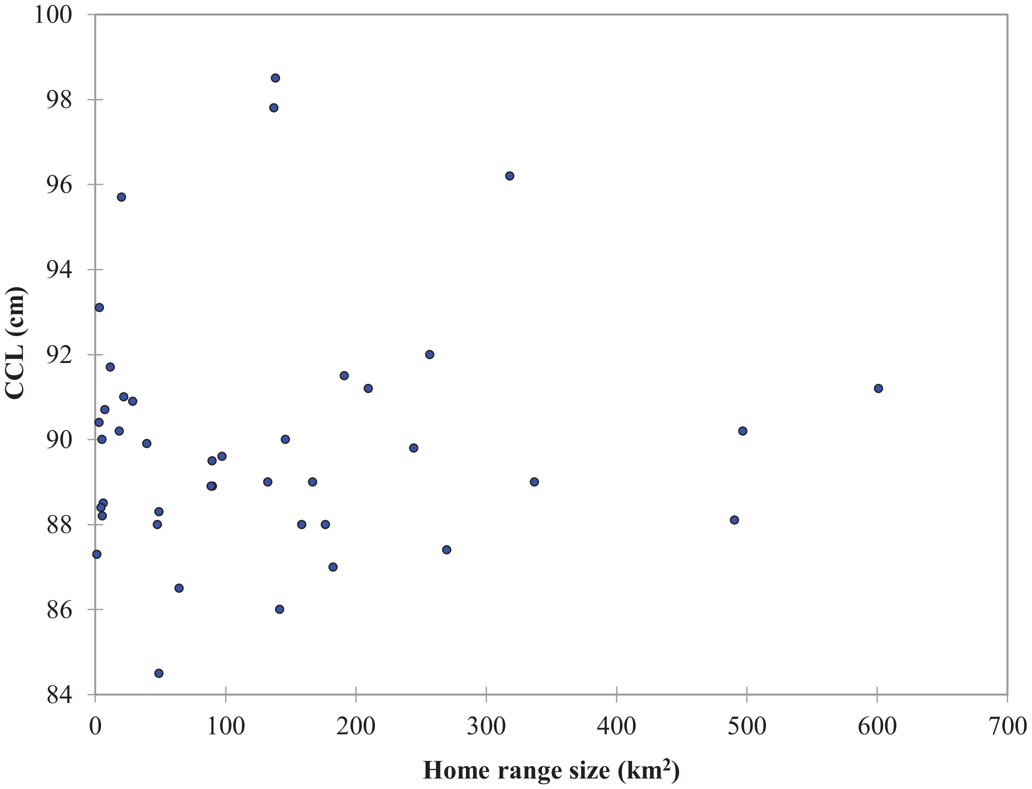

Figure 2.8 Scatterplot of adult body size (CCL) compared with home range size (FKD 50% UD) for each tracked flatback turtle from all four rookeries (*n* = 41).

2.4.6 Potential Interaction with the Industry Resources Sector

No flatback turtles tracked from Mundabullangana and Port Hedland recorded median daily positions within an offshore petroleum title area. In contrast, median daily positions of turtles from Thevenard and Barrow Islands showed a high degree of overlap with offshore petroleum title areas during their overall inter-nesting period, 80.8 ± 8.0% (range = 68.4 – 92.9, *n* = 6) and 87.3 ± 17.8% (range = 40.6 – 100.0, *n* = 33) respectively (Figure 2.4e and Figure 2.5e).

There was no overlap between inter-nesting core home range areas (50% UD FKD) of individual turtles tracked from Port Hedland and offshore petroleum title areas (Figure 2.6e). The overlap of core home range areas with offshore petroleum title areas for individual turtles tracked from Thevenard and Barrow Islands was 85.7 ± 5.3% (range = 75.2 – 89.9, *n* = 6) and 88.6 ± 19.9% (range = 27.6 – 100, *n* = 26) respectively (Table 2.1; Figure 2.4e and Figure 2.5e).

Twelve major resource developments involving offshore infrastructure or dredging were identified between Exmouth and Port Hedland (Figure 1.3); seven developments are currently operating, three are under construction and two are proposed. At Thevenard, 4 of 12 (33%) inter-nesting tracks passed within 5 km of three major resource developments located on the mainland coast: Wheatstone LNG plant (under construction), Ashburton North Multi-user Port and Handling Facility (proposed) and the Onslow Salt Jetty (operating), situated 26 km, 21 km and 25 km to the south of Thevenard, respectively. All four tracks followed the same mainland-west distribution pattern (Figure 2.4c). All inter-nesting tracks from Barrow were situated within 5 km of the Gorgon LNG development (under construction), with 26 inter-nesting tracks remaining <10 km from Barrow (Figure 2.5a). No individual inter-nesting tracks from Mundabullangana were located within 5 km of an existing or planned major resource development. All inter-nesting tracks from Port Hedland were situated within 5 km of a planned port expansion, with eight inter-nesting tracks remaining <10 km from Port Hedland (Figure 2.7a).

2.5 Discussion

Flatback turtles from four rookeries within the Pilbara Coast genetic stock demonstrated variable patterns of inter-nesting movement. At each rookery some flatback turtles remained <10 km from the nesting beach; some turtles from offshore island rookeries moved up to 62.1 km towards the Australian mainland coast; and some turtles from one mainland rookery moved adjacent to the coast, up to 56.6 km away from the nesting beach. With the exception of Mundabullangana, some turtles from each rookery were recorded in marine areas that overlap with existing and potential industry resource sector developments.

Marine turtles are believed to be capital breeders (Hamann et al. 2002) and thus need to conserve energy during the nesting season. Hence the main driver behind their inter-nesting behaviour is hypothesised to be related to optimisation of energy reserves in a manner most suited to the localised conditions to ensure maximum seasonal reproductive output (Houghton et al. 2002). It is therefore likely that, similar to other species, biophysical conditions play a role in driving the variation found in inter-nesting patterns among rookeries in this chapter (Hays et al. 2002; Sperling 2007; Shillinger et al. 2010; Schofield et al. 2010a).

One environmental variable known to directly influence the length of the inter-nesting interval is sea surface temperature (SST), with warmer SST in the inter-nesting habitat resulting in shorter intervals (Sato et al.1998; Hays et al. 2002; Fossette et al. 2012). As such, exposure of females to warmer SST across a nesting season may reduce the overall length of time required to lay the full complement of clutches (Hays et al. 2002). Data in this chapter demonstrates considerable variation in inter-nesting space use, both among and within females. This variation could be related to spatio-temporal variation of SST and behavioural thermoregulation with inter-nesting flatbacks seeking higher ambient water temperatures to maintain a higher body temperature as has been demonstrated in other marine turtle species (see Fossette et al. 2012; Schofield et al. 2009).

Another behavioural strategy employed by inter-nesting marine turtles to optimise energy reserves is to rest and remain inactive on the seabed (Hays et al. 2000; Fossette et al. 2012). In particular it is suggested that when resting: (1) turtles use deeper, slower moving water in order to remain on the seabed for longer periods, thus minimising the energy cost of commuting to the surface (see Hays et al. 2000; Houghton et al. 2002; Minamikawa et al. 2000); and (2) turtles alter their dive behaviour to utilise a specific bathymetric depth that maximises the oxygen store, while still attaining near-neutral buoyancy on the seabed (Hays et al. 2000). It is therefore possible that the inter-nesting patterns found in this chapter are related to bathymetry and could reflect a search by the females for areas of suitable depth or hydrodynamic conditions in which efficient resting can take place. This highlights an important research gap that could be addressed by combining inter-nesting habitat boundaries and travel paths overlayed with bathymetry and sea surface temperature.

The long circuitous movement patterns required to locate a suitable inter-nesting area may place pressure on their limited energy budget (Houghton et al. 2002). It is possible that the individual turtles that demonstrated longer than average movement patterns were searching for inter-nesting habitat of suitable hydrodynamic conditions. The long search times could result if no suitable habitats are encountered immediately following departure from the nesting beach. Further investigation of localised hydrodynamic conditions in relation to specific movement, orientation and dive patterns, in tandem with development of a habitat suitability model, is required to either confirm or refute this hypothesis and elucidate factors affecting inter-nesting habitat selection.

Doing so would make an important contribution to the understanding of turtle reproductive ecology (Hamann et al. 2010).

As a protected species, understanding the interactions between major resource developments, petroleum title areas and the regional distribution of inter-nesting habitat selected by flatback turtles is critical in predicting the cumulative impact, exposure to anthropogenic disturbance and establishing long-term population viability. This chapter's results indicate that flatback turtles nesting at Thevenard and Barrow Islands use inter-nesting areas that overlap with title areas released for petroleum related activities, and Thevenard turtles were exposed to three planned or operating major resource developments situated on the mainland coast away from their nesting site. Because the flatback turtle is listed as an MNES these results are important for three reasons: (1) the presence of flatback turtles within a proposed development footprint will trigger the need for an EIA and ensure the referral of the project to the EPA for approval; (2) existing environmental legislation does not account for potential cumulative impact (Grech et al. 2013); and (3) the EIA scoping process for a planned major resource development may not consider the potential offshore presence of inter-nesting flatback turtles from rookeries situated further away, with this chapter's results suggesting turtles from rookeries situated up to 62.1 km away would need to be considered (based on the maximum inter-nesting displacement distance recorded). In addition, turtles that remained in the nearshore environment at Barrow and Port Hedland were potentially exposed to industry related vessel movements associated with major resource developments situated near their respective rookeries, as well as vessel movements linked to the existing port at Port Hedland. These findings have important implications for both regulators and industry proponents when quantifying project specific and cumulative risk and when assessing the conservation management of flatback turtle nesting and inter-nesting habitat on the NWS.

Marine Protected Areas (MPAs) are recognised as a viable and proven conservation measure for species protection during biologically sensitive periods, and in ecologically sensitive areas of their known geographic and temporal ranges (Roberts 2005; Scott et al. 2012). Questions remain over the relative effectiveness of MPAs in providing adequate protection for species that are highly mobile, distributed across a wide geographic range and exhibit unpredictable movement patterns (Roberts et al. 2003; Dobbs et al. 2007; Dryden et al. 2008), features that were demonstrated by flatback turtles within this chapter. However, there were some inter-nesting features that were consistent across rookeries. In particular, at all four rookeries a nearshore (<10 km) inter-nesting distribution pattern was identified from some of the tracked turtles and their associated core inter-nesting home range areas. This consistency highlights an opportunity to implement boundary-specific protection measures, effectively encompassing a large proportion of the inter-nesting population and/or habitat (as defined by boundaries of the core home range areas) and possibly incorporating them into industry specific management or operational plans.

Australian Federal and State legislation requires protection measures designed to manage, mitigate or remove the predicted species-specific risks of each project or development. Localised protection measures are devised based on the findings of EIAs and implemented through project-specific EMPs. Lack of data regarding offshore marine turtle presence and/or distribution therefore constrains development of effective control measures for this species, or the species may be entirely overlooked during the EIA phase. The data presented in this chapter, which demonstrate that turtles can be exposed to risks from multiple projects, suggests that existing legislation may not consider cumulative risks to the same individuals and rookeries across multiple projects. Variability in inter-nesting distribution outlined in this chapter should therefore be considered when determining control measures.

Overall, the wide ranging inter-nesting movement patterns of flatback turtles on the NWS highlights a need for regulators and industry resource sector proponents to expand the scope of EIA, ensuring adequate protection is provided to inter-nesting flatback turtles that can travel up to 62.1 km away from their rookery between nesting events. In addition, the similar nearshore inter-nesting movement pattern recorded by some flatback turtles at each rookery offers an opportunity to establish boundaries for small scale spatial and temporal protection measures that could provide protection for a large proportion of the inter-nesting population.

Chapter 3

Industry resource sector and foraging flatback turtles

Chapter 2 identified movement patterns and distribution of inter-nesting flatback turtles at multiple rookeries and found that some turtles had a high overlap with the industry resource sector during their inter-nesting phase (notably for turtles from Thevenard and Barrow Islands). This information may help inform the screening/referral and scoping phases of the EIA process and to inform the need for their protection. However, their inter-nesting phase represents a very small proportion of their overall life cycle and distribution across the region, and any proposed protection measures consequently offers limited safeguards to the population as a whole. Therefore, it is necessary to investigate their offshore baseline spatial behaviour further for other life phases in order to ensure that flatback turtles are considered at the screening/referral phase and that the need for any further protection from industry resource sector activities is identified through the risk assessment within the Environmental Scoping Document.

This chapter therefore identifies the location and characteristics of foraging areas used by post-nesting flatback turtles tracked from the same rookeries that featured in Chapter 2. This chapter includes a similar methodology to Chapter 2, including identifying flatback turtle distribution and behaviour when foraging, their overlap with the industry resource sector, their need for protection and the factors that might influence their vulnerability to identified threats e.g. site fidelity, size of foraging habitat, regional distribution.

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3.1 Abstract

Satellite tracking was used to identify the foraging areas of post-nesting flatback turtles (*n* = 66) from four rookeries on the NWS (Barrow Island, Thevenard Island, Mundabullangana and Port Hedland) within the Pilbara Coast genetic stock. On average, flatback turtles took 42 days and migrated nearly 600 km before reaching their first foraging area. Foraging areas were in water shallower than 130 m and within 315 km of the shore, with many areas located in 50 m water depth and 66 km from shore. Thirty-one turtles departed their first foraging area prior to the tracking unit transmissions ceasing, with 15 turtles identified as utilising more than one separate foraging area. The furthest foraging area was situated 2511 km from the original nesting site within the Gulf of Carpentaria in Queensland state waters. Identified overlaps of individuals' foraging home range areas were used to delineate five important foraging areas, with each area utilised by flatback turtles tracked from more than one rookery. Four of these areas were situated within the Kimberley region and one area within the Pilbara region of Western Australia. There was a large overlap of foraging home range areas and foraging locations with existing protected areas in the region, with 48.5% of the combined overall home range area overlapping with a protected marine reserve. There was minimal interaction between foraging home range areas and the three identified regional fisheries, with the highest overlap occurring with the Northern Prawn Fishery (12.5% of combined overall home range area). There was a high overlap between petroleum title areas (areas that currently host, or have the potential to host, industry resource sector activities) with foraging areas (67.1% of combined overall home range area).

Characteristics of their foraging behaviour were considered to reduce their susceptibility to potential anthropogenic and natural threats within the region i.e. they foraged in areas that were broadly dispersed across the entire region, they utilised inter-connecting pathways between several foraging areas and the same foraging areas were used by multiple turtles. Foraging behaviour by some flatback turtles appeared flexible, with this strategy further reducing their susceptibility by facilitating a capability to adapt to anthropogenic or natural threats within the region.

3.2 Introduction

Marine turtles are susceptible to anthropogenic threats at every life stage thereby placing them among the most conservation dependent of marine taxa (Hamann et al. 2010). But not all species and populations are equally vulnerable (Wallace et al. 2011). The vulnerability of marine turtles to threats depends on a number of factors including the species, location, life-history phase(s) being impacted and the size of the population (Wallace et al. 2010, 2011). Despite their broad conservation dependence, efforts to conserve the species are often focused on protecting nesting female turtles and maximising egg hatching success (Fossette et al. 2008; Miller 1997; Schofield et al. 2010b). As highlighted in Chapter 2, the drive behind this conservation focus is based on a number of reasons: nesting female turtles contribute disproportionally to sustaining the overall population (Gerber & Heppell 2004; Heppell et al. 1999); nesting female turtles aggregate in large groups during the period prior to (breeding) and between nesting events (inter-nesting) (Godley et al. 2003; Chapter 2); a variety of threats exist at the nesting beach (e.g. Bertolotti & Salmon 2005; Engeman et al. 2003; Montague 2008); and in most cases, identifying the threats and implementing conservation measures on nesting beaches is less challenging compared to conserving marine areas. As a result, breeding, nesting and inter-nesting habitats for many marine turtle species are well researched and identified (Godley et al. 2008; Chapter 2), and many of these areas are afforded protection (e.g. Troëng et al. 2005a).

The period spent breeding and inter-nesting represents only a small proportion of the adult female's overall life cycle (several months in every 2 – 4 years following an extended maturation period; Miller 1997; Chapter 2). This conservation focus at the nesting and breeding areas therefore offers limited safeguards to the population as a whole. A more holistic approach to conservation would also address threats and issues at other non-breeding life stages. Doing this is challenging because the marine turtle life cycle typically spans large temporal and spatial scales (Musick & Limpus 1997; Plotkin 2003), with adult female turtles performing long-distance cyclical post-nesting migrations between individually specific breeding and foraging areas (Godley et al. 2008; Luschi et al. 2003). Their foraging areas are vital for replenishing fat stores exhausted during the multiple nesting events and numerous, sometimes unsuccessful, nesting emergences associated with reproduction (Miller & Limpus 2003).

Similar to the variability of inter-nesting movements identified in Chapter 2, satellite tracking studies have revealed individual-based variability in post-nesting migrations and foraging area use amongst populations of each marine turtle species (Hays & Scott 2013). Some studies show direct post-nesting migration towards a specific foraging area (e.g. loggerhead turtles: Limpus & Limpus 2001; Papi et al. 1997), while others demonstrate convoluted migration patterns (e.g. loggerhead turtles: Dodd & Byles 2003; Hatase et al. 2007; Hawkes et al. 2007) or possible prolonged residence in oceanic habitat (loggerhead turtles: Hatase et al. 2002; Hatase et al. 2007; Hawkes et al. 2006; Rees et al. 2010). Once at their foraging areas, some species show strong fidelity to one area (e.g. green and loggerhead turtles: Broderick et al. 2007; Marcovaldi et al. 2010; Schofield et al. 2010b), while others show movement between multiple areas across wide geographically disparate regions (e.g. green and loggerhead turtles: Blumenthal et al. 2006; Kemp's ridley turtles: Shaver et al. 2013). The individual and species level variability in migration and foraging strategies adds to the challenge of protecting foraging turtles from threats or understanding their vulnerability.

Marine turtles' broad scale post-nesting migrations and use of foraging areas can increase the range of anthropogenic threats they are exposed to compared to when at their breeding area (see Blumenthal et al. 2009; Lutcavage et al. 1997). One of the most documented and significant threats across a region is the incidental capture in fishing gear (Lewison et al. 2004; Wallace et al. 2010, 2011). The marine turtle life phase characteristics of delayed maturity and longevity makes them particularly vulnerable to threats that could result in elevated adult mortality levels (Fossette et al. 2014; Lewison et al. 2004; Wallace et al. 2010). In some cases, threats at the foraging area have resulted in a declining population despite extensive protection efforts at the breeding area (e.g. Witherington et al. 2009). Therefore, to ensure stability of the overall population it is necessary to consider implementing protection measures at their foraging areas (Crouse et al. 1987; Dryden et al. 2008; Mazaris et al. 2006) and inter-connecting pathways (Pendoley et al. 2014b: Schofield et al. 2013).

Wide ranging foraging area use by marine turtles presents challenges in implementing effective protection measures, particularly when these areas incorporate multiple legislative boundaries (e.g. Blumenthal et al. 2006) and cover extensive areas (e.g. Dobbs 2007). To overcome this, it is necessary to develop a robust understanding of their spatial ecology (Hamann et al. 2010), identify the location of foraging areas (e.g. Stokes et al. 2015) and to determine the spatial and temporal overlap of any specific anthropogenic threat within the areas (e.g. Howell et al. 2008). Developing this knowledge further is considered integral to marine turtle conservation and underpins all other facets of marine turtle conservation (Hamann et al. 2010).

As was the case in Chapter 2, the flatback turtle offers a useful case study in this regard. The species is endemic to the Australian continental shelf, widespread and abundant in northern Australia (see Limpus 2007) and listed as a threatened species under Australian legislation. Recent expansion in the industrial resource sector on the NWS of Western Australia has seen extensive monitoring of this species at known nesting sites as part of environmental approval processes. This monitoring has led to a better understanding of reproductively active populations within the same RMU including their abundance at nesting sites (Pendoley et al. 2014a), identification of their inter-nesting areas and exposure to threats (Chapter 2) and use of a migratory corridor as they depart their nesting sites towards their foraging areas (Pendoley et al. 2014b). One aspect of their reproductive cycle that remains unknown is the location and use of foraging areas during the period between breeding seasons. This gap prevents identification of the spatial and temporal overlap of anthropogenic threats within their foraging areas (e.g. from fisheries and offshore industry resource sector developments; Wallace et al. 2011), determining the likelihood of interaction and impact within an EIA and determining the need for further protection.

In addition, marine turtles are capital breeders, hence breeding depends on a female’s ability to obtain sufficient energy stores to support the development of follicles, support multiple nesting attempts and support her return migration (Hamann et al. 2002). Because they need to obtain the necessary body condition prior to breeding, the characteristics and condition of foraging areas can impact reproductive effort and influence seasonal abundance at breeding areas (Hamann et al. 2002; Limpus & Nicholls 1988; Zbinden et al. 2011). Thus, without an understanding of the location and condition of their foraging areas, it is impossible to provide a robust diagnosis of any trend in population abundance recorded at the nesting beach. An ability to diagnose these trends is of particular importance for breeding areas on the NWS due to the proximity of existing resource developments and the potential for their associated long-term activities to impact the overall population.

The post-nesting migration of individual flatback turtles from multiple breeding areas within the NWS study area has been previously described (Pendoley et al. 2014b). In this chapter, the previous analysis is extended to consider the location and characteristics of flatback turtle foraging areas, the movement of flatback turtles between their foraging areas and the overlap of foraging areas with protected areas and fisheries and hence the conservation implications. The following three aims were addressed: (1) the location and characteristics of their foraging areas were identified; (2) their exposure to threats and need for protection were examined by determining the overlap of their foraging areas with potential anthropogenic threats within the region i.e. fisheries, industry resource sector activities; and (3) those factors that influence their vulnerability to any identified threat exposure were investigated e.g. site fidelity, size of foraging habitat, regional distribution.

3.3 Methodology

3.3.1 Summary of Tracking Unit Deployments

Between 2005 and 2013, 66 adult female flatback turtles were tracked from their nesting rookeries on the Australian NWS using satellite tracking units (Barrow Island, n = 40 turtles; Mundabullangana, n = 2; Port Hedland, n = 20; Thevenard Island, n = 4) to their foraging areas (see Table 3.1 for turtle and tracking unit information). The sample size of deployed tracking units varied at each rookery due to different environmental monitoring approval requirements for proposed developments situated nearby.

Four different models of satellite tracking unit were used: KiwiSat101 and Fastloc GPS-Argos tracking units from Sirtrack Ltd., MK-10 from Wildlife Computers, and SRDL from St Andrews Sea Mammal Research Unit (for transmission details, see Chapter 2).

Table 3.1 The 66 flatback turtles successfully tracked from four rookeries from 2005 to 2013 (Barrow (BWI), *n* = 40 turtles; Mundabullangana (MDA), *n* = 2; Port Hedland (PH), *n* = 20; Thevenard (THV), *n* = 4).

Turtle ID	CCL (cm)	Year	Deployment Site	Location type	Date depart nesting site	Date arrive at first foraging site	Foraging Area 1		Foraging Area 2		Foraging Area 3	
							Duration at area (days)	Mean distance from deployment site (km)	Duration at area (days)	Mean distance from deployment site (km)	Duration at area (days)	Mean distance from deployment site (km)
1	90	2005	BWI	Argos	01/01/2006	18/02/2006						
2	90	2005	BWI	Argos	14/01/2006	18/02/2006	49.6	763.7				
3	90	2005	MDA	Argos	21/01/2006	27/04/2006	40.0	1168.1				
4	87	2006	BWI	Argos	25/01/2007	24/02/2007	199.2	772.7				
5	85	2006	BWI	Fastloc	14/01/2007	31/01/2007	77.2	363.5				
6	86	2006	BWI	Argos	21/01/2007	06/03/2007	76.2	1472.4				
7	87	2006	MDA	Argos	19/01/2007	09/02/2007	236.0	637.0	70.3	456.5		
8	91	2007	BWI	Fastloc	12/01/2008	24/01/2008	21.2	713.2	34.7	791.2		
9	92	2007	BWI	Fastloc	11/01/2008	21/01/2008	89.1	240.2				
10	89	2007	BWI	Argos	12/12/2007	02/01/2008	113.9	89.2				
11	90	2008	BWI	Argos	18/12/2008	05/02/2009	445.9	910.7				
12	89	2008	PH	Fastloc	19/01/2009	25/01/2009	100.2	402.9				
13	87	2008	PH	Fastloc	14/01/2009	28/02/2009	65.9	807.7				
14	85	2008	PH	Fastloc	27/12/2008	11/02/2009	145.3	346.3				
15	90	2008	BWI	Fastloc	04/01/2009	23/01/2009	67.5	630.7				
16	86	2008	BWI	Fastloc	03/01/2009	25/02/2009	102.0	899.7				
17	92	2009	PH	Argos	16/01/2010	11/02/2010	254.9	420.1				
18	85	2009	PH	Argos	04/01/2010	20/01/2010	399.6	330.8				
19	86	2009	PH	Argos	27/12/2009	28/02/2010	149.7	614.3				
20	87	2009	PH	Argos	22/12/2009	21/02/2010	237.2	1276.4				
21	87	2009	PH	Argos	11/12/2009	16/12/2009	303.4	66.8				
22	86	2009	PH	Argos	06/01/2010	08/03/2010	215.9	1243.2				
23	86	2009	PH	Argos	10/12/2009	28/02/2010	93.1	635.2	101.0	641.3		
24	93	2009	PH	Argos	10/12/2009	19/01/2010	245.3	518.1	46.1	507.3		
25	94	2009	PH	Argos	28/12/2009	19/03/2010	107.8	1586.7	56.0	2443.9	39.0	2511.0
26	89	2009	BWI	Fastloc	15/12/2009	13/01/2010	111.2	619.5				

Turtle ID	CCL (cm)	Year	Deployment Site	Location type	Date depart nesting site	Date arrive at first foraging site	Foraging Area 1		Foraging Area 2		Foraging Area 3	
							Duration at area (days)	Mean distance from deployment site (km)	Duration at area (days)	Mean distance from deployment site (km)	Duration at area (days)	Mean distance from deployment site (km)
27	88	2009	BWI	Fastloc	07/01/2010	01/02/2010	64.7	345.8	15.0	324.7		
28	91	2009	BWI	Fastloc	11/01/2010	13/02/2010	225.9	775.5				
29	89	2009	BWI	Fastloc	10/01/2010	10/03/2010						
30	91	2009	BWI	Fastloc	09/01/2010	30/01/2010	58.1	257.2				
31	96	2009	BWI	Fastloc	28/12/2009	07/03/2010	103.4	582.1				
32	90	2009	BWI	Fastloc	09/01/2010	13/01/2010	66.0	50.2	97.1	38.9		
33	87	2009	BWI	Fastloc	08/12/2009	19/02/2010	25.1	805.2				
34	91	2009	BWI	Fastloc	21/01/2010	11/03/2010	35.5	120.4	22.0	70.3		
35	90	2009	BWI	Fastloc	16/01/2010	17/02/2010	67.0	900.0				
36	93	2009	BWI	Fastloc	26/12/2009	07/01/2010	419.0	82.4	63.8	166.5		
37	96	2009	BWI	Fastloc	15/01/2010	31/01/2010	431.8	122.8				
38	90	2009	BWI	Fastloc	10/01/2010	03/04/2010	70.6	1604.1				
39	88	2009	BWI	Fastloc	29/12/2009	27/03/2010						
40	88	2009	BWI	Fastloc	28/01/2010	11/02/2010	38.2	321.1				
41	87	2009	BWI	Fastloc	15/12/2009	01/03/2010	218.4	788.9				
42	91	2009	BWI	Fastloc	30/11/2009	09/02/2010	227.4	865.6				
43	99	2010	THV	Fastloc	16/12/2010	07/03/2011	444.1	1021.5				
44	88	2010	PH	Fastloc	27/12/2010	07/02/2011	98.3	329.7				
45	91	2010	BWI	Fastloc	16/12/2010	13/01/2011	223.6	604.3				
46	90	2010	BWI	Fastloc	01/01/2011	08/02/2011	81.9	707.6	248.3	756.0		
47	90	2010	BWI	Fastloc	07/01/2011	23/02/2011	397.8	867.5				
48	90	2010	PH	Fastloc	22/12/2010	26/02/2011	162.8	228.4				
49	89	2010	BWI	Fastloc	02/01/2011	02/02/2011	192.8	768.0				
50	90	2010	PH	Fastloc	08/01/2011	10/02/2011	186.4	331.2				
51	88	2010	P	Fastloc	30/12/2010	20/02/2011	213.9	1241.2				
52	89	2010	BWI	Fastloc	14/01/2011	19/02/2011	86.7	789.2				

Turtle ID	CCL (cm)	Year	Deployment Site	Location type	Date depart nesting site	Date arrive at first foraging site	Foraging Area 1		Foraging Area 2		Foraging Area 3	
							Duration at area (days)	Mean distance from deployment site (km)	Duration at area (days)	Mean distance from deployment site (km)	Duration at area (days)	Mean distance from deployment site (km)
53	92	2010	THV	Fastloc	11/12/2010	21/01/2011	478.4	75.9				
54	98	2010	THV	Fastloc	16/12/2010	26/02/2011	529.2	679.6				
55	92	2010	THV	Fastloc	13/12/2010	12/06/2011	103.1	214.4	34.1	265.6	58.8	256.7
56	92	2011	PH	Fastloc	26/12/2011	09/02/2012	98.9	640.9				
57	92	2011	BWI	Fastloc	15/12/2011	31/12/2011	18.8	297.1				
58	92	2011	PH	Fastloc	03/12/2011	08/12/2011	30.5	97.9	172.2	1132.5		
59	91	2011	BWI	Fastloc	05/01/2012	04/04/2012						
60	89	2011	PH	Fastloc	22/11/2011	29/11/2011						
61	90	2011	PH	Fastloc	03/12/2011	12/12/2011	25.0	92.2	233.2	516.5		
62	88	2013	BWI	Fastloc	12/12/2013	20/01/2014	76.9	893.9				
63	89	2013	BWI	Fastloc	12/11/2013	15/12/2013	153.3	607.8				
64	93	2013	BWI	Fastloc	30/12/2013	11/02/2014	71.2	43.0				
65	93	2013	BWI	Fastloc	30/12/2013	15/02/2014	90.7	901.7				
66	92	2013	BWI	Fastloc	17/12/2013	23/01/2014						

All tracking units were attached to flatback turtles following completion of their nesting activity. A turtle was selected for tracking unit attachment if it showed no signs of carapace damage or flipper trauma/loss. Each tracking unit was attached using a harness as outlined in the protocol described by Sperling & Guinea (2004) (see Section 2.3.2 for attachment methodology).

Each tracking unit was programmed to transmit when at the surface, as indicated by a saltwater switch. Each unit provided either Global Positioning System (GPS) quality locations (n = 49) and/or Argos quality locations (n = 17) relayed via the Argos satellite system. Flipper and PIT tags were used to differentiate individual turtles and confirm that no turtles were tracked for more than one season.

3.3.2 Data Processing

To exclude implausible locations, the GPS and Argos locations were filtered using the following criteria: (1) only Argos locations with the highest Argos quality locations class were retained (LC 1, 2, 3; Hays et al. 2001a); (2) GPS locations generated using <6 satellites were removed (Witt et al. 2010; Shimada et al. 2012); (3) a minimum speed of travel was calculated between successive locations and only those locations indicating travel speeds of <5 km hr^{-1} from the previous location were retained (Hays et al. 2004a; Shimada et al. 2012); and (4) successive locations with turning angles >25º were removed because acute turning angles are often indicative of erroneous ‘off-track’ locations (Hawkes et al. 2011).

One location was retained for each 24 hour tracking period to reduce the effects of autocorrelation (de Solla et al. 1999), with the first (post-filtering) location recorded each day retained (Hawkes et al. 2007). This step was necessary due to differences in the volume of data received per turtle each day that would otherwise cause bias to a specific site allowing for comparative analysis between datasets.

3.3.3 Determining Activity

Each tracked turtles post-nesting migration, foraging and transiting (between foraging areas) phases were identified using a plot showing displacement distance from their nesting site over time (Blumenthal et al. 2006). This method of determining activity phases was verified using a visual plot of the filtered locations in ArcGIS 10.1 (ESRI) software. Foraging activity was considered to have commenced when the initial displacement from the nesting site began to plateau, remaining at a similar distance from the nesting site for an extended period of time (minimum of 30 days; see Hays et al. 2010). Further variation in displacement distances away from the initial foraging site was considered to represent transiting between different foraging sites.

3.3.4 Determining Foraging Area Characteristics

Specific characteristics of each filtered location recorded during periods when the tracked turtle was determined to be foraging were investigated. Depth values of each filtered position were extracted from the Australian bathymetry and topography grid (Whiteway 2009) to determine mean seabed depth of the areas where foraging occurred. The geographic mean (centroid) of location data was used to measure the distance of each foraging area to the nearest point of the Australian mainland and the distance displaced from the nesting site. All data are presented as mean ± StDev.

3.3.5 Home Range

Filtered locations, recorded during periods defined as foraging, were used to generate FKD estimates for each individual turtles separate foraging areas. Kernel density is a non-parametric method used to identify areas of disproportionately heavy use (i.e. core areas) within a home range boundary, with appropriate weighting of outlying observations (White & Garrott 1990; Worton 1987, 1989). FKD estimates were calculated for the 50% and 95% UD using the *kde* and *isopleth* functions within GME v0.7.2.1 software (Spatial Ecology; Beyer 2012). The 50% UD FKD was used to represent the core area of activity at foraging sites, while the 95% UD FKD was used to represent the overall foraging home range area (Hooge & Eichenlaub 2000). Kernel smoothing parameters (bandwidth) for each turtles foraging area were selected using least square cross validation (Rodgers et al. 2007). The resulting FKD polygons (both 50% and 95% UD) were mapped in ArcGIS and any portion of FKD estimates, that overlapped terrestrial areas, was removed.

A count of individual home range 95% UD FKD polygons that overlapped or partially overlapped each 20 km^2 cell within a regular grid across the entire study area was completed and repeated for 50% UD FKD home range polygons. The purpose was to identify those areas that had the highest use and to determine the overall exposure of flatback turtles within their foraging habitat to specific hazards (see Section 3.3.7).

3.3.6 Current Foraging Protection Coverage

The overlap of existing State and Commonwealth Marine Reserves with foraging home range areas was investigated to determine the current protection coverage of identified foraging home range areas (both for 50% and 95% UD). GIS layers for the State Marine Reserves were obtained from the Department of Environment and Conservation (n = 5, total area 10,047 km^2) and Commonwealth Marine Reserves from the Department of Sustainability, Environment, Water, Population and Communities (n = 18, total area 487,477 km^2). Two metrics were used to determine the protection coverage: (1) individual turtle foraging home range area polygons were merged to form one core foraging area layer (50% UD) and one overall foraging area layer (95% UD), with the percentage of each layer that overlapped the protected areas calculated using ArcGIS; and (2) the percentage of filtered locations recorded during periods of foraging situated within protected areas.

The percentage of filtered locations recorded during periods of foraging within specific maritime zones was investigated using ArcGIS. Maritime zone boundaries were downloaded from Geoscience Australia (www.ga.gov.au/metadata-gateway/metadata/record/gcat_83170). Selected maritime zones included coastal waters (3 nm limit) and the exclusive economic zone (EEZ; 200 nm limit). These zones were included as marine turtles in these zones are protected under the EPBC Act (1999) and their associated level of State and Commonwealth jurisdiction controlled activities related to fisheries and the resource sector. These activities were included as they were considered to be hazardous to foraging flatback turtles within the region (Wallace et al. 2011).

3.3.7 Potential Exposure to Hazards

3.3.7.1 Exposure to Fisheries

Three individual Commonwealth fishery zones exist within the region: the Pilbara Trawl Fishery, the North West Slope Trawl Fishery and the Northern Prawn Fishery. The boundaries of these fishery zones were downloaded from Geoscience Australia (www.ga.gov.au/metadata-gateway/metadata/record/64771).

To determine the potential exposure of foraging flatback turtles to fishing activities within these zones, the total count of 50% and 95% UD foraging home range areas within each 20 km^2 grid that overlapped the boundaries of each individual fisheries zone was compared with the overall total count within all grid cells across the entire study area. This metric aims to provide a broad indication of the extent of spatial overlap between areas utilised for fishing activities and foraging home range areas and is not to be considered as a direct indication of impact.

3.3.7.2 Exposure to Resource Sector Activities

In Western Australia, offshore petroleum exploration and development is regulated by a title system. Petroleum activities can only occur if a proponent holds a valid title, which in itself provides holders with an exclusive right to apply for further approvals to conduct petroleum operations in the area. The title areas provide boundaries, within which petroleum-related activities currently occur or can potentially occur in the future.

The type and location of currently active offshore title areas released for petroleum industry activities were provided by the DMP. Title areas are divided into graticular sections. Each section is five minutes of latitude by five minutes of longitude, with sections to the north of Western Australia having an area of ~84 km^2. Five relevant title types exist: exploration permits (for the purpose of seismic surveys and oil/gas well drilling); retention leases (a five year exploration lease); production licence (for the purpose of extracting or producing oil/gas from the ground); infrastructure licence (for the construction of offshore facilities for the storage and processing of oil/gas); and a pipeline licence (for subsea pipelines).

To determine the potential exposure of foraging flatback turtles to resource sector activities within these title areas, the total count of 50% and 95% UD foraging home range areas within each 20 km^2 grid cell that overlapped the title areas was compared with the overall total count within all grid cells across the entire study area. This metric aims to provide a broad indication of the extent of spatial overlap between areas that have the potential to be, or are, currently utilised for resource sector activities and foraging habitat, and is not to be considered a direct indication of impact.

3.4 Results

3.4.1 Foraging Site Characteristics

The mean duration for post-nesting flatback turtles to reach their first foraging area following their departure from the nesting site was 43.2 ± 29.7 days (range = 3.9 – 181.2, n = 66). The mean displacement distance from their departure point at their nesting site to their first daily location designated as foraging was 596.2 ± 399.3 km (range = 20.4 – 1568.2, n = 66).

Six turtles were recorded for <30 days within their foraging area prior to tracking ceasing and were therefore excluded from further analysis. Twenty-nine turtles remained within their initial foraging area for the remainder of their tracking time. The remaining turtles (n = 31) were recorded departing their initial foraging area after a mean duration of 120 ± 108 days (range = 19 – 444), with 16 of these turtles not recorded as arriving at a second foraging area prior to the tracking time ending.

Thirteen turtles were recorded as utilising two separate foraging areas, and two turtles were recorded as utilising three foraging areas. Four of these tracked turtles were also recorded as returning to a previously utilised foraging area. In total, 75 separate foraging events (a turtle remained at a similar distance from the nesting site for >30 days) were recorded by the 60 tracked turtles.

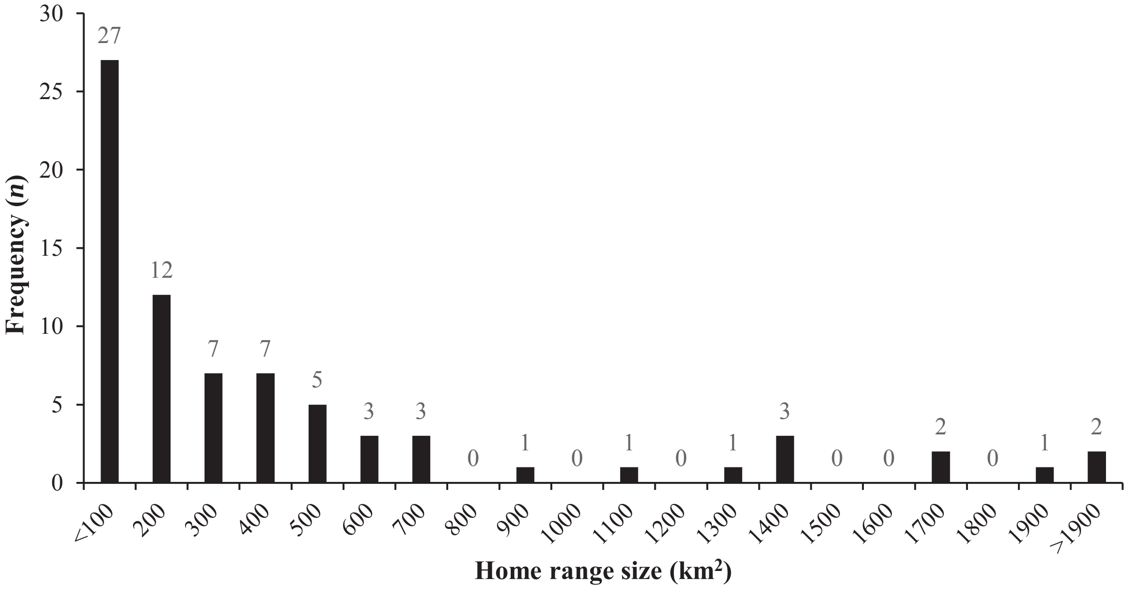
The mean seabed depth for all filtered locations recorded during periods of foraging was 36.5 ± 22.5 m (range = 3 – 130, n = 6,687; Figure 3.1). The distance between the geographic mean (centroid) of each foraging area to the nearest point of the Australian mainland was 66.2 ± 62.3 km (range = 3.4 – 313.9, n = 75; Figure 3.1 and Table 3.1). The distance of each foraging area to the departure point at their nesting site was 632.8 ± 489.4 km (range = 38.9 – 2511.0, n = 75).

The foraging area situated furthest from a nesting site (Port Hedland) was 2511 km away within the Gulf of Carpentaria in Queensland State waters (Figure 3.1).

3.4.2 Foraging Home Range

The tracked turtles first foraging event had a mean core (50% UD) home range size of 515.1 ± 1172.6 km^2 (range = 6.1 – 7145.1, n = 60) and a mean overall (95%) home range size of 2502.3 ± 5078.2 km^2 (range = 46.5 – 27883.9, n = 60; Figure 3.2). The tracked turtles second foraging event had a mean core (50% UD) home range size of 394.7 ± 472.8 km^2 (range = 0.9 – 1635.7, n = 13) and a mean overall (95%) home range size of 1783.3 ± 1914.4 km^2 (range = 7.0 – 6502.2, n = 13; Figure 3.2).

(a) Core home range areas (50% UD)



(b) Overall home range areas (95% UD)

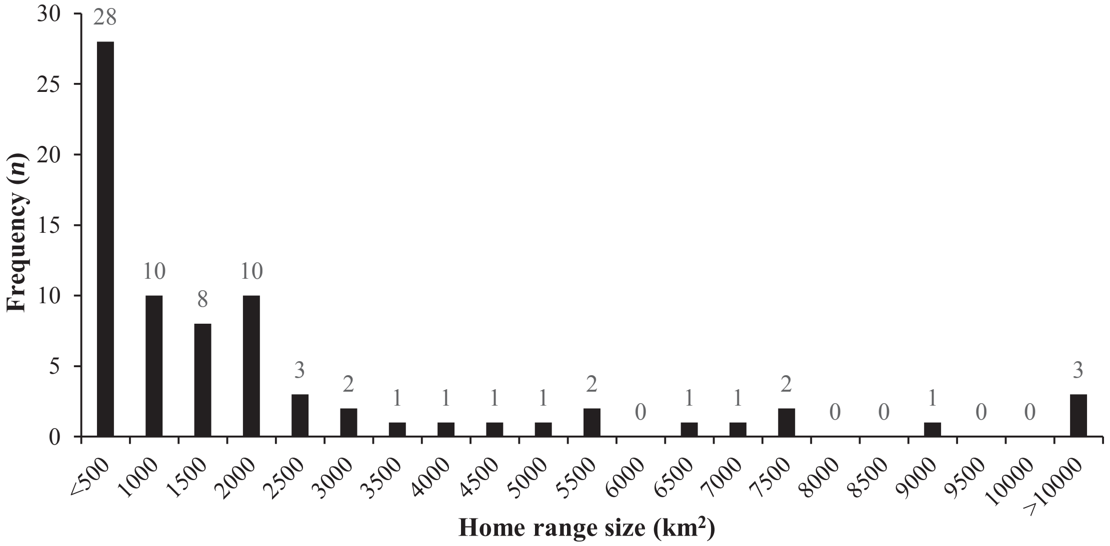


Figure 3.2 Frequency distribution showing size of (a) core home range areas (FKD 50% UD) and (b) overall home range areas (FKD 95% UD) for all tracked turtles.

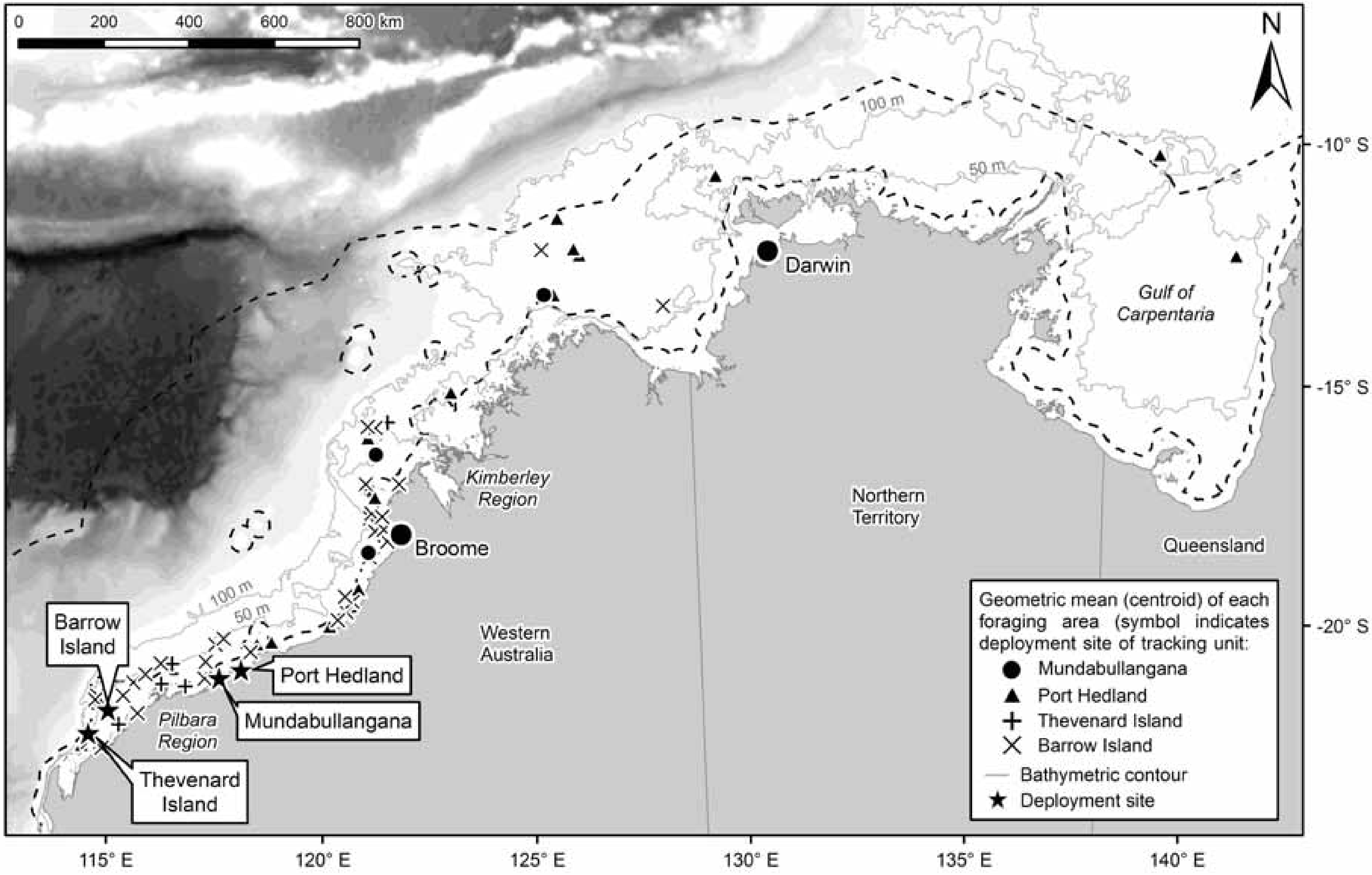


Figure 3.1 Geographic mean (centroid) of all foraging areas (n = 75) used by flatback turtles (n = 60) tracked from four rookeries on the NWS.

There was an overlap of home range area use by the tracked turtles, with core home range areas (50% UD) overlapping or partially overlapping the same 20 km^2 grid cell on nine occasions, and overall home range areas (95% UD) overlapping or partially overlapping on ten occasions (Figure 3.3). The three areas with the highest density overlap of both core and overall home range area were situated within the Kimberley region: an area close to the Lynher Banks approximately 150 km north-west of Cape Leveque; an area situated 100 km offshore from Quondong Point, extending on a similar latitude to Broome in the south to the Lacepede Islands in the north; and in an area 30 km offshore from 80 Mile beach. There was also an overlap of overall home range areas close to the Holothuria banks in the Timor Sea, situated 200 km north of Cape Londonderry (Figure 3.3). There was one main area of overlap within the Pilbara region, where four core home range areas and five overall home range areas overlapped one grid cell situated 20 km west of Thevenard Island (Figure 3.3). The five identified foraging areas where an overlap occurred were utilised by turtles tracked from rookeries of different origin, with the Lynher banks foraging area featuring tracked turtles from all four rookeries (Figure 3.3).

3.4.3 Current Foraging Protection Coverage

When the boundaries of all home range polygons were dissolved to form one combined area, the total area foraging habitat for all tracked turtles covered an area of 30,438 km^2 (50% UD) and 120,273 km^2 (95% UD). The overlap with either a State or Commonwealth protected marine reserve was 60.1% for the core home range area (50% UD) and 48.5% for the overall home range area (95% UD; Figure 3.4a). The percentage of turtle locations recorded during periods of foraging that were situated within a marine reserve was 43.3%.

The percentage of turtle foraging locations that were situated within the coastal water and EEZ maritime boundaries was 21.7% and 41.7% respectively. The percentage situated outside of Australian waters was 0.9%, with the remaining positions (35.7%) situated within the Australian territorial seas (extends 12 nm offshore).

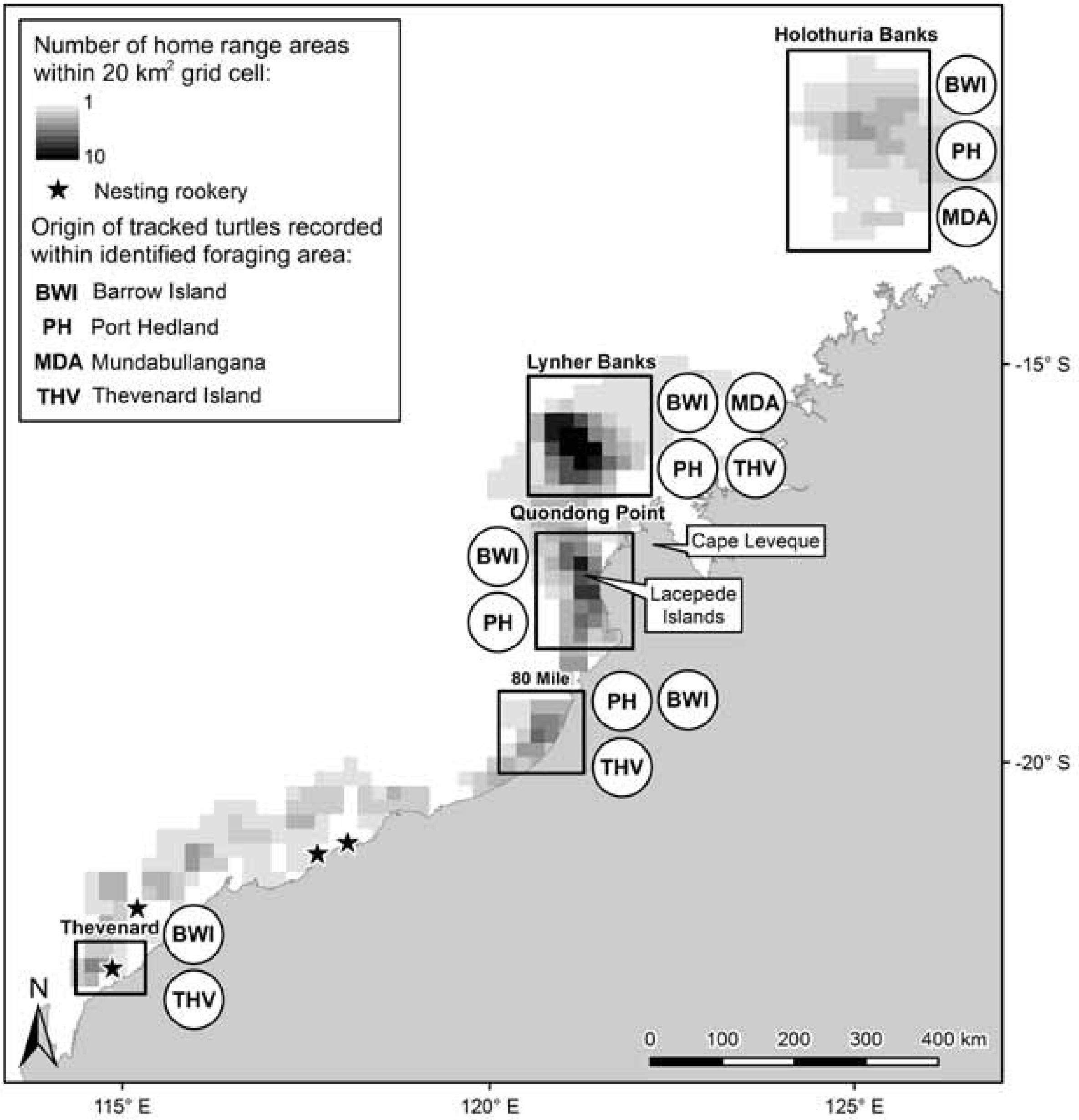


Figure 3.3 Number of overall foraging home range areas (95% UD) that overlap or partially overlap each 20 km^2 grid cells and the origin of where turtles were tracked from for each area.

3.4.4 Potential Exposure to Hazards

3.4.4.1 Exposure to Fisheries

There was minimal interaction between foraging home range areas and the three identified fisheries within the region (Figure 3.4b). The highest percentage of core and overall home range area overlap was with the Northern Prawn Fishery, with 9.4% and 12.5% overlap respectively. There was <1% overlap between the core/overall home range areas with the North West Slope Trawl Fishery. The Pilbara Trawl Fishery overlapped with 6.1% of the core home range areas and 4.5% of the overall home range areas.

3.4.4.2 Exposure to Resource Sector Activities

There was a high overlap between resource sector title areas and foraging areas, with 69.4% of the core home range area (50% UD) and 67.1% of the overall home range area (95% UD) overlapping with resource sector title areas (Figure 3.4c).

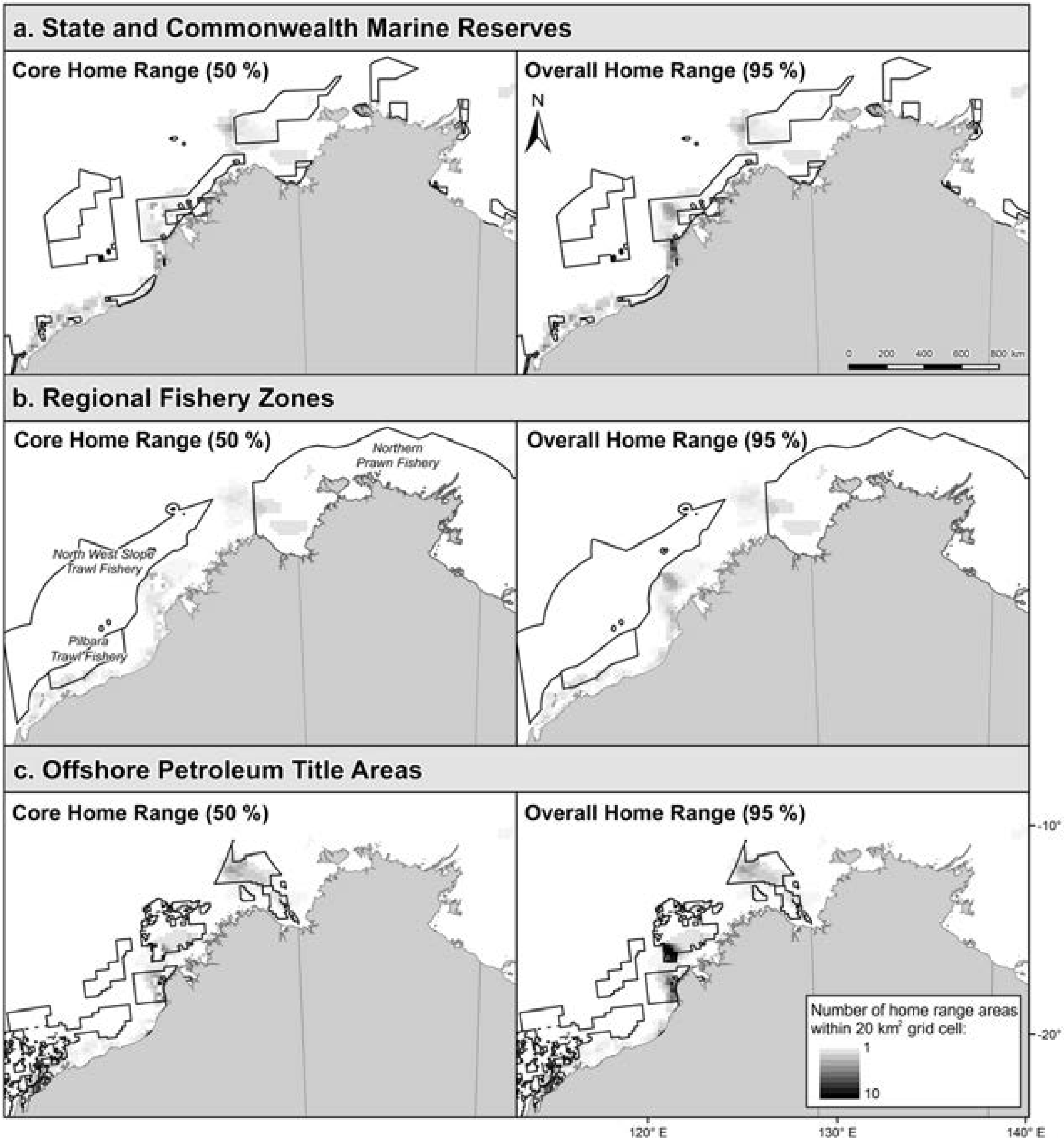


Figure 3.4 Overlap of core (50% UD) and overall (95% UD) foraging home range areas with (a) State and Commonwealth marine reserves (areas outside protected areas are highlighted); (b) Regional fishery zone boundaries (areas inside fishery zones are highlighted); and (c) Offshore petroleum title areas (areas inside title areas are highlighted).

3.5 Discussion

Satellite tracking of flatback turtles from breeding sites on the NWS revealed that their foraging areas were widely dispersed, with the furthest situated within the Gulf of Carpentaria 2511 km from their nesting site. Foraging areas were in water shallower than 130 m and within 315 km of the shore, with many areas located in 50 m water depth and 66 km from shore. As this is the first data on the characteristics of foraging areas used by flatback turtles, no comparison can be made with the characteristics of other flatback foraging areas. However, the characteristics are consistent with areas where bycatch of adult flatback turtles has been previously reported (Robins & Mayer 1998).

Five separate locations across the region were identified where an overlap of multiple individual post-nesting flatback turtle foraging home range areas occurred (Figure 3.3). The overlap indicates that these locations may provide important foraging habitat, with four of the locations situated in the north-east of the region in the Kimberly and a fifth in the Pilbara region to the west of Thevenard Island (Figure 3.3). In addition, there is evidence of foraging activity within the previously identified post-nesting migratory corridor on the NWS (Pendoley et al. 2014b), placing further importance for the protection of this area.

The selection of foraging areas by individual turtles is hypothesised to reflect passive drift experienced as hatchlings from their natal beach, with foraging site selection in this chapter therefore potentially directed by constant currents from the breeding sites (Hamann et al. 2011; Hays et al. 2010). These foraging areas could therefore also host flatback turtles at different life phases, including their post-hatchling and juvenile development phases. Further investigation of these areas may help to answer where flatback turtles go during these developmental phases.

The five foraging locations characterised by home range overlap, hosted flatback turtles tracked from rookeries of different origin (Figure 3.3). This is the first recorded occurrence of a spatial overlap between flatback turtle populations within the Pilbara Coast genetic stock and South East Indian Ocean RMU, with no spatial overlap for the same populations when inter-nesting (Chapter 2). These five foraging areas may host significant numbers of flatback turtles of reproductive age from multiple rookeries within the same genetic stock and RMU. Any hazard or threat within these areas therefore has the potential to compromise the overall status of the regional population, placing greater importance on the protection and conservation of these identified areas.

The trigger for female turtles to return from their foraging areas to their breeding grounds is likely related to a body condition threshold (Alerstam et al. 2003; Hays 2000). Their return is therefore considered dependent on the quality and availability of prey items within their foraging habitat (e.g. Hatase & Tsukamoto 2008). Consequently, the use of the same foraging areas by multiple populations within the region may result in a similar trend with regards to their life-history traits at their breeding/nesting sites across the region e.g. breeding omission probability, annual abundance. This information is particularly important for industry resource sector developments within the region that are required to monitor and diagnose trends that may manifest in the life-history traits of flatback turtle populations at both the development site and a reference site as part of their environmental approval process e.g. the Gorgon LNG development on Barrow Island and at the reference site (Mundabullangana) (Chevron 2009).

There was a large overlap of foraging home range areas and foraging locations with existing protected areas in the region, with 48.5% of the combined overall home range area and 43.3% of all foraging locations overlapping with a protected marine reserve. The larger the proportion of a species range that is overlapped by protected areas, the higher the likelihood that the protected areas provide suitable coverage (Rodrigues et al. 2004). Therefore the overlap in this chapter may indicate that the existing reserve network provides protection to flatback turtles within nearly half of the identified foraging areas on the NWS. The high level of overlap is perhaps surprising when considering the wide dispersal of foraging areas across the region, broad range of core home range sizes (6.1 – 7145.1 km^2) and that the boundaries of the marine reserves were determined by decision makers without access to flatback turtle satellite tracking data or delineated foraging home range boundaries. However, of the five foraging locations where an overlap of home range areas was identified, two were situated outside the boundaries of a protected area (foraging areas adjacent to Quondong Point and west of Thevenard Island). It is therefore recommended that protection of these areas are considered further.

The protection of a species present in a marine reserve is only adequate if the management is effective in ensuring the species' long term persistence (Rodrigues et al. 2004). Indeed, the level of protection within the marine reserves in this chapter varies and in reality foraging flatback turtles may still face permitted anthropogenic threats within the reserve boundary e.g. fishery bycatch (Lewison et al. 2004) or industry resource sector activities (Whiting et al. 2007). In addition, in areas where regulatory conditions are not well developed, protection measures may not be implemented outside of marine reserves increasing the risk of mortality to turtles in unprotected areas. However, within Australian waters (200 nm limit), flatback turtles (i.e. a MNES) are protected under the EPBC Act (1999). This provides them with protection outside of marine reserves, with any activities that have, will have, or are likely to have a significant impact on them, subject to a rigorous screening/referral, EIA and environmental approval process. This adds further significance to the identification of important flatback turtle foraging areas in this chapter, particularly as the referral process relies on data regarding the presence or potential presence of a protected species.

Fisheries bycatch is recognised as perhaps the most serious global threat to highly migratory, long-lived marine taxa, including turtles (Wallace et al. 2010, 2011). In this chapter, flatback turtle foraging areas were situated in different areas to the three defined fishery zones within the region, as indicated by the low level of overlap between the foraging home range areas and fishery zone boundaries. The low level of overlap represents minimum opportunity for interaction and is consistent with the available annual bycatch records for two of the fisheries (no bycatch records could be found for the North West Slope Trawl Fishery), with no adult flatback turtle fatalities reported for the Pilbara Trawl Fishery in 2008 (Department of Fisheries 2010) and the Northern Prawn Fishery in 2010 (Barwick 2011). In addition to the low level of overlap, the absence of any fatalities may also be attributed to implemented bycatch reduction control measures including the use of Turtle Excluder Devices (TEDs) which were made mandatory in the Northern Prawn Fishery in 2000 and in all other Western Australian trawl fisheries in 2004 (Bycatch Action Plan, WA Fisheries). The use of TEDs has been successful in reducing the bycatch of marine turtles, with the bycatch of marine turtles in the Northern Prawn Fishery reducing from approximately 5700 marine turtles in the late 1980s (Poiner et al. 1990) to 27 reported marine turtle interactions (all species) and zero fatalities in 2010 (Barwick 2011).

Fishing activities do occur outside of the defined fishery boundaries within the region, with the EEZ incorporating the Australian Fishing Zone that was established through the Fisheries Management Act 1991. The extended periods that turtles spent within their foraging areas (up to 444 days) and high overlap of foraging positions within the EEZ (41.7%) may indicate a continuing vulnerability to interaction with these fishing activities despite the demonstrated overlap with protected marine reserves (Casale et al. 2008; Lewison et al. 2004).

The NWS region produces the majority of Australian domestic and exported oil and gas, and is one of the most economically significant regions in Australia (Human & McDonald 2009). There was a large overlap between areas used for current and potential future resource sector activities and areas used for foraging, with nearly 70% of both the core and overall home range areas overlapping with title areas where resource sector activities currently, or may potentially, occur. Foraging areas generally represent habitat with high ecological value, high primary productivity where turtle prey may be aggregated (Bailey et al. 2012; Kobayashi et al. 2008; McCarthy et al. 2010) and may also provide important habitat for other protected marine fauna. The current or future presence of industry resource sector activities within these important foraging areas must be recognised by regulators when assessing their environmental approvals.

When foraging, flatback turtles demonstrated certain behavioural characteristics that could reduce their susceptibility to potential anthropogenic and natural threats within the region: they utilised foraging areas that were broadly dispersed across the region; there were apparent connections between their foraging areas; and many turtles used multiple areas. However, these characteristics may be offset by the constraint of flatback turtles remaining entirely within the boundary of the continental shelf. This neritic behaviour was observed during their inter-nesting (Chapter 2) and post-nesting migratory phases (Pendoley et al. 2014b) and when foraging (this chapter). This spatial restriction may reduce their ability to adapt, subsequently increasing their susceptibility to adverse anthropogenic and natural threats within the region should they occur (Gaston 2003). This is particularly significant when considering the overlap of some anthropogenic threats demonstrated in this chapter and the inter-annual environmental changes caused by tropical cyclones, with the region subject to the highest incidence of tropical cyclones along the Australian coast (Dare & Davidson 2004).

As observed in flatback turtles when migrating (Pendoley et al. 2014b) and in other foraging marine turtle species (e.g. Hays et al. 2010; Seminoff et al. 2008), foraging behaviour by some flatback turtles was flexible: out of the 60 turtles that were tracked, 31 departed their initial foraging ground and 15 utilised more than one foraging area. This flexible foraging strategy may reduce their susceptibility by facilitating a capability to adapt to anthropogenic or natural threats within the region (Robinson et al. 2009). This is particularly significant when considering the potential presence of anthropogenic threats within their foraging areas (as presented in this chapter) and the broad scale inter-annual environmental changes potentially caused by tropical cyclones within the region.

The limited data on turtles foraging in the neritic indicate they feed on prey such as arthropods, decapods, gastropod molluscs and other benthic invertebrates (Bjorndal 1997). There are no published studies on the diet of adult flatback turtles, though it is known that they are carnivorous, feeding principally on soft-bodied invertebrates including soft corals, sea pens, holothurians and jellyfish (unpublished data, EPA Queensland Turtle Conservation Project). Prey availability may vary temporally and spatially across the region, accounting for the broad dispersal of foraging areas identified across the region. The variability may be attributed to the episodic and spatially diverse nature of coastal upwelling within the region. In general, the eastern side of ocean basins are consistently highly productive ecosystems due to the upwelling of cold nutrient rich waters to the surface. However, the eastern side of the Indian Ocean that borders the Western Australia coast is an exception to this; upwelling is suppressed due to the poleward-flowing Leeuwin Current and the Indonesian Throughflow (Smith 1992). This suppression has resulted in the region’s waters being low in nutrients. Instead, upwelling is episodic and spatially varied, occurring when the Leeuwin Current weakens or cyclones move across the region bringing cold, nutrient rich slope waters from the Indian Ocean onto the shelf. These waters are then mixed by strong internal tides bringing the nutrients to the surface (Condie et al. 2003).

Some flatback turtle foraging areas were situated in close proximity to areas of known high primary productivity where known prey species have been recorded (McCarthy et al. 2010). The foraging habitat to the west of Thevenard Island is close to the eastern edge of the Montebello Trough which hosts increased biological productivity compared to surrounding areas (Brewer et al. 2007) and one of the most diverse slope habitats in Australia (Department of the Environment, Water, Heritage and the Arts 2008a). The foraging area identified at Quondong Point is also situated in an area of enhanced biological productivity (Department of the Environment, Water, Heritage and the Arts 2008b). The processes underlying the productivity in these areas are unclear and may be associated with a unique combination of bathymetry and oceanography where a strong current running along the coastline interacts with shallow bathymetry causing the mixing of deeper, more nutrient-rich waters, with surface waters resulting in increased productivity (Department of the Environment, Water, Heritage and the Arts 2008a). A unique bathymetry and oceanography combination may also contribute to the overall productivity in the Lynher Banks foraging area, which hosts highly variable bathymetry and significant geomorphic features (Harris et al. 2003; Figure 3.3).

The tracking data used in this chapter are likely autocorrelated because the turtles next movement has to be to a location available from its current location, leading to a pathway in which locations are autocorrelated with previous locations for long time durations (see Cushman 2010). While De Solla (1999) indicates that eliminating autocorrelation reduces the biological relevance of home range estimates, temporal autocorrelation of locations is considered to lead to an underestimation of home range size and bias in predictions of habitat selected (Swihart & Slade 1985; White & Garrott 1990). Therefore, the influence of autocorrelation should be considered when considering the results presented in this and other chapters within this thesis. Autocorrelation is an issue that the tracking community has been attempting to address, and while it cannot be eliminated entirely, there are potential options to minimise its effect including filtering data to achieve statistical independence and condensing or collapsing data into bins.

This chapter presents the foraging habitat use by adult female flatback turtles following their post-nesting migration. The importance of specific foraging areas in the Kimberly and Pilbara regions for reproductive age flatback turtles, within the same RMU, is now evident. This chapter's findings have important conservation and management implications for the regional population and will help inform the screening/referral exercise and the risk assessment within the ESD during the EIA process for future developments in proximity to identified foraging areas. The assessment of the level of potential interaction between foraging flatback turtles and specific threats, including the industry resource sector, highlights the existing level of protection, identifies opportunities for further protection and provides a pathway for prioritising dedicated action. There remain a number of limitations when considering population wide exposure to specific threats within the region, notably the gaps in available datasets for male flatbacks turtles which may differ in foraging habitat use/fidelity and for juvenile flatback turtles of both sexes.

The tracked turtles level of exposure to, and potential interaction with, the industry resource sector when foraging was lower compared to those turtles when inter-nesting at Barrow and Thevenard Islands (presented in Chapter 2). The inter-nesting life phase of flatback turtles is therefore considered to present the highest likelihood of interaction between flatback turtles and the industry resource sector activities on the NWS.

Chapter 4

Inter-nesting habitat suitability models and areas exposed to the industry resource sector on the NWS

The distribution, movement and behaviour of flatback turtles during two different life phases were identified in Chapters 2 (inter-nesting) and 3 (foraging) to help inform the screening/referral and scoping phases of the EIA process. This chapter continues to address the identified knowledge gap relating to their offshore spatial distribution on the NWS (Chapter 1) and inform the EIA process by investigating the environmental variables that influence their movement and behaviour and areas exposed to the industry resource sector during the life phase considered most at risk i.e. when inter-nesting.

An ecological niche model is used to: identify those environmental variables considered to have the greatest influence on their inter-nesting distribution; and to generate a habitat suitability map to identify those areas where inter-nesting flatback turtles may be present/absent on the NWS. This information can be used by proponents and the regulator to determine the potential presence of inter-nesting flatback turtles within a development footprint during the screening/referral phase of an EIA. The habitat suitability map is integrated with the location of resource industry activities to contextualise the likelihood of a threat from the industry sector across the entire NWS area and to identify specific areas with the greatest likelihood of interaction.

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4.1 Abstract

To predict and manage ecological impacts of anthropogenic activities effectively, an understanding of at-risk species spatial ecology is first required. This is particularly difficult in the marine environment due to limited offshore access and wide ranging movements of some species. Flatback turtles are a protected species potentially at risk from hazards associated with the industry resource sector on the NWS, yet their at-sea spatial ecology is not well understood. This chapter uses habitat suitability modelling to: identify environmental variables which influence flatback turtle inter-nesting movement; identify areas of suitable inter-nesting habitat; and determine overlap of identified inter-nesting habitat with industry resource sector hazards.

Inter-nesting movements of 47 female flatback turtles, from five rookeries in the NWS study area, were recorded using satellite tracking units between 2006 and 2010. Environmental variables including SST, bathymetry, magnetic anomalies, distance from coastline, slope and ruggedness index were combined with the tracking data from each rookery in an ecological niche model. The positions of resource sector vessels were used to represent areas of potential impact from industry resource sector hazards and identified overlap with suitable inter-nesting habitat areas as a representative of the likelihood of impact.

The primary environmental variables that influenced flatback inter-nesting movement were bathymetry, distance from coastline and SST. Suitable areas of inter-nesting habitat were located in close proximity to many known flatback turtle rookeries across the region. Areas of suitable inter-nesting habitat overlapped resource sector hazards in close proximity to four of the five rookeries and at other known flatback turtle rookeries within the area. The cumulative overlap across the overall study area indicates a high potential for interaction with resource sector hazards, demonstrating the need for regional protection measures in these areas.

This chapter provides a capability for regulators and proponents to determine the potential offshore presence of inter-nesting flatback turtles within the region and should ensure protection measures are targeted appropriately as industrial development continues.

4.2 Introduction

Human population growth has increased demand for natural resources (UNEP 2012), resulting in expanding resource extraction across the globe and an increased pressure on natural environments (Bellamy et al. 2013). The predicted consequences of such resource extraction on threatened species, habitats and ecological function, as well as the effectiveness of proposed protection measures, are often uncertain (UNEP 2012). At a species level, the uncertainty largely stems from a poor understanding of the spatial ecology including their ecosystem role and habitat preferences (Franklin 1995; Bellamy et al. 2013). Moreover, understanding these gaps is challenging (Guisan

& Thuiller 2005; Colwell & Rangel 2009) because (1) behaviour and habitat use is underpinned by influencing environmental variables (Sobeŕon 2007); and (2) environmental variables may act independently of each other or in combination.

Statistical and mathematical modelling techniques have been increasingly used to improve the understanding of species' spatial ecology (Guisan & Thuiller 2005). One technique is the generation of habitat suitability models to predict species distribution based on species preferences for different habitats across a combination of environmental variables (Guisan & Zimmermann 2000). Species distribution data, required for the model, can be simple presence or presence-absence data based on random or non-random field sampling (Guisan & Thuiller 2005). For most species, information on absence are difficult to obtain due to logistical and budget constraints associated with field sampling across their range, with multiple samples required before a species can be classified as absent (Zaniewski et al. 2002; Ottaviani et al. 2004; Hirzel et al. 2002). Therefore, when determining habitat suitability for wide ranging species, models that rely on presence data are more commonly used (Phillips et al. 2006).

An ecological niche-based model (ENM) relies on presence data only (Hirzel et al. 2002; Phillips et al. 2006) and provides valuable information on habitat choice by quantifying the relationship between the presence data and environmental variables to generate habitat suitability predictions at unsampled locations throughout the chosen study area (Guisan & Thuiller 2005). The model's output also includes a habitat suitability map detailing the predicted distribution of a species over the area based on the model's input i.e. environmental variables and presence data (Guisan & Zimmermann 2000). Consequently, an ENM can be a powerful tool in aiding the development of policy to mitigate impacts to species habitats, and offer considerable scope for use along the coastal zone.

ENMs have primarily been used for terrestrial species habitat modelling (Sattler et al. 2007; Basille et al. 2008; Falcucci et al. 2009), though more recently, they have also been applied to marine species (Degraer et al. 2008; McKinney et al. 2012; Pittman et al. 2007). Suitable habitat areas have also been overlapped with locations of anthropogenic hazards to determine the potential significance of the hazard, such as olive ridley turtle habitat overlap with fisheries (Pikesley et al. 2013) and whale shark habitat overlap with oil platforms and fisheries (McKinney et al. 2012). In general, the model outputs (i.e. habitat preferences and species distribution) have been used to identify areas where measures could be directed for further environmental protection of the species or aid in the prioritisation of future research (Hirzel et al. 2004; Sattler et al. 2007; Gomes et al. 2009).

The NWS in Western Australia provides breeding and foraging habitat to globally significant marine turtle populations and has seen rapid industrial development related to the extraction, processing and transport of natural resources. Absence of data relating to marine turtle spatial ecology, environmental drivers of change and possible species level response to an impact (e.g. Chapter 2; Grech et al. 2014), presents a key knowledge gap for regulators and industry sector proponents when minimising impact. One species identified as having a high likelihood of a potential interaction with regional industry activities is the flatback turtle (Chapter 2).

Although flatback turtles are protected under Australia's EPBC Act (1999) there is little understanding of the flatback turtles spatial ecology in the marine environment (Limpus 2007), particularly in the NWS region (Pendoley et al. 2014a). The need to develop a greater understanding of their spatial ecology in this region is particularly high as the industry resource sector is growing and may present multiple anthropogenic hazards to flatback turtles situated offshore during their nesting cycle and migration (Chapter 2; Pendoley et al. 2014a; Commonwealth of Australia 2003). Documented offshore hazards to marine turtles include: marine vessels (e.g. collision and disturbance: Dobbs 2001; Hazel et al. 2007; Meager & Limpus 2012; Chevron 2013); oil spills (e.g. ingestion: Lutcavage et al. 1995); underwater blasting/seismic surveys/pile driving (e.g. noise and vibration: McCauley et al. 2000; Keevin et al. 1997); and dredging (e.g. entrainment and habitat burial: Dickerson et al. 1991). Mitigating or preventing these hazards from impacting turtles during the breeding season is important; if female turtles are repeatedly disturbed it can lead to reduced reproductive output (Hamann et al. 2002); and mortality of reproductively active female turtles could affect the survival of the entire species as they are considered to contribute disproportionately to sustaining the overall population compared to non-reproductively-active turtles (Gerber & Heppell 2004; Heppell et al. 1999).

Protection of breeding turtles from disturbance requires knowledge of their habitat use and preferences. Like other marine turtle species it is expected that inter-nesting flatback turtles will have specific habitat preferences, and small scale variations in these will underpin variability in distribution over multiple seasons (e.g. Hays et al. 2000; Fossette et al. 2012). Quantifying habitat preferences and distribution of inter-nesting flatback turtles on the NWS is therefore critical to providing a solid empirical foundation for development, implementation and evaluation of protection measures in response to anthropogenic hazards.

The main aim of this chapter was therefore to improve understanding of flatback turtle spatial ecology within the NWS study area in light of significant industry resource sector development. Specific objectives were to: (1) identify the environmental variables that influence the spatial distribution and range of inter-nesting flatback turtles on the NWS using an ecological niche-based presence-only model; (2) produce a habitat suitability map that describes and represents the potential geographic distribution of inter-nesting flatback turtles on the NWS; and (3) integrate resource sector activities to contextualize the potential threat from industry hazards within the region.

4.3 Methodology

4.3.1 Study Area

The NWS study area size is 48,526 km^2; extending offshore from North West Cape in the west to 50 km east of Port Hedland (latitude: -18.7º to -22.5º, longitude: 114.0º to 120.0º) and borders 1500 km of coastline within the Pilbara region of Western Australia (Figure 4.1). The study area extent matched that of the North West Shelf Joint Management Study used by CSIRO for regional planning and multiple-use management of the NWS marine ecosystems (CSIRO 2007). The NWS study area's offshore boundary extends to the 60 m bathymetric contour. The 60 m contour was selected to ensure all potential inter-nesting flatback habitat within the region was included in the habitat analysis as this is deeper than inter-nesting flatback turtles have been recorded diving to within Western Australia (Bare Sand Island = 44 m; Sperling 2007) and deeper than flatback turtles have previously been found to occur in other parts of Australia (40 – 45 m; Walker 1991; Poiner & Harris 1996; Robins & Mayer 1998).

The range of flatback turtle breeding within the NWS study area extends eastwards from Cape Range across the area to Port Hedland, with many offshore islands supporting suitable nesting habitat (Pendoley et al. 2016). The most significant rookeries within the area are found at Barrow Island, Mundabullangana and collectively, the Mackerel Islands (includes Ashburton and Thevenard Islands) offshore from Onslow (Limpus 2007; Pendoley et al. 2014a; Pendoley et al. 2016). Smaller flatback turtle rookeries are found in Port Hedland; in the Lowendal Islands (including Varanus Island); at the Muiron Islands (Limpus 2007); and across the Dampier Archipelago (including Legendre and Delambre Islands; Prince et al. 2013).

The NWS study area is characterised by many natural features considered to be of high ecological value, including coastal and shallow water habitats such as mangrove forests, seagrass beds, coral reefs and shelf habitats built around complex sponge communities (Condie & Andrewartha 2008). The area experiences an average of three to four cyclones a year that can cause massive destruction to coastal areas and seabed habitats, and contribute significantly to the region's natural inter-annual variability. The area is also affected by large-scale variations in ocean temperatures and salinity. These are influenced by the Indonesian throughflow (fluctuating flows in the Indonesian Archipelago between the Pacific and Indian Ocean) and by other regional currents (Condie & Andrewartha 2008).

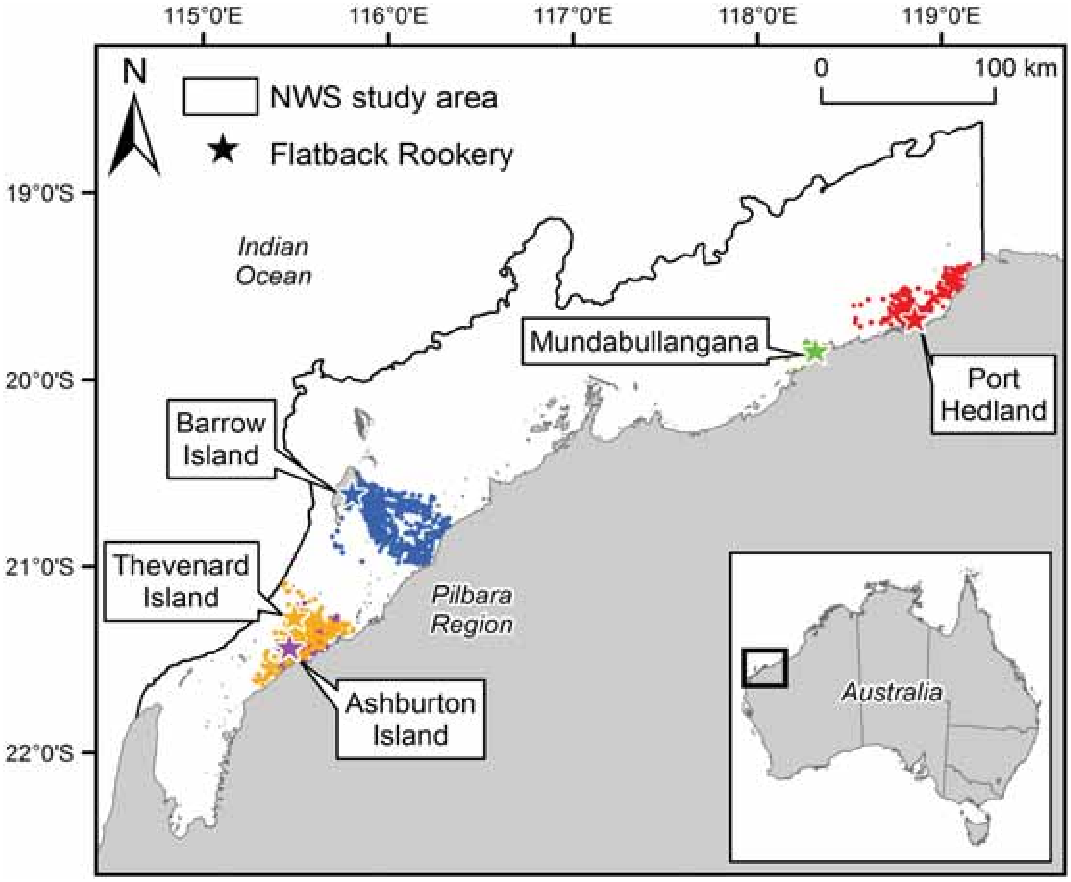

Figure 4.1 Filtered inter-nesting ‘presence’ positions (*n* = 5402) from all rookeries (*n* = 5). Coloured positions represent filtered inter-nesting positions from each rookery.

4.3.2 Turtle Tracking Dataset

The flatback turtle reproductive season in Western Australia extends from October through to February, with variations in peak nesting periods among rookeries (Pendoley et al. 2014a). Satellite tracking units were attached to 47 nesting female turtles during this period following clutch deposition at five rookeries located within the NWS study area, between 2006 and 2010; Barrow Island (*n* = 26), Thevenard Island (*n* = 6), Ashburton Island (*n* = 4), Mundabullangana (*n* = 2) and at Cemetery beach in Port Hedland (*n* = 9; Figure 4.1). A summary of individuals tracked, their sizes and tracking duration by deployment location is provided in Chapter 2. It was unknown if the selected turtles were nesting for the first time in the season at the time of attachment, therefore data used in this chapter may not represent the overall season’s inter-nesting distribution for each tracked turtle.

Four models of tracking unit were used; one model provided Argos only locations (Kiwisat 101, Sirtrack Ltd, *n* = 2) and three models provided Fastloc GPS locations (MK-10 AF, Wildlife Computers, *n* = 4; Fastloc GPS-Argos transmitters, Sirtrack Ltd, *n* = 29; SRDL, St Andrews Mammal Research Unit, *n* = 12; Table 4.1). See Chapter 2 for tracking unit attachment technique and data recovery details, Argos and GPS location accuracy details and data filtering techniques. All tracking units were set up with a duty cycle of ‘on continuously’, with a saltwater switch to restrict transmission attempts when the tracking unit was submerged.

Location data were filtered to calculate a median location for every six hour period, from all data received during this period (Schofield et al. 2010b). Where locations were missing within the six hour period, linear interpolation was used to derive a location (Bailey et al. 2008).

The absolute end of inter-nesting was indicated by the commencement of post-nesting migration, which was deemed to have begun once movement away from the nesting beach was directional and protracted (Zbinden et al. 2008). All data received following the commencement of post-nesting migration were excluded from the analysis.

Table 4.1 Summary of tracking unit attachment data detailing nesting season and release site (ASH = Ashburton Island, BWI = Barrow Island, MDA = Mundabullangana, PH = Port Hedland, THV = Thevenard Island).

Year	CCL (cm)	Attachment location	Location type	Attachment date	End of inter-nesting	Number of tracking days (*n*)
2005/06	85	MDA	Argos	09/12/2005	20/12/2005	11
2005/06	90	MDA	Argos	10/12/2005	01/01/2006	22
2006/07	88	BWI	GPS	15/12/2006	03/01/2007	19
2006/07	87	BWI	GPS	18/01/2007	13/02/2007	26
2007/08	89	BWI	GPS	16/12/2007	05/01/2008	20
2007/08	92	BWI	GPS	13/12/2007	11/01/2008	29
2008/09	86	BWI	GPS	18/12/2008	03/01/2009	16
2008/09	90	BWI	GPS	18/12/2008	31/12/2008	13
2008/09	90	BWI	GPS	17/12/2008	24/01/2009	38
2008/09	90	BWI	GPS	17/12/2008	13/01/2009	27
2008/09	87	PH	GPS	08/12/2008	04/01/2009	27
2008/09	85	PH	GPS	07/12/2008	25/12/2008	18
2008/09	89	PH	GPS	06/12/2008	30/12/2008	24
2008/09	89	PH	GPS	06/12/2008	19/12/2008	13
2009/10	90	BWI	GPS	29/11/2009	13/12/2009	14
2009/10	88	BWI	GPS	02/12/2009	15/12/2009	13
2009/10	91	BWI	GPS	01/12/2009	11/01/2010	41
2009/10	89	BWI	GPS	03/12/2009	09/01/2010	37
2009/10	91	BWI	GPS	27/11/2009	08/01/2010	42
2009/10	96	BWI	GPS	28/11/2009	28/12/2009	30
2009/10	90	BWI	GPS	29/11/2009	09/01/2010	41
2009/10	87	BWI	GPS	28/11/2009	07/01/2010	40
2009/10	91	BWI	GPS	02/01/2010	19/01/2010	17
2009/10	90	BWI	GPS	03/12/2009	14/01/2010	42
2009/10	93	BWI	GPS	28/11/2009	26/12/2009	28
2009/10	96	BWI	GPS	01/12/2009	11/01/2010	41

Year	CCL (cm)	Attachment location	Location type	Attachment date	End of inter-nesting	Number of tracking days (*n*)
2009/10	90	BWI	GPS	29/11/2009	10/01/2010	42
2009/10	88	BWI	GPS	01/12/2009	29/12/2009	28
2009/10	88	BWI	GPS	27/11/2009	20/01/2010	54
2009/10	87	BWI	GPS	29/11/2009	14/12/2009	15
2009/10	91	BWI	GPS	30/11/2009	08/01/2010	39
2009/10	88	BWI	GPS	01/12/2009	20/01/2010	50
2009/10	NR*	ASH	GPS	14/12/2009	31/12/2009	17
2009/10	87	ASH	GPS	14/12/2009	14/01/2010	31
2009/10	87	ASH	GPS	14/12/2009	17/01/2010	34
2009/10	88	ASH	GPS	14/12/2009	17/01/2010	34
2010/11	88	PH	GPS	30/11/2010	27/12/2010	27
2010/11	91	PH	GPS	27/11/2010	08/12/2010	11
2010/11	90	PH	GPS	30/11/2010	21/12/2010	21
2010/11	90	PH	GPS	01/12/2010	06/01/2011	36
2010/11	88	PH	GPS	26/11/2010	30/12/2010	34
2010/11	99	THV	GPS	14/12/2010	18/01/2011	35
2010/11	92	THV	GPS	12/12/2010	05/01/2011	24
2010/11	89	THV	GPS	12/12/2010	11/01/2011	30
2010/11	98	THV	GPS	11/12/2010	05/01/2011	25
2010/11	92	THV	GPS	11/12/2010	27/12/2010	16
2010/11	89	THV	GPS	17/12/2010	29/12/2010	12

* Not recorded

4.3.3 Objective 1: Environmental Variables that Influence Distribution and Range

Environmental variables considered for use in the model were derived from remotely sensed images and GIS analysis (Table 4.2 & Figure 4.2). An environmental variable was deemed suitable if it characterised the habitat suitability associated with the distribution of other inter-nesting marine turtle species or if it had the potential to influence the distribution of inter-nesting flatback turtles (as determined by published literature). This conservative selection approach was adopted due to the absence of primary literature relating specifically to the habitat suitability of inter-nesting flatback turtles, and follows the variable selection methods of other studies (e.g. McKinney et al. 2012).

Environmental variables included: bathymetric depth data, obtained via the General Bathymetric Chart of the Oceans (GEBCO); a ruggedness index, based on the change in bathymetric depth between adjacent neighbouring cells (Riley et al. 1999); and slope, calculated in ArcGIS using the bathymetric depth variable layer (Table 4.2 & Figure 4.2).

Monthly averaged SST data was obtained from the Group for High-Resolution Sea Surface Temperature project (GHRSST; Table 4.2). The temporal extent of the tracking dataset across each season was used to define the same temporal extent for the remotely sourced monthly SST data. The seasonal composites were averaged to provide one overall long-term SST environmental variable layer (range = 26.2 – 29.9 ºC), representative of the overall period for which satellite tracking occurred (as per Pikesley et al. 2013).

The minimum distance from the nearest coastline was calculated for each cell within the study area and used as an environmental variable layer (Figure 4.2). The layer represented the distances travelled by inter-nesting marine turtles away from the coastline before they returned to their nesting habitat on the coastline to lay subsequent clutches.

Magnetic anomaly data for the study area was obtained via Geoscience Australia and included as an environmental variable layer (Table 4.2 & Figure 4.2). This layer was included in the ENM as the prominent positive magnetic anomalies up to 1400 nT within the NWS study area (Veevers et al. 1985) may have influenced the location of nesting sites within the region and associated nearshore areas. Several marine turtle species are known to have the biological equivalent of a magnetic compass (Lohmann 1991; Lohmann & Lohmann 1993) and may use geographic variations in the Earth's magnetic field to determine their position and return to their nesting site (Wiltschko & Wiltschko 1995; Johnsen & Lohmann 2005).

Flatback turtles are considered to be capital breeders (Hamann et al. 2002) and thus are unlikely to be influenced by prey availability during their inter-nesting period. Therefore no environmental variables were included as a proxy for food availability i.e. chlorophyll, benthic habitat.

Table 4.2 Summary of environmental variables considered for use in the Ecological Niche Model.

Environmental variable	**Abbreviation**	**Unit**	**Source**	**Source resolution (km^2)**
Bathymetry	Bath	m	GEBCO[1]	0.25
Distance to coastline	Dist	km	ArcGIS derived	1
Magnetic anomaly	MagA	nano Tesla (nT)	Geoscience Australia	0.08
Ruggedness Index	Rugg	m	ArcGIS derived[2]	1
Sea surface temperature	SST	ºC	GHRSST[3]	1
Slope	Slope	º	ArcGIS derived	1

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[1] Bathymetry data obtained from the General Bathymetric Chart of the Oceans (www.gebco.net/data_and_products/gridded_bathymetry_data/)

[2] Calculated by summarising the change in elevation between adjacent neighbouring cells (Riley et al. 1999)

[3] Group for High-Resolution Sea Surface Temperature project (http://coastwatch.pfeg.noaa.gov/erddap/griddap/jplMURSST.html)

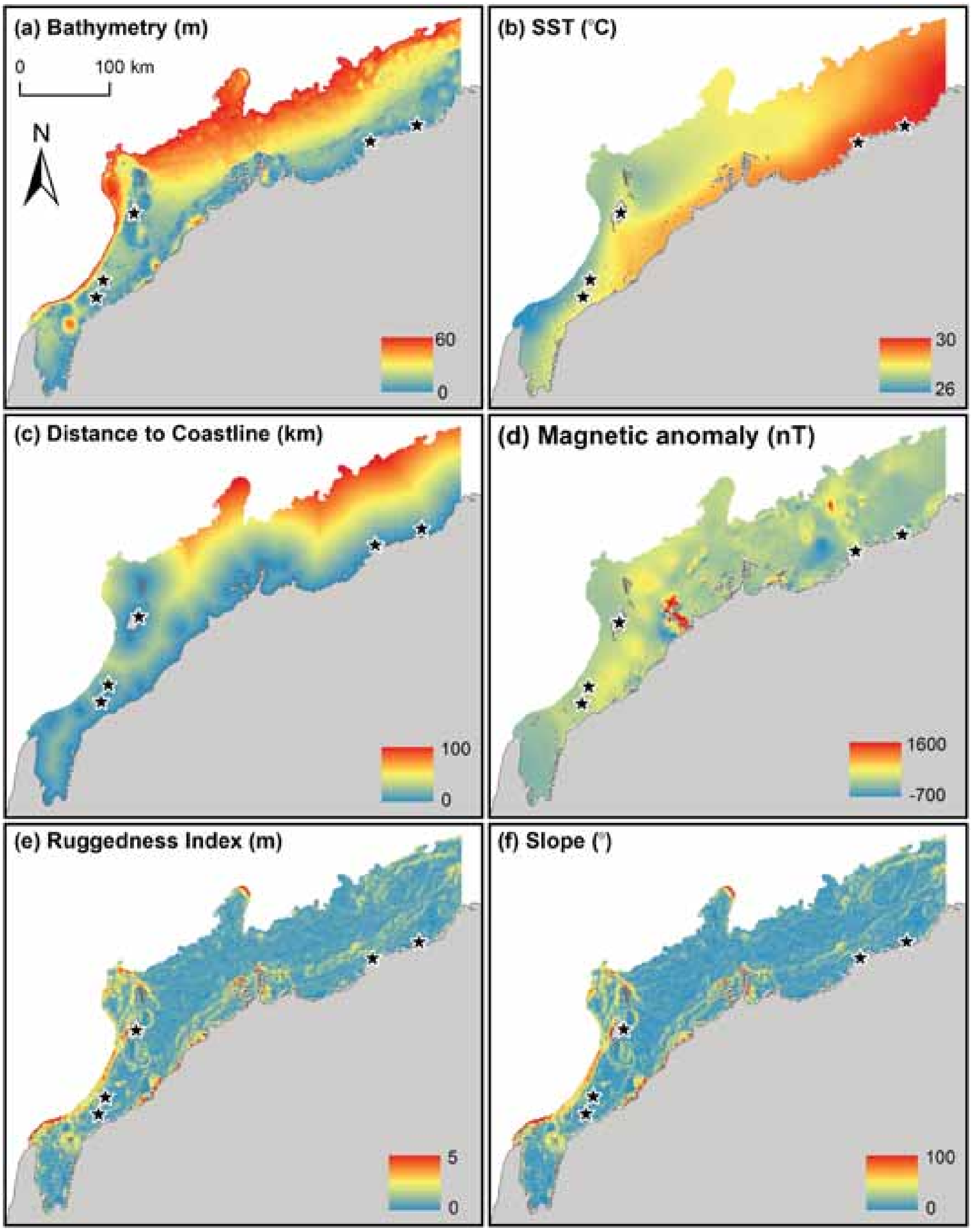

Figure 4.2 Maps of environmental variable layers ($n = 6$) considered for inclusion within the ENM. Black stars indicate location of each flatback turtle rookery.

All spatial data (turtle tracking dataset and environmental variables) were prepared and analysed using a combination of ArcGIS 10.1 (ESRI), IDRISI (Clark Labs at University of Clark), Quantum GIS (open source; www.qgis.org) and the *Raster* package for R (R Development Core Team 2013; Hijmans & Van Etten 2014). The working cell size was determined using the most common resolution of available spatial data (1 km^2; Table 4.2). All spatial data were resampled to the same 1 km x 1 km cell size (using bilinear interpolation), spatial extent, number of 1 km^2

cells and geographic datum. The resulting data surfaces provided consistent environmental variable layers for the NWS study area.

To test for correlation within the environmental variable layers, a random sample of locations (*n* = 1000) was generated and coincident environmental variable data extracted for each location. A Spearman's rank correlation test was calculated for each paired variable, with any highly correlated variables ($p > 0.7$) removed from the dataset. This ensured that only independent environmental variables were used in the final models and reduced the likelihood of the model over-fitting (Hirzel et al. 2002; Galparsoro et al. 2009).

4.3.4 Objective 2: North West Shelf Habitat Suitability Modelling

Habitat suitability modelling followed Pikesley et al. (2013) and was conducted using an ensemble ecological niche-modelling approach (Araujo & New 2007; Rangel & Loyola 2012). Modelling was conducted using the *biomod2* package in R (Thuiller et al. 2013). Three types of ENM were generated for each rookery: generalized additive model (GAM), multivariate adaptive regression splines (MARS) and MaxEnt modelling algorithms (Phillips et al. 2004).

The model's response variable was binary, either 'presence' described by the turtle tracking dataset or, due to the lack of accurate absence data, randomly generated 'pseudo-absences'; these background absence data characterise the 'available' environmental variables within the NWS study area. A 1:1 ratio of pseudo-absences to presence locations is commonly agreed as best in model building (Zuur et al. 2009) and therefore the number of pseudo-absences used in the models matched the number of presence locations included in the tracking dataset. All models were run using 10-fold cross validation with a 75:25% random spilt of the location data for calibration, and model performance testing, respectively.

The performance of each model was evaluated using five metrics: (1) area under curve (AUC; a measure of the ratio of true positives out of the positives vs. the ratio of false positives out of the negatives); (2) Cohen's kappa (Heidke skill score; KAPPA); (3) true skill statistic (TSS; a measure of accuracy relative to that of random chance); (4) success ratio (SR; the fraction of the true positives that were correct); and (5) accuracy (the fraction of the predictions (true and false) that were correct; Thuiller et al. 2009, 2013). All evaluation metrics were scaled to the range 0 – 1 to enable the evaluation of model uncertainties within and between models.

If all models performed with similar accuracy, the ENMs were combined to form an ensemble projection using an unweighted average across models. This ensemble ENM described the relative suitability of habitat for inter-nesting flatback turtles within the NWS study area, scaled between 0 and 1, where 0.5 represents areas of typical habitat suitability, 0 represents lowest suitability and 1 indicates greatest suitability.

Tracking effort in this chapter was not spatially uniform across the NWS study area and the proportion of tracking effort compared to the estimated number of females nesting at each rookery was not consistent (Spearman's rank correlation, $\rho = 0.783$). This inconsistency in tracking effort is a recognised limitation involved with conducting habitat modelling using satellite tracking data across a large geographical area (Aarts et al. 2008). Pooling the tracking data from all individuals across the NWS study area would therefore bias the results towards data-rich regions of geographical space that have been sampled more intensely i.e. Barrow Island (Aarts et al. 2008). To overcome this bias, the modelling technique was repeated to produce individual ensemble ENMs for each rookery by using only presence locations for that specific rookery and the environmental variable layers for the entire study area (Figure 4.1). The individual ensemble ENMs were combined and the maximum habitat suitability score for each cell across all five combined ensemble ENMs retained to determine the habitat suitability for the NWS study area in an overall single ensemble ENM.

The relative importance of each environmental variable, for each rookery, to the model was calculated using a randomisation process (Thuiller et al. 2009). This process calculated the correlation between a prediction using all environmental variables and a prediction where the independent variable being assessed was randomly re-ordered. If the correlation was high, the variable in question was considered unimportant for the model and conversely, if low, important. A mean correlation coefficient for each environmental variable was then calculated over multiple runs. This was repeated for each environmental variable. The calculation of the relative importance of each environmental variable was made by subtracting the mean correlation coefficients from 1.

4.3.5 Objective 3: Resource Sector Activities Hazard Analysis

The spatial risk to suitable inter-nesting flatback habitat (defined as areas with a habitat suitability score >0.5 probability) from resource sector activities in the NWS study area was estimated following methods outlined in Sutur (1993). The method involved: (1) identifying the hazards; (2) quantifying the exposure of inter-nesting habitat to the hazards; and (3) estimating the risk to inter-nesting habitat areas.

4.3.6 Hazard Identification

In general, documented hazards to individual marine turtles and their habitat from industry resource sector activities involve the use of vessels. The location of vessels directly involved in industry resource sector activities were therefore used to represent the location of the associated hazard within the NWS study area.

Vessel position data during the period of flatback turtle satellite tracking (2006 – 2010) was not available. As an alternative, vessel position data for the July 2012 – January 2014 period, available from the Australian Maritime Safety Authority (AMSA), was used. The vessel position data was collected from a variety of sources, including the terrestrial and satellite shipborne Automatic Identification System (AIS). Position data included details of the type of vessel, vessel speed at the time the position was recorded and actual time the position was recorded. Vessel types considered to be involved in resource sector activities included: cargo ships (60.5% of positions); tug vessels (26.9%); tankers (10.1%); dredge vessels (1.7%); and fishing vessels (0.8%). The provided data had been filtered to only include hourly positions for each vessel, with the first position recorded each hour retained.

4.3.7 Quantifying Hazard Exposure

Quantitative information and empirical data on the relative impact of the hazards associated with each resource sector vessel type to inter-nesting flatback turtles on the NWS is not available. In the absence of this information, available published literature in combination with the results of a regional hazard assessment for marine turtles (Wallace et al. 2011) was used to quantify the relative impact factor of each hazard presented by vessel activities within the NWS study area. The use of a relative impact factor ensured a higher weighting to those vessel types involved in resource sector activities that presented a greater hazard to inter-nesting flatback turtles and their habitats compared to other vessels.

The regional hazard assessment established scores for hazards on a 1 (low) to 3 (high) scale for flatback turtles within the South East Indian Ocean RMU, which included the NWS study area (Wallace et al. 2010). Assessed hazards relevant to this chapter included fisheries and coastal development (including construction and dredging) activities. The relative impact factor for each hazard was based on the regional hazard assessment and published literature (Table 4.3).

The monthly vessel position datasets were combined and converted to a hazard layer with the same spatial extent and cell size (1 km^2) as the environmental variable layers. Cells which averaged <1 vessel position per month were removed from the layer to ensure that only cells with regular vessel use were included. The value of each cell in the hazard layer was derived by the sum of the impact factor of positions situated within the cell.

The hazard layer cells were reclassified as low cumulative impact (<33rd percentile of all hazard layer values), medium cumulative impact (>=33rd – <=67th percentile) and high cumulative impact (>67th percentile).

The spatial risk of inter-nesting flatback turtles and their available suitable habitats to cumulative resource sector hazards was evaluated by comparing the overlap of the cumulative impact hazard layer with areas of typical suitable habitats identified within the ensemble ENM.

Table 4.3 Impact factor classification for different vessel types related to the resource sector (based on Wallace et al. 2011).

Vessel type	Regional hazard classification	Impact factor	Justification	Justification reference
Fishing vessel	Medium	2	Entanglement in fishing gear or incidental capture remains a hazard to marine turtles in Australian waters despite implementation of Turtle Excluder Devices	Meager & Limpus 2012; Woodhams et al. 2012
Dredge vessel	High	3	Dredging can cause direct habitat destruction via excavation of the seabed, or burial of habitat from dredge spoil disposal, and presents a hazard of entrainment and disturbance to inter-nesting turtles.	Dickerson et al. 2004
Transport vessels i.e. tankers, cargo ships and tug vessels, travelling <4km hr^{-1}	Low	1	Turtles were less vulnerable to collision with vessels travelling <4 km hr^{-1}.	Hazel et al. 2007
Transport vessels i.e. tankers, cargo ships and tug vessels, travelling >4km hr^{-1}	Medium	2	Turtles failed to completely avoid vessels travelling >4 km hr^{-1}, leaving them vulnerable to collision.	Hazel et al. 2007

4.4 Results

4.4.1 Turtle Tracking Dataset

Inter-nesting flatback turtles (*n* = 47) recorded a total of 5402 filtered inter-nesting positions over 1289 days of tracking time (2005/06: 33 days, 2006/07: 45 days, 2007/08: 49 days, 2008/09: 176 days, 2009/10: 715 days, 2010/11: 271 days; Figure 4.1). All tracked flatback turtles remained within the boundaries of the NWS study area (see Chapter 2 for the specific movement patterns exhibited by individual turtles from each rookery except Ashburton Island).

4.4.2 Objective 1: Environmental Variables that Influence Distribution and Range

The environmental variables of slope and ruggedness index were highly correlated (P = 0.93, P <0.0001; Figure 4.2e and 4.2f). Slope was therefore excluded from all ENM analyses. All other variables were independent (p <0.7) and included in the ENM.

Inter-nesting flatback turtles from each rookery remained in water <44 m deep (Table 4.4), with the mean depth for all turtles at each rookery <10 m. The inter-nesting locations from all five rookeries reached a maximum distance from the nearest coastline of 27.8 km, with the mean maximum distance away from the nearest coastline <6.1 km for each rookery. The mean magnetic anomaly values of inter-nesting locations from each rookery were higher than background values, except at Port Hedland (Table 4.4). Inter-nesting locations from rookeries located on the mainland coast (Mundabullangana and Port Hedland) recorded lower mean ruggedness index values than those rookeries located on offshore islands (Ashburton, Barrow and Thevenard). Mean SST was coolest for the two most southerly situated rookeries in the study area (Ashburton Island: 27.9 ± 27.8 ºC; and Thevenard Island: 27.7 ± 27.8 ºC) and highest for the most northerly located rookery (Port Hedland: 29.6 ± 29.6 ºC). The values of environmental variable layers at the random background positions were significantly different when compared to the values of variable layers of each individual rookery (p <0.05; Table 4.4).

Bathymetry was the most important contributory environmental variable at both Ashburton Island and Mundabullangana (Figure 4.3 and Appendix A). SST was the most important contributory environmental variable at Mundabullangana and Port Hedland, with the variable also important at Ashburton and Thevenard Islands (Figure 4.3 and Appendix A). Distance from the nearest coastline was the most important contributory environmental variable at Barrow and Thevenard Islands. Distance from the nearest coastline was also considered important as a contributory variable at Ashburton Island, Mundabullangana and Port Hedland. Ruggedness index was not considered to be an important environmental variable at any rookery (Figure 4.3 and Appendix A).

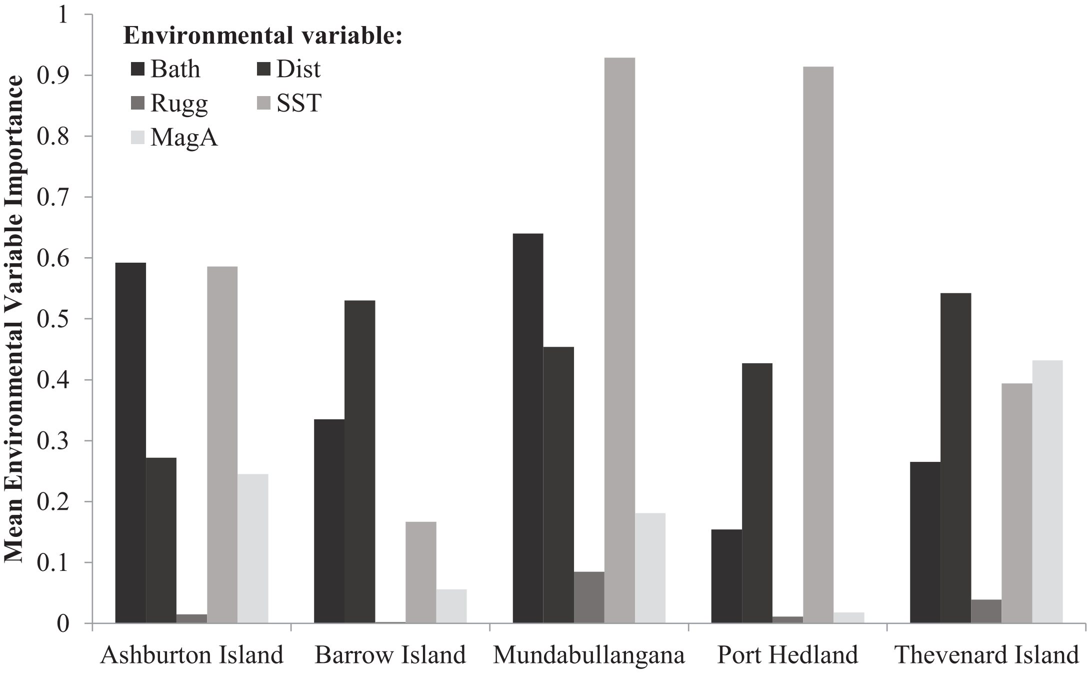

Figure 4.3 Mean environmental variable importance calculated from the ensemble ENM for each flatback turtle rookery (see Appendix A for values).

Table 4.4 Summary statistics of each environmental variable layer throughout the NWS study area (background), at all flatback turtle positions at each rookery for all years, and at areas identified as high habitat suitability for each rookery (defined as >0.9 probability). Background values are represented by 1000 random positions within the NWS study area.

Rookery	At Flatback Positions				At Areas of High Habitat Suitability			
	Mean	**StDev**	**Range**	***n***	**Mean**	**StDev**	**Range**	***n***
Bathymetry (m)								
Background	27.9	17.4	0.0 – 61.0	1000	NA	NA	NA	NA
Ashburton Island	5.4	2.4	0.0 – 16.0	619	5.5	2.0	0.0 – 9.2	593
Barrow Island	8.6	3.2	0.0 – 25.6	3562	8.8	3.1	0.0 – 21.1	974
Mundabullangana	2.2	1.8	0.0 – 5.8	34	2.4	2.2	0.0 – 6.6	126
Port Hedland	4.0	3.7	0.0 – 16.2	645	6.1	3.3	0.0 – 14.0	404
Thevenard Island	9.9	4.6	0.0 – 44.0	542	7.1	4.6	0.0 – 16.0	313
Distance from Coastline (km)								
Background	29.3	24.1	0.0 – 97.2	1000	NA	NA	NA	NA
Ashburton Island	4.9	3.4	0.0 – 11.7	619	5.1	3.2	0.2 – 11.6	593
Barrow Island	6.1	5.8	0.0 – 27.8	3562	8.7	6.2	0.0 – 25.5	974
Mundabullangana	2.7	2.5	0.1 – 9.4	34	3.2	2.5	0.4 – 11.8	126
Port Hedland	4.5	4.4	0.2 – 21.6	645	4.9	2.9	0.0 – 14.4	404
Thevenard Island	4.4	3.7	0.0 – 23.1	542	2.8	1.7	0.0 – 6.8	313
Magnetic Anomaly (nT)								
Background	23.3	166.3	-689.8 – 1587.8	1000	NA	NA	NA	NA
Ashburton Island	128.6	93.3	1.4 – 291.4	619	114.9	83.0	7.0 – 291.4	593
Barrow Island	42.1	100.1	-563.2 – 457.7	3562	42.0	163.0	-528.8 – 451.7	974
Mundabullangana	94.5	118.1	-183.5 – 277.7	34	-14.8	187.8	-242.5 – 654.7	126
Port Hedland	-3.5	125.6	-632.0 – 654.4	645	4.5	185.6	-689.8 – 654.4	404
Thevenard Island	171.3	69.6	-12.8 – 294.6	542	186.3	55.5	36.4 – 291.4	313
Ruggedness Index (m)								
Background	0.2	0.2	0.0 – 2.2	1000	NA	NA	NA	NA
Ashburton Island	0.1	0.1	0.0 – 0.7	619	0.1	0.1	0.0 – 0.7	593
Barrow Island	0.2	0.1	0.0 – 0.9	3562	0.2	0.1	0.0 – 0.7	974
Mundabullangana	0.1	0.1	0.0 – 0.3	34	0.2	0.1	0.0 – 0.6	126
Port Hedland	0.1	0.1	0.0 – 0.4	645	0.1	0.1	0.0 – 0.4	404
Thevenard Island	0.2	0.1	0.0 – 0.7	542	0.2	0.1	0.0 – 0.6	313
SST (ºC)								
Background	28.1	0.8	26.2 – 29.9	1000	NA	NA	NA	NA
Ashburton Island	27.9	27.8	27.4 – 28.1	619	27.9	0.1	27.5 – 28.1	593
Barrow Island	28.0	28.2	27.6 – 28.7	3562	28.0	0.2	27.8 – 28.7	974
Mundabullangana	29.4	29.3	29.3 – 29.5	34	29.4	0.1	29.3 – 29.4	126
Port Hedland	29.6	29.6	29.3 – 29.8	645	29.6	0.1	29.5 – 29.8	404
Thevenard Island	27.7	27.8	26.9 – 28.3	542	27.7	0.2	27.0 – 28.2	313

4.4.3 Objective 2: North West Shelf Habitat Suitability Modelling

All models (GAM, MARS and MaxEnt) performed better than random. The mean scores from all five evaluation metrics ranged from 0.90 – 0.98 (Appendix A), indicating that the models had a substantial agreement with the testing dataset. Evaluation scores demonstrated that no one model outperformed the others (Appendix A).

Typical suitable habitat (defined as areas >0.5 probability) was identified in close proximity to all five rookeries (Figure 4.4). Typical suitable habitat was also identified across the Dampier Archipelago, including Delambre and Legendre Islands, and surrounding other islands within the Lowendal Island group, including Varanus Island. Overall, 5847 km^2 (12.0% of total study area) was identified as typical habitat suitability (>0.5 probability) and 1049 km^2 (2.1% of total study area) as high habitat suitability (>0.9 probability) (Figure 4.4).

Summary statistic values for each environmental variable that overlapped with areas of high habitat suitability are described in Table 4.4 for each rookery. Areas of high habitat suitability for Barrow Island turtles were deeper (8.8 ± 3.1 m) and further away (8.7 ± 6.2 km) from the nearest coastline compared to all other rookeries (bathymetry: range = 0 – 21.1 m; distance from coastline: range = 0.0 – 25.5 km). Bathymetry values in areas of high habitat suitability were deeper compared to bathymetry values in all areas where flatback data were recorded for each rookery, except at Thevenard Island (Table 4.4). Areas of high habitat suitability were also situated further from the nearest coastline compared to the areas where all flatback data were recorded for each rookery, except at Thevenard Island (Table 4.4). There was no suitable habitat within areas where bathymetry >25 m, >27 km from the nearest coastline and SST <27.1 ºC (see areas of absence in Figure 4.4).

The overall mean value of important contributory environmental variable layers that overlapped with areas of high habitat suitability across the overall NWS study area were: bathymetry: 7.4 ± 3.1 m, range = 0.0 – 16.5; distance from coastline: 4.3 ± 3.4 km, range = 0.0 – 19.3; and SST: 28.2 ± 0.6 ºC, range = 27.6 – 29.8.

4.4.4 Objective 3: Resource Sector Activities Hazard Analysis

Areas of high cumulative impact associated with offshore resource sector activities were identified in close proximity to major resource developments and ports across the study area, including: Onslow (Wheatstone LNG development), Barrow Island (Gorgon LNG development), Dampier Port, Cape Lambert (port expansion) and Port Hedland (port expansion) (Figure 4.5a). Other areas of high cumulative impact exist within designated shipping channels that either extend beyond the NWS study area or provide connections between ports and resource developments within the NWS study area (notably between Dampier Port and Barrow Island).

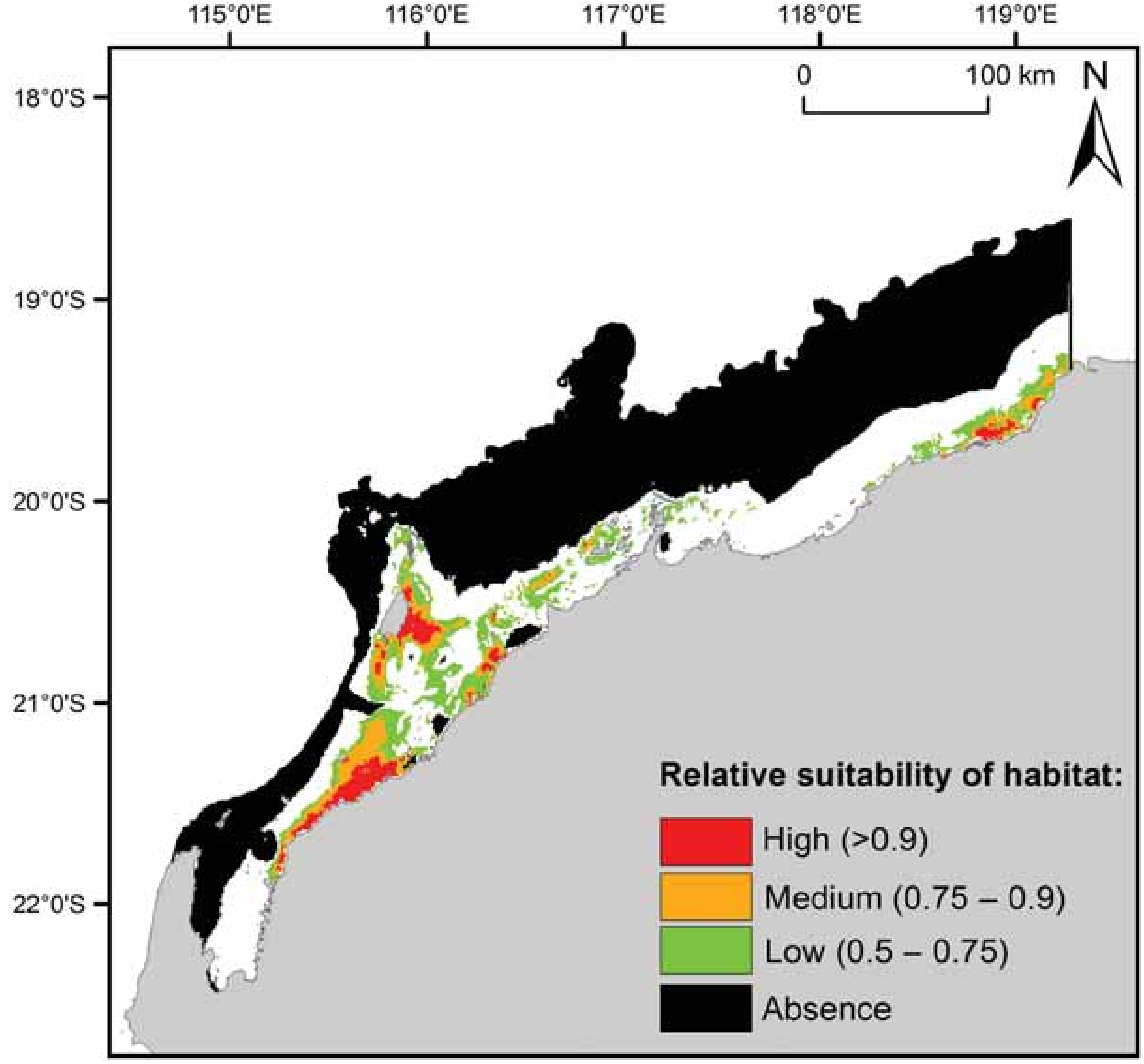

Figure 4.4 Combined overall ensemble ENM based on turtle tracking dataset and environmental variables within the NWS study area. Areas of absence are where environmental variable values are outside the range of environmental variable values that overlap areas of suitable habitat.

Areas of high habitat suitability were found to overlap industry resource sector areas: 18% (546 km^2) overlapped areas with a high cumulative impact; 27% (808 km^2) overlapped areas with a medium and high cumulative impact; and 35% (1061 km^2) overlapped areas with a low, medium and high cumulative impact. Areas of overlap existed in close proximity to all individual rookeries, with the exception of Mundabullangana (Figure 4.5b). Overlap between areas of high cumulative impact from industry resource sector activities and high habitat suitability were also present in the Dampier Archipelago area and at Cape Lambert (Figure 4.5b).

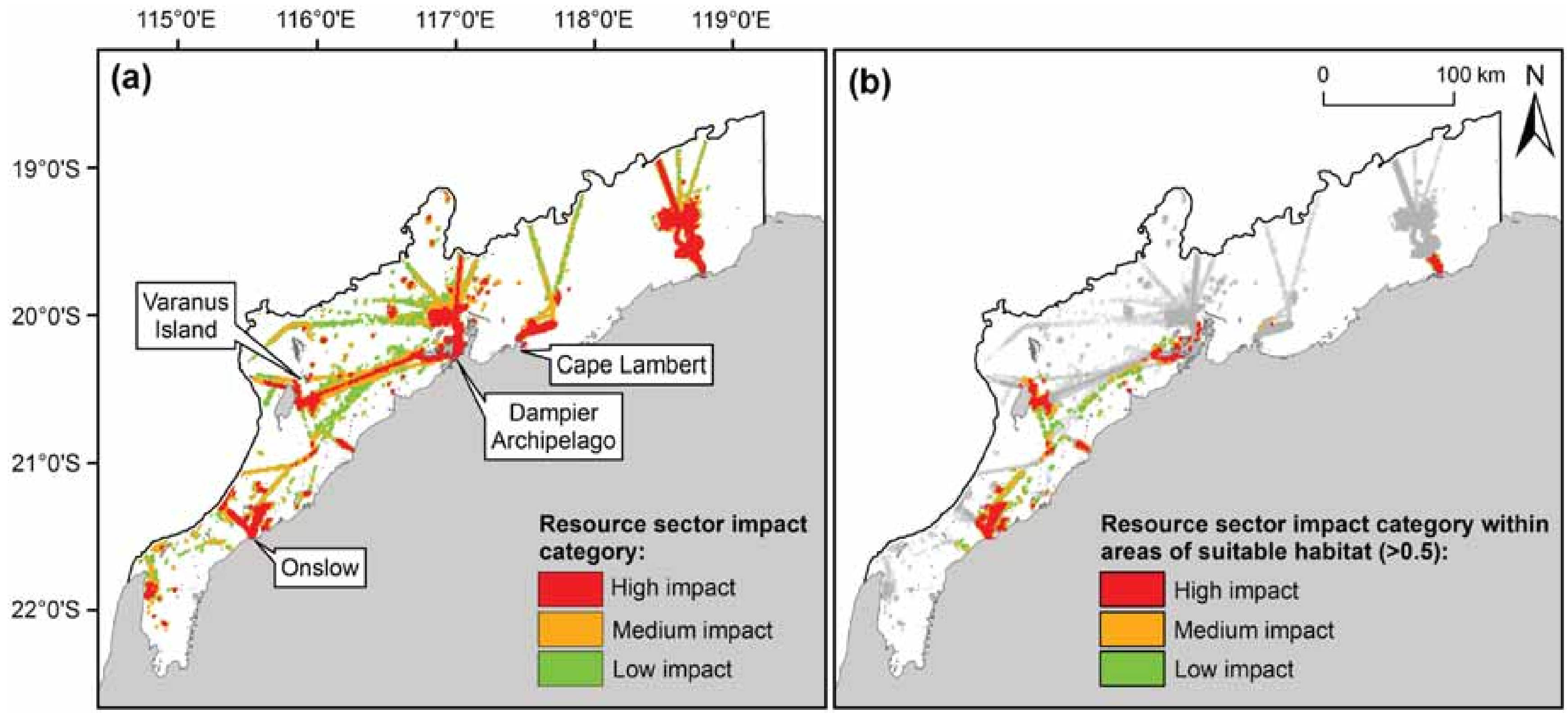

Figure 4.5 (a) Resource sector cumulative impact categories across the NWS study area. (b) Resource sector impact categories that overlap areas of typical habitat suitability (>0.5).

4.5 Discussion

This is the first use of ENMs to spatially quantify the areas of habitat suitability for inter-nesting marine turtles of any species and to identify environmental variables that potentially influence their distribution across multiple rookeries within the same RMU.

Areas of suitable inter-nesting habitat were identified for five flatback turtle rookeries in the NWS study area, representing all significant rookeries within the Pilbara Coast genetic stock. Suitable nesting habitat were in areas with a SST ranging between 27.0 – 29.9 ºC, within water depths ranging from 0 – 16.5 m and remaining in close proximity to areas of coastline (typically between 5 – 10 km). SST, bathymetry and distance from coastline were the most important contributory environmental variables to the models at four of the five rookeries. The ruggedness index variable layer was not considered an important contributory variables for any of the five rookeries and the magnetic anomaly variable layer only considered important at one rookery (Thevenard Island). The models also allowed identification of areas where suitable inter-nesting habitat may be absent within the study area (Figure 4.4): no areas of high suitable habitat occurred in water deeper than 25 m; >27 km from the nearest coastline; and in areas with SST <27.0 ºC and >29.8 ºC. This information is particularly useful for informing regulators and proponents charged with managing impacts to inter-nesting flatback turtles. For example, it could inform spatial or temporal based closures to areas within the footprint of development or be used to guide the referral/screening exercise as their presence within a development footprint will trigger the referral of the project to the regulator for approval and possibly an EIA.

Inter-nesting flatback turtles have a high fidelity to their preferred nesting site and as capital breeders the distance they travel between their nesting area and inter-nesting site has consequences for energy balance (Chapter 2; Pendoley et al. 2014b). Therefore, availability of an offshore inter-nesting area is dictated by the location of the terrestrial nesting area. This spatial limitation supports the methods used in this chapter to prepare an ENM for each individual rookery and combine into an overall ensemble ENM across the study area, as the suitable areas of inter-nesting habitat should be unique for each rookery based on habitat availability in proximity to the nesting site.

The contribution of SST to suitable inter-nesting habitat areas indicates that inter-nesting flatback turtles are seeking and using areas with water temperatures that are higher than in surrounding areas. This thermo-regulation behaviour could be related to egg development (see Fossette et al. (2012) and Schofield et al. (2009) for other species of marine turtle), with warmer water and body temperatures ultimately speeding up egg development rates prior to oviposition (Sato et al. 1998). As such, exposure of females to warmer temperatures across a nesting season may optimise the overall length of time required to lay the full complement of clutches (Hays et al. 2002) resulting in efficient energy expenditure across a nesting season.

Areas of high inter-nesting habitat suitability were situated in deeper areas compared to the inter-nesting positions at all rookeries, except at Thevenard Island. Deeper areas may be suitable for inter-nesting for the following reasons: deep areas may provide more stable hydrodynamic conditions for resting allowing flatback turtles to conserve energy reserves; deep areas may allow flatback turtles to remain immobile on the seabed for longer periods minimising the energy cost of commuting to the surface (Hays et al. 2000; Houghton et al. 2002; Minamikawa et al. 2000); or deep areas may be optimum for flatback turtles to maximise their oxygen store while still attaining near-neutral buoyancy on the seabed (Hays et al. 2000). It is recommended that dive behaviour of flatback turtles on the NWS is investigated to determine the actual activity of these turtles when inter-nesting in these suitable deeper areas.

The identification of suitable inter-nesting habitat across the entire study area provides an indication of the regional presence of inter-nesting flatback turtles. Known flatback turtle rookeries situated within the NWS study area which were not featured in this chapter include Varanus Island within the Lowendal Island group, and Delambre and Legendre Islands within the Dampier Archipelago. The overall ENM included the presence of suitable inter-nesting habitat in proximity to these three islands (Figure 4.4) providing support for the model's output, as it would be more likely for areas of suitable habitat to exist in close proximity to these rookeries (as identified for other flatback turtle rookeries in Chapter 2).

The use of vessel positions to identify anthropogenic hazards associated with the industry resource sector within the NWS study area allowed the identification of areas of high cumulative risk and areas in proximity to known operational, and currently under construction, major resource developments (Figure 4.5a). One hazard not represented by a vessels position is an oil spill event from an offshore installation such as a platform or drilling rig. The NWS study area is host to a number of installations; however, they were not considered as part of the hazard analysis because of the following reasons: (1) a review of oil spill incidents on the NWS showed low historical incidence from offshore installations (Swan et al. 1994); (2) Kagi (1983) determined that oil produced from the NWS is generally light in nature and that if an incident did occur and oil was released, the oil would likely dissipate rapidly; and (3) studies suggested that the highest risk of an oil spill occurring on the NWS is from shipping activity resulting in the release of the heavier and more persistent bunker oil (Flood 1992; May 1992). Vessel positions were therefore considered appropriate to represent the location of an oil spill that would be of greatest hazard to inter-nesting flatback turtles.

Overall, 35% of areas of high suitable inter-nesting habitat overlapped spatially with cumulative resource sector impact areas. This indicates that there is potential for flatback turtles to interact with industry resource sector activities when inter-nesting in parts of the study area. This is particularly notable in areas offshore from the Gorgon LNG development at Barrow Island and the existing port at Port Hedland, where areas of high cumulative impact overlap with suitable habitat areas.

The results presented in this chapter provide a platform for proponents to assess the likelihood of interaction between future development activities and inter-nesting flatback turtles situated in the NWS study area, and inform one of two components needed before the overall level of risk from an activity can be quantified in a development's EIA and environmental protection measures considered. The second component of the EIA process is to predict the consequence of the development activity on the species or their habitat. Predicting a likelihood of interaction alone is therefore of little use for quantifying the level of risk and supporting the need for environmental protection measures, as this needs to be combined with a confident prediction that the interaction will actually result in a consequence (Osenberg & Schmitt 1996). Increasing this confidence can be achieved through conducting follow-up exercises, involving retrospectively comparing and evaluating both the likelihood and consequence predictions featured in a developments EIA with the actual effect of the completed activity on the species/habitat. Until follow-up exercises are routinely completed, uncertainty surrounding the consequence of the predicted interactions, and an inability to anticipate future anthropogenic impact, will remain. It is therefore recommended that likelihood and consequence predictions that feature in EIAs and relate to the likelihood of an impact from offshore activities i.e. dredging, on inter-nesting flatback turtles, are reviewed and compared with the realised effect or impact following the completion of the activity. Identifying the actual impact of a development's activity on inter-nesting flatback turtles and how they react to the activity will also help to develop an understanding of how vulnerable flatback turtles are to specific activities, potentially allowing for further emphasis to be placed on the requirement for protection.

It is not often feasible for proponents or regulators to consider the potential spatial extent of inter-nesting flatback turtle movement from rookeries situated nearby to a development during the environmental approval process. This is primarily due to short time-scales involved with development proposals, the high cost involved with identifying the spatial extent of inter-nesting flatback turtles and logistical constraints involved with accessing remote sites. One advantage of using ENMs in this chapter is that the full spatial extent of inter-nesting movement from each rookery has been considered and all areas within the region have been assessed for their suitability as inter-nesting habitat. The generated habitat suitability map also provides proponents and regulators with a capability to identify areas in proximity to a proposed development that may host inter-nesting flatback turtles. This is important as it addresses the knowledge gap highlighted in Chapter 2 in providing effective protection from development activities within the NWS study area as inter-nesting flatback turtles can move up to 63 km away from their nesting site, often passing in close proximity to other developments that may not have considered their potential presence or need for protection.

It is of concern that a number of flatback turtle rookeries within the NWS study area (and rookeries within the Dampier Archipelago) are exposed to industry resource sector hazards. Marine turtle species are considered particularly vulnerable when inter-nesting, as areas of suitable habitat can host large aggregations of individual turtles within a relatively small area. Industry resource sector hazards that overlap with these habitat areas therefore have the potential to cause realistic effects on the overall population. Overlap of resource sector activities with other phases of the flatback life cycle may also occur, e.g. during the phase of post-nesting migration to their foraging areas located in the Kimberley region further north from the study area (Pendoley et al. 2014b), providing further pressure on individuals and the overall population.

This chapter provides valuable information for regulators, managers, policy-makers and proponents on the spatial distribution and habitat preferences of inter-nesting flatback turtles from multiple rookeries within the NWS study area. An ecological niche-based modelling technique was used to determine areas of inter-nesting habitat suitability, along with the environmental variables that contributed to its suitability. Areas of high habitat suitability were integrated with industry resource sector hazards to identify those areas with the highest potential for interaction between flatback turtles and resource sector activities in the region. The development of a greater understanding of resource sector interaction, influential environmental variables and typical properties of suitable inter-nesting habitat, should enable more appropriate, effective and targeted mitigation measures for future developments within the NWS study area.

Chapter 5

Consequence of industry resource sector activities to inter-nesting flatback turtles

Chapters 2 and 4 identified that inter-nesting flatback turtles and areas of suitable habitat nearby to Barrow Island had a high potential for interaction with activities associated with the industry resource sector. This understanding informs one component of assessing the likelihood score of the risk matrix within an Environmental Scoping Document produced during an EIA, but does not help inform the assessment of the potential consequence of the activity. Since a combination of likelihood and consequence scores identifies the overall inherent risk of impact and dictates the need for control measures, there is a need to ensure this consequence score is well informed and accurate.

This chapter involves an EIA follow-up exercise and presents a case study that evaluates the consequence of an industry resource sector activity (dredging) to inter-nesting flatback turtles at Barrow Island, appraises the predicted consequences within the Environmental Scoping Document with the actual consequences of the dredging operation (as determined by marine fauna observer records) and considers the suitability of implemented control measures to manage the potential impact.

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http://www.sciencedirect.com/science/article/pii/S0006320716310436

5.1 Abstract

Dredging presents a risk of injury or mortality to protected marine turtles via entrainment, vessel strike or the effects of noise and vibration. However, the behaviour of marine turtles around an active dredging operation has never been quantified and reviewed concurrently with an assessment of their survivorship. The results of a case study that involved deploying satellite tracking units on inter-nesting flatback turtles before, during and after a dredging operation are presented in this chapter. The dredge-related impact predictions stated in the EIA are compared with the quantified dredge-related impact to marine turtles as represented by flatback turtle injury and mortality events recorded by onboard MFOs. Additionally, the effectiveness of implemented dredging-related control measures in preventing injury or mortality is also considered.

Flatback turtles were found to increase their use of the dredging area when the dredging operation was active. Dive behaviour results showed that they were undertaking longer and deeper resting dives, utilising the now deeper waters of the dredging area. The most likely driver for this change in movement and behaviour was considered to be the increase in turbidity within the dredging area, resulting in a predator-free refuge for the tracked turtles. Despite this increased use and the presence of active dredge vessels, no events of injury or mortality were recorded. The implemented control measures may have been effective in preventing injury or mortality, though the spatial scale of their effectiveness may be smaller than anticipated.

5.2 Introduction

Growing economic and societal demands, within the coastal zone, have seen a worldwide increase in the requirement of land reclamation, coastal construction, beach renourishment and port construction. Dredging is often required to enable these coastal changes and the total turnover for dredging contractors worldwide, more than doubling from 2000 to 2012, is further evidence of its growth (IADC 2012). Dredging involves excavation, transportation and disposal of benthic substrate, and impacts of these activities have been reviewed (see Brunn et al. 2005; Thomsen et al. 2009; CEDA 2011; Tillin et al. 2011; WODA 2013).

Dredging can cause direct and indirect negative impacts to benthic habitats, including coral reef and seagrass beds (reviews by Erftemeijer et al. 2012; and Erftemeijer & Lewis 2006, respectively); excavation can cause habitat loss (van't Hof 1983), substrate disposal can cause habitat burial or smothering (Fabricius & Wolanski 2000) and excavation and disposal activities can cause habitat degradation through increased turbidity and nutrient loading (Filho et al. 2004). Dredging can also cause direct and indirect negative impacts to mobile marine fauna (see reviews by Newell et al. 1998; Thrush & Dayton 2002; Tillin et al. 2011), though these impacts are not as well understood compared to those described for benthic habitats (Todd et al. 2014). Direct impacts from dredging to marine fauna include: entrainment (Dickerson et al. 1991; Best et al.

2001; Goldberg et al. 2015), vessel strike (see reviews by Laist et al. 2001; Jensen and Silber 2003; Van Waerebeek et al. 2007; Neilson et al. 2012), noise disturbance (Thomsen et al. 2009) and increased turbidity (Weiffen et al. 2006). Indirect impacts from dredging to marine fauna can also remain following completion of activities: there can be an increased utilisation of completed dredged areas potentially increasing the risk of entrainment during subsequent maintenance dredging (USAE WES 1997); and loss or damage to benthic habitat can alter the local food chain, with recovery dependant on species and the extent of loss and changes to the marine ecosystem (Erftemeijer & Lewis 2006).

Depending on a country's law or regulation, the use of dredging can trigger the need for an EIA (Glasson et al. 2005). The EIA's main function is to evaluate potential impacts (Erickson 1994) and, in general, it includes aspects such as: an outline of the dredging activity; a description of baseline environmental conditions; an assessment of the potential dredging impacts to key receptors; and an EMP, describing actions designed to reduce the environmental impacts and risks from the dredging operation to the environmental receptors (Glasson et al. 2005).

For benthic habitats, the regulator will often stipulate the requirement for habitat monitoring data to be recorded through the lifetime of the dredging program as a condition of approval, allowing the actual dredge-related habitat loss to be quantified and to identify the requirement for a further management response (e.g. Badalamenti et al. 2006; Newell et al. 1998). Following completion of a dredging campaign, this quantified habitat loss data can be used in a post-dredging follow-up review of the actual impact of dredging against the predicted impact of dredging identified in the EIA (e.g. Read 1994; Morrison-Saunders 1996). The outcome of the follow-up can identify the requirement for further mitigation or offset (Glasson et al. 2005; Morrison-Saunders 1996), inform initial impact predictions for similar activities situated elsewhere (Munro 1987; Sadler 1988; Bingham 1992) and over time, lead to advances in utility and predictive capability of the EIA process (Buckley 1991; Glasson et al. 2005).

The process of EIA follow-up is a relatively new concept and consists of four key components: monitoring (before and after activity implementation), evaluation of conformance, management in response to monitoring/evaluation results, and communication to stakeholders (Arts et al. 2001). The approaches and techniques used in EIA follow-up range from rigorous scientific studies to more informal and pragmatic approaches involving simple checks and use of existing management systems and data sources (Morrison-Saunders & Arts 2004).

Despite the potential for direct and indirect dredging-related impacts, additional monitoring of protected marine fauna during construction or operations is seldom stated in an EMP or imposed by regulators. As a result, no data exists that quantifies marine fauna survivorship, movement or dive behaviour during or after a dredging program. This data gap prevents a post-dredging review, inhibiting improvements in the accuracy of initial dredge-related impact predictions for mobile marine fauna for other dredging programs situated elsewhere (see Morrison-Saunders 1996). In addition, access to this marine fauna data will contribute to future assessment of the suitability and performance of control measures outlined in the EMP and ultimately in determining best practice in managing dredging impacts to marine fauna (Sadler 1988; Culhane 1993; Glasson et al. 2005).

There is, however, a recent exception, with a proponent including a number of commitments within their EMP to monitor protected flatback turtles that were likely present in proximity to a dredging operation in Western Australia. Two commitments were to (1) use satellite tracking technology to monitor their movement and dive behaviour when breeding i.e. inter-nesting, during different stages of the dredging operation, and (2) ensure marine fauna observers (MFOs) were present on dredging vessels to identify mortality and/or injury. While this is the first commitment to apply satellite tracking technology to a marine turtle species as part of a dredge operation’s environmental monitoring program, the technology has been applied elsewhere to investigate marine turtle spatial use or interaction with anthropogenic threats (e.g. Revuelta et al. 2015; McClellan & Read 2009; Fossette et al. 2014), and for other marine megafauna (e.g. Irvine et al. 2014; McKenna et al. 2015).

While these two commitments are based on a local dredging operation and protected marine turtle population, the required monitoring results are of great value for stakeholders involved in marine turtle conservation and managing dredging operations worldwide. This is because no comparison of quantified marine turtle survivorship, movement and behaviour data at different stages of a dredging program has been recorded or reported previously. To date, there has been no opportunity to complete a comprehensive post-dredging follow-up review of impacts on marine turtles; and no review of the effectiveness of control measures to reduce impacts from dredge activities to marine turtles has been completed.

This chapter therefore presents the data generated from the dredge related monitoring commitments and addresses three objectives. Firstly, a comparison of the initial dredge-related impact predictions stated in the EIA with the actual dredge-related impact to marine turtles was completed by investigating injury and mortality records. Secondly, movement and dive behaviour characteristics of satellite tracked turtles were compared between each stage of the dredging program (before dredging i.e. baseline, during dredging and post-dredging) to investigate behavioural changes as a result of dredging. Thirdly, the effectiveness of implemented dredging-related control measures was investigated by considering any behavioural changes concurrently with injury and mortality records while the dredging operation was underway.

5.3 Methodology

5.3.1 Study Site

Barrow Island is situated approximately 1600 km north of Perth on Australia's NWS and is afforded the highest conservation protection status available under Australian Legislation (A-class nature reserve). The island's east coast supports a significant population of approximately 5000 reproductively active flatback turtles, a species listed as threatened under Australian legislation, of which between 834 and 1449 have been recorded nesting at Barrow Island each season (Pendoley et al. 2014a).

In 2009, approval was granted by State and Commonwealth governments to construct the Gorgon LNG development in close proximity to the flatback turtle population's nesting habitat on the island's east coast. The development involves many components including the construction of a LNG processing plant and a dredging program involving the extraction of approximately 7.6 million tonnes of marine sediment. Ministerial conditions relating to the monitoring and management of the Barrow Island flatback turtle population and dredging program were set by the federal EPA. The condition relating to flatback turtles outlined the requirement to implement a Long-term Marine Turtle Management Plan (LTMTMP) that included a monitoring program to measure and detect changes to their population at Barrow Island (Chevron Australia 2009). The LTMTMP included the commitment to monitor the movement and dive behaviour of reproductively-active flatback turtles at different stages of the dredging program.

The condition(s) relating to dredging activities outlined the requirement for a Dredging and Spoil Disposal Management and Monitoring Plan (DSDMMP) to be implemented (Chevron Australia 2011). The DSDMMP included the following: a commitment to ensure MFOs were onboard each dredge vessel; operating procedures for the detection, recording and reporting of any marine turtle injury or mortality from dredging or spoil disposal activities; and methods to detect marine turtle injury and mortality from the operation of the Trailer Suction Hopper Dredge.

5.3.2 Dredging Program Dataset

The Gorgon LNG development dredging program was completed offshore of Barrow Island between May 2010 and November 2011. The program involved dredging two separate areas: a Materials Offloading Facility (MOF) area and shipping channel, 1.6 km x 120 m in size and dredged from ~2 m to 6.5 m relative to chart datum; and a LNG jetty area and turning basin, 1.7 km x 300 m in size and dredged from ~10 m to 16 m relative to chart datum (Chevron 2011; Figure 5.1). Four vessels were used to complete the dredging, including: a trailing suction hopper dredge (TSHD); a cutter suction dredge (CSD); a back hoe dredge (BHD); and a grab dredge.

One aim of the control measures and procedures implemented to reduce dredging impacts to marine turtles was to restrict the operational time of dredge vessels that presented a higher risk of entrainment to marine turtles i.e. the TSHD vessel (Chevron Australia 2011). Measures included: identifying areas where lower risk dredge vessels (i.e. BHD) could be used to complete dredging tasks; using a bed leveller to reduce the clean-up time required by the TSHD; and altering the initiation and termination of the TSHD drag head suction. The drag head of the TSHD was also fitted with chains specifically designed to disturb turtles away from the area of the drag head (Chevron Australia 2011).

The methods to detect evidence of, and response to, marine turtle injury/mortality attributed to the TSHD vessel included inspection by trained MFOs of overflow screens, drag heads and any accessible parts of the dredge. The use of overflow screens was implemented as an additional design feature to ensure that in the event of an entrainment, marine turtles, or marine turtle remains, were identified following inspection at the end of each dredge cycle. Audits of the dredge operator were also undertaken by the proponent to validate inspections and record keeping.

Other methods used to detect evidence of mortality i.e. marine turtle remains, applicable to all dredge vessel types, included inspecting the onshore MOF reclamation area by trained machine operators working in the area following discharge of each dredge load and periodically inspecting the underwater dredge spoil disposal ground with towed cameras or divers (Figure 5.1).

The DSDMMP also outlined control measures to guide response actions in the event of sightings or interactions with marine turtles and other marine fauna during vessel operations. Measures included: monitoring and recording of locations of marine mammal and turtle sightings in proximity to operating vessels, notification of sightings to the vessel operator and surrounding vessels and, where practical, manoeuvring away, adjusting vessel speed or stopping the vessel or dredge vessel. A strategy was also in place to guide an incident response in the event an injured or dead turtle was detected.

5.3.3 Tracking Unit Deployment

Tracking units were deployed on adult female flatback turtles at four of six primary nesting beaches; spread ~6 km apart on the island's east coast (Figure 5.1). Selected turtles were allowed to complete their nesting activity prior to tracking unit deployment. As flatback turtles at Barrow Island do not have a strong site fidelity to one nesting beach within the same season (Pendoley et al. 2014a), deployment over multiple beaches was considered to provide an overall representation of the Barrow Island flatback turtle population.

To ensure inter-nesting data was gathered, tracking units were deployed at a similar time each year at the beginning of the nesting season (Table 5.1). It was unknown if the selected turtles were nesting for the first time in the season at the time of attachment, therefore data presented in this chapter may not represent the overall season's inter-nesting movement for each turtle.

Two models of tracking unit were used (series 9000X SRDL; *n* = 38); St Andrews Mammal Research Unit and SPLASH10-BF-296C (SPLASH; *n* = 10); Wildlife Computers). The setup of the SRDL tracking units was the same for each season of monitoring. The SPLASH tracking unit featured the same setup as the SRDL tracking unit, with a duty cycle of 'on continuously'. Each tracking unit model provided Fastloc GPS locations, with only the SRDL tracking unit featuring a TDR to provide dive profile data. For tracking unit attachment technique, data recovery details and GPS location filtering techniques see Chapter 2.

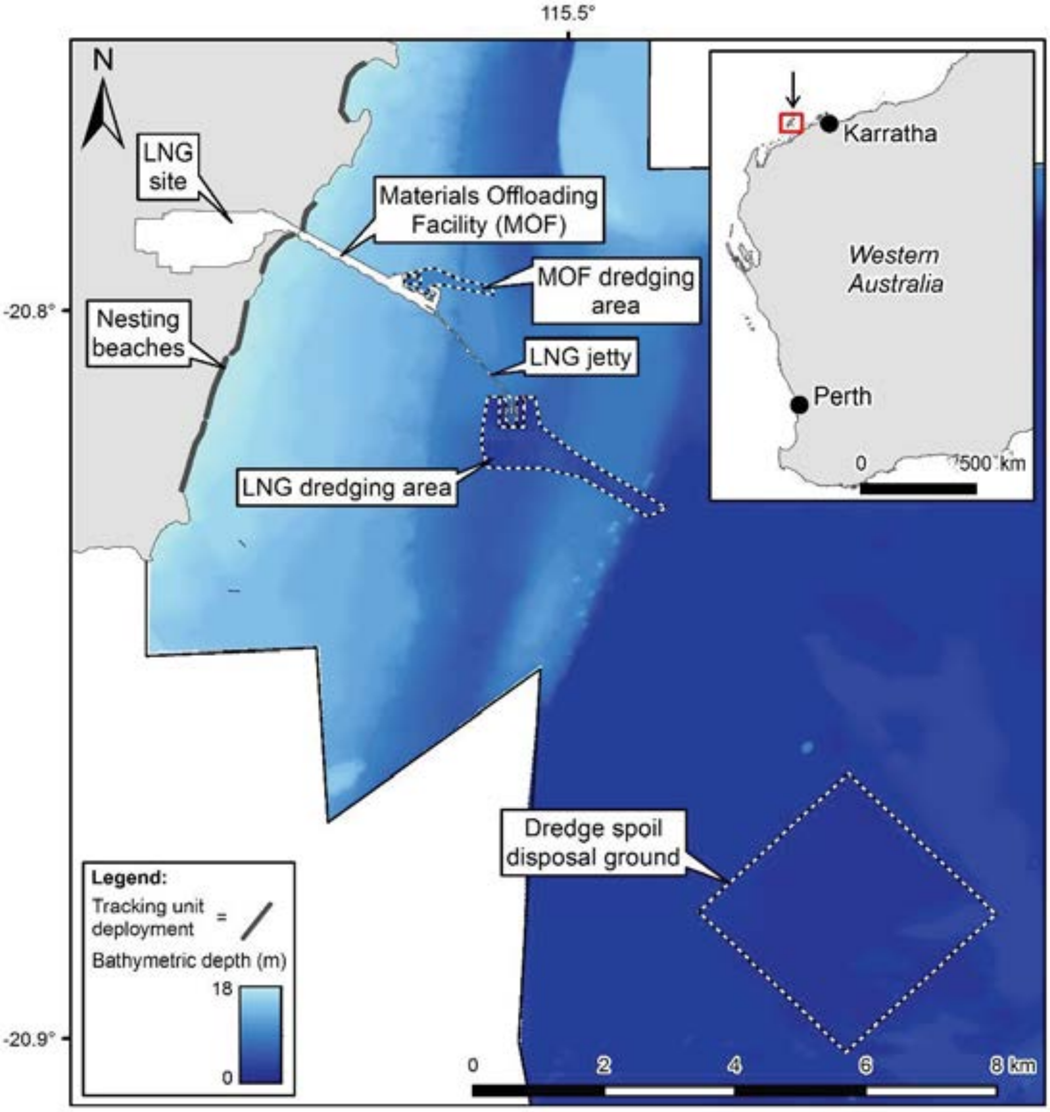

Figure 5.1 Location plan of Barrow Island study area showing dredging areas and offshore infrastructure.

5.3.4 Turtle Tracking (Movement) Dataset

SRDL tracking units (with TDR) were deployed on flatback turtles for one season during each stage of the dredging program (baseline (*n* = 20) = 2009/10, dredging (*n* = 10) = 2010/11 and post-dredging (*n* = 8) = 2011/12; Table 5.1). In addition, SPLASH tracking units (with no TDR) were deployed for one season during the post-dredging stage of the program (*n* = 10, 2013/14).

The absolute end of the inter-nesting phase was indicated by the commencement of post-nesting migration, deemed to have begun once movement away from the nesting beach was directional and protracted (Zbinden et al. 2008). All data received between the date of tracking unit deployment and commencement of post-nesting migration was retained for this chapter (Table 5.1).

5.3.5 Dive (Behaviour) Dataset

The SRDL tracking unit measured dive depth at a resolution of 0.5 m and to an accuracy of ± 1% of the reading. Dives were defined as starting once the unit was below 1.5 m depth and ending when above 1.5 m depth. The TDR accumulated time-depth values until the end of the dive and then calculated five internal points (based on set depth bin values) that gave the best fit to the entire dive profile (Fedak et al. 2002), allowing for substantial compression of the dive data and more reliable transmission rates over the data-restricted Argos system (Hays et al. 2004b). The compressed dive profile data was stored temporarily on the tracking unit and randomly selected for transmission to the Argos system. The approximate location of the start and end of each dive was also transmitted, with locations identified by interpolating the transmission time of inter-nesting positions recorded before and after the dive.

The bathymetric depth at the start and end location of each received dive profile was adjusted to include the tide level at the time the dive started. This adjustment was required because the bathymetric depth does not account for the extensive tidal range at Barrow Island (0 – 5 m) which, if unaccounted for, would cause inaccurate estimates of the relative depth of each dive to the bottom depth i.e. the seabed. Baseline bathymetric data at Barrow Island was recorded using a Laser Airborne Depth Sounder (LADS; spatial resolution of 1 m) in an area extending 16 km from the island’s east coast (referred to herein as the bathymetry area; Figure 5.1), with the data collection repeated following the completion of dredging. Detailed high resolution bathymetric data was not available for areas situated >16 km from Barrow Island, therefore dives recorded as starting or ending beyond this area were not able to be accurately adjusted to account for tidal range and were therefore excluded from the relative depth analysis.

Each received dive profile was assigned to one of four different dive types, with the type of dive determined visually based on the shape of the dive profile. The shape of each dive type’s profile, and the inferred marine turtle activity exhibited to generate the profile shape, has been described in detail in other published studies (see Figure 5.2; Minamikawa et al. 1997; Hochscheid et al. 1999; Houghton et al. 2002). Type 1 dives show a rapid descent, long bottom time and a rapid ascent, and are considered to be generated by turtles remaining inactive or resting close to the seabed. Type 2 dives shows a steep descent followed by an immediate steep ascent and are considered to represent exploratory behaviour. Type 3 dives show a rapid descent followed by a gradual ascent phase and ending with a rapid return to the surface and are considered to represent changes in buoyancy due to activity and may indicate resting in mid- water during periods of travelling. Type 4 dives consist of a rapid descent, followed by a quick first ascent to a point where the ascent slows as a result of buoyancy changes, before reaching the surface.

The SRDL tracking units also recorded and transmitted statistics of diving events based on all dive data recorded within six hour summary blocks. Summarised diving events included the average maximum depth and duration of all recorded dives during the six hour summary block, with depth and duration values based on specific pre-defined bin values. The data was summarised and binned due to data transmission restrictions over the Argos system and to preserve the unit’s battery life.

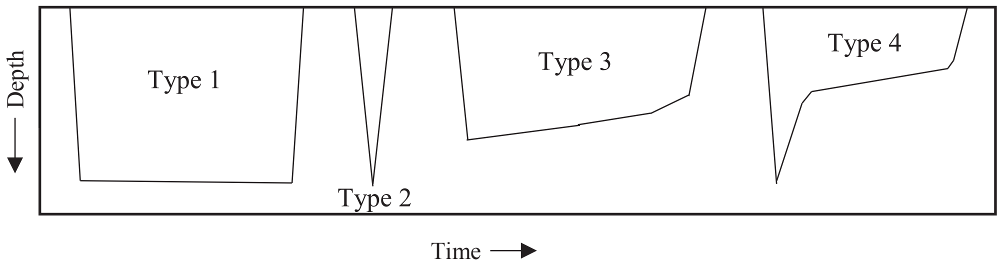

Figure 5.2 Dive type characterisation according to dive profile (adapted from Sperling et al. 2010).

5.3.6 Seawater Temperature Dataset

The SRDL tracking unit recorded seawater temperature to an accuracy of 0.1 ºC. The tracking units recorded up to 12 water temperature measurements (based on pre-defined bin values) at selected depths during dives. A subset of recorded temperature measurements were randomly selected by the tracking unit for transmission via the Argos system. The approximate location of the start and end of the dive for which the temperature data had been recorded was also transmitted.

Table 5.1 Summary of tracking unit deployments on inter-nesting flatback turtles at Barrow Island. [1]Indicates turtle immediately commenced post-nesting migration following tracking unit attachment; [2]Indicates tracking unit was recovered; [3]Indicates tracking unit failed to provide suitable Fastloc GPS positions (data retained for dive behaviour).

Season	**Stage of dredging program**	**Tracking unit model**	**CCL (cm)**	**Attachment date**	**End of inter-nesting**	**Number of tracking days (*n*)**	**Number of Fastloc GPS positions**
2009/10	Prior to dredging (baseline)	SRDL	91	27/11/2009	08/01/2010	42	387
			90	27/11/2009	20/01/2010	54	588
			96	28/11/2009	28/12/2009	30	323
			87	28/11/2009	07/01/2010	40	392
			93	28/11/2009	26/12/2009	28	288
			90	29/11/2009	14/12/2009	15	182
			90	29/11/2009	09/01/2010	41	405
			90	29/11/2009	10/01/2010	42	398
			87	29/11/2009	14/12/2009	15	193
			91	30/11/2009	08/01/2010	39	427
			91	01/12/2009	11/01/2010	41	450
			96	01/12/2009	14/01/2010	44	392
			90	01/12/2009	NA[1]	NA	NA
			88	01/12/2009	29/12/2009	28	349
			88	01/12/2009	21/01/2010	51	580
			88	02/12/2009	18/12/2009	16	217
			90	02/12/2009	NA[1]	NA	NA
			89	03/12/2009	09/01/2010	37	403
			90	03/12/2009	15/01/2010	43	380
			91	02/01/2010	20/01/2010	18	220
2010/11	Dredging	SRDL	89	26/11/2010	NA[1]	NA	NA
			91	27/11/2010	08/12/2010	11	49
			90	27/11/2010	07/01/2011	42	279
			90	28/11/2010	15/12/2010	18	90
			89	28/11/2010	02/01/2011	36	235
			90	29/11/2010	27/12/2010	28	277
			90	29/11/2010	01/01/2011	34	221
			91	30/11/2010	16/12/2010	17	134
			89	30/11/2010	14/01/2011	46	321
			90	01/12/2010	01/01/2011	32	209
2011/12	Post-dredging	SRDL	90	19/11/2011	30/12/2012[3]	42	NA
			92	20/11/2011	15/12/2011	24	192
			89	20/11/2011	20/12/2011[3]	30	NA
			92	21/11/2011	20/01/2012[3]	60	NA
			91	21/11/2011	05/01/2012	45	242
			90	22/11/2011	04/01/2012[3]	43	NA
			93	22/11/2011	04/01/2012	43	155
			88	23/11/2011	NA[1]	NA	NA

Season	Stage of dredging program	Tracking unit model	CCL (cm)	Attachment date	End of inter-nesting	Number of tracking days (*n*)	Number of Fastloc GPS positions
2013/14		SPLASH	88	12/11/2013	12/12/2013	30	312
			89	12/11/2013	NA[1]	NA	NA
			87	12/11/2013	09/01/2014[2]	58	1984
			93	13/11/2013	30/12/2013[2]	47	1590
			93	13/11/2013	30/12/2013	47	504
			92	14/11/2013	16/12/2013	32	379
			93	14/11/2013	17/12/2013	33	348
			95	14/11/2013	02/01/2014	49	616
			92	15/11/2013	17/12/2013	32	309
			89	15/11/2013	18/12/2013	33	788

5.3.7 Data Analysis

Analysis was undertaken to compare the movement (tracking) and behaviour (dive) datasets recorded at each stage of the dredging program (baseline, dredging and post-dredging). The movement dataset for the post-dredging stage was represented by two seasons of data (2011/12 and 2013/14) which were combined to form one dataset (Table 5.1). The behaviour dataset for the post-dredging stage was represented by one season of data (2011/12), with the SPLASH tracking units deployed in 2013/14 not equipped with a TDR.

To enable comparison between each dataset, characteristics considered to provide a representation of each turtles movement and behaviour, were determined (Table 5.2). Issues with autocorrelation when comparing dataset characteristics were minimised by using filtered location data to calculate a median location for every six hour period from all location data received during this period.

To investigate the thermal environment of the active dredging areas (DA), the seawater temperature data recorded from dives situated within the active DAs were compared with seawater temperature data recorded during dives undertaken within 10 km of the DAs. The 10 km distance limitation was used to exclude dives not considered to be in close proximity to the DAs, allowing for a more suitable comparison between the thermal environment of the active DAs and the surrounding nearshore area.

Spatial analysis of movement patterns and dive behaviour was conducted using ArcGIS 10.2 (ESRI). All data were tested for distribution normality. A non-parametric Mann-Whitney test was used to test for differences between characteristics of each dredging stage dataset.

Table 5.2 Characteristics of each turtles movement pattern and dive behaviour that were used for comparison between each dataset.

Type	Characteristic
Movement Pattern	Mean daily distance travelled (km)
	Mean distance displaced between each median location and the original deployment site (km)
	Proportion of inter-nesting phase spent within the boundary of the dredging areas (%)
	Proportion of inter-nesting phase spent within each grid cell (400 m x 400 m) across the Barrow Island study area (%) (Figure 5.5)
Dive Behaviour	Average dive duration of the turtles recorded dives from each six hour summary period (min)
	Average maximum dive depth of the turtles recorded dives from each six hour summary period (m)
	Percentage of dive profile type for all turtles transmitted dives (%; Type 1, 2, 3 and 4; Figure 5.2)

5.4 Results

5.4.1 Predicted Dredging Impact

The Gorgon LNG development LTMTMP included the assessment of dredging-related hazards to reproductively-active flatback turtles (Chevron Australia 2009; Table 5.3). No hazards were assessed as presenting a high residual risk and six hazards were assessed as presenting a medium residual risk. Control measures were required to be implemented for those hazards assessed as medium.

Of the six hazards, four were considered ‘in scope’ as their activities had the potential to result in direct injury or mortality to inter-nesting flatback turtles (underwater blasting, vessel strike, entrainment and noise and vibration; Table 5.3), with the two ‘out-of-scope’ hazards (artificial light and suspended sediment) not considered to result in direct injury or mortality. There was no consideration of the consequence or likelihood of a behavioural change in inter-nesting flatback turtles within the LTMTMP.

5.4.2 Quantified Dredging Impact

MFOs maintained inspection effort for the total duration of the dredging stage. During this time there was no detection of any marine turtle injury or mortality from onboard visual observations and from inspections of the TSHD overflow screens, the MOF reclamation area and the dredge and dredge spoil grounds via towed camera and divers.

Onboard MFOs recorded over 2500 marine fauna sightings including whales, dolphins, dugongs and marine turtles. Approximately 60% of these were marine turtle sightings, recorded predominantly between October 2010 and March 2011. MFO records demonstrated numerous response measures taken following the sighting of a marine turtle in proximity to the vessel.

5.4.3 Comparison of Movement and Behaviour Datasets

Of the 48 tracked turtles, five turtles commenced their post-nesting migration immediately following deployment, resulting in no inter-nesting data being recorded (Table 5.1). The mean tracking time of the remaining 43 turtles (baseline *n* = 18; dredging *n* = 9; post-dredging *n* = 16) prior to the commencement of their post nesting migration was 36 ± 12 days (range = 11 – 60).

Four turtles tracked during the 2011/12 post-dredging season received insufficient or inaccurate location data required for analysis and were therefore excluded from analysis (Table 5.1). The reason for the tracking unit's poor performance is unknown. Three of these four turtles did transmit suitable dive data which was retained for analysis.

5.4.4 Baseline Stage (2009/10)

Inter-nesting flatback turtles (*n* = 18) demonstrated three types of generalised movements: some remained within the nearshore area of Barrow Island; some moved to the Australian mainland approximately 50 km from Barrow Island; and others moved to an area half way between Barrow Island and the Australian mainland before returning (Figure 5.3; movement patterns of individual inter-nesting periods are described in Chapter 2). Flatback turtles travelled a mean distance of 6.5 ± 5.8 km each day (range = 0.0 – 38.7, *n* = 647) and were situated a mean distance of 12.6 ± 15.1 km from the original tracking unit deployment site (range = 0.0 – 59.4, *n* = 2522). Those turtles that remained in close proximity to Barrow Island spent their time in the deepest nearshore area (~11 m depth) situated between two limestone reefs, ~5 km east of Barrow Island. Inter-nesting flatback turtles were not generally located within the boundary of the proposed DAs, with 5.7% of median locations (*n* = 143) within the boundary (Figure 5.5).

The tracked turtles recorded a total of 39,703 dives across 2417 six hour summary periods. Tracked turtles spent 79.5% of their inter-nesting time diving. The mean maximum depth of recorded dives within each six hour summary period was 9.1 ± 4.4 m (range = 0 – 35, *n* = 2417; Figure 5.4). The mean duration of the recorded dives within the summary period was 23.8 ± 14.3 minutes (range = 0 – 70, *n* = 2417).

A total of 2717 dive profiles were transmitted and received by the Argos system, with 137 of these (5.1%) situated within the boundary of the proposed DAs and 1580 (58.1%) within the bathymetry area. On average, the maximum depth of each recorded dive was within 1.9 ± 2.0 m of the tidally adjusted seabed (range = 0.0 – 17.2, *n* = 1580). Out of all dives, the most common dive type profile shape was a Type 1 (65%, *n* = 1753), followed by Type 2 (18%, *n* = 491), Type 4 (8%, *n* = 205) and then Type 3 (4%, *n* = 118), with 6% (*n* = 150) categorised as unknown.

Table 5.3 Assessment of dredge-related hazards to reproductively-active flatback turtles as part of the Gorgon LNG development at Barrow Island (Chevron Australia 2009; 2011). Grey background indicates those assessed hazards that were considered out of scope of this studies assessment.

Hazard	**Potential impact/issue to flatback turtles**	**Potential worst case impact to flatback turtles**	**Consequence ranking (1 – 6)**	**Likelihood ranking (1 – 6)**	**Residual risk level**
Noise and vibration	• Shock waves, noise and vibration from underwater blasting and drilling	• Mortality or injury to marine turtles in the vicinity of blasting	6 – Incidental *Impacts such as localised or short term effects on habitat, species or environmental media*	1 – Likely *Consequence can reasonably be expected to occur in life of facility*	Medium
Vessel strike(s)	• Boat strikes	• Death or injury to turtles • Animal stranding due to injuries sustained • Reduced reproductive success in the long term	6 – Incidental *Impacts such as localised or short term effects on habitat, species or environmental media*	1 – Likely *Consequence can reasonably be expected to occur in life of facility*	Medium
Physical interaction	• Underwater blasting	• Mortality or physiological impacts to turtles (permanent and/or temporary hearing loss), injury or mortality	6 – Incidental *Impacts such as localised or short term effects on habitat, species or environmental media*	1 – Likely *Consequence can reasonably be expected to occur in life of facility*	Medium
Physical interaction	• Interaction with the Trailer Suction Hopper Dredge	• Entrapment in dredge resulting in injury or mortality	5 – Minor *Impacts such as localised, long term degradation of sensitive habitat or widespread, short-term impacts to habitat, species or environmental media*	2 – Occasional *Conditions may allow the consequence to occur at the facility during its lifetime, or the event has occurred within the Business Unit*	Medium
Artificial light	• Light emissions from marine vessels and construction equipment and navigation aids	• Potential displacement and/or relocation of nesting female turtles from beaches adjacent to construction and dredging works, with potential for less reproductive viability at alternative beaches • Mate finding inhibited at night where lighting is present in mating areas • Hatchling disorientation	6 – Incidental *Impacts such as localised or short term effects on habitat, species or environmental media*	1 – Likely *Consequence can reasonably be expected to occur in life of facility*	Medium
Loss of habitat	• Decrease in water quality (turbidity) due to suspension of sediment during dredging, blasting and running of anchors and discharge from the MOF construction.	• Indirect effects – loss of foraging habitat (food sources) for marine turtles caused by lowering of light levels to Benthic Primary Producers (BPP) • Displacement and/or relocation of animals to elsewhere to seek alternate food sources	6 – Incidental *Impacts such as localised or short term effects on habitat, species or environmental media*	1 – Likely *Consequence can reasonably be expected to occur in life of facility*	Medium

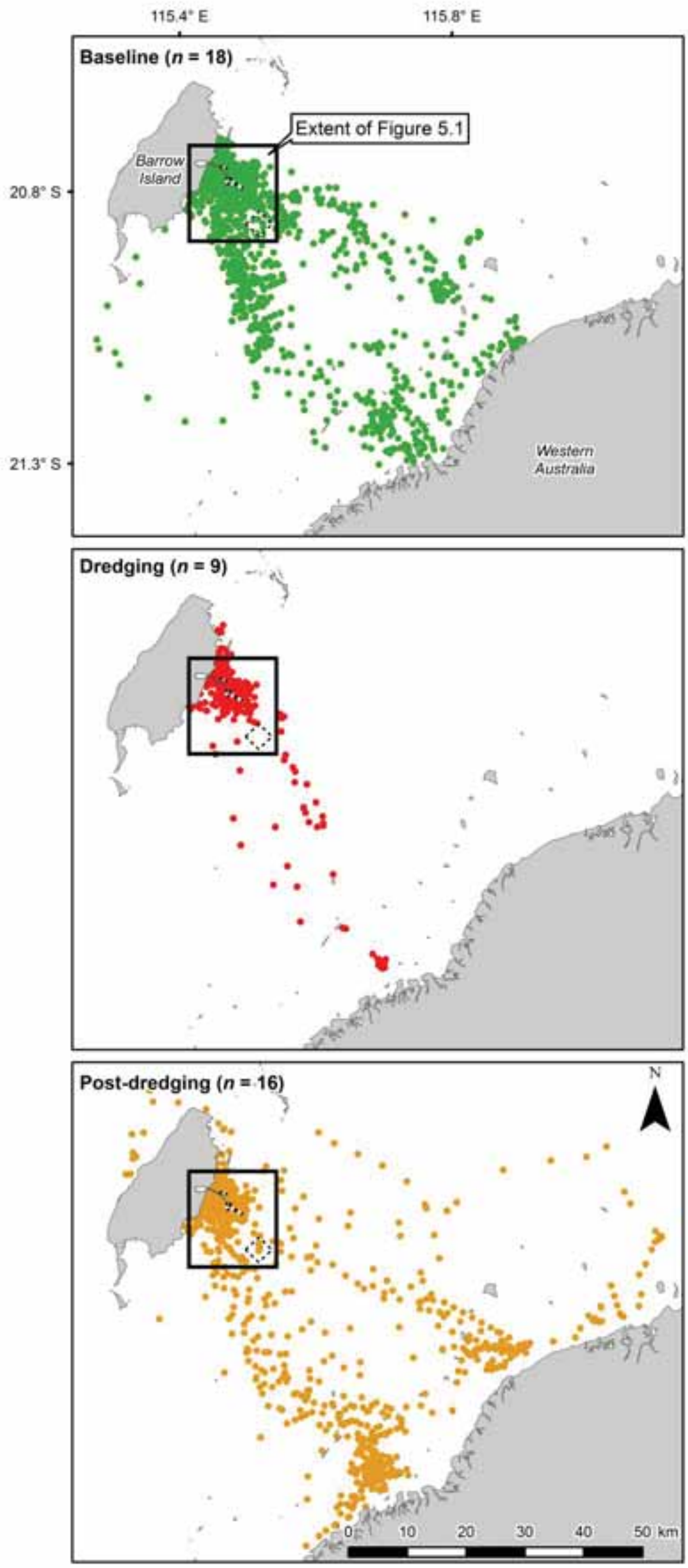

Figure 5.3 Median locations (selected from all location data received within a six hour period) recorded by all turtles tracked during each phase of the dredging operation (baseline, dredging and post-dredging).

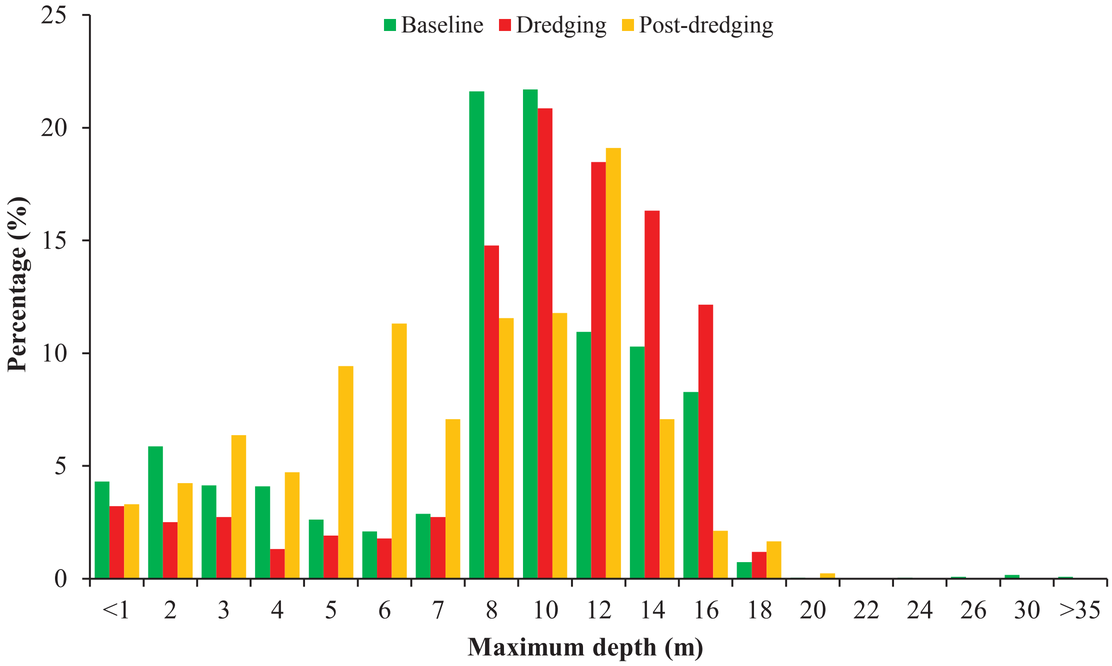

Figure 5.4 Frequency distribution showing maximum depth of all dives transmitted during each phase of the dredging operation.

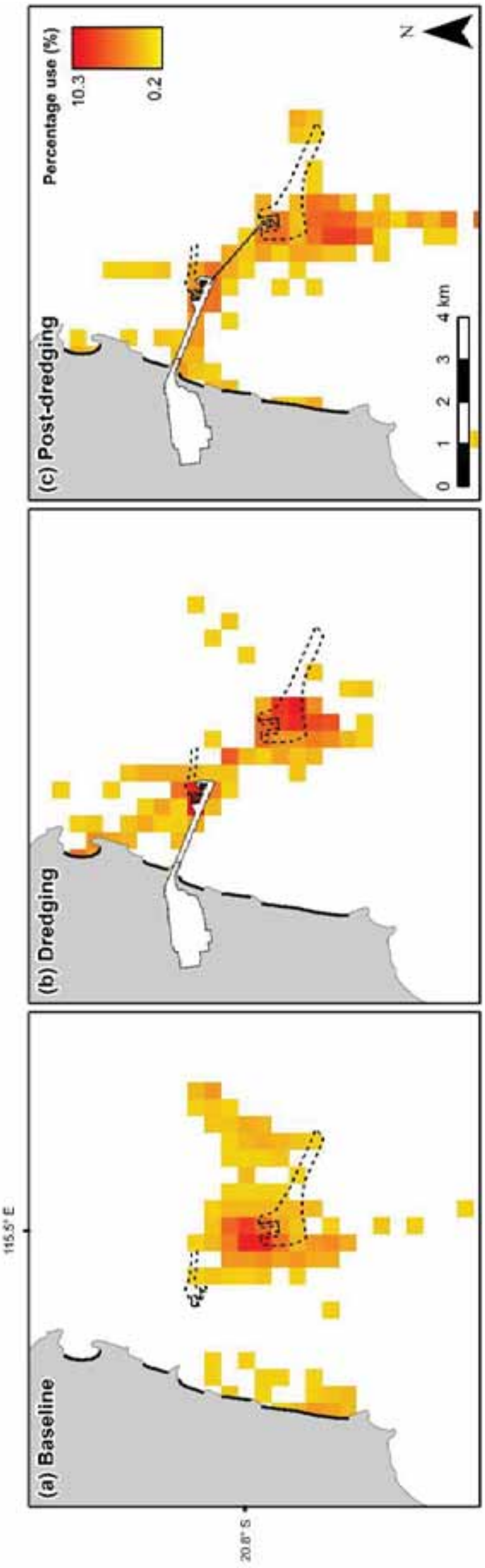

Figure 5.5 Percentage use of inter-nesting flatback turtles within a grid (400 m x 400 m cell size), during different stages of dredging: (a) baseline (b) dredging (c) post-dredging.

5.4.5 Dredging Stage (2010/11)

Of the 49 day period when inter-nesting turtle tracking data was recorded (27th November 2010 – 14th January 2011), 22 days (45%) overlapped with days when the TSHD was operating. When the operational period of all four dredge vessels was considered (including the TSHD vessel), 37 inter-nesting tracking days (76%) overlapped with a day when at least one dredge vessel was operational, with 13 of these days overlapping when two dredge vessels were operating, 13 days overlapping when three dredge vessels were operating and two days when all four dredge vessels were operating.

The nine tracked inter-nesting flatback turtles remained entirely within the nearshore area (<10 km) of Barrow Island (with the exception of one turtle that moved to the Australian mainland on two occasions; Figure 5.3). Flatback turtles did not use the same nearshore area as those tracked during baseline and instead were recorded primarily within an area that overlapped the active DAs, with the percentage of locations situated within the boundary of the active DAs increasing from 5.7% during baseline to 39.5% (n = 408 locations). The mean daily distance travelled (3.5 ± 4.4 km, range = 0.0 – 39.1, n = 263) and mean distance to the original tracking unit deployment site (7.0 ± 9.9 km, range = 0.0 – 58.5, n = 1033) were both significantly shorter distances compared to baseline (p <0.0001, U = 119683 and p <0.0001, U = 1030098, respectively).

The tracked turtles recorded a total of 12,340 dives across 839 six hour summary periods. Tracked turtles spent 81.1% of their inter-nesting time diving. The mean maximum depth of recorded dives within each six hour summary period was 10.9 ± 4.1 m (range = 0 – 18, n = 839; Figure 5.4) and was significantly deeper than baseline (p <0.0001, U = 1302775). The mean duration of the recorded dives within each summary period was 26.0 ± 14.1 minutes (range = 0 – 60, n = 839) and was significantly longer than baseline (p <0.0001, U = 1127750).

A total of 823 dive profiles were transmitted and received by the Argos system, with 296 of these (36.0%) situated within the active DAs and 772 (93.8%) within the bathymetry area. The mean maximum dive depth was within 1.3 m of the seabed (range = 0.0 – 14.5, n = 772). Out of all dives, the most common dive type profile was Type 1 (75%, n = 621), which was a higher percentage than during baseline. The next most common dive type profile was Type 2 (13%, n = 106), followed by Type 4 (5%, n = 41) and then Type 3 (2%, n = 18), with 5% (n = 37) categorised as unknown. For dives situated within the active DAs, the most common dive type profile was Type 1 (81%, n = 241), followed by Type 2 (8%, n = 24), Type 3 (2%, n = 5) and Type 4 (1%, n = 1), with 8% of the dives (n = 24) categorised as unknown.

A total of 99 seawater temperature profiles were transmitted by the tracking units and received by the Argos system, with the depth of measurements ranging from 3 – 11 m. The depth with the warmest seawater temperature was at 6 m (28.3 ± 0.7 ºC, range = 27.1 – 30.6, n = 37), with the coldest temperature at 3 m (28.1 ± 0.7 ºC, range = 27.0 – 30.6, *n* = 99). The seawater temperature recorded from dives situated within the boundary of the active DAs was not significantly different to the seawater temperature recorded from dives situated within a 10 km buffer of the DAs (at all depths).

5.4.6 Post-dredging Stage (2011/12 and 2013/14)

The tracked flatback turtles (*n* = 16) demonstrated two general movement patterns; some remained within the nearshore area of Barrow Island and some moved to an area close to the Australian mainland. The location of nearshore areas used by the tracked turtles was different compared to baseline and dredging stages; one area was situated 2 – 3 km south of the LNG jetty and another area was situated to the south-east of the MOF (Figure 5.5 and Figure 5.6). The tracked turtles spent a similar amount of time within the boundary of the dredged areas compared to turtles tracked during baseline, and a shorter amount of time compared to turtles tracked during the active dredging stage, with 4.8% of median locations (*n* = 90) situated within the areas. The mean daily distance travelled by each turtle was 7.0 ± 8.0 km (range = 0.0 – 39.7, *n* = 479), which was similar to baseline (p <0.05, U = 119683) and significantly longer than during dredging (p <0.05, U = 112332). The mean distance to the original tracking unit deployment site was 19.9 ± 9.9 km (range = 0.0 – 72.1, *n* = 1033) which was significantly longer compared to baseline (p <0.0001, U = 1030098) and dredging stages (p <0.0001, U = 1030098), likely reflecting the increased occurrence of movements made by the tracked turtles to the mainland compared to baseline and dredging.

A total of 7206 dives were recorded from 424 six hour summary periods. Tracked turtles spent 81.8% of their inter-nesting time diving. The mean maximum depth was 8.4 ± 4.2 m (range = 1 – 19, *n* = 424; Figure 5.4) which was significantly shallower than baseline (p <0.05, U = 564753) and dredging (p <0.0001, U = 116647). The mean duration of each dive was 24.2 ± 13.9 minutes (range = 0 – 60, *n* = 424) which was similar to baseline (p >0.05, U = 5105183) and significantly shorter than dredging (p <0.05, U = 162110).

A total of 315 individual dive profiles were transmitted and received by the Argos system, with three of these dives (1.0%) situated within the completed DAs and 164 (52.0%) within the bathymetry area. On average, the maximum dive depth was within 1.6 ± 1.9 m of the seabed (range = 0.0 – 10.2, *n* = 164). The highest percentage of dive type profiles was Type 1 (76%, *n* = 238), followed by Type 2 (14%, *n* = 43) and then Type 4 (3%, *n* = 10), with 7% of the dives (*n* = 22) classified as unknown.

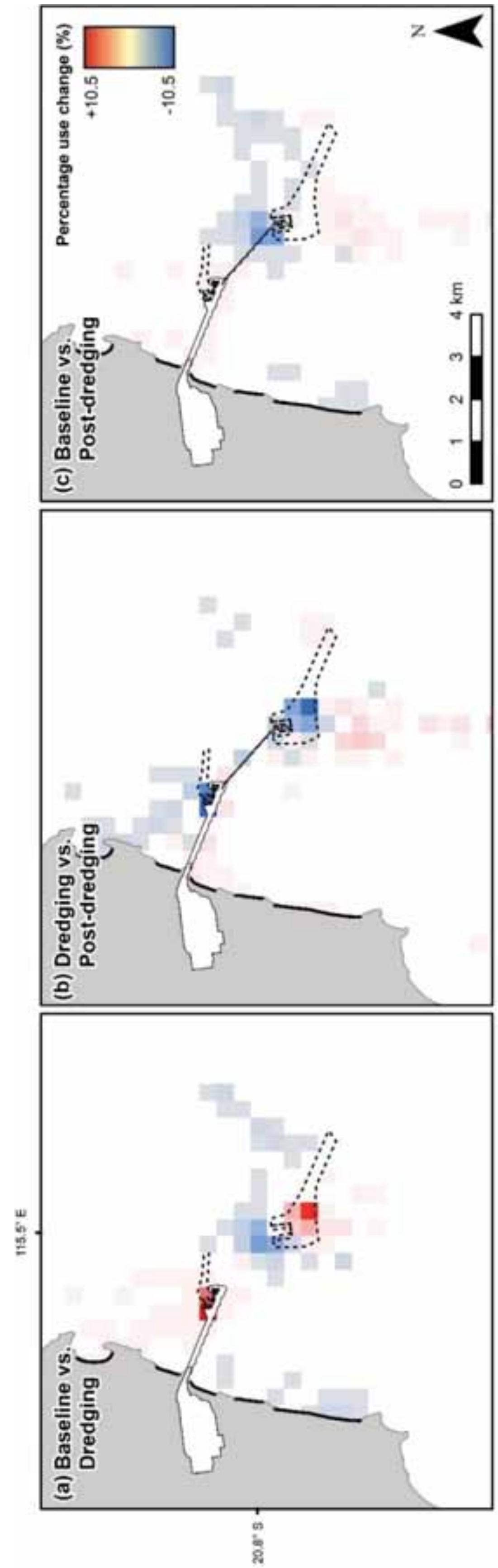

Figure 5.6 Difference in the percentage use of inter-nesting flatback turtles between different stages of dredging within each grid cell (400 m x 400 m): (a) baseline vs. dredging (b) dredging vs. post-dredging (c) baseline vs. post-dredging.

5.5 Discussion

Coastal development and associated dredging activities have increased in recent years (IADC 2012), yet there remains an absence of supporting information for managers and policy makers to determine accurate dredge-related impact predictions for many marine fauna. This absence can have implications for the conservation of the marine fauna involved, particularly as certain dredging impacts may be overlooked or the implementation of control measures and response strategies may be ineffective. For marine turtles, understanding their offshore movement and behaviour surrounding an active DA, in tandem with an indicator of survivorship i.e. recorded dredge-related mortality events, is important information in the support of management decisions at all stages of a dredging program. In this chapter, a follow-up case study is presented involving a major resource development whose proponent undertook satellite tracking of reproductively-active flatback turtles from a nearby rookery at different stages of its dredging operation, as well as ensuring trained MFOs were onboard dredge vessels to mitigate interaction with marine fauna and detect injury and mortality events.

Determining variation in the tracked turtles movement and behaviour between each stage of the dredging program generated this chapter's pre-eminent result: the tracked turtles increased their use of the DAs during the dredging operation and, despite this increased use, there was a concurrent absence of injury or mortality records. This result appears positive because turtles survived to commence their post-nesting migration despite their increased use of the DAs. However, upon review of the DSDMMP (Chevron Australia 2011) and LTMTMP (Chevron Australia 2009), the increased use of the DAs by the turtles was not a predicted consequence, with the control measure of using chains on the TSHD drag head, in addition to existing cumulative disturbance sources from dredge vessels i.e. noise and vibration, suspended sediment and the TSHD suction field, considered adequate in deterring turtles entirely from the DAs during the operation.

The turtles increased use of the DAs resulted in their greater exposure to dredging hazards, with tracked turtles situated within the DAs during 37 of 49 tracking days when at least one dredge vessel was operating. This result contradicts the initial EIA predictions relating to the likelihood of a dredging-related consequence occurring (Table 5.3) as it was not anticipated that flatback turtles would remain within, let alone increase their use of, the DAs. This information reinforces the importance and value of reviewing EIA predictions (see Marshall et al. 2005) and should be considered by environmental practitioners and regulators when proposing initial impact predictions and control measures within an ESD or EMP for dredging operations situated elsewhere. Further, our research highlights the need to conduct similar tracking-based research on other threatened species to provide much needed baseline data from which to infer the degree they may be impacted during dredging operations. Such research programs are highlighted as key knowledge gaps in a recent review of the biophysical impacts of dredging in the Great Barrier Reef (McCook et al. 2015).

The initial EIA likelihood prediction (determined with control measures in place) for the physical interaction hazard (i.e. entrainment) occurring to flatback turtles was categorised as occasional, which is defined as conditions may allow the consequence to occur during the dredging operation (Chevron Australia 2011). Based on the movement and behaviour data and the tracked turtles presence within the active DAs, this likelihood prediction was accurate as conditions were suitable for the consequence to occur during times when the tracked turtles were present within the DAs. However, onboard MFOs did not record a dredge-related injury or mortality event indicating that the implemented control measures may have been effective in preventing the consequence occurring. It would be useful to examine whether these, or similar, control measures would work on other marine species or life stages.

It is clear from the literature that little is known about how dredging operations may affect marine species and community structure (McCook et al. 2015). While there are tracking studies that describe seasonal variation in marine turtle and dugong movement around human dominated landscapes (Schofield et al. 2010; Shillinger et al. 2010; Zeh et al. 2015; Whittock et al. 2014), this chapter is the first to describe the variation of any marine turtle species' movement and behaviour concurrently with different stages of a dredging operation. It is therefore unknown if the behavioural change to increase their use of an area where dredging was occurring is common for reproductively-active marine turtles, or other marine species worldwide or is unique to this location or species. To understand this behavioural change further, it is recommended that future dredging operations consider the implementation of tracking of threatened or migratory marine species populations during different stages of dredging, assess habitat change and use MFOs on active dredge vessels to quantify changes to behaviour, habitat use or understanding critical thresholds of habitat condition (e.g. Bolam & Rees 2003; Cruz-Motta & Collins 2004; Macreadie et al. 2014). A further understanding will also improve the confidence of initial impact predictions made within EIAs for future dredging operations situated elsewhere (Morrison-Saunders 1996; Grech et al. 2013).

Developing an understanding of the main driver behind the turtles behavioural change within the active DAs is important as it may be relevant for other marine turtle species situated elsewhere and could be used to determine the need for additional control measures when dredging. As the majority of marine turtle species globally are considered to be capital breeders (Hamann et al. 2002) i.e. they do not forage when breeding, the main driver behind any movement and behavioural change is suggested to be related to optimising energy in a manner most suited to the localised conditions (Houghton et al. 2002). Therefore, a change in localised conditions during dredging may have made the area more suitable for optimising energy compared to during baseline. This is supported by evidence that tracked turtles did not continue to utilise the DAs during the post-dredging stage, suggesting the behavioural change is linked to conditions generated during dredging.

One altered condition within the active DAs was the bathymetric depth, with the LNG jetty DA becoming the deepest nearshore area available to the tracked turtles. Marine turtles can optimise their energy by utilising a specific bathymetric depth that maximises their oxygen store, while still attaining near-neutral buoyancy (Fossette et al. 2012; Hays et al. 2000). Maximising their oxygen store allows them to rest and remain on the seabed for longer periods, minimising the energy cost of commuting to the surface (see Houghton et al. 2002; Minamikawa et al. 2000). However, the tracked turtles movement and behaviour characteristics were not consistent between the dredging and post-dredging stages, despite the consistent deeper conditions provided within the LNG jetty DA during the same two stages. The change in bathymetric conditions was therefore not likely to have influenced the tracked turtles to increase their use of the DAs to optimise energy. Instead, the opportunity to utilise the deeper bathymetry to optimise energy (as indicated by an increased percentage of Type 1 dives, proximity to seabed and significantly deeper dives during dredging compared to baseline) was likely an indirect effect of another condition change.

Some inter-nesting marine turtles are hypothesised to thermo-regulate their behaviour to influence egg development (see Fossette et al. 2012; Schofield et al. 2009), with warmer water and body temperatures ultimately speeding up egg development rates prior to oviposition (Sato et al. 1998). As such, exposure of females to warmer temperatures across a nesting season may reduce the overall length of time required to lay the full complement of clutches (Hays et al. 2002) resulting in optimisation of energy across a nesting season. In this chapter there was no difference in the seawater temperature at multiple depths within the active DAs compared to seawater temperature at the same depths within 10 km of the DAs. Therefore, the increased use of the DAs between baseline and dredging stages is unlikely to be related to any localised change in seawater temperature conditions.

Another altered condition within the active DAs was the availability of a foraging source. While flatback turtles are considered to be capital breeders, no published studies exist that rule out opportunistic foraging by inter-nesting flatback turtles to supplement their energy reserves. The benthic disturbance caused by dredging can, if present, expose infaunal animals providing an opportunity for foraging, and was suggested by Dickerson et al. (1990) as one potential factor that influenced the increase in use of a dredged area in the Cape Canaveral and King’s Bay shipping channels in the USA by non-inter-nesting marine turtles. However, in this chapter, dive profile data received from tracked turtles within the active DAs did not reflect foraging behaviour (only 8% of dives were Type 2 profiles considered to represent exploratory behaviour) and there was an absence of median locations within the dredge spoil disposal area (Figure 5.1) during the dredging and post-dredging stages where infaunal animals, if present, would have been deposited as disposal sediment by dredge vessels (Figure 5.3). Altogether, this indicates that tracked turtles in this chapter did not increase their use of the DAs during dredging due to increased opportunities to forage.

An alternative driver behind the tracked turtles change in inter-nesting movement and behaviour is predator avoidance. Marine turtles are prone to predation at all life phases (Musick & Limpus 1997), and for inter-nesting flatback turtles within the region, the main predator is the tiger shark (*Galeocerdo cuvier*; e.g. Witzell 1987; Simpfendorfer 1992; Lowe et al. 1996). Indeed, at Barrow Island, nesting adult flatback turtles are regularly observed with missing flippers consistent with shark predation (K. Pendoley, pers. comm). Their risk to predation may increase as they enter shallow waters adjacent to nesting beaches, as these areas host large aggregations of turtles that potentially attract predators (e.g. Raine Island; Fitzpatrick et al. 2012). In response to the presence of predators, some large-bodied and long-lived marine fauna (including marine turtles) have been known to induce anti-predator behaviour including changes in dive patterns (Heithaus & Frid 2003; Frid et al. 2007) and habitat use (e.g. Lima & Dill 1990; Lima 1998; Heithaus et al. 2007). Changes in marine turtle dive behaviour that may reduce predation risk include undertaking Type 1 dives, with the ascent of these dives reducing silhouetting against the surface and hence detection by sharks (Hays et al. 2001b) and allows them to scan the area for predators before surfacing (Glen et al. 2001).

During the dredging stage, a significant level of noise and vibration would have been generated within the DAs from the operation of the dredge vessels i.e. from winches, mechanical parts, engines, propellers, pumps and trailing drag head (Dickerson et al. 2001). The level of noise and vibration may have been high enough to disturb sharks from the DAs resulting in the area becoming a predator-free refuge for the tracked turtles (Robinson et al. 2011; Hawkins et al. 2015). The turtles increased use of the active DAs may therefore have been an instinctive predator avoidance response, indirectly allowing them to rest more efficiently and minimise energy use by utilising the deeper depths of the DAs. This suggestion is supported by the increased use of DAs recorded by tracked turtles during dredging when compared to both baseline and post-dredging phases when no operational noise or vibration disturbances were present.

One condition within the active DAs that may have further reduced the predation risk was the high level of turbidity caused by benthic sediment disturbance during dredging operations. At

Barrow Island, satellite imagery identified an extensive sediment plume within the active DAs and dredge spoil disposal area (Pollock et al. 2014). The increased turbidity was temporary following completion of dredging as sediment plumes are short lived, generally lasting a maximum of four to five tidal cycles (Hitchcock & Bell 2004). During dredging, the tracked turtles may have used the increased turbidity within the DAs as camouflage to reduce the risk of predation, with sharks unable to visually sight them, relying solely instead on their electroreception sensory ability for prey detection. The risk of predation to those tracked turtles that moved to the mainland during the baseline and post-dredging stages (Figure 5.3) may also have been reduced, as many of the coastal areas of the NWS also experience high levels of turbidity (Brewer et al. 2007).

Many control measures have tested the use of noise or vibration to “startle” and disperse marine turtles away from the path of a dredge drag head. Controls have included sonic pingers, air cannons, drag head chains, bubblers and electricity (USAE WES 1997). In this chapter, the proponent’s DSDMMP considered the noise generated from the vessels themselves, as well as from the drag head chains, to be suitable in disturbing or deterring turtles from the area and thus reducing the likelihood of entrainment (Chevron Australia 2011). The absence of any marine turtle injury or mortality records at Barrow Island indicates that these measures were effective in preventing entrainment, particularly when considered alongside the large amount of time tracked turtles spent within the active dredge areas (39.5% of overall inter-nesting time) and their close proximity to the seabed (and operating TSHD drag head) when diving.

Based on known responses of marine turtles to underwater noise, the tracked turtles may have initially avoided the DAs due to sudden disturbances (Lenhardt et al. 1983; McCauley et al. 2000). However, repeated exposure may have reduced their avoidance response over time due to a habituation of the tracked turtles to the area. A similar response has been documented elsewhere for juvenile loggerhead turtles, and was attributed to either habituation to the noise or hearing impairment caused by the noise itself (Moein et al. 1995). If this habituation effect occurred for flatback turtles at Barrow Island then the use of response measures implemented by dredge vessels following the sighting of a marine turtle may have been an important and effective concurrent control measure in reducing the likelihood of an injury or mortality.

Observations of dredge-related entrainment of flatback turtles are rarely reported, with the only available information for flatback turtles from Queensland, Australia, where zero mortality events were reported from all dredging operations state-wide from 1999 to 2011 (Limpus et al. 2013). However, without appropriate consideration of the factors that influence the probability of mortality detection e.g. training of onboard MFOs, use of overflow screens and the legislative requirements, it is unknown if flatback turtles avoided entrainment or if entrainment was not detected. It should also be considered that any marine turtle entrapped on the underside of an operating drag head would not be able to free itself and, while on the bottom, the drag head could pulverise the turtle beyond recognition preventing subsequent detection (Dickerson & Nelson 1990).

A generalised additive mixed model (GAMM) was not used to investigate the impact of the dredging operation to flatback turtle dive behaviour between different stages of dredging. GAMMs use a link function to establish a relationship between the mean of the response variable (i.e. dive behaviour) and a 'smoothed' function of the explanatory variable(s). The strength of using a GAMM is its ability to deal with highly non-linear and non-monotonic relationships between the response and the set of explanatory variables (Guisan et al. 2002). While the use of a GAMM may have provided a more robust analysis of the dive behaviour dataset, it is unlikely to have provided a different result.

While appearing successful, the spatial scale in which the control measures were effective may be smaller than anticipated, with some turtles still remaining close to the dredging activity (as confirmed by onboard MFO records, satellite tracking data and the need for the vessel to implement response measures). It is also unknown how close the tracked turtles were to the operational dredge vessels and whether they interacted at all with the dredge vessels. The two DAs are large in size and, despite increasing their use of the areas, tracked turtles may not have spent time in the vessel's direct path or in close proximity to the vessel itself. One recommended method to address this knowledge gap is the use of 3D accelerometer tracking devices combined with acoustic recorders to record the frequency of interaction and the marine turtles response following acoustic disturbance.

This chapter contributes to a key research goal identified by the marine animal tracking community to translate tracking data generated when marine fauna are exposed to anthropogenic threats into strategies for conservation management (Hays et al. 2016). It also provides an example of how interactions with anthropogenic threats determines the behaviour and survival of a marine fauna species, which is also a key knowledge gap identified by the marine animal tracking community (Hays et al. 2016).

The results presented in this chapter have relevance for dredging operations occurring in proximity to marine turtle habitat as this is the first time the movement and behaviour of a nearby marine turtle population has been investigated during all stages of a major dredging operation and their survivorship quantified. When inter-nesting, marine turtles may prefer the conditions provided by dredging operations, resulting in an increased presence within the active dredge area. The ability for a proponent to prevent injury or mortality to marine turtles through the use of control measures has been demonstrated in this case study. It remains unknown if this behavioural change is unique to the inter-nesting phase of their life cycle or if it is only observed in flatback turtles. The results of this follow-up case study should be considered for future impact predictions within EIAs to help improve accuracy in the assessment and the implementation of appropriate controls to reduce the risk of dredge-related entrainment.

Chapter 6

General Discussion

Flatback turtles are endemic to Australia and are considered the least studied of all marine turtle species globally (Red List Standards & Petitions Subcommittee 1996). This is largely attributed to the health and safety, logistical and financial challenges in undertaking long-term studies at remote nesting sites within their breeding range along the northern coast of Australia. While afforded protection under state, federal and international legislation (Environment Australia 2003), their conservation status is defined by the IUCN as 'data deficient' which is assigned to species where there is insufficient abundance or spatial distribution information to confidently assign a status.

An increased global demand for natural resources has driven a recent expansion in Western Australia's industry resource sector, notably within the NWS region (ABARE 2010). This demand has increased industry resource activities both offshore e.g. exploration, drilling, production, and nearshore of the NWS's coastal boundary e.g. dredging, construction, underwater blasting. Elsewhere, these activities are known to present a threat to marine turtles (see Witherington 1999; Goldberg et al. 2015; Nelms et al. 2016), and there is a potential for the expanding industry resource sector to present an emerging threat and risk of impact to flatback turtles that are known to occur within the same NWS region.

Threats posed to flatback turtles by new developments and activities associated with the industry resource sector are managed through the EIA process. The process includes two important phases: firstly, a screening/referral exercise is conducted to consider the potential presence of protected species (e.g. MNES) within the development's footprint and to determine the subsequent scale of the EIA; and secondly, an ESD is completed and includes a risk-assessment process that helps inform the need and design of control measures required to remove or reduce the risk of impact to a species from a particular development's activity. The screening exercise and ESD rely on baseline species information and prior knowledge gained from follow-up of case studies that involve the species and a similar development/activity/control measure in order to be effective (Glasson et al. 2005; Morrison-Saunders 2007).

For flatback turtles and proposed industry resource sector developments/activities on the NWS, there are knowledge gaps that may prevent effective screening/referral and ESD phases potentially resulting in an insufficient level of protection during construction or operation (see Chapter 1). This PhD thesis has therefore been applied in nature to address these gaps and contribute information and knowledge that can be applied during the different EIA phases outlined above to contribute to the conservation of flatback turtles within the NWS region.

6.1 Summary and Synthesis of Research Findings

Objective 1

The first objective was to identify the baseline spatial movement and distribution of flatback turtles on the NWS and determine the extent of the industry resource sector threat by investigating their potential for interaction during different life phases.

To achieve this I used data from satellite tracking units that were attached to nesting flatback turtles at multiple rookeries on the NWS and investigated their movements and behaviour during their inter-nesting (Chapter 2) and subsequent post-nesting foraging (Chapter 3) life phases. I undertook a broad scale assessment of the potential likelihood for interaction and threat from the industry resource sector by identifying their overlap with areas that have the potential to host activities associated with the industry resource sector in the region (as represented by petroleum title areas).

I found that flatback turtle baseline inter-nesting spatial movements were varied, with displacement distances from their nesting sites ranging from 3.4 to 62.1 km. Flatback turtles showed strong fidelity to their rookery, only one of the 56 tracked turtles moved to another rookery between nesting events (from Port Hedland to Mundabullangana). I identified a consistency in flatback turtle movement patterns; there were turtles at all four rookeries remaining <10 km from their nesting beach during their inter-nesting period.

I found differences between rookeries with regards to the extent of the threat from the industry resource sector. Flatback turtles tracked from offshore islands (Thevenard and Barrow) demonstrated the largest overlap of their inter-nesting home range (85.7% and 88.6% respectively) and time (80.8% and 87.3% respectively) with areas that have the potential to host industry resource sector activities. Extended inter-nesting movements from these offshore islands to the coastline close to the mainland also increased their exposure to current and planned major resource developments (notably for those turtles tracked from Thevenard Island). I found no overlap of inter-nesting home range areas and time with petroleum title areas for turtles tracked from mainland rookeries (Mundabullangana and Port Hedland), though some inter-nesting movements of Port Hedland turtles were in close proximity to a proposed port expansion.

Following the completion of their inter-nesting phase, I further investigated their movements, behaviour and likelihood of interaction with the industry resource sector during their foraging life phase (Chapter 3). I found that flatback turtles took 42 days and migrated an average of nearly 600 km from their nesting site before reaching their first foraging area. Foraging areas were situated in water shallower than 130 m and within 315 km of the shore, with many areas situated in 50 m water depth and 66 km from shore. Some turtles showed a low site fidelity to a particular foraging area; 31 of the 66 tracked turtles departed their first foraging area prior to the tracking unit transmissions ceasing. I found that foraging areas were broadly dispersed across the region, the furthest being situated 2511 km from the original nesting site (Port Hedland), within the Gulf of Carpentaria in Queensland state waters. I delineated five main areas of concentrated foraging use. One area was situated within the NWS boundary to the west of Thevenard Island and four areas situated outside the NWS boundary within the Kimberley region. I recorded an overlap of habitat use by flatback turtles from multiple rookeries within the same RMU for the first time. Some individual foraging areas were utilised by flatback turtles tracked from rookeries of a different origin.

I considered that during the flatback turtle foraging life phase, the extent of the threat from the industry resource sector was lower compared to their inter-nesting life phase: nearly half of their foraging areas were situated within an existing protected area; there was a smaller overlap of their home range areas with petroleum title areas when foraging (67.1%); and their behaviour appeared more flexible when foraging, showing low site fidelity and movement between multiple areas distributed across a broad region.

Objective 2

The second objective was split into two parts. Firstly, I investigated the environmental variables that influenced flatback turtle distribution during their inter-nesting life phase (confirmed as the life phase that presented the highest likelihood of interaction with industry resource sector activities; see Chapters 2 and 3). Secondly, I identified areas of the NWS where inter-nesting flatback turtles may be present and where they have the highest likelihood of impact from the industry resource sector.

In Chapter 4, I used an ensemble ecological niche-modelling approach to identify the environmental variables that influenced inter-nesting flatback turtle distribution across the NWS study area, based on the method used in Pikesley et al. (2013). This is the first time that this modelling approach had been applied for marine turtles during this particular life phase. Inputs into the model included selected environmental variables and flatback turtle presence data based on inter-nesting tracking positions from multiple rookeries in the region. Outputs of the model included the importance of each variable and a regional flatback turtle inter-nesting habitat suitability map. I compared the inter-nesting habitat suitability map with a cumulative resource sector impact layer (determined using the positions of resource sector vessels) to produce a regional risk map and used areas of overlap to identify specific inter-nesting areas with the highest likelihood of interaction with the industry resource sector across the region.

I found the primary environmental variables that influenced flatback turtle inter-nesting distribution were bathymetry, distance from coastline and SST. The habitat suitability map demonstrated areas of inter-nesting habitat in close proximity to many known flatback turtle rookeries across the region. In addition to their likely presence, I used the models output to identify the characteristic of those areas where flatback turtles were also likely to be absent (>25 m bathymetry; >27 km from the nearest coastline; and <27.0 ºC and >29.8 ºC SST). I found areas of suitable inter-nesting habitat overlapped spatially with resource sector impact areas in close proximity to nearly all known flatback rookeries within the NWS study area, with notable overlaps of highly suitable habitat with areas of high cumulative impact in areas offshore from the Gorgon LNG development at Barrow Island and the existing port at Port Hedland.

Objective 3

In Chapter 1, I highlighted that an absence of follow-up case studies that evaluated the predicted vs. actual consequence of an industry resource activity on a marine species limited the confidence and accuracy of consequence predictions within an ESD’s risk matrix for the same activity situated elsewhere.

The third objective was therefore to contribute a follow-up case study by evaluating the predicted vs. actual consequence of the Gorgon LNG dredging operation (Barrow Island; an area identified in Chapter 4 as having an overlap of highly suitable inter-nesting habitat and high cumulative resource sector impact) to inter-nesting flatback turtles. I also considered the suitability of implemented control measures by comparing flatback turtle movement and behaviour at different phases of the dredging operation and combining this with actual survivorship data, as represented by injury/mortality observations recorded by onboard MFOs.

To achieve this objective, I attached satellite tracking units and TDRs to nesting flatback turtles at different phases of the Gorgon LNG dredging operation: before (baseline), during (dredging) and after (post-dredging). I compared specific inter-nesting movement and behavioural characteristics recorded during each of these dredging phases and reviewed the observation records of onboard MFOs.

In Chapter 5, I found that during the active dredging operation, flatback turtles had a substantially higher use of the dredging areas compared to the baseline and post-dredging phases. During the dredging operation, they used the areas being dredged to undertake longer and deeper dives compared to baseline and post-dredging phases, utilising the now deeper and highly turbid waters of the active dredging areas. Despite their increase in time spent within the active dredging areas and subsequent increase in potential exposure to entrainment or vessel strike, no events of injury or mortality were detected by the onboard MFOs. I considered that the implemented control measures may have been effective in preventing their injury or mortality. However, based on the results showing that turtles remained within the active dredging areas, the spatial scale of the control measures' effectiveness in deterring turtles from the areas may be smaller and less effective than first anticipated.

I further reviewed the potential drivers behind their increased use of the dredging areas during the active dredging operation. The most likely driver was considered to be a combination of the increase in turbidity and acoustic noise within the dredging areas; potentially resulting in a predator-free area and an area that may have reduced the occurrence of predator detection.

6.2 Implications for Conservation Management

As previously highlighted, flatback turtles are considered the least studied marine turtle species globally (Red List Standards & Petitions Subcommittee 1996). The likely basis for this assumption is that flatback turtles are the only marine turtle species listed by the IUCN as Data Deficient reflecting the absence of data and existing knowledge gaps highlighted in Chapter 1. However, the expansion of Australia's industry resource sector combined with a regulated EIA process has seen the generation of datasets relating to flatback turtles that feature within grey literature, including consultant reports, ESDs and EMPs. As a result, much of this proponent-owned data is very rarely published or combined and analysed as part of a larger regional scale dataset.

This PhD thesis is an exception: it is the first to focus exclusively on flatback turtle rookeries within the NWS region; and it received approval from multiple industry resource sector proponents to combine and publish data that was previously used as part of the EIA process for proposals on the NWS. Combining the datasets provided a number of advantages: it allowed for a regional scale assessment of the risk of the industry resource sector to flatback turtles on the NWS; and it supported the new science, holistic approach needed in order to consider the multiple facets of the Western Australian EIA process that proponents/regulators follow when assessing risk i.e. the screening/referral and scoping phases.

The regulator should recognise the conservation implications, management outcomes and the biological/ecological knowledge that this PhD thesis provides, and impose a mechanism that may facilitate further published studies that incorporates data generated through the EIA process. Suggestions include forming a marine turtle-specific, standardised and secure data repository that allows proponent- or consultant-generated data to be shared and used by other proponents, researchers or regulators. The repository could be equipped with a feature for due attribution and credit to data publishers allowing for data ownership rights to be respected, whilst promoting free and open sharing of data (see GBIF 2011). In addition, animal handing licences or Ministerial approvals could impose a specific (legally binding) condition that features a deadline, before data generated by the approved activity can be used or published by the regulator or other nominated stakeholder. Implementing the suggestions listed above would require a serious change of mindset, and it is hoped that the benefits that publishing this PhD thesis has for improving the understanding of risk to flatback turtles and addressing the highlighted knowledge gaps will help to bring about that change.

Since nothing is known about the spatial distribution of flatback turtles from rookeries on the NWS and the extent of the emerging threat of the industry resource sector, I assessed flatback turtle movement and behaviour during their inter-nesting and foraging life phases and investigated their overlap with areas that may host industry resource sector activities. My finding that some turtles demonstrated a nearshore distribution <10 km from the nesting site at all rookeries was consistent with a number of studies that investigated the inter-nesting distribution of other marine turtle species at other locations (e.g. Stoneburner 1982; Godley et al. 2003; Hays et al. 1999; Craig et al. 2004; Troëng et al. 2005a; Fuller et al. 2008; Troëng et al. 2005b; Whiting et al. 2006; Seney & Landry 2008; Shaver & Rubio 2008; Maxwell et al. 2011). This consistency, and high degree of spatial concentration, offers the potential for regulators to implement boundary-specific and temporally restricted marine protected areas that may achieve substantial conservation benefit. Implemented protection areas would effectively encompass a large proportion of the inter-nesting population and/or habitat (potentially defined by boundaries of the inter-nesting core home range areas outlined in Chapter 2) during certain periods of the year (i.e. between October and February). Furthermore, boundary-specific protection measures could be incorporated into a proponent's EMP for certain activities and, should there be a risk of environmental harm, the regulator could potentially impose this as an environmental approval condition for the proponent. In addition, any implemented protection areas would likely benefit the conservation of other species within the area or turtles of other life phases i.e. post-hatchling, juvenile, sub-adult.

Under the EPBC Act (1999), a proponent who considers that their activity or development has the potential to cause a significant impact on a MNES e.g. flatback turtles, must complete a screening/referral exercise to determine if the proposal requires further review and approval as part of the EIA process. Difficulties for proponents and regulators arise when determining potential impacts of offshore activities and developments, as the presence of flatback turtles are much more poorly understood and there is no information on the extent their movements may reach from their defined nesting sites during their inter-nesting and foraging life phases. This knowledge gap was addressed in Chapters 2, 3 and 4 by identifying the spatial distribution, movement and home range areas during their inter-nesting and foraging life phases. I also identified those areas of the NWS where inter-nesting flatback turtles are likely to be present or absent. This previously unavailable information can now be used by a proponent or regulator to help inform the screening/referral exercise by determining the potential presence of inter-nesting or foraging flatback turtles, with the spatial component offering an opportunity to overlap the information with the footprint of the activity/development.

At a broad scale, Chapters 2, 3 and 4 highlighted that flatback turtles have the potential to interact with industry resource sector activities within the NWS study area during both their inter-nesting and foraging life phases, with the extent of the threat varying by rookery location. When inter-nesting, movement patterns of some turtles from offshore islands were found to increase their exposure to industry resource activities, notably those turtles at Thevenard Island that were displaced up to 42.5 km from the previous nesting site resulting in them passing within 5 km of three resource sector developments situated along the mainland coast. Blumenthal et al. (2006) considered the challenges of providing protection to marine turtles that cross multiple international legislative boundaries, and while turtles in this study remained within Australian waters, their movements near to multiple development boundaries present comparable challenges in providing protection within the existing EIA process. Firstly, based on the existing knowledge gaps, the EIA process for these mainland developments is unlikely to have considered the presence of inter-nesting flatback turtles from Thevenard Island and secondly, while the regulator may consider the cumulative impact with other developments during the screening/referral phase (see factors listed in Section 1.4), the ESD is limited in its scope and does not consider the cumulative impact of multiple developments. The results presented in Chapters 2, 3 and 4 may now allow proponents and regulators to consider the potential presence of flatback turtles from multiple rookeries within a development footprint and also allow the consideration of the cumulative impact component when forming a decision during the screening/referral phase. This is particularly relevant for the areas of the NWS study area where an overlap of high inter-nesting habitat suitability and areas of high resource sector use occurred (see Chapter 4), notably offshore from Barrow Island and Port Hedland.

Chapter 3 addressed the knowledge gap relating to the location of flatback turtle foraging areas. Based on the overlap of foraging home range areas, five main separate foraging areas were delineated, with turtles tracked from multiple rookeries found to use the same foraging areas. Since it is known that turtles will return to their breeding grounds when they reach a certain body condition threshold (Alerstam et al. 2003; Hays 2000), the use of the same foraging area by multiple rookeries may result in a similar trend with regards to their life-history traits at their breeding/nesting sites across the region e.g. breeding omission probability, annual abundance. This has implications for the management of populations at the nesting sites, particularly when management decisions are based on comparisons of monitoring results at a reference site and reinforces the importance of using multiple reference sites from within the same genetic stock e.g. the Gorgon LNG development at Barrow Island and reference site at Mundabullangana.

The presence of flatback turtles from multiple rookeries within the same foraging areas highlights the conservation value of these areas. While Chapter 3 highlighted that 60% of their core foraging areas were afforded protection, regulators should consider expanding existing protected areas to increase this protection coverage. This should be considered for the identified Quondong Point foraging area (Figure 3.3) which is not currently afforded protection and has historically been under pressure from proposed major resource developments in the area e.g. James Price Point LNG hub. Adequate protection at all of the identified foraging areas is particularly important when considering the potential impact that any anthropogenic threat or hazard could have on the status of the overall regional population e.g. from an oil spill event. In addition, foraging areas generally represent habitat with high ecological value, high primary productivity where turtle prey may be aggregated (Bailey et al. 2012; Kobayashi et al. 2008; McCarthy et al. 2010) and may provide important habitat for other protected marine fauna, including other marine turtle species and marine turtles of different life phases.

Proponents and regulators should review the results of the Gorgon LNG dredging follow-up case study (Chapter 5) when considering future consequence risk matrix scores and the need for control measures/procedures to reduce the impact of dredging operations to flatback turtles elsewhere within the region. One out-of-scope control measure was the time of year that the dredging operation was conducted, with temporal variation in flatback turtle spatial distribution across the region (as highlighted in Chapers 2, 3 and 4) providing an opportunity for proponents to minimise dredging operation exposure to the receptor. For example, dredging operations could avoid areas close to a marine turtle nesting beach during their breeding and inter-nesting phases as they are likely to host a large aggregation of reproductively-active female (and potentially male) turtles e.g. ~October to February for flatback turtles on the NWS. The Gorgon LNG dredging operation presented in Chapter 5 was unable to avoid this seasonal window for the Barrow Island flatback rookery, and yet was able to prevent injury and mortality to the reproductive population through the use of control measures. Therefore, until further follow-up case studies are completed for other dredging operations in proximity to marine turtle nesting beaches, regulators and proponents should consider the implemented control measures for the Gorgon LNG dredging operation as best practice i.e. tickler/disturbance chains on the dredge vessel’s drag head; onboard presence of suitably trained MFOs; well defined response measures within a dredging operation’s EMP; and to seek alternatives to the use of dredge vessels considered to present a greater risk of entrainment to marine turtles i.e. trailing suction hopper dredges or cutter suction dredges.

Chapter 5’s results are the first to describe the variation of any marine turtle species’ movement and behaviour concurrently with different stages of a dredging operation. It is therefore unknown if the behavioural change to increase their use of an area where dredging was occurring is common behaviour for reproductively active marine turtles worldwide, or is unique to this location or species. While there is immense value in the experience and lessons learned gained from completing and communicating the follow-up for a resource sector activity, there is a need for a larger sample size and regulators should consider imposing (legally binding) Ministerial approval conditions on proponents to conduct satellite tracking of at-risk marine turtle populations (all species and life phases) during different stages of dredging and to use onboard MFOs to quantify marine turtle survivorship. Furthermore, regulators should consider the recommendations in Morrison-Saunders et al. (2007) surrounding the best practice for EIA follow-up and impose an approval condition that requires the proponent to complete an EIA follow-up and to communicate the results (Grech et al. 2013). These further experiences and lessons learned will improve the confidence of initial impact predictions made within EIAs for future developments situated elsewhere, better inform the design of control measures and to provide better protection to marine turtles during future dredging operations situated on the NWS and elsewhere.

This PhD thesis presents data that addresses knowledge gaps that fall outside the objectives and scope of this study but still have important implications for conservation management. For example, nothing is known about the diving behaviour of flatback turtles from rookeries on the NWS. The baseline dive behaviour dataset presented in Chapter 5 highlights that flatback turtles dive for an average period of 24 minutes and for a maximum period of 70 minutes. This information is particularly useful to proponents when designing response measures within a vessel/dredge EMP or when addressing potential impacts of fisheries or other in-water activities, particularly if they need to incorporate a delay before operations can recommence following the sighting of a flatback turtle at the surface.

6.3 Management Outcomes

My published work (Chapter 3) is currently being used within the revision of the Australian Government's *Recovery Plan for Marine Turtles in Australia* (Environment Australia 2003). The main objective of the recovery plan is to reduce detrimental impacts on Australian populations of marine turtles and hence promote their recovery in the wild. The recovery plan was originally implemented in 2003 to guide marine turtle management efforts in accordance with the requirements of the EPBC Act (1999). The plan is now in revision and not yet publicly available (due for release towards the end of 2016/early 2017), information relating to the location of the delineated flatback turtle foraging areas has been used by the Plan's authors to guide the spatial range of flatback turtles from the Pilbara Coast genetic stock. Additionally, the broad scale assessment involving a review of the likelihood of interaction with the industry resource sector during the inter-nesting and foraging life phases (Chapters 2, 3 and 4) has also contributed to identifying sources of potential detrimental impacts to marine turtles within the plan.

6.4 Research Limitations

This thesis utilised datasets from multiple resource sector developments, with the environmental approval and proponent for the particular development often determining the quantity of tracking unit deployments. As a result, the sampling effort in terms of tracking unit deployment was not consistent across the multiple rookeries where tracking took place. This limitation led to greater emphasis on those sites where multiple tracking units were deployed e.g. Barrow Island.

Satellite tracking data was analysed at a broad scale, providing many insights into flatback turtle spatial movements and behaviour in Western Australia for the first time. Other modern statistical and analytical tools could have been used to extract even more information from the dataset, notably through the use of switching state space models (SSSM). SSSMs allow estimation of hidden states from time series and have been widely used for modelling animal movement data (e.g. Morales et al. 2004; Bestley et al. 2012; McClintock et al. 2012), including satellite tracking data for marine turtles (e.g. Jonsen et al. 2007; Maxwell et al. 2011; Bailey et al. 2012).

6.5 Future Research or Management Direction

Undertaking a Strategic Environmental Assessment of regional development plans/policy

When considered alone, individual wells, rigs or coastal resource sector developments may not have the potential to provide realised population wide impacts to flatback turtles within the NWS study area. However, the widespread growth of the industry and the sheer quantity and scale of developments (see Figure 1.3) may present potential population wide impacts when combined (as highlighted by substantial overlaps with activities and flatback turtle distribution in Chapters 2, 3 and 4). This potential for impact is further enhanced by the broad distribution and transient, migratory behaviour exhibited by flatback turtles from the multiple populations (see Chapters 2 and 3), potentially exposing them to successive, incremental and/or combined effects of multiple project activities across the region.

The ability for an individual development to consider cumulative impact is a recognised weakness in the EIA process (Glasson 1999; Grech et al. 2013). Despite this, at present, cumulative impacts are considered by the regulator on a project-by-project basis at the screening/referral phase of an EIA, and by the proponent if required as an approval condition. Overall, this weakness in the EIA process may lead to sub-optimal environmental outcomes and inadequate protection to the target species (Glasson 1999).

One method that considers cumulative impact is through a Strategic Environmental Assessment (SEA). In Western Australia, SEA falls under Part 10 of the EPBC Act (1999) and provides for strategic assessments at a regional scale. SEA examines the potential impact of actions that might stem from one or more policy, program or plan to environmental aspects including MNES, and identifies both conservation and planning outcomes at a much larger scale compared to what can be achieved through project-by-project assessments.

SEA offers the opportunity to look at, and potentially approve, a series of new proposals or developments over a much larger scale and timeframe (even if the proponent is currently not known). Advantages of undertaking SEA include: early consideration of MNES in planning processes; greater certainty to proponents over future development; capacity to achieve better environmental outcomes; and, perhaps most importantly in this context, address cumulative impacts at a regional level (Fischer 2007).

At present, there is no known SEA for any plan or policy relating to regional development, the industry resource sector or large-scale industrial development on the NWS. Without this, there will remain little guidance to direct planning and impact management systems for addressing cumulative impacts to flatback turtles from the industry resource sector across the NWS region.

Undertaking a global review of best practice in reducing impacts of dredging to marine turtles

The results of an EIA follow-up case study involving the evaluation of the control measures implemented for the Gorgon LNG dredging operation were presented in Chapter 5. This was the first follow-up case study that included the movements and behaviour of a marine turtle population and their associated survivorship as part of the evaluation.

Considering the potential future growth of global dredging activities (see IADC 2012) and ongoing need for maintenance dredging, there is a need for a global review of dredging practices and outcomes with regards to the impact to marine turtles. The review should consider the type of dredging works, an evaluation of the methods to prevent, control or mitigate impacts on marine turtles and their habitats from the project itself, and a comparison of the predicted impacts with the realised impacts as determined using MFO records, satellite tracking data (if available) or anecdotal observations. The output guide would be useful for government agencies, port authorities and proponents, consultants, dredging related industries and other stakeholders active in the nearshore coastal zone or offshore waters.

Investigating the threat to alternative flatback turtle life phases

This PhD thesis focused on investigating the risk of the expanding industry resource sector to reproductively active female flatback turtles within the NWS region. While this life phase is considered to contribute disproportionately to sustaining the overall population compared to non-reproductively-active turtles (Gerber & Heppell 2004; Heppell et al. 1999), any emerging threat at developmental habitat utilised by flatback turtles during their post-hatchling, juvenile and sub-adult life phase has the potential to compromise the overall population if not identified and addressed (see Hamann et al. 2010). As the selection of foraging areas by individual turtles is hypothesised to reflect a combination of passive drift and active swimming experienced as hatchlings from their natal beach (Hays et al. 2010; Hamann et al. 2011), the location of foraging areas identified in Chapter 3 could host flatback turtles at different life phases. Therefore the results of Chapter 3 provide the opportunity for further investigation of these areas to not only address the existing knowledge gap of where flatback turtles go during their development phases, but may also facilitate further research using satellite tracking technology or passive drift models to help identify their potential distribution across the region, their behavioural characteristics and their potential interaction with industry activities.

Understanding the influence of turbidity and acoustic disturbance on flatback turtle distribution and behaviour

Chapter 5 suggested that a combination of turbidity and acoustic noise, generated by the active Gorgon LNG dredging operation, provided inter-nesting flatback turtles with a predator-free refuge and an area with a reduced occurrence of predator detection. As a result, turbidity and noise were considered the main contributing factor that influenced the tracked turtles to increase their use of the active dredging areas.

At present, the actual influence of both acoustic noise and turbidity on marine turtle behaviour and distribution is poorly understood (see Lenhardt 1994), with the only published study on the influence of turbidity existing for freshwater turtles (Grosse et al. 2010). It therefore remains unknown if it is a common occurrence for turbidity and noise to influence marine turtle distribution and behaviour, or if it was a one-off and an artefact of the location, conditions, species or implemented control measures.

Further research involving the use of 3D accelerometer tracking devices combined with acoustic recorders to record the frequency of interaction and the marine turtles response following acoustic disturbance is one recommended method to increase the understanding of acoustic noise and marine turtle behaviour/distribution. Depending on the conditions, the influence of turbidity on marine turtle behaviour/distribution could be investigated using tracking devices equipped with light detection meters to record the level of turbidity, or inter-nesting habitat use could be overlapped with turbidity plume data from deployed sensors or remote sensing techniques.

Investigate analysis techniques that minimise the influence of autocorrelation on animal tracking data

The advent of satellite tracking technology has led to major discoveries relating to the spatial and temporal use of multiple terrestrial and marine species. The technology has generated entirely new kinds of data, which in turn has driven the emergence of new analytical and statistical approaches. As highlighted in Chapter 3, satellite tracking data is generally highly autocorrelated and, at present, there are limited options for the animal tracking community to consider or reduce its effects during analysis. To overcome this it is suggested that a research project is conducted that investigates the performance of various methods in reducing the effects of autocorrelation on home range size and other spatial parameters. The project could investigate current filtering techniques and the influence of binning location data into different length bins.

6.6 Concluding Remarks

This thesis demonstrates that the expanding industry resource sector provides a risk of impact to NWS flatback turtles when inter-nesting and foraging offshore, though any realised impact from this threat is likely dependent on the scale that it is assessed at. At a project-by-project scale, the potential for an individual development or activity to provide a population wide impact to adult flatback turtles situated offshore is limited due to the existing regulated EIA process and variations in flatback turtle spatio-temporal movement and behaviour characteristics demonstrated at multiple rookeries in this study. At a regional scale, the movement and behaviour characteristics, spatial extent of the industry resource sector and limitations within the EIA process for assessing cumulative impact, provides potential for population wide impacts to NWS flatback turtle rookeries from the industry resource sector.

The current ‘data deficient’ status for flatback turtles is based on an IUCN assessment undertaken in 1996. Flatback turtles are therefore due for reassessment by the Marine Turtle Specialist Group (MTSG) and information provided within this PhD thesis will aid in contributing data to that reassessment.

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Appendix A

Table A Ecological Niche-Modelling variable importance for 10 fold cross validation at each rookery**.**

Ashburton Island						
Variable	**Model**			**Mean**	**StDev**	***n***
	GAM	**MARS**	**MaxEnt**			
Bath	0.517	0.796	0.463	0.592	0.149	30
Dist	0.504	0.000	0.311	0.272	0.212	30
MagA	0.366	0.094	0.275	0.245	0.116	30
Rugg	0.035	0.003	0.008	0.015	0.015	30
SST	0.570	0.636	0.552	0.586	0.038	30
Barrow Island						
Variable	**Model**			**Mean**	**StDev**	***n***
	GAM	**MARS**	**MaxEnt**			
Bath	0.371	0.287	0.347	0.335	0.050	30
Dist	0.512	0.629	0.448	0.530	0.080	30
MagA	0.086	0.006	0.078	0.056	0.037	30
Rugg	0.006	0.000	0.001	0.002	0.003	30
SST	0.245	0.087	0.170	0.167	0.070	30
Mundabullangana						
Variable	**Model**			**Mean**	**StDev**	***n***
	GAM	**MARS**	**MaxEnt**			
Bath	0.741	0.825	0.354	0.640	0.216	30
Dist	0.701	0.156	0.504	0.454	0.249	30
MagA	0.351	0.028	0.165	0.181	0.140	30
Rugg	0.224	0.001	0.030	0.085	0.102	30
SST	0.959	0.923	0.907	0.929	0.048	30
Port Hedland						
Variable	**Model**			**Mean**	**StDev**	***n***
	GAM	**MARS**	**MaxEnt**			
Bath	0.401	0.007	0.056	0.154	0.179	30
Dist	0.470	0.465	0.347	0.427	0.062	30
MagA	0.021	0.027	0.004	0.018	0.010	30
Rugg	0.030	0.000	0.002	0.011	0.014	30
SST	0.900	0.942	0.899	0.914	0.023	30
Thevenard Island						
Variable	**Model**			**Mean**	**StDev**	***n***
	GAM	**MARS**	**MaxEnt**			
Bath	0.265	0.045	0.205	0.265	0.045	30
Dist	0.542	0.806	0.434	0.542	0.806	30
MagA	0.432	0.340	0.379	0.432	0.340	30
Rugg	0.039	0.001	0.005	0.039	0.001	30
SST	0.394	0.251	0.369	0.394	0.251	30

Table B Summary statistics for Ecological Niche-Modelling evaluation metrics for 10 fold cross validation at each rookery. Algorithm abbreviations: Generalized Additive Model (GAM), Multivariate Adaptive Regression Splines (MARS) and Maximum Entropy (MaxEnt).

Ashburton Island				
Model	**Mean**	**StDev**	**Range**	***n***
GAM	0.95	0.05	0.84 – 1.00	50
MARS	0.93	0.07	0.79 – 1.00	50
MaxEnt	0.96	0.04	0.86 – 1.00	50
Barrow Island				
Model	**Mean**	**StDev**	**Range**	***n***
GAM	0.93	0.05	0.84 – 0.99	50
MARS	0.91	0.07	0.79 – 1.00	50
MaxEnt	0.93	0.06	0.84 – 1.00	50
Mundabullangana				
Model	**Mean**	**StDev**	**Range**	***n***
GAM	0.93	0.10	0.67 – 1.00	50
MARS	0.86	0.17	0.37 – 1.00	50
MaxEnt	0.91	0.13	0.53 – 1.00	50
Port Hedland				
Model	**Mean**	**StDev**	**Range**	***n***
GAM	0.95	0.05	0.83 – 1.00	50
MARS	0.96	0.05	0.84 – 1.00	50
MaxEnt	0.95	0.05	0.84 – 1.00	50
Thevenard Island				
Model	**Mean**	**StDev**	**Range**	***n***
GAM	0.91	0.10	0.68 – 1.00	50
MARS	0.89	0.13	0.63 – 1.00	50
MaxEnt	0.93	0.09	0.74 – 1.00	50