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Flexible foraging: Post-nesting flatback turtles on the Australian continental shelf

Paul A. Whittock [a,b,*], Kellie L. Pendoley [a], Mark Hamann [b]

[a] Pendoley Environmental Pty Ltd, 12a Pitt Way, Booragoon, WA 6154, Australia
[b] College of Marine and Environmental Sciences, James Cook University, Townsville, QLD 4811, Australia

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ABSTRACT

Satellite tracking was used to identify the foraging areas of post-nesting flatback turtles ($n = 66$) from four rookeries (Barrow Island, Thevenard Island, Mundabullangana and Port Hedland) within the South East Indian Ocean Regional Management Unit. 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 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 individual's 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, 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.

1. 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).

It has been widely considered how information on the use of space by marine turtles during their post-nesting life history phase can help inform conservation efforts (e.g. Schofield et al., 2010; Fossette et al., 2014; Pendoley et al., 2014a). Satellite tracking studies have revealed individual-based variability in post-nesting migrations and foraging area use among populations of each marine turtle species (Hays and Scott, 2013). Some studies show direct post-nesting migration towards a specific foraging area (e.g. Limpus and Limpus, 2001; Papi et al., 1997), while others demonstrate convoluted migration patterns (e.g. Dodd and Byles, 2003; Hatase et al., 2007; Hawkes et al., 2007) or possible prolonged residence in oceanic habitat (Hatase et al., 2002, 2007; Hawkes et al., 2006; Al Saady et al., 2010). Once at their foraging areas, some species show strong fidelity to one area (e.g. Broderick et al., 2007; Marcovaldi et al., 2010; Schofield et al., 2010), while others show movement between multiple areas across wide, geographically disparate regions (e.g. Blumenthal et al., 2006; 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.

Wide-ranging foraging area use by marine turtles presents challenges in implementing effective protection measures, particularly when these areas cross-multiple legislative boundaries (e.g. Blumenthal et al., 2006) and cover extensive areas (e.g. Dobbs, 2007). To overcome this, it is

* Corresponding author at: Pendoley Environmental Pty Ltd, 12a Pitt Way, Booragoon, WA 6154, Australia.
E-mail addresses: paul.whittock@penv.com.au, pwhittock@aol.com (P.A. Whittock).

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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).

The flatback turtle (*Natator depressus*) 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, making it a “Matter of National Environmental Significance (MNES)” under the Environment Protection and Biodiversity Conservation (EPBC) Act. Recent expansion in the industrial resource sector on the North-West Shelf (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 regional management unit (RMU) including their abundance at nesting sites (Pendoley et al., 2014b), identification of their inter-nesting areas and exposure to threats (Whittock et al., 2014) and use of a migratory corridor as they depart their nesting sites towards their foraging areas (Pendoley et al., 2014a). One aspect of their reproductive cycle that remains less known is the location and use of foraging areas during the period between breeding seasons. This gap prevents identification of the spatial and temporal overlaps of anthropogenic threats within their foraging areas (e.g. from fisheries and offshore resource developments; Wallace et al., 2011) and determining the need for their 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 and 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 from the same RMU (South East Indian Ocean) on the Australian NWS has been previously described (Pendoley et al., 2014a). Here the previous analysis is extended to consider the movement of flatback turtles on their foraging grounds, the overlap with protected areas and fisheries and hence the conservation implications. The following three aims were addressed: firstly, the location and characteristics of their foraging areas were identified. Secondly, 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, resource sector activities. Thirdly, those factors that influence their vulnerability to any identified threat exposure were investigated e.g. site fidelity, size of foraging habitat, range of areas.

2. Methods

2.1. Summary of tracking unit deployments

Between 2005 and 2013, 66 adult female flatback turtles were tracked from their nesting rookeries within the South East Indian Ocean RMU on the Australian North West Shelf (NWS) using satellite transmitters (Barrow Island, $n = 40$ turtles; Mundabullangana, $n = 2$; Port Hedland, $n = 20$; Thevenard Island, $n = 4$) to their foraging areas (see Supplementary Table 1 for turtle and transmitter information). The sample size of deployed transmitters varied at each rookery due to different environmental monitoring requirements for potential developments situated nearby.

Four different models of satellite tracking unit were used: KiwiSat101 and Fastloc GPS-Argos transmitters from Sirtrack Ltd., MK-10 from Wildlife Computers and Satellite-Relayed Data Loggers (SRDL) from St Andrews Sea Mammal Research Unit (for transmission details, see Pendoley et al., 2014a).

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 and Guinea (2004) and using the method described in Pendoley et al. (2014a).

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.

2.2. 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., 2001), (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 h^{-1} from the previous location were retained (Hays et al., 2004; Shimada et al., 2012) and (4) successive locations with turning angles >25° 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 h 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.

2.3. Determining activity

Each tracked turtle's 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 (version 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.

2.4. 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