Chapter 2: Distribution and abundance of nesting marine turtles in the Kimberley: pairing the landscape and local perspectives.

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Executive summary

An increased demand for knowledge on Kimberley marine turtle resources is driven by the establishment of new Kimberley Marine Parks, the Indigenous ranger groups responsible for on-country management, and the release of the 2017 Recovery Plan for Marine Turtles in Australia. We synthesized a background from Traditional Knowledge spanning millennia, historical accounts that spanned two centuries, and the industry related surveys of the last decade. Collectively, this information confirmed that systematic turtle nesting surveys over Kimberley coasts should span midsummer and midwinter periods at minimum.

The WAMSI Turtle Project 1.2.2 addressed this knowledge gap by conducting Kimberley-wide aerial surveys of turtle tracks in January and August 2014 which were complimented by on ground surveys for verification and temporal coverage. The aerial photos of beaches included all known rookeries and 91% of the Kimberley islands and mainland coasts. Over 44,000 georeferenced aerial images were annotated to quantify visual evidence of turtle tracks or body pits. On-ground surveys were conducted in 37 accessible locations after 22 field trips and 44 meetings to verify species by visual inspection of track characteristics. A single summer and winter season snapshot inventory quantified Kimberley turtle nesting at scales of 1-10s-100s-1000s of tracks.

The track data for GIS layers were classed into low, medium, and high track counts. Tracks can be discerned on almost all silica sand beaches across the Kimberley, with fewer tracks recorded in coastal stretches bordered by rocky cliffs or mangroves. The higher aggregations of tracks (above median of 20 nests) identify beaches significant to management interests. The most important rookeries ranked by track counts and density were winter flatbacks at Cape Domett, summer greens at the Lacepede Islands and summer flatbacks at Wallal Downs-Eighty Mile Beach. Aerial surveys had low probability to detect olive ridley or hawksbill turtles because these species are believed to be sparse and isolated in the Kimberley, the relatively shallow tracks of lighter-bodied species do not have a long duration and the survey period was not in phase with their seasonal phenology. No leatherback or loggerhead tracks were recorded although migrations through the region are known through Indigenous knowledge, fisheries bycatch or satellite telemetry.

The surveys enabled a preliminary multi-objective decision framework relevant to landscape understanding for Commonwealth and State interests and new detailed data for local management by Traditional Owners through land claims, Indigenous Protected Areas and Healthy Country Plans. Integrating landscape and local perspectives has identified the priority turtle beaches and facilitated strategic recommendations for future studies and monitoring.

1. Introduction

Six of the world's seven species of marine turtles are found in the Kimberley: green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), flatback (*Natator depressus*), loggerhead (*Caretta caretta*), olive ridley (*Lepidochelys olivacea*) and the leatherback (*Dermochelys coriacea*). However, the Kimberley coast presents a large quantitative gap in marine turtle knowledge for Indian Ocean waters.

Limited quantitative data and anecdotal evidence indicates that green and flatback turtles nest in significant numbers in the Kimberley region, with minor records of olive ridley and hawksbill turtles. No leatherback turtles have been recorded nesting, with only incidental records of loggerhead turtles recorded on offshore islands in Commonwealth waters.

1.1 Pre- WAMSI knowledge of Kimberley turtle stocks

A systematic collation and review of all available Indigenous Traditional Knowledge, historical records from early explorers and Fisheries Department archives, anecdotal information, tourist operator photographic records, grey literature, publicly available satellite imagery, industry reports and the published literature was carried out to identify knowledge gaps and to provide a basis for designing a regional monitoring program to identify the seasonal marine turtle habitat use in the Kimberley.

Indigenous traditional knowledge of turtles has a strong connection with cultural use and consumption and is passed on verbally in reference to seasonality, e.g. where local green turtles feed, recognising seasonal migration of incoming fatter green females, or the seasonal abundance of turtle eggs to harvest. The rich empirical knowledge is understood within the context of each group's saltwater country, but is not assimilated collectively across group boundaries at a broader spatial scope of the Kimberley.

Early maritime explorers left accounts of marine turtle presence for the Kimberley region (King 1827), as did the Macassan trepang trade (Macknight 1969; Macknight 1976), other explorers (Stuart 1923) and early settlers (Green 2011). The accounts identify the turtle species for consumption, by tracks on a beach, egg harvests, or those removed in tortoiseshell trade. The historical accounts offer modern biologists an opportunity to extract details about species by date or place. For example, the flatback turtles on Lacrosse Island were at first erroneously identified as loggerheads (Stuart 1923), which is understandable given that flatback turtle were not formally described until 1977. Jones Island was identified as a place for harvest of tortoiseshell (King 1827). The large turtle numbers reported from Jones and Lacrosse Islands are much reduced in abundance today, and might correlate with the passage of cyclones that altered or removed nesting beaches or over fishing of hawksbills for the tortoiseshell trade.

Early compilations were derived on Coastwatch flights and interviews with coastal residents for a WA synthesis of turtle biology by Prince (1984, 1994), augmented nationally by Limpus (2002), with both recognizing the challenges in accessing the Kimberley, hampering dedicated surveys. Limited accounts for six marine turtle species were reported, with selected rookeries recognized as having high activity although unquantified nesting density. Environmental consultants engaged during the 2000's during a decade of petroleum and natural gas exploration (RPS 2009, 2010, Waayers 2014) evaluated turtle activities in areas overlapped by industrial operations. Potential options for construction of production facilities were explored, but not completed, on Cassini Island and Maret Island by INPEX, and in the Dampier Peninsula/Lacepede areas adjacent to Woodside's James Price Point plans. Aerial surveys, tracking studies and on-ground surveys were conducted bounding the Lacepede Islands, and a selection of the north Kimberley islands, under evaluation for petroleum refineries or airbase operations (RPS 2010). These published accounts added new locations onto a growing industrial awareness of Biologically Important Areas for Kimberley turtles at the nesting grounds. Satellite telemetry studies are completed or ongoing for many of these Kimberley rookeries (Waayers et al. 2017).

Focal place studies have been conducted in the Kimberley, investigating nesting seasonality (Whiting et al. 2008) and crocodile predation (Whiting and Whiting 2011, Koeyers et al. 2015). Sparse nesting by olive ridleys in the Kimberley was detailed by Prince et al. (2011). Loggerhead migration records terminated in the Kimberley but no nesting was noted north of the south Pilbara boundaries (Prince 1998). Genetic studies that included selected WA rookeries were able to define preliminary management units of loggerheads, greens, hawksbills, flatbacks, and olive ridleys (FitzSimmons and Limpus 2014). However, the Kimberley region was not systematically resampled to delineate stock structure in the Indian Ocean until WAMSI. Accounts for northern Australia flatback turtles distinguished a northern winter nesting component and southern summer nesting component (Limpus 2003). Green turtle rookeries had summer nesting peaks, although there was limited evidence of low nesting nearly year-round in the north latitudes. Hawksbill nesting was considered sparse and scattered in the Kimberley, but complicated to investigate when the dispersed nesting on small upper beaches would be difficult to document in the same manner as other species that aggregate in large numbers to nest.

Kimberley history on hawksbill harvest is sketchily related to early records of Jones Island which was visited for tortoiseshell harvests by Macassan and Indonesian sailors for trepang (Stacey 2007), but records of trade were not detailed on take of turtles by rookery (Halkyard 2009). The hawksbills taken by Indonesian fishers in the Kimberley waters were not well documented and export trade was underestimated from the actual historical exploitation that took place. Illegal, undocumented and unreported harvest by the tortoise shell industry likely had a significant impact on hawksbill populations in the state’s north even though it is difficult to pinpoint where the fishing effort was concentrated and which foraging and/ breeding aggregations were most impacted, as many of the records are missing in the WA fishing license records(Aldrich 1934).

In recent years, joint surveys between NAILSMA, CSIRO and Kimberley ranger groups have counted turtles during in-water surveys at selected sites; i.e. Montgomery Reef with Dambimangari, Sunday Island with Bardi Jawi, and Mary Island with Wunambal Gaambera. The in-water surveys are valuable for knowledge sharing and for the rigorous methods used in data collection (Bayliss et al. 2015, Jackson et al. 2015), however these results are disassociated with nesting beach studies that collect track census data and are the primary means of tracking trends in turtle population status (SWOT 2011).

Marine turtles are important to Kimberley Indigenous residents for cultural purposes and as food resources. Many Healthy Country Plans contain specific details regarding important nesting and foraging places, maps or seasonal timing of breeding and migration (Kimberley Land Council 2010, Wunambal Gaambera Aboriginal Corporation 2010, Balanggarra Aboriginal Corporation 2011, Dambimangari Aboriginal Corporation 2012, Bardi Jawi Niimidiman Aboriginal Corporation 2013, KaraJarri Traditional Lands Association 2014).

We systematically searched for images displayed on the internet by Kimberley tourist boats or private boats. Although this data set was sparse, images were accepted with geo-tags or if place-named and if the species track could be identified independently by two turtle experts.

This desktop study recognized that the knowledge gaps in turtle nesting for the Kimberley could only be filled efficiently by a spatially and temporally coordinated aerial survey to capture images of the nesting tracks left on all beaches. The background established an essential foundation to the WAMSI turtle study: determining the distribution and abundance of marine turtle nesting in the Kimberley.

1.2 Kimberley marine turtle stocks-current status

1.2.1 Green turtles

Green turtle breeding in the Kimberley occurs within three genetic stocks (north-west Australia, Scott Reef/Browse Island and Ashmore Reef) (FitzSimmons and Limpus 2014). Inshore breeding locations include the Lacepede Islands and several other medium density nesting sites along the North Kimberley coast. Green turtles that were flipper tagged on the Lacepede Islands in 1987-2002 have migrated to the Pilbara, the Northern Territory and Indonesia (Prince 1994; 1998). Green turtle post-nesting migration and inter-nesting studies have been conducted using satellite telemetry from Scott Reef, the Lacepede Islands and Maret Island by consultants (Pendoley 2005;reviewed by Waayers et al. 2017)

Green turtles feed predominantly on seagrass and algae and therefore foraging sites occur in shallow predictable habitats. Green turtle foraging locations will be spread along the Kimberley coast with some hot spot areas correlated with amount and quality of food. Montgomery Reef and Long Reef are known to support significant numbers of green turtles. Green turtles foraging on the Kimberley coast have also been tracked from their nesting sites in Java [http://www.wildlifetracking.org/index.shtml?project_id=275&dyn=1509436089].

1.2.2 Flatback turtles

The genetic stocks are still being refined for flatback turtles with new information offered in Chapter 3. The

Kimberley has not been sampled adequately except for Cape Domett, which appears to be a separate stock to the Northern Territory and Pilbara stocks. The stock composition is a major gap for flatbacks in the Kimberley.

Flatback turtles nest throughout the Kimberley with major known nesting sites occurring at Cape Domett (Whiting et al. 2008) and the Lacepede Islands (Prince 1998). Moderate nesting occurs on the other islands such as Helpman and Slate Islands (Prince 1994) and Maret Islands, while low density nesting occurs on many beaches through the region (S. Whiting pers. comm.). Flatback nesting is restricted to the mainland coast and inshore islands with no flatback nesting occurring on the mid and outer shelf islands.

Knowledge of foraging habitats for flatback turtles has come from trawl by-catch records and satellite tracking data. Since 2000 and the introduction of TED's few turtles are captured. However, more than 100 satellite tags have been attached to turtles, principally from Pilbara rookeries, providing a comprehensive record on migration and foraging habitat locations (Pendoley et al. 2014, Whittock et al. 2016, Thums et al. 2017, Waayers et al. 2017). Although many studies are ongoing with data yet unpublished, available data suggest key Kimberley foraging sites are in depths of 50-100 m NW of Dampier Peninsula and extending north to the Holothuria Banks.

1.2.3 Hawksbill turtles

There are currently two identified breeding stocks of hawksbill turtles (NE Queensland and Western Australia) (Vargas et al. 2015). The NE Arnhem Land nesting aggregation is managed as a separate management unit (Department of Environment and Energy 2017). Hawksbill nesting in WA is centred on the Pilbara (Dampier Archipelago). Incidental hawksbill nesting has been recorded in the Kimberley (Prince 1994) and at Ashmore Reef (Whiting and Guinea 2005). Hawksbills are likely to be found throughout the Kimberley waters. Reef types (coral, sponge and algal communities) in the Northern Territory, that are similar to Montgomery Reef, support some of the highest densities of hawksbills in the world (Whiting 2001).

1.2.4 Olive ridley turtles

Olive ridley nesting in Australia is aggregated in two locations: Arnhem Land and Western Cape York that are recognized as separate genetic stocks (Jensen et al 2013). Incidental nesting by olive ridleys has been recorded in the Kimberley (Prince et al. 2011) but yet to be considered in stock determination (Jensen and FitzSimmons, pers. comm.)

In Australia, olive ridley foraging habitat has been defined by two satellite tracking studies (Whiting et al 2008, McMahon et al 2008), trawling bycatch records (Robins et al. 2002) and two mortality events (Guinea 1992; Guinea and Whiting 1997). Together, these indicate that the foraging habitat ranges from 10 to 200 m in depth and both nearshore and offshore locations.

1.2.5 Loggerhead turtles

Loggerheads nest in two genetically distinct aggregations in Australia: SE Queensland and Pilbara WA. Loggerhead turtles are usually temperate nesters, although a verified nesting record exists for Ashmore Reef (Whiting and Guinea 2005)

Loggerhead turtles are likely to feed through the Kimberley waters over a wide depth range (10-60m) and wide range of habitats. They have been found in muddy nearshore waters of the Northern Territory (Guinea 1992) but also occur in clear water on the reef flats at Ashmore Reef in significant numbers. Unpublished tracking of post-nesting female loggerheads from Ningaloo indicates mid-shelf foraging habitat in the Kimberley (Mau et al. 2013).

1.2.6 Leatherback turtles

Leatherbacks are sporadic and irregular nesters in Australia at the rate of a few records a year. Regular nesting that did occur in southern Queensland no longer occurs because of high mortality in the Pacific. The only other nesting location is at Danger Point, Cobourg Peninsula, Northern Territory where low density nesting is recorded every three or four years. No genetic analysis of this stock has been conducted.

Leatherbacks are pelagic feeders and are expected to occur intermittently throughout the Kimberley region, but more commonly offshore.

2 Materials and methods

2.1 Background

Our aims were to map the distribution and relative density of marine turtle nesting across the Kimberley from the Northern Territory border to the southern end of Eighty Mile Beach. The Kimberley bioregion includes 2633 islands and 1375 mainland beaches, all of which were easily recognised in close views of Google Earth images, or identified via remotely sensed data with GIS methods.

Turtles might feasibly visit any beaches with well drained silica sands. Also, longer contiguous beach lengths correlate with medium to higher density over a nesting season. We selected 100m beach lengths to coincide with the smallest beaches measured for the Australian Beach Safety and Management Program dataset (Short 2006a, 2006b) and because beaches >100 were distinguished readily on remotely sensed images. Potential flight paths that link the nesting beach targets were planned to enable efficient coverage with georeferenced aerial images.

The primary mission was to photo-capture and quantify all recent turtle tracks at a landscape scale. The survey specifically included low density nesting beaches since snapshot counts across a vast coastline can extrapolate to a large number of nesting females over a season spanning many months. Also, of interest was the identity of hotspot areas of medium to higher track counts or density since the identification of potential sites for a more detailed study by ground truth survey must take into account both nesting activity (as measured by the track counts), and logistic and accessibility considerations.

Sites demonstrating high track counts will be important to monitor, but logistics to access the beaches will determine the frequency and likelihood of long-term data collection. Beaches with low nesting effort but with high convenience in access and logistics might be relevant for a community conservation group to manage at modest agency expense. The middle ground for a population study might have more detailed information collected by a specific tagging study, whether saturation mark-recapture involving nocturnal patrols, or more selective tracking by satellite telemetry or biologging technology as complimentary methods.

Aerial surveys are an additional tool that can be used as part of a larger monitoring program, recognising that there is a trade-off between low altitude flights with high detail, or high altitude to define larger scale phenomena (Eckert et al. 1989, Hopkins and Schroeder 1989, SWOT 2011).

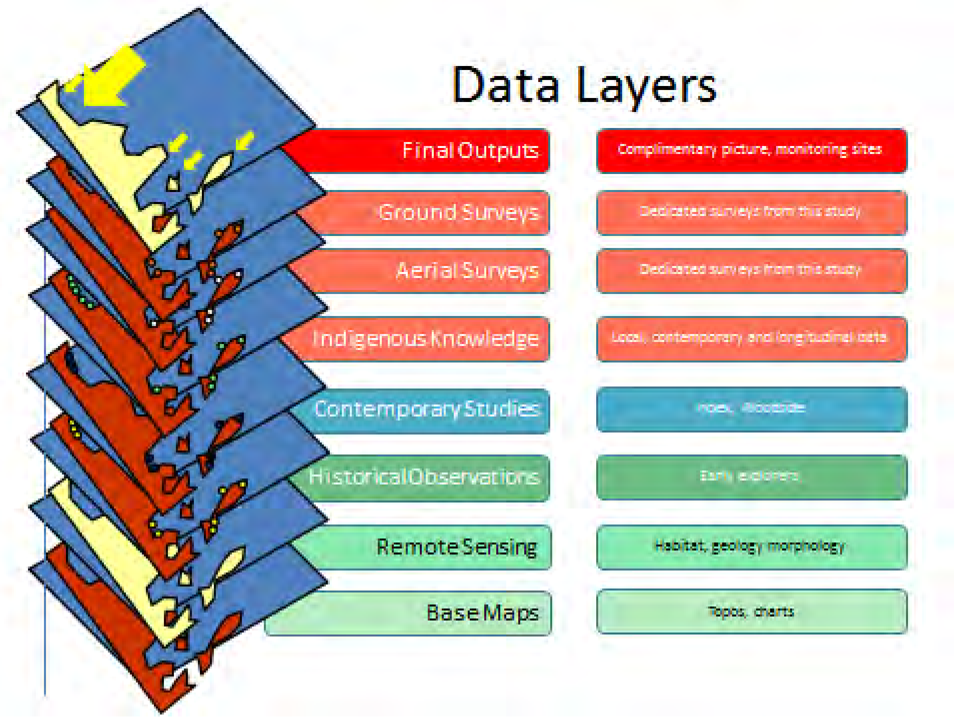


Figure 1. Knowledge from a diversity of sources and different perspectives was merged to yield a baseline inventory.

2.2 Locations distilled from pre-WAMSI surveys

The distillation of the desktop study of known nesting locations (Section 1.1) was used to compile a first layer of essential targets for image acquisition (Figure 1). Rookeries recognised from earlier ground-based surveys as high density nesting were included by default (e.g., Cape Domett, Maret Island, Montelivet Island, Cassini Island, and Lacepede Islands Eighty Mile Beach). A second layer of mainland beaches >100 m was added from the Surf Lifesaving Atlas (Short 2006). A third layer of offshore island beaches was added from Google Earth Images showing visible beaches. We made ad hoc searches for internet images by search terms 'Kimberley turtle' by Kimberley tourist boats or private boats. Although sparse in number compared to other data sources, images were accepted with geo-tags or place-named images if the species track could be recognized by two turtle experts. A fourth layer was evaluated for offshore island names from Department of Land Acquisition (DOLA). These preliminary layers offered a search structure for further refinement by predictive modelling and classification. Aerial surveys of nesting density at Eighty Mile Beach were conducted independent of the WAMSI flights in 2012, 2014, and 2016 (Pendoley Environmental 2017).

2.3 Predictive modelling (GIS) of potential beaches

Desktop GIS models classified the white pixels visible in Landgate images in ARCGIS as potential nesting beaches with highly reflective, dry sand beaches using medium resolution Landsat Thematic Mapper (TM) 5 and Landsat Enhanced Thematic Mapper (ETM) 7 satellite imagery with 25m pixels. This method involved detecting “bright white pixels” as beaches across the Kimberley Coastline by applying a simple brightness index using Landsat bands 1 (Blue), 2 (Green) and 3 (Red)and thresholding the brightest pixels in each band. Geology regions were used where the spectral signature for beaches changed so then the threshold values was also altered to suit.

Where higher resolution satellite imagery such as Rapideye was available (a pixel resolution of 6 m) the same method was applied to give a more detailed beach dataset. Both high resolution and medium resolution beach datasets were cleaned by removing everything picked up inside a buffer for the mainland and islands. These buffers removed anything detected as bright white at a distance greater than 1300m from the mainland coastline and at a distance greater than 500 m from the Island coastline. A quick visual inspection and clean-up of false positive was also carried out. The final remotely sensed “beach” dataset was then used to visually identify all significant beaches across the Kimberley mainland and Island coastline to plan a conservative flight path.

2.4 Flight Path Planning-efficiently connecting the sandy pixels (beaches)

The combined products of Marine Sciences and GIS formed initial maps of known or assumed beach habitats. The 'sand pixels' of adjacent beaches were connected by a flight path between two refuelling stops at remote Kimberley airstrips. A desktop planning phase connected all significant beaches (>100m) and offshore islands as potential targets on linked flight paths accounted for 8+ days of flights considering re-flights or bad weather days. Recent (2014) Google Earth Imagery was cached to a tablet for ready reference during the flight and for pre-flight planning. The flight dates coincided with morning low tides and spring tides to enhance visibility of fresh turtle tracks (Schroeder and Murphy 1999). Factors affecting data collection and quality during the survey included smoke from bush fires, local cloud cover, and technical malfunction which caused gaps in coverage or degraded images on a subset of flights, which were re-flown the following day where logistical constraints permitted.

2.5 Image Capture- overflights in summer and winter for georeferenced images

Flight planning and logistics were managed by Pendoley Environmental staff and were consistent with similar surveys at Eighty Mile Beach (Pendoley Environmental 2017). A digital camera was mounted inside the wing of a small, fast and manoeuvrable Cirrus SR20 aircraft to acquire overlapping geotagged images of turtle tracks on the selected survey beaches (Figure 2). The digital camera was operated by the crew. A visual count from aircraft cockpit was carried out in tandem with the images. Images were partially overlapping because of variable weather conditions (i.e. wind effects on flight path), logistical constraints (fuel availability and mobilisation distances each day), flight altitude or speed during the survey, but were planned to achieve a 20% overlap between adjacent images.

Aerial surveys were flown for 8 consecutive days of winter and summer 2014 to completely span the Kimberley coast (Figure 3). The images were obtained during sequential daily flight segments, beginning at the WA/NT border (-14.8818 S, 129.9875 E) and continued until reaching the western limit of Eighty Mile Beach Marine Park (-19.9664 S, 119.0814 E) (Table 1). Daily flight segments were constrained by the limited availability of both accommodation facilities for the survey crew and air strips with aviation fuel. The segments between the NT border and York Sound were mobilised out of Kalumburu for Day 1 – Day 4, while the southern Kimberley from York sound to the De Grey River were mobilised from Derby for the balance of the survey.

Data extracted from the images (Figure 4) included the geo-referenced ID number, by latitude and longitude in decimal degrees, with flight attributes of date/time, altitude, heading, and sequence. The metadata for all images were timestamped with geo-references from the flight navigation instruments. Images were downloaded to a portable hard drive and transferred to DBCA.

The primary limitations of this initial scoping survey were based around delineation of survey sections. Other limitations associated with the track census survey included overnight winds, high tides and cyclonic activity can erase tracks making accurate interpretation difficult. The survey targeted the known peak of the nesting season when nesting density is high and therefore some tracks may have been partially obscured, negatively impacting data resolution. In addition, a turtle may re-emerge on the same or several consecutive nights if nesting is unsuccessful, obscuring tracks or increasing the number of recorded tracks for an individual. Marine turtles nest over approximately 3+ months in this region. A three to four day snap shot survey of each beach is limited and greater temporal coverage (i.e. over more days during the peak nesting season) would provide greater confidence in results. The aircraft height and speed impacts on the collection of aerial images as a result of environmental factors (wind and rain), aircraft operations and flight planning. The impact of the vast distances that must be covered and the complete lack of support facilities for the aircraft and crew cannot be underestimated. The length of the survey and its position within the lunar cycle may introduce some error relating to tidal state, particularly at Eighty Mile Beach where the tidal range is large and the intertidal zone is very broad. While a statistical relationship between nesting effort and lunar phase has not been established, anecdotal evidence suggests lunar phase may influence temporal distribution of adult emergencies and thus the recorded track figures may vary depending on position of the sampling period within the lunar cycle.

Moreover the persistence of track features below the vegetated dune crests can vary depending on weather (recent rain or extended dry), wind (orientation and extent of exposure to prevailing winds), time of day (AM flights with heightened contrast), season (winter flights with lower sun angles), tide (spring high tides better to distinguish recent tracks from older tracks), sand colour (white quartz sand has high reflectance and images show low contrast), suspended particulates or aerosol (terrestrial burning and hazy days yield a unfocused image).

Despite these variables, aerial images at 160-200 m altitude gave enough image contrasts to reliably recognize tracks or old pits (1 m wide), whether or not it was possible to define species (unknown, flatback, green, and hawksbill were choices). Better image quality could resolve and document a range of vertebrates (predated nests by foxes = 0.5 m, hatchling track fans=10 cm wide; human footprints and cattle tracks = 10-20 cm, turtles swimming = 1 m, turtle tracks = 1 m, crocodiles 3-5 m; humpback whales 12-16m).

Beach characteristics of the Kimberley coasts were provided in a GIS dataset that accompanies an atlas of Australian mainland beaches (Short 2006a, 2006b). A systematic verification and granulometric analysis (a bag of sand collected, n = 50 turtle beaches from Dirk Hartog National Park north to Cape Domett) confirmed a good match of sand characteristics regardless of mainland or island source. Previous studies have demonstrated turtle preference for certain sand characteristics defined by acceptable ranges of humidity, drainage, albedo, and thermal retention.

Figure 2. The aircraft used for aerial surveys (Image: Pendoley Environmental).

Figure 3. Illustration of planned flight paths for Kimberley aerial surveys of turtle tracks.

2.6 Image review, annotation, classification, quantification

The laboratory quantification of images and annotations was conducted with a simultaneous display on two LCD screens. One screen displayed an Excel worksheet for annotation and Google Earth. The second screen displayed an image library in Picassa 3.9 using its sidebar location for georeferenced images to “re-fly” the flight path, and enlarge each image to examine or enumerate features of interest.

DBCA biologists reviewed the geotagged images to classify and count fresh or old tracks, and establish species if possible from track characteristics. The excel spreadsheets on images were further annotated with terrain (water, sand, rock, land, reef, mud, mangrove, sandflat), track counts, pit counts, species or other detail, and a descriptive text to cross reference to named features on nautical charts or terrestrial maps.

The compiled survey data were classified by log-log transformation of track counts and nest density and plotted to evaluate classes at small (S: 1-10), medium (M: 10-100), large (L: 100-1000), and extra-large (XL: >1000) levels.

Figure 4. This aerial image obtained from photo-documentation during aerial surveys shows the track evidence available for interpretation for species identification, behavioural assessment (up and down tracks shown by red arrows) and potential nests (circled area indicating fluffy thrown sand, and human activity (footprints indicate scale). Image: Pendoley Environmental.

This aerial image obtained from photo-documentation during aerial surveys shows the track evidence available for interpretation for species identification, behavioural assessment (up and down tracks shown by red arrows) and potential nests (circled area indicating fluffy thrown sand, and human activity (footprints indicate scale). Image: Pendoley Environmental.

2.7 Ground truthing coordinated with established ranger groups (11 groups)

The aerial images were also used to identify sites for a local ground truthing visual inspection (Figure 5). We conducted daytime ground patrols during or shortly after flight dates to give verification of species ID and track counts to the aerial images. The ground team coordinated with the Kimberley Land Council Research Ethics Advisory Committee and while the objective was to ground truth a flight segment on the day it was flow, it was proven to be logistically impractical due to the large distances involved in the wide-spread flights and the coordination across 11 indigenous groups. Although helicopter flights were considered, the logistic constraints around refuelling discounted this as an option.

To complete the ground truth surveys, we opportunistically took advantage of boats scheduled to travel to remote/outer islands or mainland coasts, float planes, helicopter or aeroplane surveys employed in other researcher programs (weed removal, materials transport, fire management). Overall, we established 37 locations that could be evaluated for species identification by an experienced or reliable set of observers. Track photos submitted by untrained viewers were accepted after evaluation of images at higher magnification. Photo verification and training was consistent with the DBCA turtle monitoring field guide (2016) or in the field training of indigenous rangers (all 11 groups). We observed that TOs were unfailingly accurate for species ID with the most frequently encountered species in summer or winter seasons (99% were either flatback or green, with isolated tracks for olive ridley and hawksbill turtles). Field validation was conducted on 27 field trips or 44 meetings or presentations by project staff in 2013-2017 to add ground-level verification on turtle species and traditional knowledge from 11 groups of indigenous rangers.

Ground truth surveys ideally occurred at six beaches during summer flights (including the two most abundant track counts for Lacepede Islands and Eighty Mile Beach, and lesser rookeries scattered across the outer islands) and 29 beaches on winter flights (including Cape Domett, Cassini Is, Maret Isles, Helpman Isles, Troughton Is, Jones Is, and lesser rookeries).

Figure 5. Rangers undertake patrols to check the species and activity in Camden Sound Marine Park.

2.8 GIS products

Photo-mosaics were assembled as a GIS product for geospatial analysis of track counts to establish densities in summer and winter. Post-processing the multiple days of the 2014 aerial survey data was undertaken in steps:

- Producing a single dataset containing all aerial turtle survey points representing the location of individual image capture;
- Completing attribution to agreed specification to include Image file name, date of survey, season, and

turtle observation data for each image;
- Defining a polygon feature dataset containing the extents of individual images as part of the aerial turtle survey;
- Producing final datasets that included a priority rating for turtle sites identified by aerial photography;
- Linking image files to spatial data; and
- Producing image mosaics for individual beach sections so that analysis of turtle tracks can be completed from composite images.

Original data from the 2014 Aerial Turtle Survey included image point location data in .xlsx format for both winter and summer and included attributes such as – latitude, longitude, location name, tracks, pits, species and observations. Image metadata were supplied in .txt format while .kml files for each flight segment contained the geographical footprint extent of each image captured. Separate folders contained images captured for each daily flight segment, organised by survey date.

Work required preparing the dataset ready for processing, analysis and online viewing included the linking of the each image's metadata to the appropriate image folder by adding the date attribute to the turtle survey point data. Additional attributes were added for SEASON, PROJECT_NAME and PRIORITY. Point features for each day of the aerial turtle survey were then annotated into one point feature dataset: Turtle_Aerial_Survey. The kml files containing the spatial extent of each image were examined as closed line features. FME was used to convert these lines to polygons. For any .kml files that lacked attribution, the image attribution was carefully aligned to the correct image extent polygon. Once attributed the polygons for the image extents were loaded into one polygon feature. Additional features were generated to illustrate priority sites and priority site coverage for the 2014 survey.

Based on a review of the raw aerial survey data the following recommendations should be considered for future aerial surveys:

- data attribution should be to a pre-defined and agreed upon design;
- where attributes are captured as a .csv or .xlsx file correct attribution according to data type should be defined and collected;
- KML files containing image extents should be generated with polygon features; and
- each polygon feature should be attributed with the image name and date.

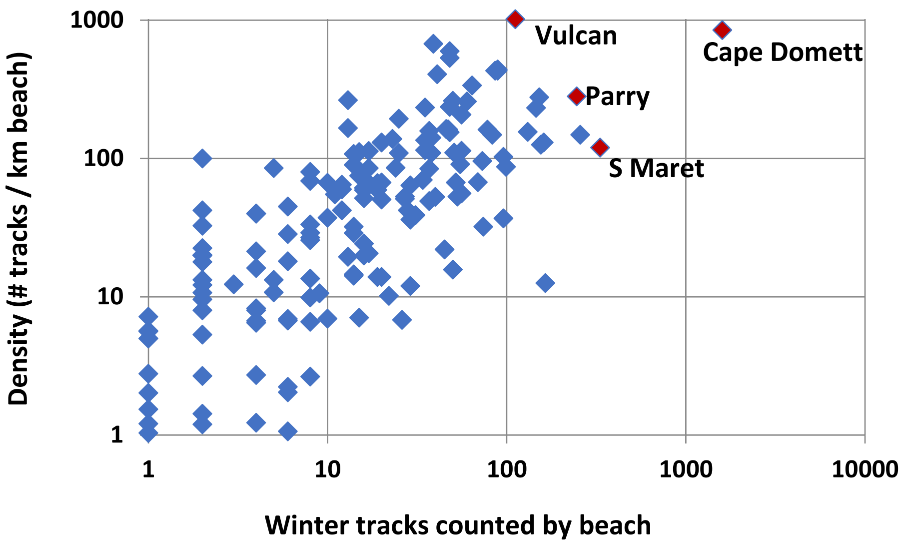
3 Results

3.1 Coverage and track determination

Near complete coverage of the Kimberley islands and coast was achieved in survey snap shots of eight to nine flight days in summer nesting season and again for winter nesting season. We captured >44,000 georeferenced aerial images to analyse and annotate with classifications of terrain type, and to quantify the visual evidence of crawl tracks or body pits. Flights were repeated in summer 2014 and winter 2014 to cover presumed midpoints of the nesting seasons since the Kimberley has diffuse year round nesting by green turtles but also summer and winter nesting by flatbacks. We estimate that >90% of all beaches among the 2,633 islands and 1,375 mainland beaches were covered by flights. These provided guidance for later verification by ground surveys in accessible areas.

The broad findings were referenced to the Dampier Peninsula. The North Kimberley (East of the Dampier Peninsula) encompasses two nesting seasons: winter nesting is primarily by flatback turtles and summer nesting is primarily by green turtle nesting. The West Kimberley (Southwest from the Dampier Peninsula through the western boundary of Eighty Mile Beach) hosts summer nesting primarily by flatback turtles.

A scatterplot of track counts against density at a log-log scale (Figure 6) identified three locations (Eighty Mile Beach, Lacepede Islands, and Cape Domett) as clear outliers in the highest scaled category. These rookeries were reported separately to avoid numeric bias of outlier values in statistical analyses. We add a caveat to the conservative estimates at the three high density rookeries because we likely missed tracks that were covered or obscured by later females. Raw data are given for season, placename, track counts, beach length, and density in Appendix 1 and 2.



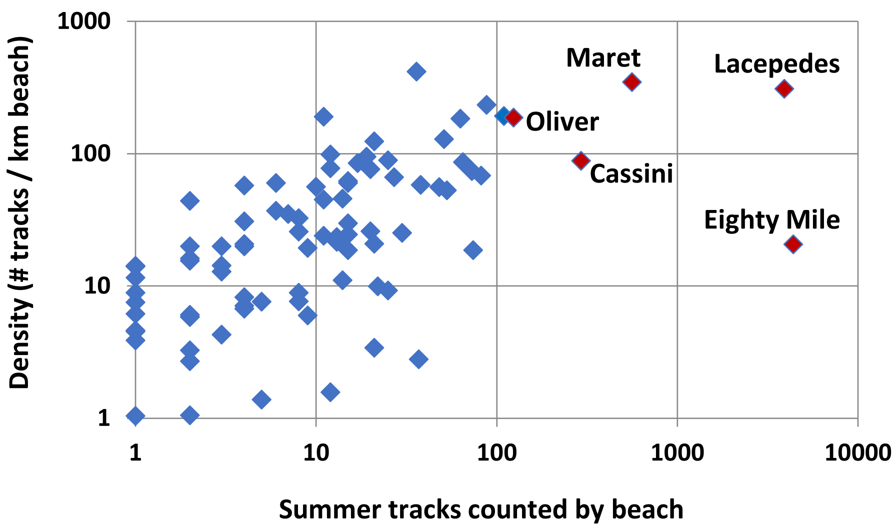


Figure 6. Scatterplots of track counts by beach against density (# tracks/ km beach) on log-log scale indicate three rookeries in the largest categories at upper right. We treated these rookeries separately (Cape Domett, Lacepede Islands, and Eighty Mile Beach) and excluded them from statistical analysis to avoid numerical biases.

3.2 Winter nesting

A total of 167 beaches hosted visible winter tracks (Figure 7, Figure 8). The high track activity at Cape Domett is reported separately before excluding it from further statistics. Cape Domett had a track count of 1598 tracks for 1.9 km and a density of 847.2 tracks per km.

Excluding Cape Domett, the mean number of winter tracks was 32.1 (n=166, SD = 48.2, range 0-333), a mean beach length was 0.7 km (n=166, SD = 1.3, range 0.1 -13.1 km) and mean track density was 85.4 tracks per km, SD = 137.5, range 0.7 – 1017 tracks per km.

Ranking the top ten winter rookeries for tracks counted (Appendix 1, Table 3) were Cape Domett followed by South Maret (333), Cassini (257), Parry Island (246), East Shakespeare Hill (164), SW Osbourne Island (161), Coronation Island (155), Keraudren Island (152) Kunjumal Kutangari Island (146), East Montalivet (131), Vulcan

Island (112) and North Maret Island (99). Ranking by density was biased by some short beaches that inflated the density. However, the same rookeries found by track counts commonly had density of >100 tracks/ km with the exceptions of North Maret (87/ km) and East Shakespeare Hill (13/ km).

3.3 Summer nesting

A total of 91 beaches hosted visible summer tracks (Figure 7, Figure 8). The high track activity at the Lacepede Islands and Eighty Mile Beach is reported separately before excluding the locations from further statistics. The Lacepede Islands had 3910 tracks over 12.6 km, for a density of 309 tracks/ km.

Eighty Mile Beach had 4387 tracks, over 212 km, and density of 20.7 tracks per km. However, the means do not reveal that Eighty Mile tracks are concentrated into two beach sections, Wallal in the south and Anna Plains in the north which are interspersed by coastal stretches of barren sand flats or exposed limestone that preclude any nesting. Track counts adjacent to Wallal represented 31.2-52.4 % of all tracks on Eighty Mile Beach, and were consistent with the results of the biennial aerial surveys in 2012, 2014, 2016 which were independent of the WAMSI flights (Pendoley Environmental 2017).

Excluding the Lacepede Islands and Eighty Mile Beach, the mean number of summer tracks was 27.4 (n=89, SD = 68.9, range 1-562), a mean beach length was 1.2 km (n=78, SD = 2.3, range 0.1 -13.2 km) and a mean track density was 48.1 tracks per km, SD = 74.9, range 0.7 – 417 tracks per km.

Ranking the top ten summer rookeries for tracks counted per beach (Appendix 2, Table 4) were Eighty Mile Beach and Lacepede Islands, followed by Maret Island (562) Cassini (293), Parry Island (124), Oliver Island (110), Bougainville Peninsula (88), West Montelivet Island (82), Sir Graham Moore (74) and Condillac Island (73). Ranking by density was biased again by the short beach stretches that inflate the density. High track densities (tracks per kilometre) were recorded from: Maret Island (345), all the Lacepede Islands (309), Oliver Islands (192), Parry Island (186), and Cassini Island (88).

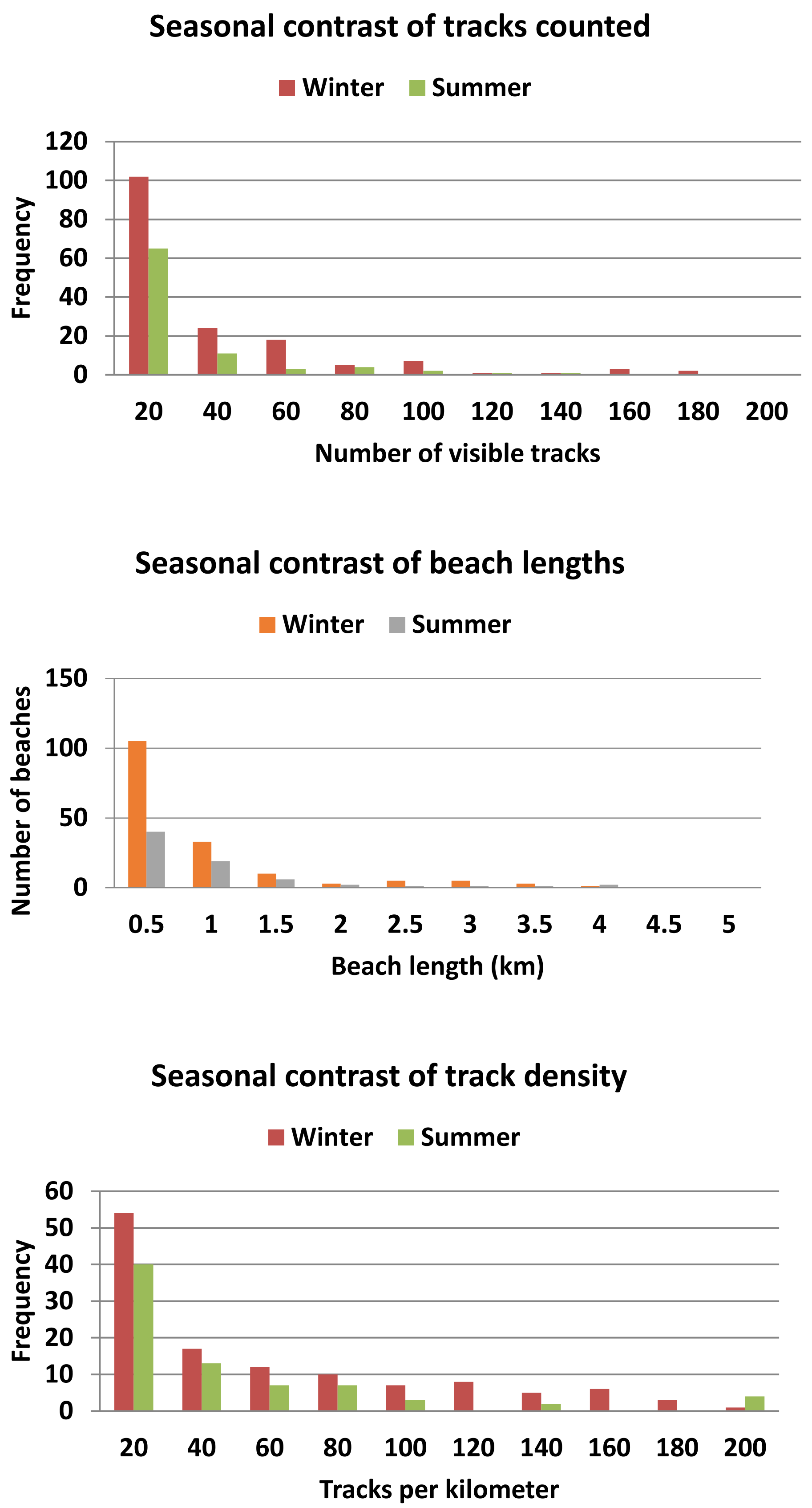


Figure 7. The seasonal contrasts for the Kimberley marine turtle track distribution. The Dampier Peninsula is a changeover point where summer green turtle nesting occurs to the east, winter flatback nesting occurs to the east, and summer flatback nesting occurs to the west.

3.4 On-ground surveys

On-ground surveys were conducted in 37 accessible locations after 22 field trips and 44 meetings to verify species by visual inspection of track characteristics. The overlap of summer and winter nesting was defined during on-ground surveys by Kimberley ranger groups. The easternmost summer flatback nesting for the mainland was at One Arm Point verified by Bardi Jawi rangers. An easternmost summer flatback nests for offshore islands were on the Lacepede Islands, verified by the Nyul Nyul rangers. A westernmost winter nest on the mainland was near Lombadina reported by Nyul Nyul rangers.

3.5 Common, uncommon, and absent nesting

The GIS layers for the track data were classed into low (1-10 tracks), medium (10-100 tracks), and high (>100 tracks) track counts. Medium level counts of tracks are dispersed across the Kimberley, with fewer tracks recorded in coastal stretches bordered by rocky cliffs or mangroves. The higher aggregations of tracks (greater than a median of 20 nests) signify beaches of management interest. The most important rookeries ranked by track counts and density were winter flatbacks at Cape Domett, summer greens at the Lacepede Island and summer flatbacks at Wallal-Eighty Mile Beach.

Aerial surveys had low power to detect smaller and less frequent olive ridley or hawksbill turtle tracks. Those species are believed to be at range margins or uncommon/depleted status in the Kimberley. The relatively shallow tracks of lighter-bodied species do not persist as long and the survey period was not in phase with their seasonal phenology. No leatherback or loggerhead tracks were recorded although migrations through in the Kimberley region by both species are known by indigenous knowledge or separate satellite telemetry studies conducted outside the WAMSI project

4 Discussion and Conclusions

The WAMSI turtle project represents a first comprehensive study of remote mainland beaches and islands for the Kimberley. The added spatial information allows a better evaluation of conservation options at rookeries that vary in abundance or density and distance to Traditional Owners/Park Rangers operational bases. The improved spatial understanding will enhance protection of turtle rookeries at both landscape and local scales.

4.1 Management Relevance-local and landscape needs

A critical question for regional managers is how to identify management priorities around species, season and conservation status. We evaluated the high priority beaches across the Kimberley for regional planning, and within Traditional Owner boundaries for local management (Figure 9). The two largest flatback rookeries (Cape Domett-winter season; Eighty Mile Beach-summer season) are bordered by established Marine Parks with Traditional Owners/Park Rangers invested in ongoing annual marine turtle monitoring and management. Many of the smaller or less dense flatback rookeries are located on offshore islands which are more logistically challenging and expensive to monitor (e.g. Maret, Montelivet, and Cassini) but may be protected by the difficult or distant access. Some of the medium sized flatback rookeries are accessible by boat and with some planning could be monitored annually when they are accessed for traditional food (West Governor Island, Helpman Island). The more accessible, low density rookeries at Eco Beach, Cable Beach, and Berkley River may be better utilised for educational opportunities.

The major summer green turtle rookery (Lacepede Islands) is protected as part of a terrestrial Nature Reserve, but is not currently part of an ongoing monitoring or management arrangement. WAMSI partnerships with the Nyul Nyul or Bardi Jawi might be strengthened if an annual monitoring project could be coordinated. A tagging project was conducted by CALM in 1986-2000 and given the high numbers, it may be a better target for a tagging study than a track count monitoring site if research interest were to resume there. Many of the turtles tagged there have historically been harvested on foraging grounds ranging from Cape Leveque and Camden Sound to Arnhem Land (Prince unpublished data). Other high track count green turtle rookeries are grouped on offshore islands (mainly Dambimangari or Wunambal Gaambera country such as Maret, Montelivet, Cassini, Prudhoe and others identified in Waayers 2014). The isolation by distance is currently adequate to afford protection.

No leatherback or loggerhead nesting was found in the Kimberley surveys, although those species may feed there or migrate through the region. The olive ridley and hawksbill were recorded in low numbers and can be considered as separate management topics for reasons that follow.

Isolated new records for olive ridley nesting were added at beaches of Camden Sound. While rare in the Marine Park, the species is abundant outside of the Kimberley (Limpus 2009). With increasing patrols and awareness, it is predicted more nesting activity will be recorded by Parks patrols within Camden Sound. Results from an August 2017 ground-truth trip suggest Deception Bay should be monitored for this species together with the other confirmed Kimberley nest locations bounded by Cape Leveque to Vulcan Island, Darcy Island, Freshwater Cover, in addition to investigating anecdotal accounts of Dambimangarri rangers at Langgi. However, the low numbers and encounter rates, relative to NT or QLD nesting populations, and the effort required to conduct a focused monitoring program makes this study difficult to justify. Instead, opportunistic collection of presence/absence data may be sufficient in the short term with annual patrols focused on visiting the mainland beaches adjacent to Deception and Smokey Bay.

The hawksbill nesting evidence was extremely limited, comprising sparse records. It is unclear the Kimberley nesters are linked to the Pilbara or Arnhem Land nesters or are a unique stock . It is speculative that the hawksbill population is depleted following a long-term and undocumented harvest by Macassan trepangers (Fisheries Department 1900, Halkyard 2009). As Halkyard (2009) observed, "even though commercial fishing pressure on WA marine turtle populations ceased nearly 40 years ago, it is likely that the historical harvest increased the vulnerability of green and hawksbill turtles to modern-day pressures and if the depletion in turtle numbers was severe enough, full recovery of the turtle population could take several generations (Daley et al., 2008; Limpus, 2002).

The WAMSI surveys enabled landscape understanding for Commonwealth and State interests and new detailed data for local management by Traditional Owners through land claims, IPAs and Healthy Country Plans. Pairing landscape and local perspectives offer a novel overview of priority turtle beaches and strategic recommendations for future studies and monitoring.

4.2 Management relevance- Dingo predation on the mainland

During the on ground-truthing, we observed that dingo predation occurs at mainland beaches of Smokey Bay and Deception Bay in Camden Sound Marine Park. The sparse nesting numbers of olive ridley turtles mingled among the green and flatback nests are clearly being impacted. It remains unclear whether intervention would be possible in this remote area. A rule of thumb is management intervention may be considered if a threshold of 10% of nests is disturbed by predators. In comparison, dingo predation is relatively low at Cape Domett at a rate of one nest per night (Whiting et al. 2008) with secondary predation by crocodiles and night herons. No data are available by camera traps (as on Eighty Mile Beach) and the Camden Sound locations are not visited regularly enough for monitoring. Nesting is not subjected to dingo predation threat at offshore islands.

4.3 Management relevance-Bigger picture on population pressures

Regional scale pressures include climate change, marine debris, illegal international harvest and potentially Indigenous harvest that occurs within and outside the Kimberley region (e.g. NT). Green turtles can be harvested in Indonesia or Papua New Guinea that have Australian genetic affinities and vice versa. Plastic marine debris is ubiquitous in the marine environment and a threat to all marine turtle species (Nelms et al. 2015). The regions of highest risk to global marine turtle populations are off the east coasts of the USA, Australia and South Africa; specifically, the East Indian Ocean, and Southeast Asia (Schuyler et al. 2016) which are areas Australian turtle migrate to or through. Climate change is threat that will be discussed in Chapter 5.

4.4 Prioritizing monitoring effort

While management priorities may naturally be focused towards the large rookeries for common species, small rookeries may fall into a higher priority level if the numbers represent naturally rare or low density occurrences. The National Recovery Plan for Australian Marine Turtles can guide consideration whether a rookery in the small to medium category warrants special management consideration.

The survey results indicate that management priorities will shift among geographical isolated rookeries across the seasons and also by species as illustrated in Figure 10. A summary of numerical results is given in Tables 3 and 4. Summer nesting (XL category) is focused on major rookeries of 80 Mile Beach (flatbacks) and the Lacepede Islands (green turtles), with lesser densities at the Maret Island and Cassini Island (greens). Winter nesting (XL category) is focused on major rookeries of Cape Domett (flatback) with additional rookeries of Vulcan Island, Maret Island, Cassini Island, Keraudren Island, Kuntjumal Kutangarri and Parry Island (flatback). It should be noted that a management emphasis solely upon the L and XL categories would deemphasize any sparse nesting by hawksbill, olive ridley or putative leatherback nesting. These respective species may be rarer nesters in current times because of historical harvests, low density at range margins for that species, or simply considered extra-limital records.

The survey documents that Kimberley turtle nesting is regionally substantial and likely to be vital for sustaining populations. Turtle behaviour varies from season to season so it would be ideal to conduct aerial surveys for four years running to span multiple nesting cohorts and thereby accurately evaluate any trends. The present aerial surveys establish a baseline for future surveys and comparisons. This pilot study is a model to be replicated for Kimberley winter and summer nesting, and also extends to the Pilbara's summer nesting to provide improved geospatial understanding of turtle activity, and to facilitate any on-ground action to assist breeding turtles or control predators.

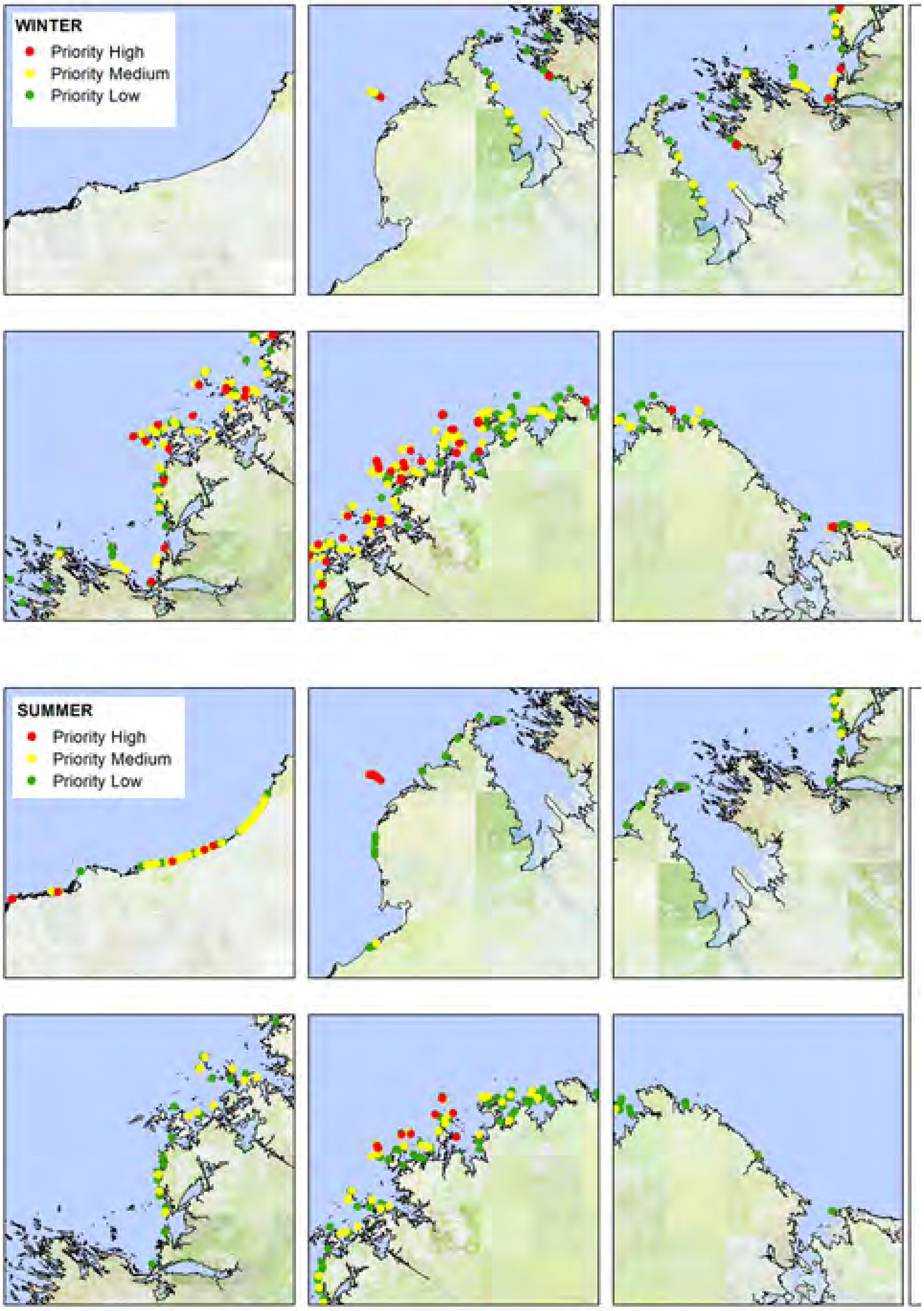
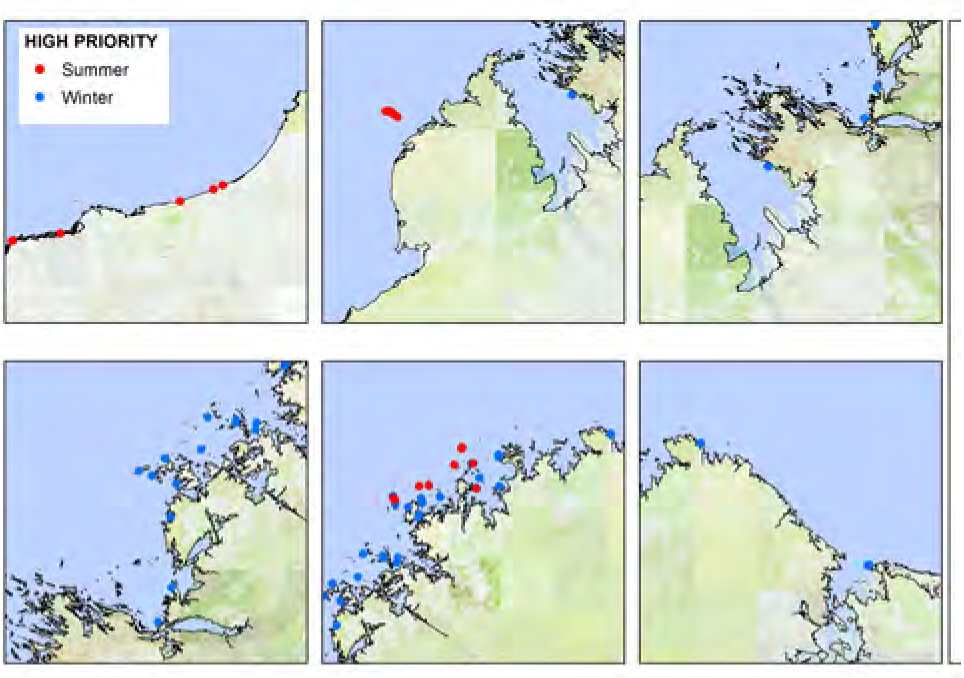


Figure 8. The seasonal contrasts for the Kimberley marine turtle track distribution. The Dampier Peninsula is a changeover point where summer green turtle nesting occurs to the west, winter flatback nesting occurs to the east, and summer flatback nesting occurs to the west.



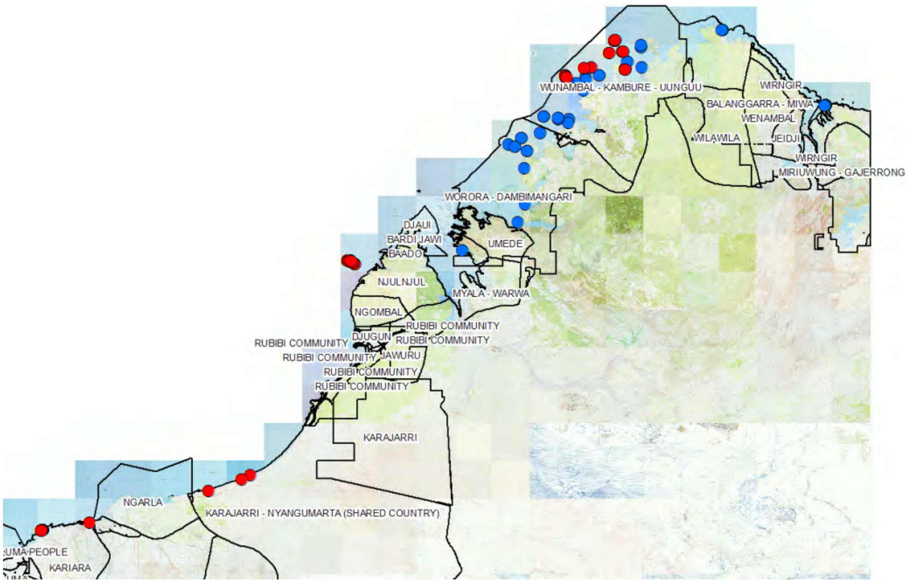


Figure 9. The highest priority rookeries are based upon the summer and winter highest density and highest abundance of track counts with the Kimberley marine turtle track distribution, plotted on a log-log scale (refer also to Figure 8). When plotted over the Kimberley ranger/traditional owner boundaries (black lines), it combines a local operational scale with the regional scale.

Figure 10. To communicate the findings in a simple manner, we generated a word cloud (www.tagul.com) with font size reflecting a numerical input for turtle track counts at island or mainland beaches of the Kimberley region. A large font size shows higher track counts; small font indicates lower track counts. Left image shows the high summer abundances of green turtle at the Lacepede Islands but flatbacks at Eighty Mile with relatively few other secondary sites in smaller font size. Right image shows the high winter abundance of flatback turtles at Cape Domett and a widespread nesting across many secondary sites.

4.5 Future Monitoring-scaled aerial surveys

In order to better refine the data on the high-density Kimberley rookeries the summer and winter aerial surveys could be repeated but with a focus on the high density (>100 nests/km) rookeries only. A scaled down well focussed survey can be flown in a shorter time frame (e.g. 3 days vs. 8 days) and would not be constrained by the logistics difficulties faced by on-ground monitoring. In scaling to the TO relevant boundaries, an alternative is to set camera monitoring systems or drone surveys in place that can remotely monitor the daily tracks, with satellite uplinks or irregular visits to download and export the images and data.

4.6 Future monitoring-new sites

An outcome of this program is to assess the potential for future monitoring, and the methods to be used, while considering the biological importance of species and the practical considerations of implementing programs tailored specifically to TO groups and in the context of the challenging regional logistics.

A high density rookery is typically not ideally suited to monitoring if:

- the field team cannot physically process sufficient numbers of animals to represent the nesting population size;
- the site is remote or logistically difficult to access (emergency responses, cyclone evacuations, crocodile presence); and
- the site is expensive to travel to and support (provisioning);

We set a hypothetical framework for a multi-objective decision support system (Figure 11) to evaluate the competing costs for of biological importance (track counts, density, species abundance or rarity), logistics (distance from base, mode of travel), resources (funding for field staff, travel), and agency commitment (TO connection to country, IPA/ Healthy Country Plan alignment; DBCA Marine Park or Nature Reserve; Commonwealth recovery plans or Marine Reserve). The model parameters can vary to resolve a project undertaking the best trade-off among these factors, which will be a unique solution to each TO group in a homeland region with a recognized turtle resource. Planning may involve traditional or novel partnerships. Groups that have few nesting beaches may develop a greater interest for in-water studies. In places with few rangers, training and linkage with a neighbouring group or during ranger meetings may be a substitute. Adjacent groups may be interested that they share stocks outside their homeland and adopt a broader understanding of mixed foraging grounds and nest site fidelity.

4.7 Index site recommendations

In a balance of management and TO relevant scales of interest (Table 2), we compiled a list of recommended index beaches within ranger group operating boundaries that offer strategic value with convenient access (Figure 10). A monitoring project is a realistic long-term (10 yr) commitment to a minimum 2-3 week monitoring period. Two such index beaches are already underway at Eighty Mile Beach for summer flatbacks and Cape Domett for winter flatbacks. Replicate sites might also include Coronation Islands, South Maret, Cassini Island, or West Governor for winter flatbacks. A Kimberley index site that could be considered for summer green turtles is the Lacepede Islands, continuing the work that ran 1986-2002. Secondary sites might include Coronation Islands, South Maret, or Cassini Island. Hawksbill nesting appears to be broadly dispersed at low density across the Kimberley. It remains unclear if that pattern results from historical overharvest by the Macassan/Indonesian tortoiseshell take or is occurring naturally at a low density. Periodic surveys would be desirable for Jones Island and nearby Islands. An aerial survey during October with selected outer islands might be undertaken in the future to better discern levels of hawksbill that remain. Olive ridleys are sparse but irregular visitors to the Camden Sound region, with new sites described for Smokey Bay and Deception Bay and it would be helpful to see if there are populations of note.

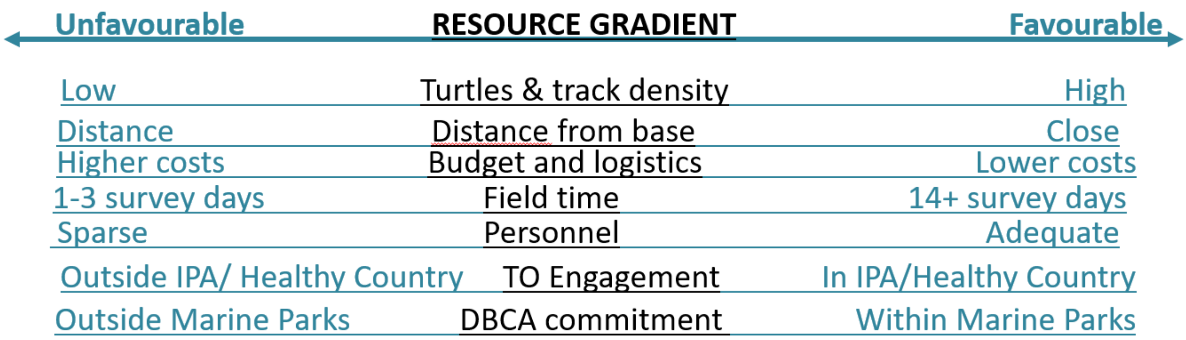


Figure 11. Structural framework of a multi-objective decision support model for managers to evaluate turtle monitoring programs in the Kimberley.

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Marine Turtles in the Kimberley: key biological indices required to understand and manage nesting turtles along the Kimberley coast

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WAMSI Kimberley Marine Research Program

Final Report

Project 1.2.2

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