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Human use patterns and impacts for coastal waters of the Kimberley

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WAMSI Kimberley Marine Research Program

Final Report

Project 2.1.1

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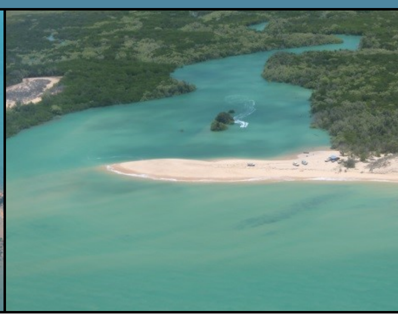

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Government of Western Australia Department of Fisheries

Murdoch University

WAMSI Kimberley Marine Research Program

Initiated with the support of the State Government, the Kimberley Marine Research Program is co-invested by the WAMSI partners to provide regional understanding and baseline knowledge about the Kimberley marine environment. The program has been created in response to the extraordinary, unspoilt wilderness value of the Kimberley and increasing pressure for development in this region. The purpose is to provide science based information to support decision making in relation to the Kimberley marine park network, other conservation activities and future development proposals.

Front cover images (L-R)

Image 1: Satellite image of the Kimberley coastline (Image: Landgate)

Image 2: Tourist boats negotiating the white water at Horizontal Falls. (Image: Lynnath Beckley)

Image 3: Boat trailers at Entrance Point, Broome (Image: Lynnath Beckley)

Image 4: Recreational activity at a secluded coastal creek at Cape Bertholet on the Dampier Peninsula, Kimberley. (Image: Lynnath Beckley)

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Contents

Executive Summary

In Australia, coastal and marine environments are highly valued for the range of cultural, traditional, commercial and recreational opportunities they provide. The Kimberley coast represents a remote area that has been used by indigenous peoples for thousands of years for subsistence and cultural activities with more recent uses including pearling, commercial fishing, mining, oil and gas, aquaculture, tourism and recreational activities. In 2011, the WA State government committed to the creation of a network of marine protected areas across the Kimberley in recognition of the unique marine and coastal values of the region and to ensure their sustainable management and conservation. To achieve this goal, knowledge of the spatial and temporal extent of human use is necessary for appropriate management of the coastal waters of the Kimberley. This report addresses this need by providing a benchmark of human use patterns at various scales in the Kimberley marine and coastal environment and assessing the potential for impacts on marine and coastal habitats from the identified activities.

While there is existing information on the commercial activities across the Kimberley, e.g. commercial fishing effort and catch, resource development, pearling and aquaculture, there is little existing quantitative information on recreational activity across the Kimberley. This lack of information has been compounded by the difficulties associated with surveying vast, remote stretches of coastline and coastal waters with limited access points. A range of techniques to collect information at different spatial and temporal scales are broadly available and can be used to create an overall picture of human use patterns with varying levels of detail, e.g., aerial survey, interviews, counts of vehicles and/or boat trailers. Each technique has strengths, limitations and biases which must be taken into consideration both in planning a research or monitoring program and in the interpretation of the data.

This research project undertook to investigate human use patterns in coastal and marine environments of the Kimberley at various spatial scales prior to the implementation of the marine park system in order to provide a benchmark for the human use of the region and to inform ongoing management of the Kimberley. Chapters 1 and 2 of this report describe the use of aerial surveys to benchmark use of the southern (Port Hedland to Crab Creek, Roebuck Bay) and western (Crab Creek, Roebuck Bay to Point Torment, King Sound) regions of the Kimberley, respectively, throughout the year. Given the remoteness of the region to the north-east and logistical challenges with respect to regular flights, only exploratory surveys of the central (King Sound to Camden Sound) and eastern (Augustus Island to Wyndham) Kimberley were used to provide an understanding of relative human use across these vast stretches of coast during the peak tourist season (Chapter 3).

As an alternative to the quantitative assessment provided by aerial survey, other techniques were used to investigate use by cruise vessels and launching of recreational boats. Chapter 4 provides an assessment of the cumulative visitation by expedition vessel cruising throughout the central and east Kimberley using a desktop study of the advertised itineraries, the number and passenger capacity of expedition cruise vessels, the sites visited and the activities offered. Insight into local recreational fishing pressure was obtained by using remote camera surveillance to record the temporal pattern and number of recreational boats launched at Entrance Point boat ramp in Broome (Chapter 5). The number of boat launches was correlated with several temporal (e.g., week vs weekend, holidays, season) and environmental (e.g., wind speed and direction) factors.

The final chapter reviewed the potential environmental impacts from recreational and tourism activities, providing a better understanding of the key impacts on which natural resource managers should focus to ensure the sustainability of the unique Kimberley environment.

Collectively, this information gives a broad understanding of the extent of human pressures along the Kimberley coastal and highlights important considerations for management including those targeted at specific high use areas as well as more generally across the newly gazetted and planned marine protected area network.

Key Findings and Implications for Management

While each of the chapters contains relevant results, there are some key findings about human use patterns across the Kimberley that will support management of the region. This study provides a benchmark of human activity across the Kimberley with a seasonal understanding of human use from Port Hedland to Derby including 80 Mile Beach and Roebuck Bay Marine Parks together with a dry season snapshot of the extent of visitation in the more remote central and eastern Kimberley. Further, it has established a repeatable technique using aerial surveys to undertake this quantitative and broad-scale assessment. This sets the stage for long term monitoring to be able to periodically evaluate changes in tourism and recreational activity across the Kimberley. While aerial survey is a suitable tool for large and remote areas, it can be logistically challenging and expensive in the Kimberley. Two additional techniques that could be employed by managers to provide indicators of use that complement aerial surveys were also examined. These were analysis of itineraries of expedition cruise vessels and remote camera surveillance of a boat ramp in Broome.

Specific findings from the separate research chapters and how these may be considered and used by managers are summarised below, with more detail to follow in the relevant chapters. Considerations for management are highlighted in italics. The study on the south-western extent of the Kimberley between Port Hedland and Derby provides temporally and spatially explicit data on coastal recreational activities in the nearshore marine and coastal environment. These data can be used as a benchmark of level of use prior to the implementation of 80 Mile Beach and Roebuck Bay Marine Parks or any major coastal development such as sealing the road north of Broome to Cape Leveque. Visitor use of the south-western Kimberley is strongly seasonal and nodal with most human presence and activity focused around few sites where there is road access to the coast, a population centre or available tourist accommodation (e.g. caravan parks or camp sites).

For the less populated area between Crab Creek (Roebuck Bay) and 4 Mile Creek (Port Hedland) the seasonal contrast and visitor focus at nodal areas were more defined and dominated by shore-based fishing. A somewhat different pattern of activity was noted around the Dampier Peninsula where walking and relaxing on the beaches dominated, particularly at Cable Beach and along the western side of the peninsula. While activities were similarly nodal and often radiated from access points via 4WD vehicles, there were much higher numbers of vessels and vehicles in general along the Dampier Peninsula, particularly around Broome. This is consistent with Broome being both a tourism hub as well as having local residents who actively engage in coastal and marine activities throughout the year. Implications for management include:

- *Having a benchmark of human use prior to the gazettal of marine protected areas as a basis from which to detect trends.*
- *Identification of activity patterns and high density areas will inform local management so that operational activities can be spatially and temporally targeted.*
- *While aerial survey can be a costly monitoring tool, it can be used on a periodic basis to assess use of marine parks, including to identify new areas of use as they emerge, and to plan operational management.*

Boating activity was concentrated around boat ramps and also near places where boats could be launched from the beach. Shore-based fishing, particularly in the southern Kimberley, was observed to extend along shore from access points, largely because of the use of 4WD vehicles. Considerations for management include:

- *The concentration of fishing at specific sites can lead to changes in fish community structure and should be taken into consideration in planning monitoring programs for fish in the marine parks.*
- *Education and compliance activities for those fishing from boats can be directed to the boat launching areas identified in this study.*

Recreational use is far more restricted along the central and eastern Kimberley coast (Derby east to Wyndham) because of very limited road access. The exploratory surveys indicated low numbers of people, mainly associated with tourist destinations (e.g. Horizontal Falls), camping areas (e.g. Kalumburu) or commercial operations (e.g. Koolan Island and Cone Bay). Numbers of vessels were also low, with any nodes of activity generally around commercial operations such as pearl farming, mining and aquaculture.

This information will be useful for management at high use locations across this remote region and also provides input into the logistics and design required to monitor human use and possible pressures in the Kimberley marine park network north and east of Broome. In particular, it establishes a benchmark for comparison prior to any large regional change in infrastructure or industry, such as the paving of the road from Broome to One Arm Point.

Tourist visitation to the central and northern Kimberley is mainly conducted by recreational or expedition cruises. Overall visitation is low compared to other tourist destinations both in Australia and globally, and most of the vessels are small with limited passenger capacity (<20 passengers). However, the number of individuals visiting the region appears to be growing because of the introduction of some larger vessels with increased passenger capacities (> 100 passengers). There are some particularly popular sites that are targeted by the majority of expedition cruises that can be exposed to an increasing number of visitors who engage in activities including excursions ashore to visit rock art sites, walking or exploring. Many of the activities advertised by cruise vessels occur on the shore – a point that needs to be considered by relevant land managers. Considerations for managers include:

- *A cost-effective desktop survey method was developed to enable regular monitoring of tourist visitation by expedition cruise vessels, to all sites covered by itineraries along the Kimberley coast.*
- *This study identified sites of relatively high use that can be used by natural resource managers to guide operational activities (including monitoring, compliance and education) to ensure cultural and environmental targets are achieved.*

The site-specific evaluation of the use of Entrance Point boat ramp found that while boats were launched year round, activity at the boat ramp was related to temporal and environmental factors, with periods of greatest vessel activity in the mornings, on non-school holiday weekends during the dry season when wind was light. The method of remote camera surveillance to record vessel launches allowed cost-effective assessment of vessel activity, requiring fewer resources than traditional surveys and the collection of information after hours, on weekends and holidays without additional cost. However there are logistical restraints with this method and the additional man-hours required to review video/photographs.

- *Management should consider this data collection technique for use at boat launch ramps, particularly at sites where there are planned changes to infrastructure such as One Arm Point.*

The review of potential impacts of human use on coastal habitats in the Kimberley highlighted that visitation to the Kimberley is increasing which may lead to greater pressures to coastal habitats. The most likely environmental impacts will be from litter and rubbish, sewage and other pollution, coastal track formation, fishing, impacts of boating and trampling of coastal vegetation and intertidal reefs. However, due to the remote nature of the Kimberley and seasonal inaccessibility of many areas, visitation to even popular sites remains relatively low.

- *Management can, and should, focus attention on sites highlighted through this study as 'higher use' to monitor for potential impacts and to implement management strategies including education that will prevent potential impacts from occurring.*

Products and Tools

This project has produced a number of data products and tools that can be made available to managers where relevant.

Heat maps have been produced using monthly surveys of the number of people and vessels engaged in different activities over a 12 month period from 4 Mile Creek (Port Hedland) to Point Torment (King Sound). Point maps of the number of people and vessels engaged in different activities during the dry season from Point Torment (King Sound) to Wyndham using four seasonal surveys for the section from Point Torment to Camden Sound and a single survey from Camden Sound to Wyndham were also produced. These maps highlight the patterns of human use of the coastal area including different activities relative to locations, providing guidance on the recreational values associated with sites and consequent need for particular management emphasis. Spatially explicit data supporting the heat maps are available for planners and managers as necessary to inform planning and on ground management at key sites.

Protocols have been developed for the following research activities and could be taken on board by managers for long term monitoring programs, with appropriate training or advice on design and analysis:

- *A protocol to design and undertake aerial surveys of coastal and near shore activities including use of software that is commercially available to record data.*
- *A desktop-based template and protocol to assess cruise vessel itineraries in the Kimberley that can be undertaken on an annual basis to identify trends in the number of vessels and their capacity and estimated visitor numbers accessing sites or engaging in specific activities.*
- *A technique and protocol for using remote camera surveillance to record vessel numbers at boat ramp launch sites as an indicator of recreational vessel use of an area.*

Key residual knowledge gaps

While this study has clearly identified sites where human pressures are relatively high and has established a benchmark for type and level of activities across the Kimberley in 2013, there are important questions that remain which will be important into the future as visitation to the Kimberley increases. These include:

- *Assessment of catch, fishing effort and compliance of boat-based recreational fishing from the three One Arm Point boat launching sites before, and after, the upgrade of the road from Broome to One Arm Point (which will allow more direct access to the Buccaneer Archipelago and Horizontal Falls);*
- *Regular aerial surveys out of Kununurra to ascertain human use of the eastern section of the North Kimberley Marine Park particularly the more accessible Wyndam to Kalumburu section.*
- *Assessment of the actual uptake by passengers of the activities advertised by cruise vessels in the Kimberley.*

While some additional monitoring techniques and potential indicators were assessed, there are others that could be considered for the Kimberley. For example, the use of vehicle counters to monitor the number of vehicles entering key sites along 80 Mile Beach where there are existing access points and camp grounds could prove a useful means of assessing visitation and temporal use of beaches.

Communication

Presentations

Beckley, L.E., Fisher, E. & Davies, H. 2014. Cumulative visitation by expedition cruise vessels along the remote Kimberley coast. *Australian Marine Sciences Association Conference*, Canberra.

Beckley, L.E. 2015. Benchmarking human use of Eighty Mile Beach Marine Park prior to implementation of the management plan. *2015 WAMSI Conference*, Perth.

Other communications achievements

Community presentation in Broome, April 2015.

Presentation to Dambimangari Aboriginal Corporation, Derby, April 2015

Knock on opportunities created as a result of this project

Student project re-evaluating current visitation by expedition cruise vessels of key sites throughout the Kimberley.

Additional aerial surveys of the north Kimberley prior to the gazettal of the North Kimberley Marine Park were discussed.

Key methods for uptake

Presentations and discussions have been held with managers in Parks and Wildlife, both in the Region and in Perth. These have involved representatives from a range of divisions and functions (management, operations, science, visitor services and planning). Key people in Marine Science are working with Prof Beckley to develop a departmental guideline on monitoring human use of marine and coastal areas in the Kimberley using a combination of periodic aerial survey, assessment of expedition cruise itineraries and targeted indicators at high use sites.

This project directly addresses the following questions outlined in the Kimberley Marine Research Program Science Plan and those proposed by managers during the program.

Key Question Informed Response
What are the historical, current and future patterns and trends of human use? Current patterns of use in the western Kimberley have been well documented from aerial surveys. The survey results for the central and eastern Kimberley were more exploratory. Detailed analysis of the itineraries of cruise vessels indicate current patterns of use particularly in the central and eastern Kimberley. Daily patterns in boat launching at a major boat ramp in Broome are also included. Where available and appropriate, the report indicates evidence of historical use and some commentary is provided on possible changes in the future.
What impacts and risks did/does/will this use pose to the marine biodiversity? A review chapter indicating potential impacts of human use across the different habitats in the Kimberley is included in the report.
What management response is needed to address these impacts? The Department will have to decide on management response as there are considerable logistical and economic implications in remote areas.
What are the anticipated effects of increased access to remote locations? There is commentary on this in some of the chapters and the review on impacts indicates potential effects.
How might climate change influence human use? This has not been explicitly addressed.
What human use 'indicators' are best used to monitor human pressure on marine resources? Spatially-explicit counts of people (and boats) and their associated activities through aerial survey provide the most comprehensive information on human use along the vast Kimberley coast. Land-based counts of vehicles and boat trailers can be used as "indicators" of human use but generally suffer from not being definitive with respect to actual activities conducted. They also tend to be site-specific rather than covering the whole area and do not pick up any changes in spatial extent of use.

Chapter 1: A spatially explicit benchmark of human use along Eighty Mile Beach prior to implementation of the Marine Park

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Summary

Human use of the coast between Broome and Port Hedland in north-western Australia was examined by undertaking monthly aerial surveys (November 2012 to October 2013) using a Cessna 210 aircraft with two observers equipped with digital cameras and a GPS logger and use of Aerial Survey Assistant and GIS software for analyses. The numbers of people along the shore and boats in coastal waters showed much higher usage in the dry season (May to October) than the wet season (November to April). Areas with highest densities of people were near 80 Mile Beach Caravan Park, Cape Keraudren and Barn Hill and, to a lesser extent, Port Smith and Bidyadanga. Of the people recorded, 46% were fishing from the shore and 33% were walking along the beach. Fishing was particularly popular near Eighty Mile Beach Caravan Park with anglers, and their associated four-wheel drive vehicles, spread along about 30 km of coastline. Camping along the coast during the dry season was largely within the confines of the large caravan parks at Eighty Mile Beach and Port Smith but there were also nodes of camping at Barn Hill Station and Cape Keraudren. Boating activity occurred mainly in the northern part around Port Smith and, to a lesser extent, near Cape Keraudren. The recreational boats were engaged in fishing or motoring and pearling vessels were also recorded between Port Smith and Barn Hill. The distribution of human use was also examined relative to the designated sanctuary zones of the new Eighty Mile Beach Marine Park. This study provides spatially explicit data on coastal recreational activities that can be used by managers as a benchmark of use prior to the implementation of the management plan for the marine park.

1 Introduction

The remote coast of north-western Australia between Port Hedland and Broome has been used by Indigenous people for subsistence and cultural activities for thousands of years (O'Connor 1999). Since the late 1800s, pearling and commercial fishing have taken place (Saville-Kent 1896, Bach 1955, Burton 2000, Nowara & Newman 2001, Fletcher & Santoro 2014) and, in more recent years, coastal tourism and recreational activities have also become valued in this region (Davies & Cammell 2009, Strickland-Munroe et al. 2014). The coast is characterised by extensive intertidal mud flats and mangroves and, in the south, there is a change in the geomorphology with more extensive rocky shores (Semeniuk 2008). The area is renowned for its biodiversity, particularly shore birds and turtles (Pendoley 2005, Dethmers et al. 2006, Limpus 2007, Rogers et al. 2003, 2011, Pendoley et al. 2014) and some 900 species of neritic fishes have distribution ranges over this part of the north-west shelf (Fox & Beckley 2005). Eighty Mile Beach Marine Park, extending along 260 km of coast from Cape Missiessy to Pardoo Creek (Figure 1), was proclaimed in 2012 with the management plan released in December 2014 (WA Department of Parks and Wildlife 2014).

In marine spatial planning, particularly with respect to protected areas, an understanding of the pressures placed on the environment is necessary and this requires information on human use of the coast and adjacent waters (St. Martin & Hall-Arber 2008, Dalton et al. 2010). The Eighty Mile Beach region has limited road access and, as far as can be established, there have been no prior attempts to survey human use along the coast and adjacent waters. Nevertheless, various recreational activities are known to take place along this coast (e.g., fishing), and sites used for coastal camping (e.g., Cape Keraudren), as well as caravan parks at Eighty Mile Beach and Port Smith and accommodation at Eco Beach are well known (Davies & Cammell 2009, Davies et al. 2009). Recreational catches of fishes at Cape Keraudren have been estimated (Williamson et al. 2006) and the whole area was also included in the recent state-wide assessment of boat-based recreational fishing (Ryan et al. 2013). Several commercial fisheries extend across the study area and these include trawl, trap and line fisheries for demersal finfish as well as the pearl oyster fishery (Fletcher & Santoro 2014), which has operated in the region for nearly 150 years (Burton 2000).

The aim of this study was to use aerial surveys to map the location of people and boats engaged in activities along the coast and in adjacent waters between Broome (Crab Creek) and Port Hedland (Four Mile Creek) over a period of 12 months covering both the wet and dry seasons. This study provides spatially-explicit benchmark data on distribution and extent of human use in the Eighty Mile Beach Marine Park prior to the implementation of the management plan and zoning. The study also provides information that can assist with the logistics and design of future, temporally-appropriate, monitoring of the Eighty Mile Beach Marine Park.

2 Materials and Methods

2.1 Study area

The study area for the aerial surveys of human use extended from Crab Creek south-east of Broome to Four Mile Creek east of Port Hedland (Figure 1). The flight path included the Eighty Mile Beach Marine Park as well as the southern part of Roebuck Bay, which is a proposed marine protected area.

2.2 Survey design

The design of the survey was based upon the maximum count method often used in studies of recreational fishing where surveys are conducted during periods of maximum recreational activity (Volstad et al. 2006, Veiga et al. 2010, Smallwood 2011a, Smallwood et al. 2012a). As there is a large tidal range in the region with expansive mud flats exposed at low tides, surveys were standardised around high tides. During high tides, vessels can access coastal creeks, and fishing from the shore is generally limited to periods of flood tides and high water (Fletcher & Santoro 2012). Tidal information from the port of Broome was used to schedule the Eighty Mile Beach surveys.

Surveys at Eighty Mile Beach were stratified by season, with the peak (dry) season defined as May – October and the off-peak (wet) season extending from November – April (Table 1). The remote location of the Eighty Mile Beach study area, and the fact that other areas of the Kimberley were also surveyed during the same monthly field trip, meant that survey days could not be randomly selected and surveys were grouped into consecutive days (i.e., a five-day trip to the Kimberley included several aerial surveys covering different areas). To accommodate any extreme weather conditions (i.e., thunderstorms, strong winds or rain), illness or plane malfunction a replacement day was incorporated into the end of each trip to allow for re-scheduling of flights. In addition to this, replacement trips were also included for the wet season, as cyclones could have led to cancellation of an entire trip to the Kimberley. However, all flights were able to be completed on their allocated day during the study period.

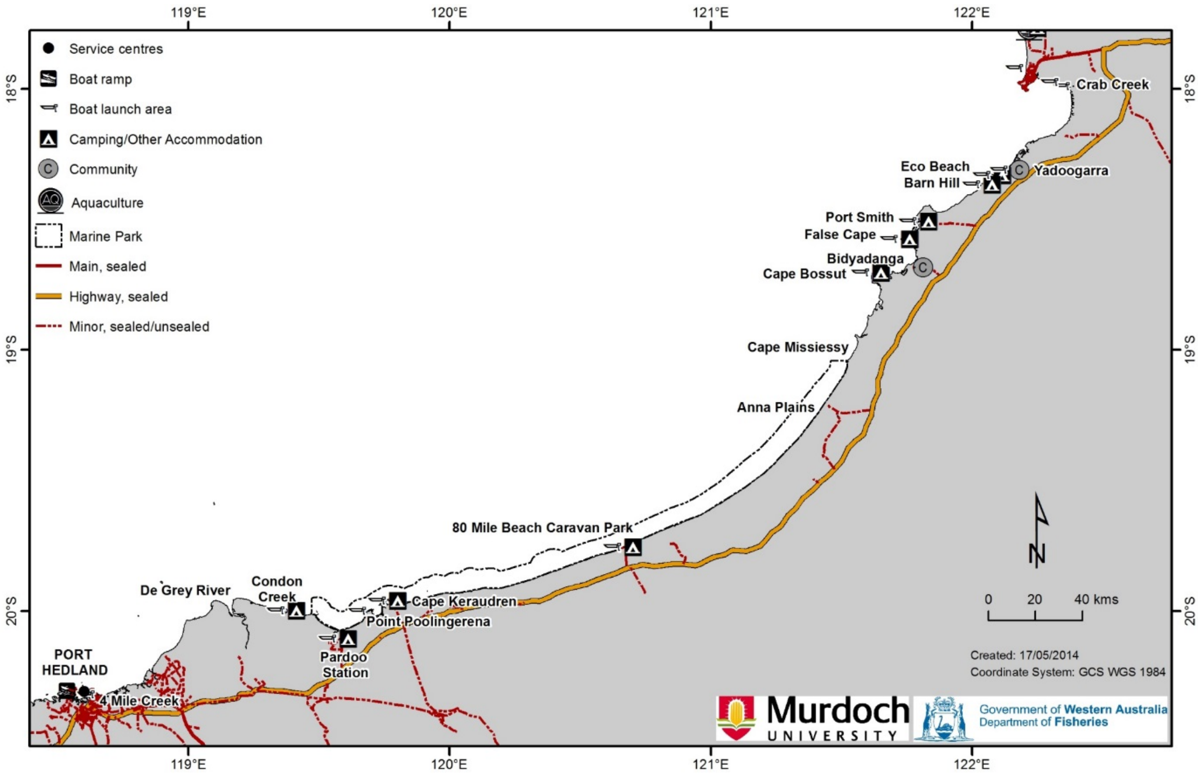

Figure 1. Study area for the Eighty Mile Beach aerial surveys between Crab Creek (Broome) and Four Mile Creek (Port Hedland) during the period November 2012 to October 2013.

Table 1. Design features of the Eighty Mile Beach aerial surveys conducted between November 2012 and October 2013.

Design aspect	Design details
Extent	Four Mile Creek (Port Hedland) to Crab Creek (Broome)
Length of coast	~500 km
Study period	November 2012 – October 2013
Number of survey days (n)	12 (6 peak; 6 off-peak)
Approximate day length	Peak (dry season): 6 am – 5 pm; Off-peak (wet season): 5.30 am – 6 pm
Survey duration	2.5 hours (plus 0.5 hours for refuelling and 2.5 hours for return trip)
Stratification & randomisation	
Season	Stratified by season into peak (dry) and off-peak (wet)
Month	Stratified by month, with each sampled at the same intensity
Tide	Surveyed at high tide on days when it occurred between 8 am – 5 pm
Trip allocation	Randomly allocated using a series of steps to maximise the equal probability of each day being selected
Site	Random selection was used to allocate surveys within each trip
Day type	Uniform probability for weekends/public holidays and weekdays
Time of day	Not included because time of high tide was expected to have greater influence
Starting location	Randomly selected from start or finish location (i.e., no mid-survey starts)
Direction of travel	Linked with starting location and therefore randomly selected

The flight path for the survey followed the coastline with the plane generally positioned about 200-300 m offshore to enable the best viewing of activities along the shore. For small creeks and inlets it was possible to obtain good coverage without deviating from the flight path. However, for larger inlets (e.g., Port Smith) the flight path was altered to complete a circuit of the inlet.

There can be a reduction in the quality of data if the plane moves too fast for the observers to record all activity at a specific location, or parts of the plane obscure the observer's view while turning. To avoid such situations, the pilot was instructed to slow down or complete a loop in order to provide a second opportunity to capture the information. Awareness of the features of the coastline, looking forward along the flight path, and open communication with the pilot also ensured that the plane was not turning at a time when a clear view of the coastline was required. These actions also assisted with reducing the effect of poor sightings of objects close to the aircraft because of obstruction of downward visibility (Leatherwood et al. 1982, Quang & Becker 1997). As it is also difficult to observe recreational activity in poor light conditions, no surveys were scheduled to start before an hour after sunrise or end in the hour prior to sunset.

Visibility issues can be a concern during aerial surveys (Pollock & Kendall 1987, Bayliss & Yeomans 1989, Marsh & Sinclair 1989) and it can sometimes be difficult to see people on rocky shores unless they are wearing bright clothing. To assist with minimising such issues, photographs were taken so they could be examined post-flight to identify all recreational activity. Following the method applied by Smallwood et al. (2011a), boat-based activity was recorded at the 'boat' rather than the 'person' level to address difficulties in establishing the actual number of people on vessels.

2.3 Data collection

Aerial surveys were conducted by two observers in a Cessna 210 plane (4-seater with high wing configuration) with a cruising speed of 120 knots, which could be slowed to 100 knots at sites which required more time for observation. Surveys were flown at a height of 300 m (1000 ft).

Data on shore-based activities were collected by the observer in the rear seat and data on boat-based activities were collected by the observer in the front seat. Each observer had a Canon EOS 600D digital camera to document each observation and a data sheet for recording the time of observation, activity type, vessel type (if a boat-based activity) and number of people (if a shore-based activity). Shore-based activities within 500 m of the water's edge were recorded and vessels were documented out to about 5 km perpendicular to the flight path. A route for each survey was loaded onto a Garmin GPS, along with every named location along the way, to ensure consistency between surveys. A data logger which collected geographical co-ordinates at one second intervals along the track of each flight was also mounted on the dashboard of the plane.

Aerial Survey Assistant (ASA) software was used to merge track logs and photographs from each survey and enable the observers to identify shore- and boat-based activities to a specific geographic co-ordinate (Ocean Vision Environmental Research 2010). This technique has been successfully utilised in previous aerial surveys of recreational shore-based activity in Western Australia (Smallwood et al. 2011b, Smallwood et al. 2011c, Smallwood & Gaughan 2013). For this project, the ASA software was further developed to capture information for boat-based activities.

2.4 Categories for coastal activities

Categories for activity types were based on previous research conducted in Western Australia (Smallwood & Beckley 2008, Smallwood 2010, Smallwood et al. 2012b) and elsewhere (Horneman et al. 2002). After considering some of the unique activity types in the Kimberley (i.e., commercial pearling) a total of 17 shore-based activity and 18 boat-based activity categories were utilised in the study (Table 2).

Categories ascribed to types of boats were also based on previous research conducted in Western Australia (Smallwood & Beckley 2008, Smallwood et al. 2011a) and elsewhere (Adams et al. 1992, Widmer & Underwood 2004, Warnken & Leon 2006). In total, 11 categories of motorised vessels and six categories of non-motorised vessels were available for selection (Table 3).

Counts of camps, boat trailers, vehicles, anchored or moored boats and boats on the beach were also made during the aerial surveys. This is similar to previous research conducted in Western Australia (Hughes & Mau 2006, Smallwood 2010, Smallwood et al. 2011a, Smallwood & Gaughan 2013) and elsewhere (Hockings & Twyford 1997). Standard definitions of each of these objects are provided in Table 5. It should be noted that vehicles were only counted at day-use sites, and not if they were associated with a coastal campsite. Additionally, camps were not counted within demarcated caravan parks (i.e., Port Smith or Eighty Mile Beach).

Table 2. Categories for shore-based and boat-based activities ascribed to observations during aerial surveys of Eighty Mile Beach.

Activity type	Characteristics
Shore-based	
Beach games	Sporting activities conducted on the beach (e.g., frisbee, beach cricket, skim-boarding)
Boating	Loading or unloading charter passengers
Crabbing	Use of drop nets or scoops
Exercise	Jogging, yoga etc.
Commercial	People involved in commercial or industrial activity (may be wearing high visibility gear)
Line fishing	Extraction of marine organisms using a hook and line and includes fly fishing
Netting	Using a cast, haul or set net of mesh to collect marine organisms
Relaxing	Sunbaking, standing, sitting or resting along the shore and includes sitting under a sun shelter
Riding	Includes camel tours
Snorkelling	Viewing of marine organisms using a face mask
Spearfishing	People targeting aquatic organisms with a spear gun
Spectating/sightseeing	Looking at features of interest in the natural environment or people participating in recreational activities and includes photographers and videographers
Surfing	Use of a board or stand-up paddleboard to ride waves
Swimming	Partial or full immersion in water and includes wading
Unknown	Activity of the person could not be ascertained
Walking	People travelling on foot along the shoreline and includes walking the dog and reef walking
Other	All other activity types
Boat-based	
Crabbing	Use of drop nets or scoops
Diving	Use of compressed air (SCUBA) by private or commercial groups from a boat
Fishing	Use of fishing lines
Jetskiing	Use of jet propelled craft, also known as Personal Water Craft (PWC)
Kayaking	Vessel powered by paddles and includes private and commercial kayaks
Kite surfing	Wind-driven sport using a kite. Includes people rigging or setting up a kite
Line fishing	Extraction of marine organisms by hook and line and includes fly fishing
Moored	Boat moored within an 'authorised' mooring area and not being used for any activity. Pearling vessels moored off pearling leases are often in this category
Motoring	Vessel transiting at high speed
Netting	Using a cast, haul or set net of mesh to collect marine organisms
Pearling/aquaculture	Vessels involved in pearling or aquaculture activity
Research	Activities from an identified research vessel
Sailing	Yacht or dinghy under sail power
Spearfishing	People targeting aquatic organisms with a spear gun
Towing sports	Activity where people are towed behind a vessel (e.g., skiing, knee-boarding, skurfing and tubing)
Unknown	Activity of vessel could not be ascertained
Wildlife interaction	People view wildlife from close proximity (e.g., swimming with manta rays)
Wildlife viewing	People viewing wildlife from a distance (e.g., whale watching, turtle watching and coral viewing from glass bottom boats)
Windsurfing	Wind-driven sport using a windsurfer and includes people rigging or setting up a windsurfer
Other	All other activity types

2.5 Analysis

After processing with ASA software, the data points were imported into ArcGIS10.2 for analyses. Data were collected in WGS84, which approximates GDA94, and was sufficient for presentation of raw data points using graduated symbols to represent the number of vessels, boats or other indicators of recreational activity.

The point density tool in Spatial Analyst was used to calculate the density of data points across the various strata incorporated into each survey route. For this analysis, data were converted to UTM51S, the central UTM zone in the study area. This tool calculated the density of point features in a grid cell by counting the total number of point features within a specified search radius, and dividing by its area. Each point was weighted by the number of units associated with each observation (i.e., number of fishers, number of boat trailers). In this study, a grid size of 0.25 km^2 was specified for Eighty Mile Beach, with a search radius of 2.5 km. Similar techniques have been used in studies of recreational use in Australia (Smallwood et al. 2011a) and elsewhere (Dalton et al. 2010, Thompson & Dalton 2010). A point density layer was calculated for each flight, and these were aggregated to calculate a mean density for each stratum using the cell statistics tool. Similarly, the standard deviation of the mean density was also calculated using this tool.

Table 3. Categories of vessels ascribed to observations during aerial surveys of Eighty Mile Beach.

Vessel type	**Characteristics**
Motorised vessels	
Cruise ship	Large vessel (>25m) taking paying passengers
Cabin cruiser	Vessel with sleeping accommodation and in-board engine (private vessel)
Charter	Vessel (<25m) with paying passengers undertaking recreational activities or live-aboard trip
Commercial	Used for commercial purposes (e.g., fishing, research, rig tender, pearling)
Open >5 m	No sleeping accommodation, out-board engine, >5 m in length and may include cruise ship tenders
Open <5 m	No sleeping accommodation, out-board engine, <5 m in length and may include cruise ship tenders
Tinnie	Small aluminium vessel with out-board engine, generally <5 m in length
Jetski	Jet-propelled craft, also known as Personal Water Craft (PWC)
Tender	Small vessel powered by oars or motor, used to transport people to or from a larger vessel
Other	Includes other vessels such as a float plane or hydrofoil
Unknown	Unknown motorised vessel type
Non-motorised vessels	
Yacht	Vessel >7 m in length with the ability to be powered by sail
Dinghy	Vessel <7m in length with the ability to be powered by sail
Kayak	Vessel powered by paddles, can carry one or two passengers
Windsurfer	One person vessel consisting of a board and single sail
Kitesurfer	Small surfboard with sail harnessing wind power
Unknown	Unknown non-motorised vessel type

Table 4. Categories for other indicators of human use recorded during the aerial surveys of Eighty Mile Beach.

Object	**Characteristics**
Camp	One (or more) tents, caravans or camper trailers which share a communal area in an identifiable clearing (may have associated vehicles)
Vehicle	Vehicle with four wheels
Motorbike	Motorbike or quadbike
Boat trailer	An empty boat trailer attached to a vehicle, often at a boat ramp or boat launching area. If no vehicle attached then still counted as a boat trailer
Anchored boat	Boat anchored (or tied to a mooring), often near a campsite or boat ramp but outside of an ‘authorised’ mooring area. Not currently being used for an activity
Boat on beach	Boat dragged up on the beach, often near a campsite

3 Results

3.1 Aerial surveys

Twelve survey flights were flown along Eighty Mile Beach during the study period (Table 5).

Table 5. Dates, survey times, start and finish locations for Eighty Mile Beach aerial surveys between November 2012 and October 2013.

Date	Survey start time	Survey finish time	Survey start	Survey finish
16/11/2012	09:42	12:11	4 Mile Creek	Crab Creek
15/12/2012	10:22	12:40	Crab Creek	4 Mile Creek
15/01/2013	10:41	13:16	4 Mile Creek	Crab Creek
11/02/2013	09:42	12:15	4 Mile Creek	Crab Creek
16/03/2013	11:30	13:54	Crab Creek	4 Mile Creek
10/04/2013	08:44	11:02	4 Mile Creek	Crab Creek
25/05/2013	08:49	11:22	4 Mile Creek	Crab Creek
16/06/2013	12:00	14:19	Crab Creek	4 Mile Creek
15/07/2013	11:56	14:16	4 Mile Creek	Crab Creek
08/08/2013	10:18	12:41	Crab Creek	4 Mile Creek
07/09/2013	10:32	12:48	Crab Creek	4 Mile Creek
05/10/2013	10:05	12:22	Crab Creek	4 Mile Creek

3.1.1 Shore activities

Very few people were recorded along the shore of the study area during the November to April off-peak, wet season surveys (n=136) but there was a twelve-fold increase in the number of people observed during the May to October peak, dry season surveys (n=1569 people) (Figure 2). Areas with greatest densities of people were near Eighty Mile Beach Caravan Park, Cape Keraudren and Barn Hill and, to a lesser extent, Port Smith and Bidyadanga. The highest mean density was 7 people per 0.25 km^2 on the beach adjacent to the Eighty Mile Beach Caravan Park during peak season. The standard deviations of mean density values were high, largely because people were found in low numbers and were seldom located in exactly the same geographic location (Appendix 1).

Of the people recorded, 46% were engaged in fishing from the beach and 33% were walking along the beach (Table 6). Fishing was particularly popular near Eighty Mile Beach Caravan Park with anglers and their associated four-wheel drive vehicles spread along about 30 km of coastline (Figure 3). The maximum number of people observed to be engaged in shore fishing in this area during any survey flight was 109 in September 2013. People walking along the beach had a similar spatial distribution to those engaged in fishing (Figure 4).

Table 6. Number of people observed to be engaged in different activities along the coast in the survey area between Crab Creek and Four Mile Creek during the period November 2012 to October 2013.

Activity	Number of people recorded
Beach games	10
Line fishing	783
Netting	2
Relaxing	133
Sightseeing	1
Swimming	62
Walking	563
Other activities	141
Unknown	10
Total	1705

Four-wheel drive vehicles are indicators of people engaging in activities along the coast. Highest densities of vehicles were near Eighty Mile Beach Caravan Park, Cape Keraudren and Barn Hill (Figure 5). In terms of actual numbers, the highest counts along the beach in the vicinity of the Eighty Mile Beach Caravan Park during any survey flight were 70 vehicles in June 2013 and 18 quad bikes in September 2013. Camping along the coast during the dry season was mainly within the confines of the large caravan parks at Eighty Mile Beach (200 sites) and Port Smith (100 sites) where occupancy was not evaluated. There were also nodes of camping along the cliffs at Barn Hill Station and at Cape Keraudren (Figure 6). Boat launching was very limited along the coast of the study area with boat trailers recorded along the shore at three main sites, namely, Barn Hill, Port Smith and Cape Keraudren (Figure 7).

3.1.2 Boat-based activities

Boat-based activities occurred mainly in the northern part of the study area, particularly around Port Smith and the low mean densities had relatively high standard deviations (Figure 8, Appendix 2). A few vessels were recorded near Cape Keraudren but no vessels were observed in coastal waters between Cape Keraudren and Anna Plains during the study. The observed vessels were generally engaged in recreational fishing (Figure 9) or motoring (Figure 10) although pearling vessels were responsible for the increased density of vessels at Gourdon Bay between Port Smith and Barn Hill (Figure 11) during both seasons.

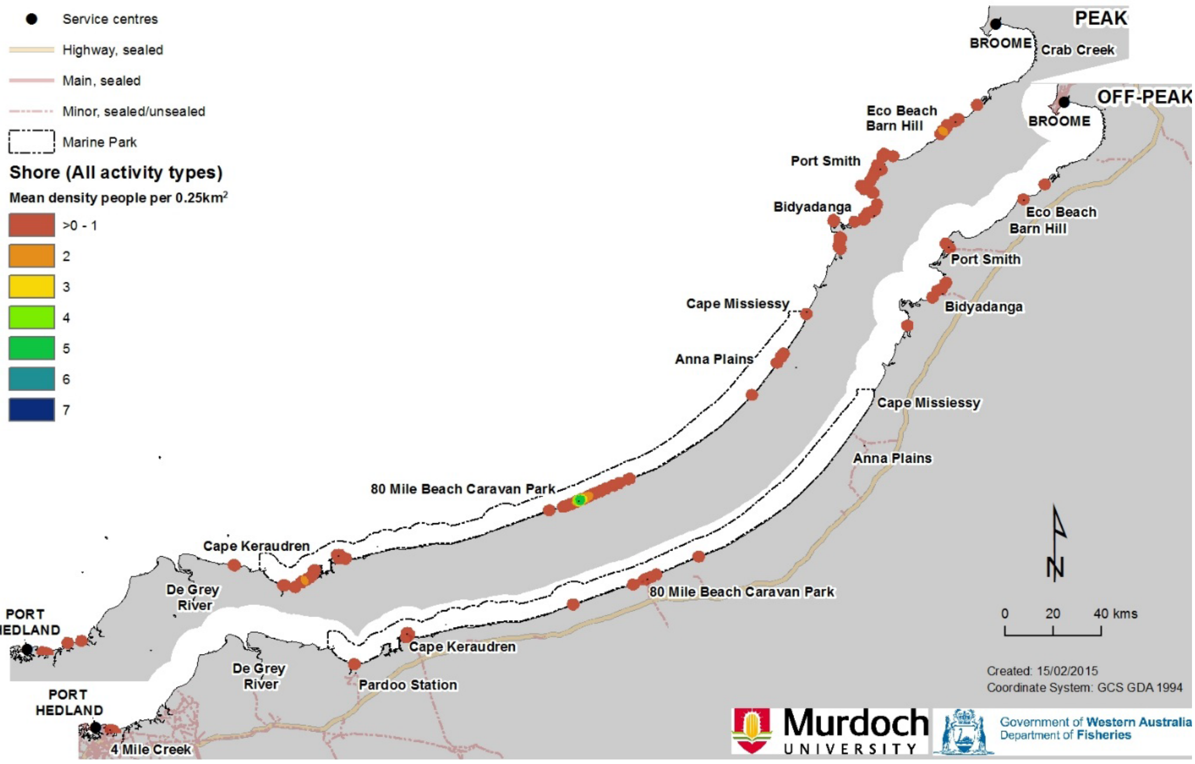

Figure 2. Mean density of people recorded along the shore between Crab Creek (Broome) and Four Mile Creek (Port Hedland) during the peak (dry) and off-peak (wet) seasons (n= 6 survey flights each season).

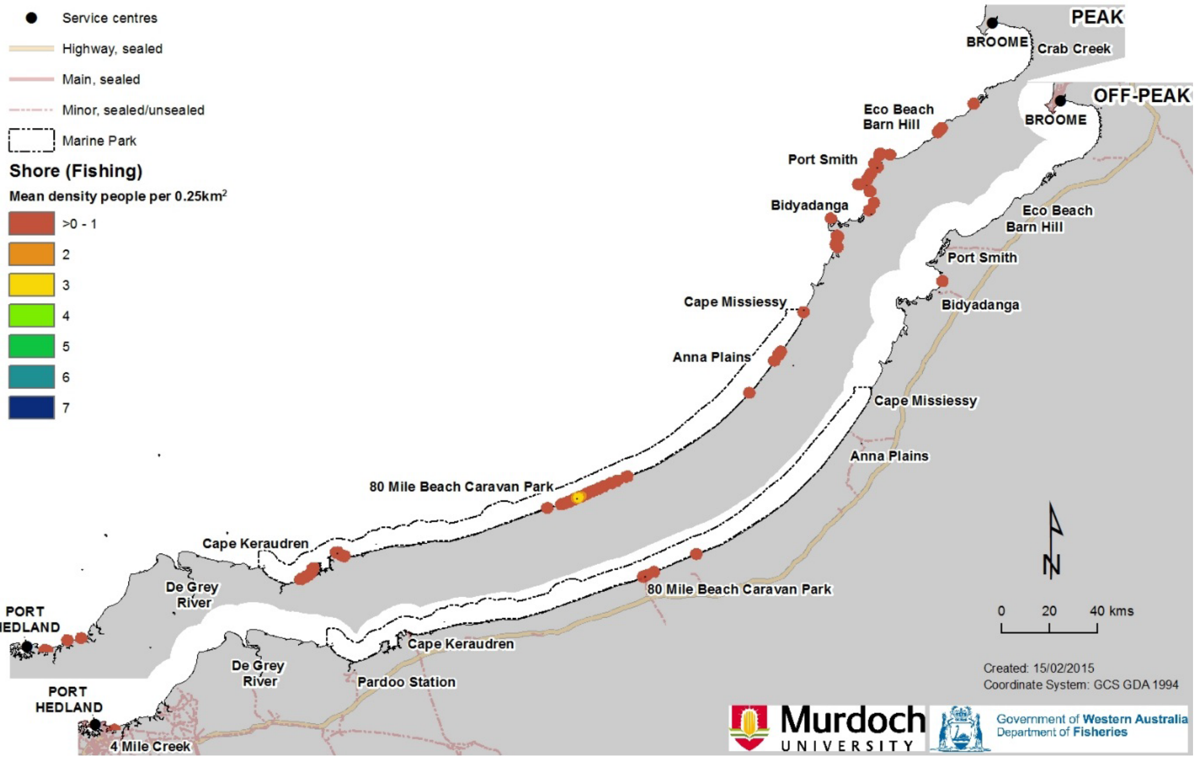

Figure 3. Mean density of people recorded as fishing from the shore between Crab Creek (Broome) and Four Mile Creek (Port Hedland) during the peak (dry) and off-peak (wet) seasons (n = 6 survey flights per season).

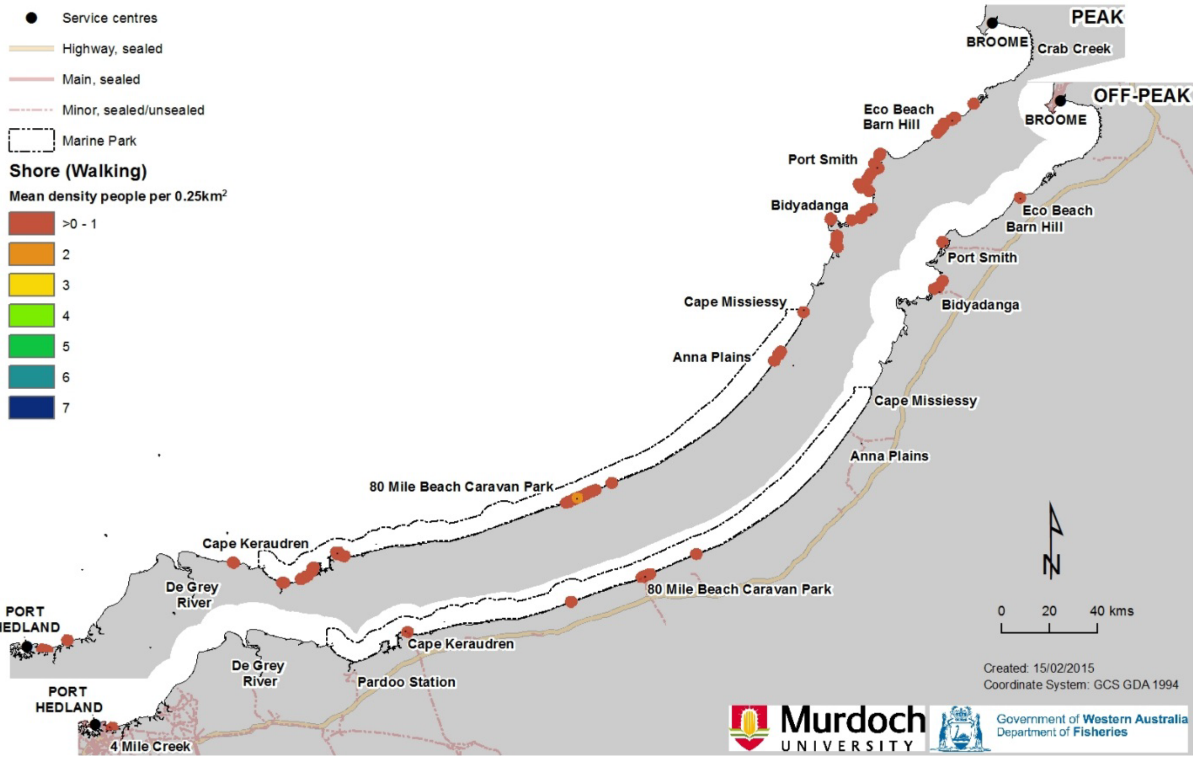

Figure 4. Mean density of people recorded walking along the shore between Crab Creek (Broome) and Four Mile Creek (Port Hedland) during the peak (dry) and off-peak (wet) seasons (n = 6 survey flights per season).

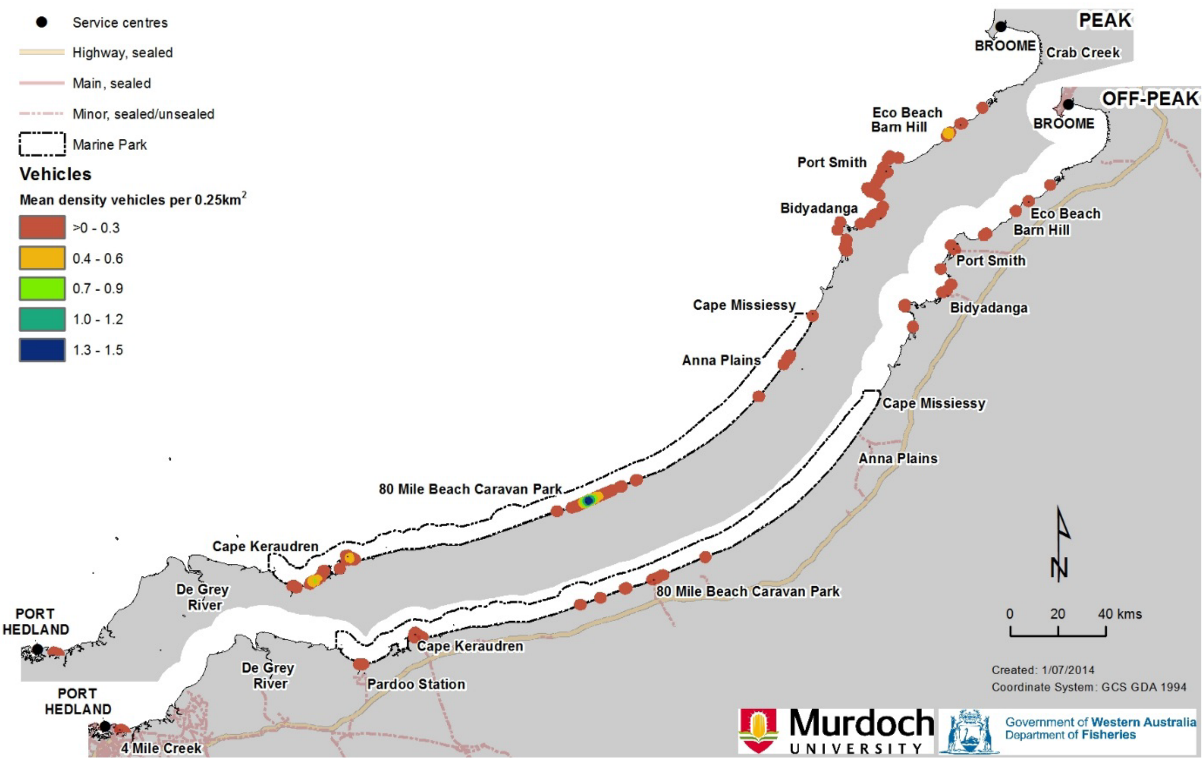

Figure 5. Mean density of vehicles recorded along the shore between Crab Creek (Broome) and Four Mile Creek (Port Hedland) during the peak (dry) and off peak (wet) seasons (n= 6 survey flights per season).

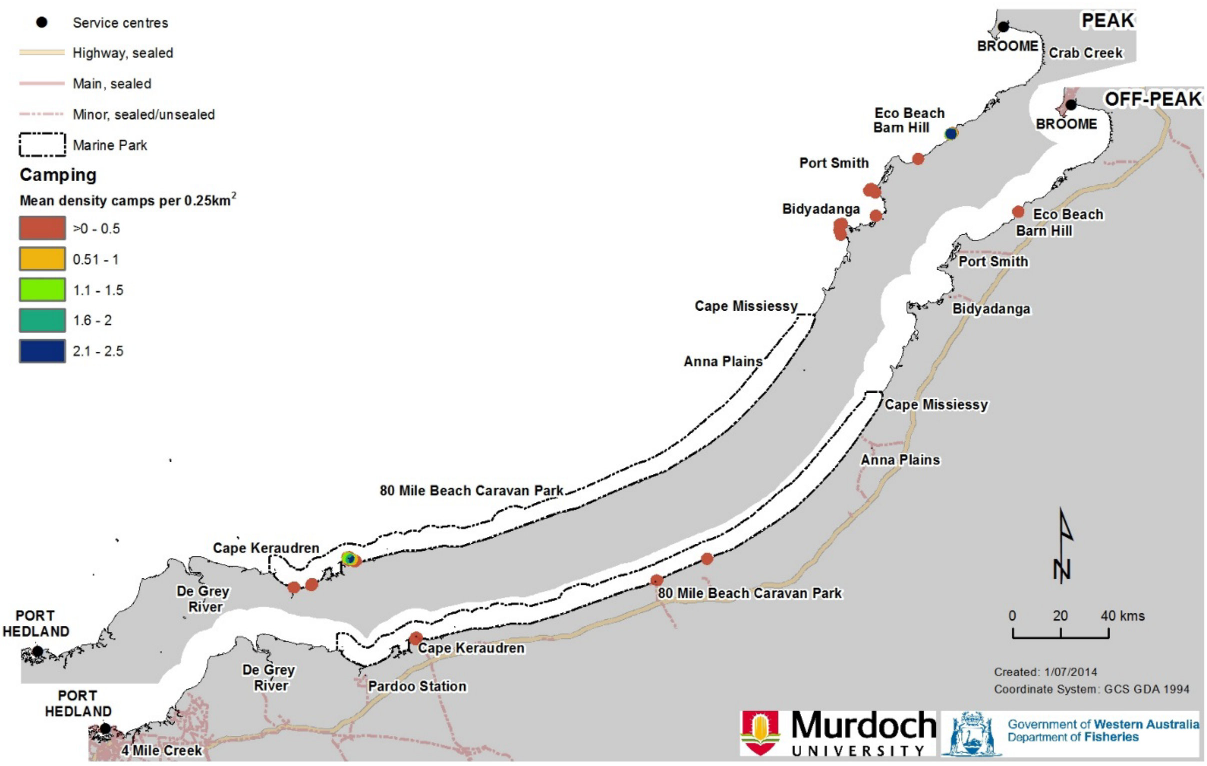

Figure 6. Mean density of camps recorded along the coast shore between Crab Creek (Broome) and Four Mile Creek (Port Hedland) during the peak (dry) and off-peak (wet) seasons (n = 6 survey flights per season). Note that camps within the confines of the Eighty Mile Beach Caravan Park (200 sites) and Port Smith Caravan Park (100 sites) were not included.

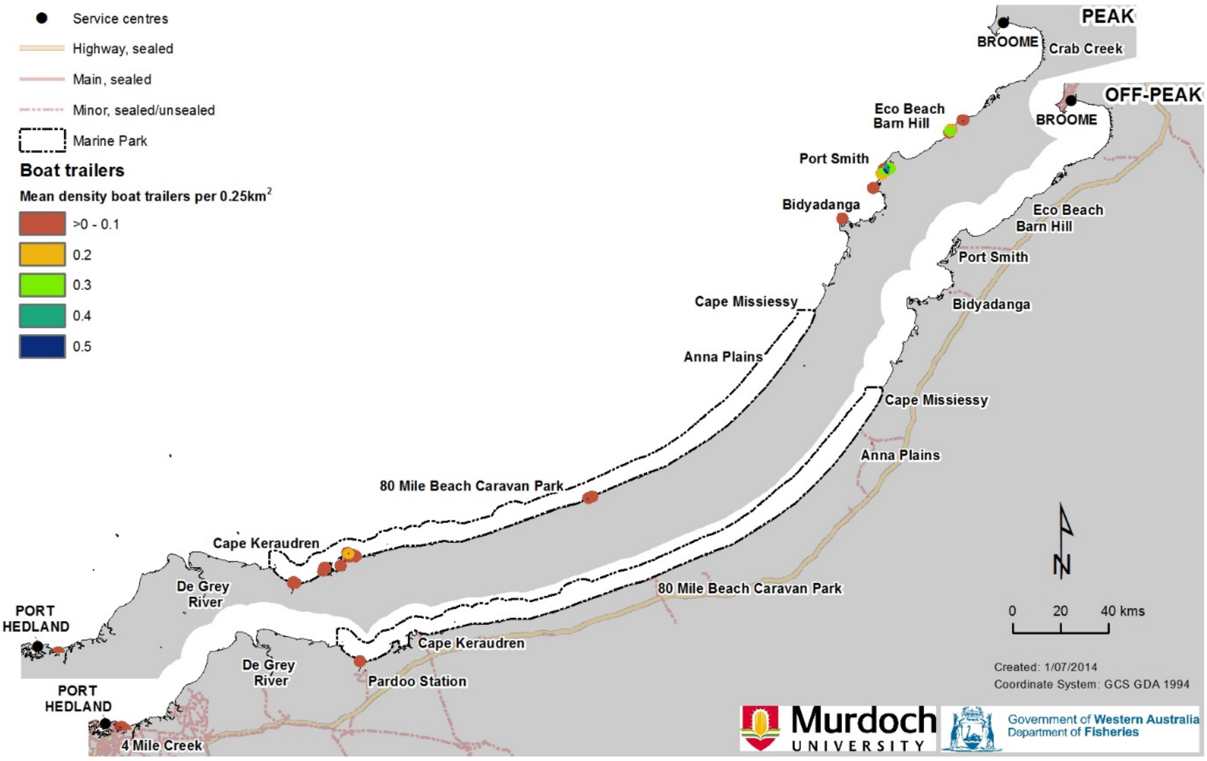

Figure 7. Mean density of boat trailers recorded along the shore between Crab Creek (Broome) and Four Mile Creek (Port Hedland) during the peak (dry) and off-peak (wet) seasons (n = 6 survey flights per season).

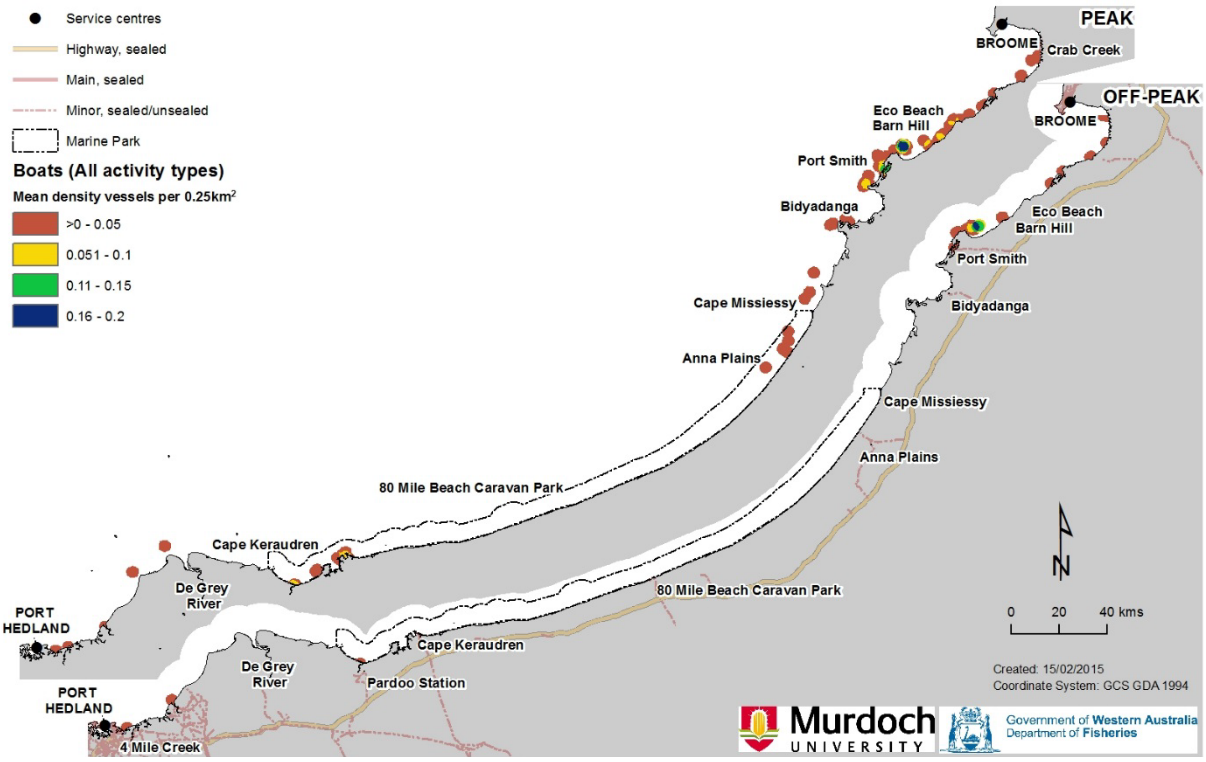

Figure 8. Mean density of all vessels recorded in coastal waters between Crab Creek (Broome) and Four Mile Creek (Port Hedland) during the peak (dry) and off-peak (wet) (n = 6 survey flights per season).

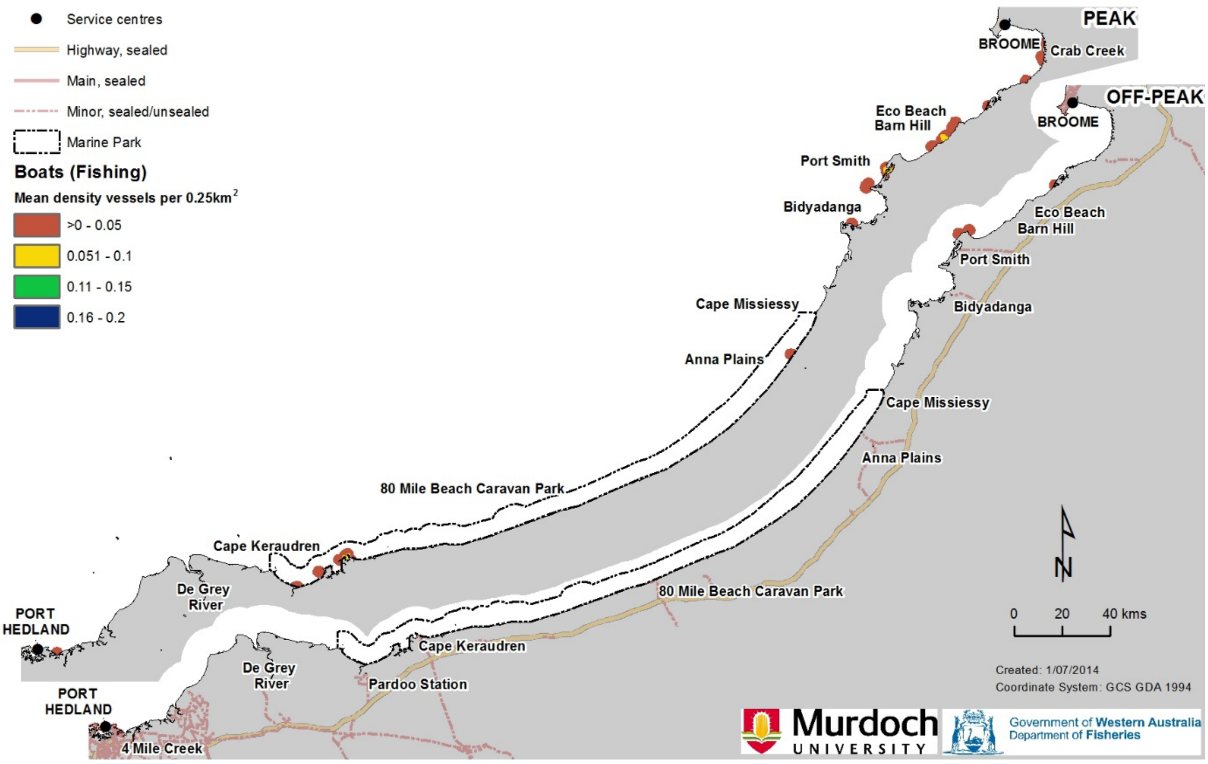

Figure 9. Mean density of vessels engaged in recreational fishing in coastal waters between Crab Creek (Broome) and Four Mile Creek (Port Hedland) during the peak (dry) and off-peak (wet) seasons (n = 6 survey flights per season).

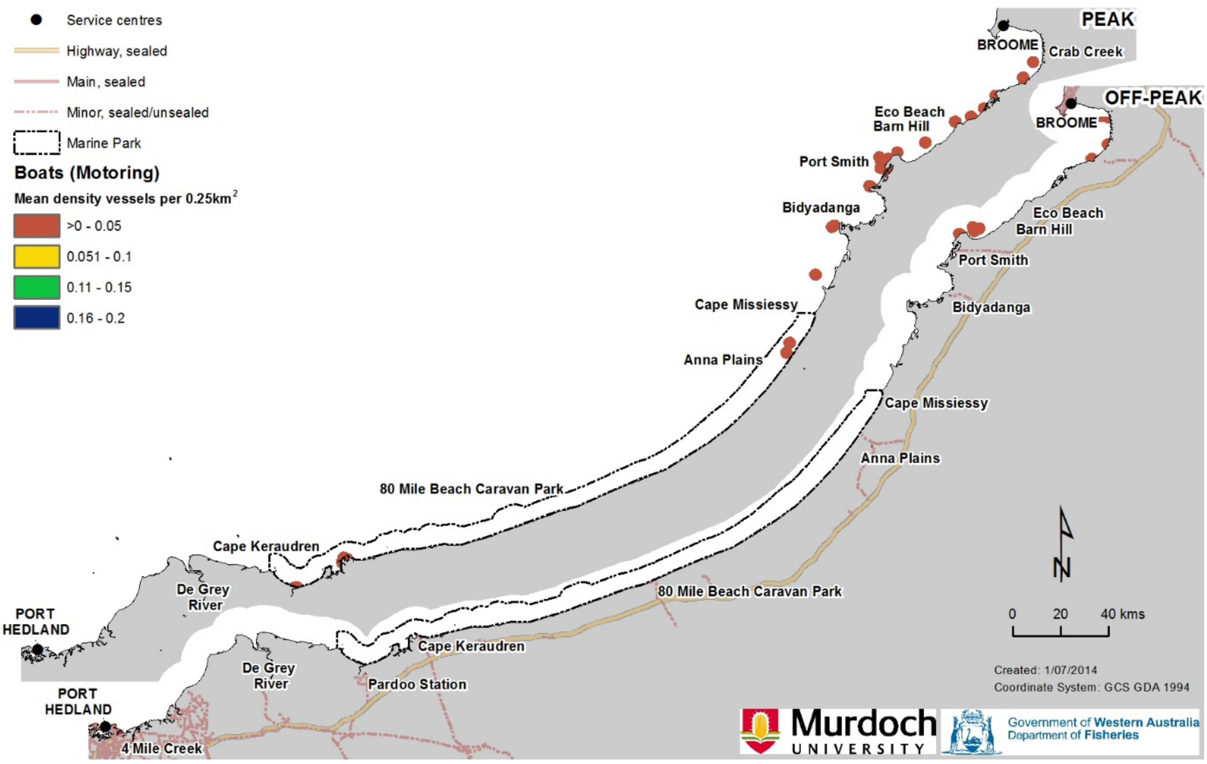

Figure 10. Mean density of vessels motoring in coastal waters between Crab Creek (Broome) and Four Mile Creek (Port Hedland) during the peak (dry) and off-peak (wet) seasons (n = 6 survey flights per season).

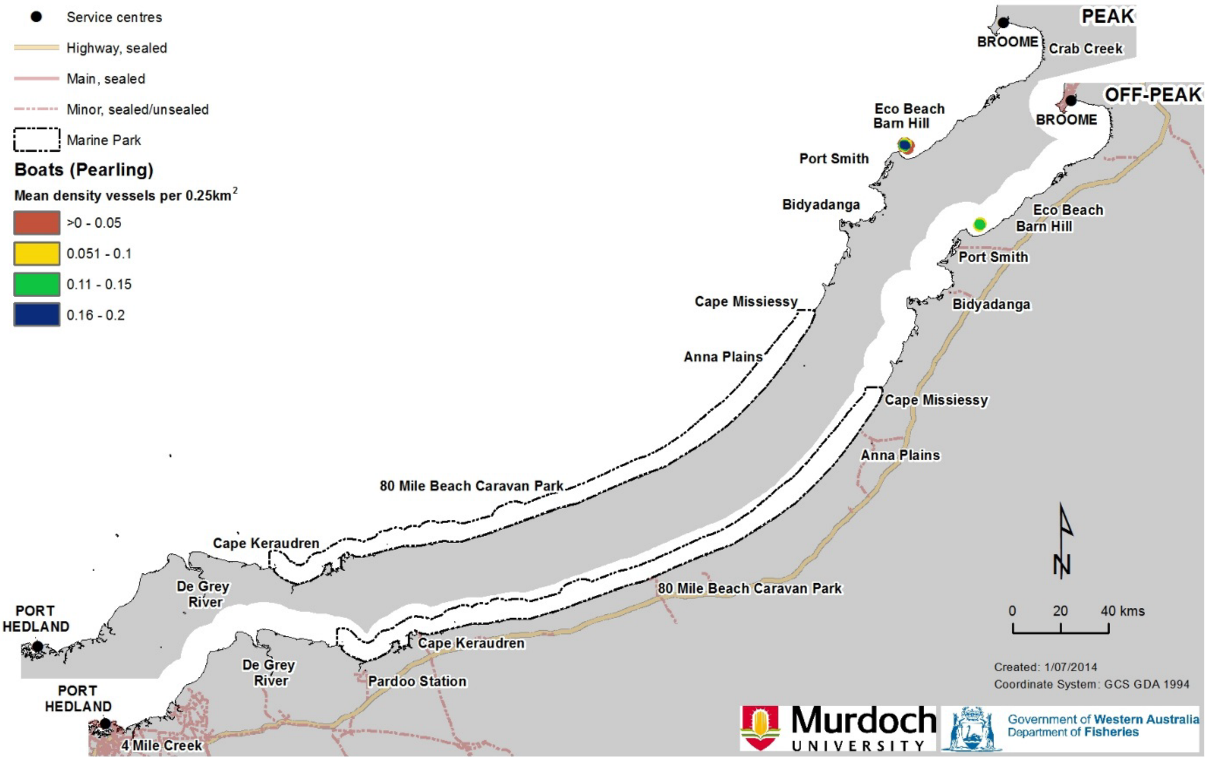

Figure 11. Mean density of vessels engaged in pearling operations between Crab Creek (Broome) and Four Mile Creek (Port Hedland) during the peak (dry) and off-peak (wet) seasons (n = 6 survey flights per season).

4 Discussion and Conclusions

The aerial surveys between Broome and Port Hedland identified clear seasonality in the use of the coast with significantly more people present during the dry, winter months and relatively little activity during the hot, summer months. This was similar to that found for the Ningaloo coast of north-western Australia which experiences a comparable climate (Smallwood et al. 2011a). There were distinct nodes of use located around Eighty Mile Beach Caravan Park, Cape Keruadren, Eco Beach, Barn Hill, Port Smith and Bidyadanga. With the exception of the resident community at Bidyadanga, which has a population of 595 people (Australian Bureau of Statistics 2013), the nodes of use coincided with locations where camp sites and/or tourist accommodation were available. There were also long stretches of coast were no human activity was observed. This was largely because access to the coast is limited; there are few formal roads and vast pastoral stations (e.g., Anna Plains) occupy much of the land adjacent to the coast. Further, in some areas, the beaches are intersected by tidal creeks which tend to restrict four-wheel drive vehicles. Nevertheless, recent construction of an airstrip for light aircraft at Eco Beach and frequent shuttle flights from Broome will probably change the nature of use in the northern part of the study area in the near future.

A limitation of this study was that, for logistical reasons, only six flights were conducted per season. Further, as generally low numbers of people and boats were observed, and they were seldom in exactly the same geographic location, variability was high. Nevertheless, there were clear nodes across the study area where higher use occurred and the study provides a benchmark of use prior to the implementation of the management plan for the Eighty Mile Beach Marine Park.

Shore-based fishing was the dominant activity along the coast with 46% of the people recorded in the survey engaged in this activity. The area adjacent to the Eighty Mile Beach Caravan Park had the highest mean density of recreational fishers. Walking was also popular with 33% of people recorded as undertaking this activity and 8% relaxing on the beach. This contrasts with Ningaloo Marine Park, where Smallwood et al. (2012b) found relaxing on the beach was the dominant activity (38%) followed by walking (19%), snorkelling (12%) and fishing (9%). It should be noted that, as all flights in the survey area were conducted around high tide, it is possible that any activities specific to low tide periods would have been underestimated. Further, some activities such as shell collecting or wildlife viewing, which have been reported to occur in the study area (Davies & Cammell 2009), cannot readily be discerned from the air and any people engaged in such activities were likely to have been reported as walking or unknown activity.

Four-wheel drive vehicles are generally used to reach the coast and were particularly abundant near the access points at Eighty Mile Beach Caravan Park, Cape Keraudren and Barn Hill. Camping was largely confined to the large caravan parks at Eighty Mile Beach (200 sites) and Port Smith (100 sites) though seasonal camping at Cape Keraudren (managed by the shire of East Pilbara) and along the cliffs at Barn Hill Station was also pronounced. Unlike the Ningaloo coast, where coastal camping extends over long stretches of coastline (Smallwood et al. 2011a), currently, coastal camping between Broome and Port Hedland is strongly nodal. Similar to that found at Ningaloo Marine Park, there was evidence of distance decay in distribution of people and vehicles from the camping areas (Smallwood et al. 2012c)

There are few recognised anchorages along this stretch of coast and much of it shoals from some distance offshore (Putt 2014). From the aerial surveys, boating was found to be very limited in coastal waters and was generally observed in proximity to sites where boats were launched at Barn Hill, Port Smith and Cape Keraudren. Although there is a small concrete boat ramp at Cape Keraudren, at the other two sites, boats are launched directly off the beach. Most of the observed vessels were recreational boats that were either motoring or engaged in fishing. The pearling activities recorded at Gourdon Bay north of Port Smith fall into the Zone 2 fishing area for pearl oysters demarcated by the WA Department of Fisheries (Fletcher & Santoro 2014).

Most of the shore-based activity along this stretch of coast was associated with sandy beaches and the negative impacts of beach use on fauna and dune flora are well known (Brown & McLachlan 2002, Priskin 2003, Foster-Smith et al. 2007, Defoe et al. 2009, McLachlan et al. 2013, Tonge & Beckley, this report). In particular, because of the importance of migratory shorebirds and nesting of turtles on Eighty Mile Beach, the impacts of four-wheel drive vehicles need to be carefully monitored. Fortunately, the migratory shorebirds and nesting turtles are in greatest abundance during the austral summer (Pendoley 2005, Rogers et al. 2011) which is the off-peak period for visitors to the Eighty Mile Beach coastline. Impacts of recreational boating and fishing on biodiversity are also well documented (McPhee et al. 2002, Davenport & Davenport 2006, Hardiman & Burgin 2010, Burgin & Hardiman 2011). All being well, compliance with the regulations pertaining to recreational fishing in the region (WA Department of Fisheries 2014) should ensure sustainable use and maintenance of adequate fish stocks in the area.

The Eighty Mile Beach Marine Park extends over 260 km of the study area (WA Department of Parks and Wildlife 2014) and the aerial survey findings enable comment to be made about human use of the coast within the demarcated zones in the park. Within the Anna Plains Sanctuary Zone, there was little activity recorded observed in the dry season (only two yachts, four vehicles, three walkers and two shore-based fishers) and nothing in the wet season. In contrast, adjacent to the Kurtamparanya Sanctuary Zone offshore of Cape Keraudren, and in the Pananykarra Sanctuary Zone and Special Purpose Zone (shore-based activities) near Pardoo, coastal camping and both shore and boat-based fishing were more prevalent, particularly during the peak season.

The Wallal Recreation Zone extends along 20 km of shoreline near the Eighty Mile Beach Caravan Park. This area was occupied by vehicles and people engaged in fishing, walking or relaxing along the shore during the peak season. The highest density of people recorded during the survey was along the beach adjacent to the caravan park. In the Malamalajungunya Special Purpose Zone (mangrove protection), no shore-based activities or boats were observed during any of the survey flights.

The northern part of the study area encompassed the southern shores of Roebuck Bay where another protected area is planned (Government of Western Australia 2011). Despite the surveys being flown when the creeks were tidally inundated, very few boats were recorded in this area. Further, no shore activities were observed, probably because of the extensive mangrove forests lining the shore.

In conclusion, human use of this remote section of coast is highly seasonal and located around a few access nodes where roads to the coast exist and camp sites and/or tourist accommodation are available. No activity was observed over long stretches of the coast within the boundaries of the newly established Eighty Mile Beach Marine Park. This study provides spatially-explicit, quantitative data on human use, particularly recreational activities along the coast and in adjacent waters, and can be used as a benchmark for managers and traditional owners at the inception of the Eighty Mile Beach Marine Park.

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6 Appendices

APPENDIX 1

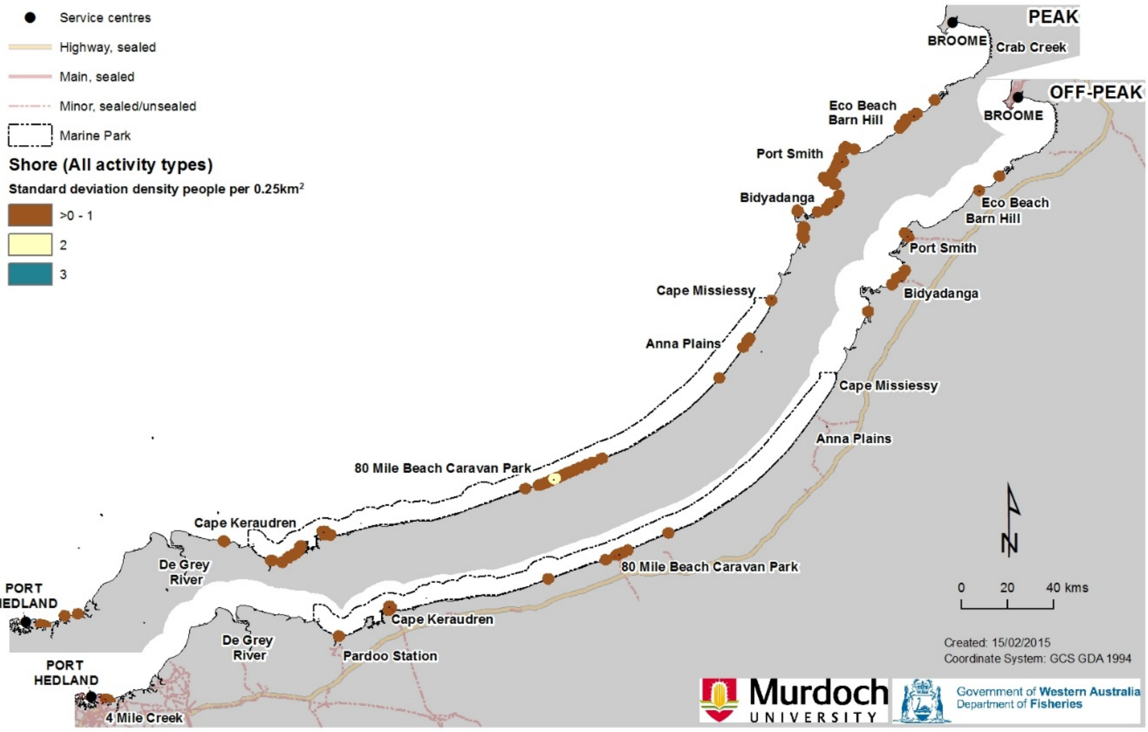

Figure 12. Standard deviation of the mean density of people recorded along the shore between Crab Creek (Broome) and Four Mile Creek (Port Hedland) during the peak (dry) and off-peak (wet) seasons (n = 6 survey flights each season).

APPENDIX 2

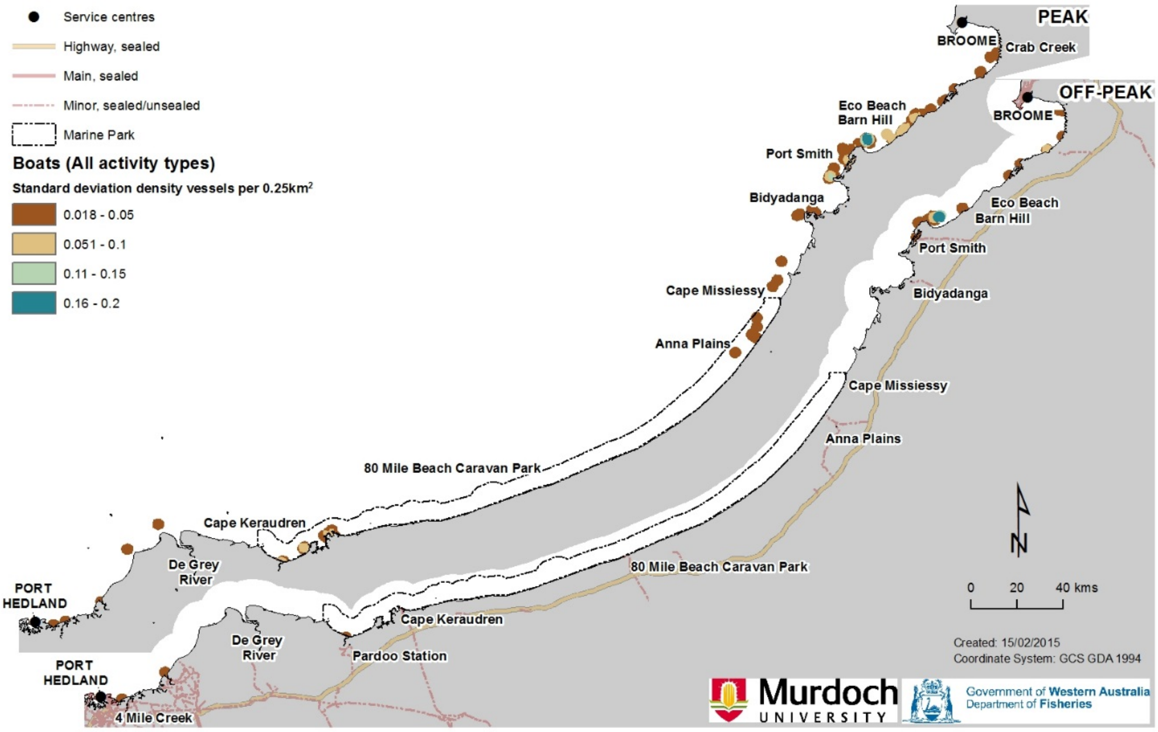

Figure 13. Standard deviation of the mean density of all vessels recorded in coastal waters between Crab Creek (Broome) and Four Mile Creek (Port Hedland) during the peak (dry) and off-peak (wet) seasons (n = 6 survey flights per season).

Chapter 2: Aerial survey of human use along the coast and adjacent waters of the Dampier Peninsula, western Kimberley

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Summary

Aerial surveys of human use were conducted along the Dampier Peninsula coast and adjacent waters over 12 months (November 2012 - October 2013). A Cessna 210 aircraft was used with two observers equipped with digital cameras and a GPS logger; Aerial Survey Assistant and GIS software were used for analyses. The majority of people using the coast were recorded during the peak (dry) season (n=5688) with considerably less during the off-peak (wet) season (n=1151). Although widely distributed along the coast, 51% of all people observed were along the 5 km extent of Cable Beach at Broome. Mean densities of people were low (<10 people per 0.1 km^2) everywhere except at Broome, particularly along the northern end of Cable Beach. During the peak season, people were generally using the coast from Broome northwards to Coulomb Point and around Beagle Bay, Middle Lagoon, Cape Leveque and One Arm Point. More people were recorded along the western shores of the Peninsula than along the eastern side within King Sound. Of the people recorded, 40% were walking along the shore, 27% were relaxing, 10% were swimming and 6% were engaged in fishing. In general, these activities were clustered around the south-west of the Peninsula although, during the peak season, there were more records from Beagle Bay northwards. Boating activity was largely concentrated in the south-western part of the study area in both seasons, particularly around the port of Broome. Boats were also more frequent in Beagle Bay, at Middle Lagoon, around the northern tip of the Peninsula and near Derby during the peak season. This survey provides spatially-explicit, quantitative data on the extent of human use, particularly recreational activities and boating, around the Dampier Peninsula during both the off-peak (wet) and peak (dry) seasons. For western Kimberley traditional owners, residents, managers and planners, this study provides a bench mark of use prior to any major coastal development such as the proposed construction of a sealed road northward to Cape Leveque or tourist infrastructure such as hotels, marinas and larger boat ramps on the Dampier Peninsula.

1 Introduction

Indigenous people have used the coast of the Dampier Peninsula in the western Kimberley for subsistence and cultural activities for thousands of years (O'Connor 1999, Burton 2000, Vigilante et al. 2013). Pearling and commercial fishing have taken place since the late 1800s (Saville-Kent 1896, Bach 1955, Nowara & Newman 2001, Fletcher & Santoro 2014) and, in more recent years, coastal tourism and recreational activities have also become important in this region (Zell 2007, Collins 2008, Davies & Cammell 2009, Scherrer et al. 2011).

Broome, a multi-cultural town located at the south-western end of the Peninsula, is the regional centre. The Shire of Broome, which includes the town and much of the Peninsula, had a population of 15,000 at the 2011 census (Australian Bureau of Statistics 2011a). Numerous Indigenous communities are located on the Peninsula and include, amongst others, those at Beagle Bay (255 people), Djarindjin-Lombardina (245 people) and One Arm Point (334 people) (Australian Bureau of Statistics 2011b). Although a road extends from Broome to Cape Leveque and One Arm Point at the northern end of the Peninsula (Figure 1), much of it is not sealed and it can be difficult to negotiate, particularly during the wet season. The town of Derby, on the shores of King Sound, is located to the east of the Peninsula, and has a population of 3261 (Australian Bureau of Statistics 2011b).

A holistic approach to coastal management (comprising social as well as biological elements) requires the collection of data on human activities to provide a complete understanding of pressures placed on the coast and adjacent waters (Wilkinson et al. 2003, Eastwood et al. 2007, Ban & Alder 2008, Halpern et al. 2008, Dalton et al. 2010). Knowledge of the spatial and temporal extent of human use (traditional, recreational and commercial) is essential for adequate management of the coast and coastal waters of the Kimberley. Considerable information already exists in state government departments on the spatial and temporal extent of most regulated activities (e.g., commercial fishing; Fletcher & Santoro 2014). Collation and integration of Indigenous knowledge about use of the Kimberley coast for conservation and management constitutes another component of the on-going Kimberley Marine Research Programme (WAMSI 2011).

There have been no prior attempts to survey recreational use around the coast of the Dampier Peninsula in a spatially explicit manner. Davies & Cammell (2009) noted that many coastal recreational activities were undertaken by residents and visitors, both in Broome and on the Peninsula, and these included fishing, swimming, boating, four-wheel driving and coastal camping. About a dozen coastal camping sites have been identified on the Dampier Peninsula (Davies et al. 2009). The catch and effort by recreational fishers at Broome has been examined as part of a study of recreational fishing along the Pilbara coast (Williamson et al. 2006). In a more recent assessment of boat-based recreational fishing in Western Australia, the Dampier Peninsula was included in a phone-diary survey and boat launches at Broome Entrance Point boat ramp were monitored using a remote camera system (Ryan et al. 2013).

The aim of this study was to use aerial surveys, during both the wet and dry seasons, to map the location and abundance of people and boats engaged in activities along the coast and in the waters adjacent to the Dampier Peninsula between Broome and Derby. The study was focussed on recreational activities but all activities were included because, during aerial surveys, it is usually difficult to distinguish traditional activities from some recreational pursuits. In the south, attention was paid to the areas covered by the Sport and Recreation Master Plan of the Shire of Broome and the Joint Management Plan of the Yawuru Park Council. In the north, attention was focussed on the Bardi Jawi Indigenous Protected Area (IPA) created in May 2013 across 354,867 hectares of the northern extent of the Dampier Peninsula (Government of Australia, Department of Environment 2013). This study also provides information to assist and design future, temporally-appropriate, monitoring surveys for the Dampier Peninsula.

2 Materials and Methods

2.1 Study area

The study area for the aerial surveys of human use on Dampier Peninsula extended from Crab Creek, south-east of Broome, to Point Torment north of Derby (Figure 1).

2.2 Survey design

The design of the survey was based upon the maximum count method often used in studies of recreational fishing where surveys are conducted during periods of maximum recreational activity (Volstad et al. 2006, Veiga et al. 2010, Smallwood et al. 2012a). As there is a very large tidal range in the region, with expansive mud flats exposed at low tides, surveys were standardised around the period of high water. During high tides, vessels can access coastal creeks and shore-fishing is generally limited to periods of flood tides and high water (Fletcher & Santoro 2012). Tidal information from the port of Broome was used to schedule the Dampier Peninsula surveys.

Surveys at Dampier Peninsula were stratified by season, with the peak (dry) season defined as May – October and the off-peak (wet) season extending from November – April (Table 1). The remote location of the Dampier Peninsula study area, and the fact that other areas of the Kimberley were also surveyed during the same field trip, meant that days could not be randomly selected and surveys were grouped into consecutive days (i.e., a five-day trip to the Kimberley may include several aerial surveys covering different areas). To accommodate any extreme weather conditions (e.g., thunderstorms, strong winds or rain), illness or plane malfunction, a replacement day was incorporated into the end of each trip to allow for re-scheduling of flights. In addition to this, replacement trips were included for the wet season, as cyclones could have led to cancellation of an entire trip to the Kimberley. However, during the study period, all flights were able to be completed on their allocated day.

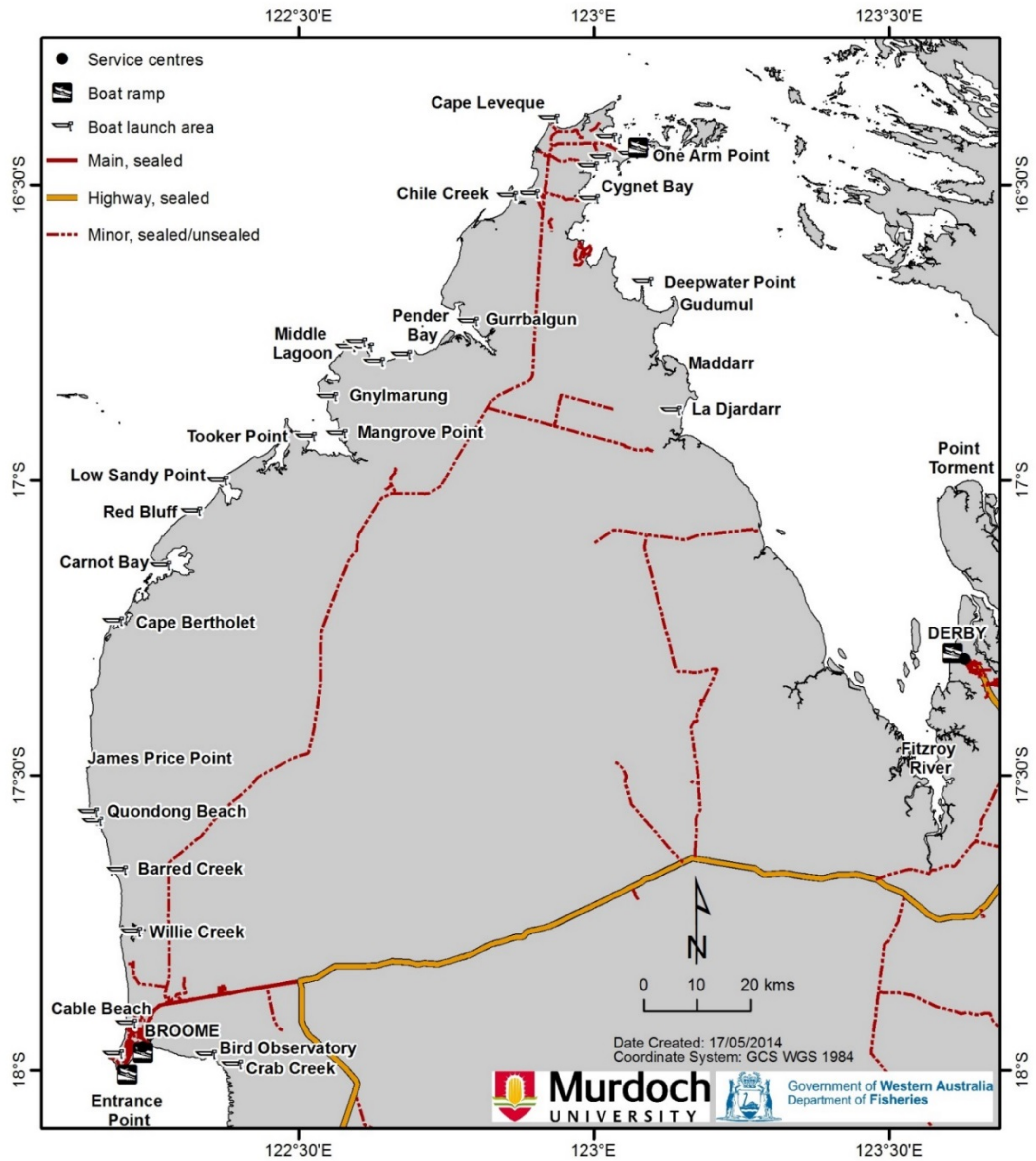

Figure 1. Study area for aerial surveys of the Dampier Peninsula in the Kimberley (November 2012 to October 2013).

Table 1. Design features of the aerial surveys along the Dampier Peninsula coast conducted between November 2012 and October 2013.

Design aspect	Design details
Extent	Crab Creek (Broome) to Point Torment (Derby)
Length of coast	~500 km
Study period	November 2012 – October 2013
Number of survey days (n)	24 (12 peak; 12 off peak)
Approximate day length	Peak (dry season): 6 am – 5 pm; Off-peak (wet season): 5.30 am – 6 pm
Survey duration	2.5 hours plus 1 hour to/from survey start/finish
Stratification & randomisation	
Season	Stratified by season into peak (dry) and off-peak (wet)
Month	Stratified by month, with each sampled at the same intensity
Tide	Surveyed at high tide on days on which it occurred between 8 am – 5 pm
Trip allocation	Randomly allocated using a series of steps to maximise the equal probability of each day being selected
Site	Random selection was used to allocate surveys within each trip
Day-type	Random allocation of weekdays and weekends/public holidays
Time of day	Not included because time of high tide was expected to have greater influence
Starting location	Randomly selected from start or finish location (i.e., no mid-survey starts)
Direction of travel	Linked with starting location and therefore randomly selected

The flight path for the survey followed the coastline with the plane generally positioned about 200 – 300 m offshore to enable the best viewing of activities along the shore. For small creeks and inlets it was possible to obtain good coverage without deviating from the flight path. However, for larger inlets (e.g., Willie Creek and Beagle Bay) the flight path was altered to complete a circuit of the inlet.

There can be a reduction in the quality of data if the plane moves too fast for the observers to record all activity at a specific location, or parts of the plane obscure the observer's view while turning. To avoid such situations, the pilot was instructed to slow down or complete a loop in order to provide a second opportunity to capture the information. Awareness of the features of the coastline, looking forward along the flight path, and open communication with the pilot also ensured that the plane was not turning at a time when a clear view of the coastline was required. These actions also assisted with reducing the effect of poor sightings of objects close to the aircraft because of obstruction of downward visibility (Leatherwood et al. 1982, Quang & Becker 1997). As it is difficult to observe recreational activity in poor light conditions, no surveys were scheduled to start before an hour after sunrise or end in the hour prior to sunset.

Visibility issues can be a concern during aerial surveys (Pollock & Kendall 1987, Bayliss & Yeomans 1989, Marsh & Sinclair 1989) and it can sometimes be difficult to see people on rocky shores unless they are wearing bright or contrasting clothing. To assist with minimising such issues, photographs were taken so they could be examined post-flight to identify all recreational activity. Following the method applied by Smallwood et al. (2011a), boat-based activity was recorded at the 'boat' rather than the 'person' level to address difficulties in establishing the actual number of people on vessels.

2.3 Data collection

Aerial surveys were conducted by two observers in a Cessna 210 aircraft (4-seater with high wing configuration) with a cruising speed of 120 knots, which could be slowed to 100 knots for sites which required more time for observation. Surveys were flown at a height of 300 m (1000 ft).

Data on shore-based activities were collected by the observer in the rear seat and data on boat-based activities were collected by the observer in the front seat. Each observer had a Canon EOS 600D digital camera to document each observation and a data sheet for recording the time of observation, activity type, vessel type (if a boat-based activity) and number of people (if a shore-based activity). Shore-based activities within 500 m of the water's edge were recorded and vessels were observed out to about 5 km of the flight path. A route for each survey was loaded onto a Garmin GPS, along with every named location along the way, to ensure consistency between surveys. A data logger which recorded geographical co-ordinates at one second intervals along the track of each flight was also mounted on the dashboard of the plane.

Aerial Survey Assistant (ASA) software was used to merge track logs and photographs from each survey and enable the observers to identify shore- and boat-based activities to a specific geographic co-ordinate (Ocean Vision Environmental Research 2010). This technique has been successfully utilised in previous aerial surveys of recreational shore-based activity in Western Australia (Smallwood et al. 2011b, Smallwood et al. 2011c, Smallwood & Gaughan 2013). For this project, the ASA software was further developed to capture information for boat-based activities.

2.4 Categories for coastal activities

Categories for activity types were based on previous research conducted in Western Australia (Smallwood & Beckley 2008, Smallwood 2010, Smallwood et al. 2011a) and elsewhere (Horneman et al. 2002). After considering some of the unique activity types in the Kimberley (i.e., commercial pearling) a total of 17 shore-based activity and 18 boat-based activity categories were utilised in the study (Table 2).

Categories ascribed to boats were also based on previous research conducted in Western Australia (Smallwood & Beckley 2008, Smallwood et al. 2011a) and elsewhere (Adams et al. 1992, Widmer & Underwood 2004, Warnken & Leon 2006) resulting in 11 categories of motorised vessels and six categories of non-motorised vessels being available for selection (Table 3).

As indicators of recreational use, counts of camps, boat trailers, anchored or moored boats, boats on the beach and vehicles along the shore were also made during the aerial surveys. This is similar to previous research conducted in Western Australia (Hughes & Mau 2006, Smallwood 2010, Smallwood et al. 2011a, Smallwood & Gaughan 2013) and elsewhere (Hockings & Twyford 1997). Standard definitions of each of these objects are provided in Table 4. It should be noted that vehicles were only counted at day-use sites, and not if they were associated with a coastal campsite. Additionally, camps were not counted within the many demarcated caravan parks at Broome or at Kooljaman at Cape Leveque.

Table 2. Categories for shore-based and boat-based activities ascribed to observations during aerial surveys of the Dampier Peninsula.

Activity type	Characteristics
Shore-based	
Beach games	Sporting activities conducted on the beach (i.e., frisbee, beach cricket, skim-boarding)
Boating	Loading or unloading charter passengers
Crabbing	Use of drop nets or scoops
Exercise	Jogging, yoga etc.
Commercial	People involved in commercial or industrial activity (may be in high visibility gear)
Line fishing	Extraction of marine organisms using a hook and line and includes fly fishing
Netting	Using a cast, haul or set net of mesh to collect marine organisms
Relaxing	Sunbaking, standing, sitting or resting along the shore and includes sitting under a sun shelter
Riding	Includes camel tours on Cable Beach
Snorkelling	Viewing of marine organisms using a face mask
Spearfishing	People targeting aquatic organisms with a spear-gun
Spectating/sightseeing	Looking at features of interest in the natural environment or people participating in recreational activities and includes photographers and videographers
Surfing/paddle-boarding	Use of a board or stand-up paddleboard to ride waves
Swimming	Partial or full immersion in water and includes wading
Unknown	Activity of the person could not be ascertained
Walking	People travelling on foot along the shore and includes walking the dog and reef walking
Other	All other activity types
Boat-based	
Crabbing	Use of drop nets or scoops
Jet skiing	Use of jet propelled craft, also known as Personal Water Craft (PWC)
Kayaking	Vessel powered by paddles. Includes private and commercial kayaks
Kite surfing	Wind driven sport using a kite; includes people rigging a kite
Line fishing	Extraction of marine organisms using a hook and line and includes fly fishing
Moored	Boat moored within an 'authorised' mooring area and not being used for any activity; pearling vessels moored off pearling leases are often in this category
Motoring	Vessel transiting at high speed
Netting	Using a cast, haul or set net of mesh to collect marine organisms
Pearling/aquaculture	Vessels involved in pearling or aquaculture activity
Research	Research activities from an identified research vessel
Sailing	Yacht or dinghy under sail power
Spearfishing	People targeting aquatic organisms with a spear-gun
Towing sports	Activity where people are towed behind a vessel (e.g., knee-boarding, skiing and tubing)
Unknown	Activity of vessel could not be ascertained
Wildlife interaction	People view wildlife from close proximity (e.g., swimming with manta rays)
Wildlife viewing	People view wildlife from a distance (e.g., whale watching, turtle watching and coral viewing from glass bottom boats)
Windsurfing	Wind driven sport using a windsurfer. Includes people rigging or setting up a windsurfer
Other	All other activity types

Table 3. Categories of vessels ascribed to observations made during aerial surveys of coastal waters off the Dampier Peninsula.

Vessel type	Characteristics
Motorised vessels	
Cruise ship	Large vessel (>25m) taking paid passengers
Cabin cruiser	Vessel with sleeping accommodation, in-board engine (private vessel)
Charter	Vessel (<25 m) with paying passengers undertaking recreational activities or live-aboard trip
Commercial	Used for commercial purposes (e.g., fishing, research, rig tender, pearling)
Open >5 m	No sleeping accommodation, out-board engine (>5 m); may include cruise ship tenders
Open <5 m	No sleeping accommodation, out-board engine (<5 m); may include cruise ship tenders
Tinnie	Small aluminium vessel with out-board engine, generally <5 m
Jetski	Jet propelled craft also known as Personal Water Craft (PWC)
Tender	Small vessel powered by oars or motor, used for transport to or from a larger vessel/shore
Other	Includes other vessels such as a float plane or hydrofoil
Unknown	Unknown motorised vessel type
Non-motorised vessels	
Yacht	Vessel (>7 m) powered by sail
Dinghy	Vessel (<7 m) powered by sail
Kayak	Vessel powered by paddles, can carry one or two passengers
Windsurfer	Single person vessel consisting of a board and one sail
Kitesurfer	Small surfboard with sail harnessing wind power
Unknown	Unknown non-motorised vessel type

Table 4. Categories for other indicators of human use recorded during the aerial surveys of the Dampier Peninsula.

Object	Characteristics
Camp	One (or more) tents, caravans or camper trailers which share a communal area in an identifiable clearing (which may have associated vehicles)
Vehicle	Vehicle with four wheels
Motorbike	Motorbike or quadbike
Boat trailer	An empty boat trailer attached to a vehicle, often at a boat ramp or boat launching area. If no vehicle attached then still counted as a boat trailer
Anchored boat	Boat anchored (or tied to a mooring), often near a campsite or boat ramp but outside of an 'authorised' mooring area. Not currently being used for an activity
Boat on beach	Boat dragged up on the beach, often near a campsite

2.5 Analysis

After processing with ASA software, the data points were imported into ArcGIS 10.2 for analyses. Data were collected in WGS84, which approximates GDA94, and was sufficient for presentation of raw data points using graduated symbols to represent the number of vessels, boats or other indicators of recreational activity.

The point density tool in Spatial Analyst was used to calculate the density of data points across the various strata incorporated into each survey route. For this analysis, data were converted to UTM51S, the central UTM zone in the study area. This tool calculated the density of point features in a grid cell by counting the total number of point features within a specified search radius, and dividing by its area. Each point was weighted by the number of units associated with each observation (e.g., number of fishers, number of boat trailers). In this study, a grid size of 0.1 km^2 was specified for Dampier Peninsula, along with a search radius of 1 km. Similar techniques have been used in studies of recreational use in Australia (Smallwood et al. 2012b) and elsewhere (Dalton et al. 2010, Thompson & Dalton 2010). A point density layer was calculated for each flight, and these were aggregated to calculate a mean density for each stratum using the cell statistics tool. Similarly, the standard deviation of the mean density in each grid cell was also calculated using this tool.

3 Results

3.1 Aerial surveys

Twenty-four survey flights were flown around Dampier Peninsula during the study period from November 2012 to October 2013 (Table 5).

Table 5. Dates, survey times and start and finish locations for aerial surveys of the Dampier Peninsula.

Date	Survey start time	Survey finish time	Survey start	Survey finish
15/11/2012	10:10	12:29	Point Torment	Crab Creek
17/11/2012	11:20	13:35	Crab Creek	Point Torment
14/12/2012	10:07	12:20	Crab Creek	Point Torment
16/12/2012	11:54	14:18	Point Torment	Crab Creek
13/01/2013	10:37	12:53	Point Torment	Crab Creek
14/01/2013	11:08	13:25	Point Torment	Crab Creek
10/02/2013	09:34	11:40	Point Torment	Crab Creek
13/02/2013	11:21	13:43	Crab Creek	Point Torment
17/03/2013	12:24	14:38	Crab Creek	Point Torment
18/03/2013	12:50	15:21	Point Torment	Crab Creek
11/04/2013	10:14	12:37	Crab Creek	Point Torment
13/04/2013	11:07	13:25	Crab Creek	Point Torment
26/05/2013	10:04	12:59	Crab Creek	Point Torment
27/05/2013	10:53	13:35	Crab Creek	Point Torment
13/06/2013	12:00	14:28	Crab Creek	Point Torment
16/06/2013	13:34	16:05	Point Torment	Crab Creek
14/07/2013	13:07	15:34	Point Torment	Crab Creek
17/07/2013	13:03	15:17	Crab Creek	Point Torment
09/08/2013	11:14	13:36	Crab Creek	Point Torment
10/08/2013	11:27	13:54	Crab Creek	Point Torment
06/09/2013	10:17	12:46	Crab Creek	Point Torment
08/09/2013	10:39	12:57	Point Torment	Crab Creek
04/10/2013	10:12	12:32	Crab Creek	Point Torment
06/10/2013	10:31	12:47	Point Torment	Crab Creek

3.2 Shore-based activities

In total, 6389 people were recorded along the shore during the 24 aerial surveys of the Dampier Peninsula. The majority were recorded during the peak (dry) season (n=5688) with considerably less during the off-peak (wet) season (n=1151) (Figures 2 and 3). Although people were widely distributed along the coast, 51% of all those observed were along the 5 km extent of Cable Beach at Broome. Mean densities of people were low everywhere except near Broome where there was a high mean density of people particularly at the northern end of Cable Beach (Cosy Corner) during the peak season (93 people per 0.1 km^2). The standard deviations of mean density values were high, largely because people generally occurred in low numbers and were seldom located in exactly the same geographic location (Appendix 1). During the peak season, people were generally using the coast from Broome northwards to Coulomb Point and around Beagle Bay, Middle Lagoon, Cape Leveque and One Arm Point. More people were recorded along the western shores of the Peninsula than along the eastern side within King Sound.

Of the people recorded, 40% were walking along the shore, 27% were relaxing, 10% were swimming and 6% were engaged in fishing (Table 6). Spatial distributions of these activities during both seasons are shown in Figures 4 to 7, respectively. In general, these activities were clustered around Broome and the south-west of the Peninsula although, during the peak season, there were more records from Beagle Bay northwards.

Table 6. Total number of people recorded to be engaged in different activities along the coast of the Dampier Peninsula during 24 survey flights over 12 months (November 2012 – October 2013).

Activity	Number of people
Beach games	28
Exercising	2
Line fishing	405
Netting	7
Relaxing	1852
Riding	60
Snorkelling	11
Sightseeing	180
Surfing	129
Swimming	652
Walking	2773
Other activities	731
Unknown	9
Total	6839

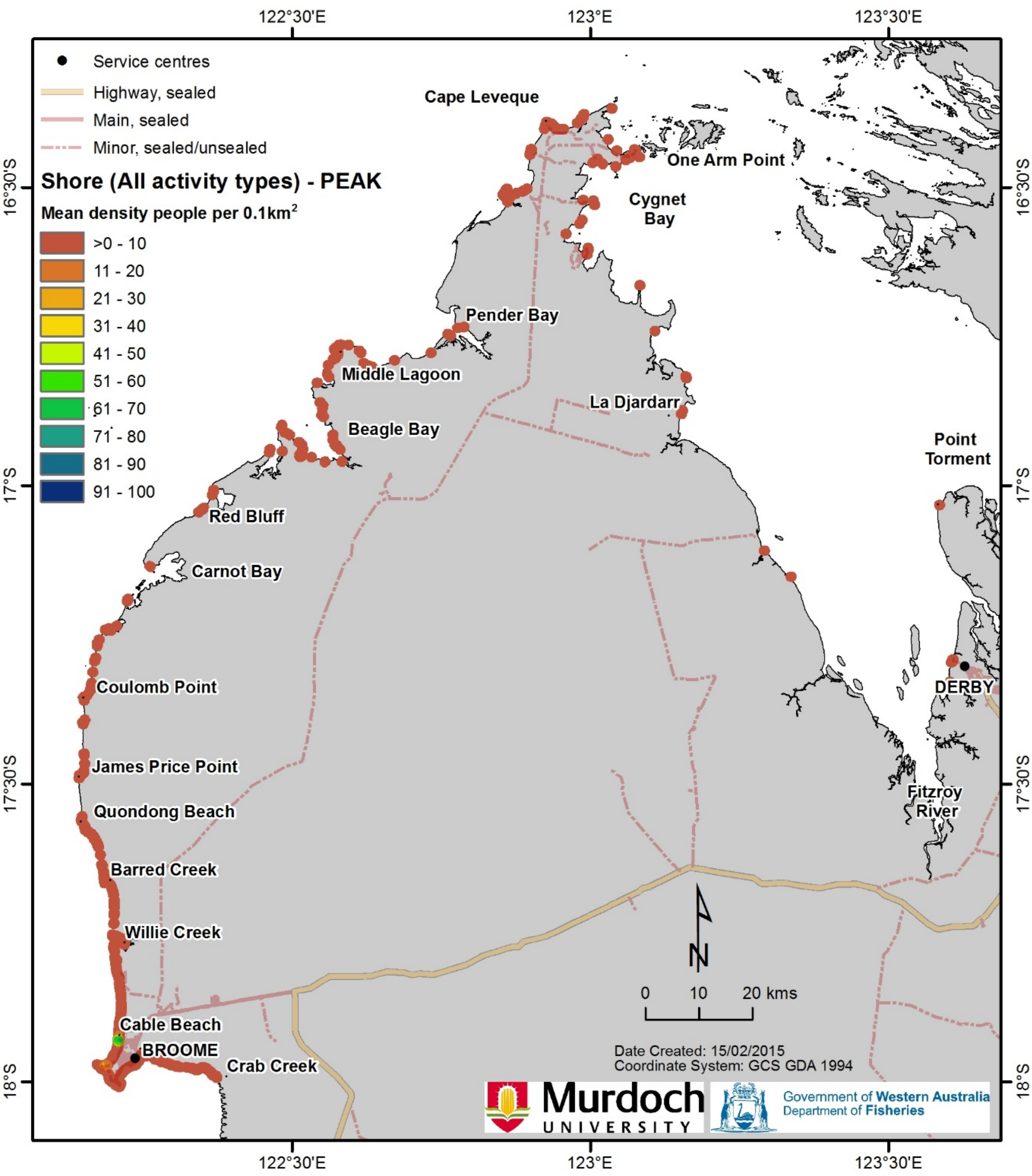

Figure 2. Mean density of people recorded along the shore between Crab Creek (Broome) and Point Torment (Derby) during the peak (dry) season (May 2013 – October 2013; n= 12 survey flights).

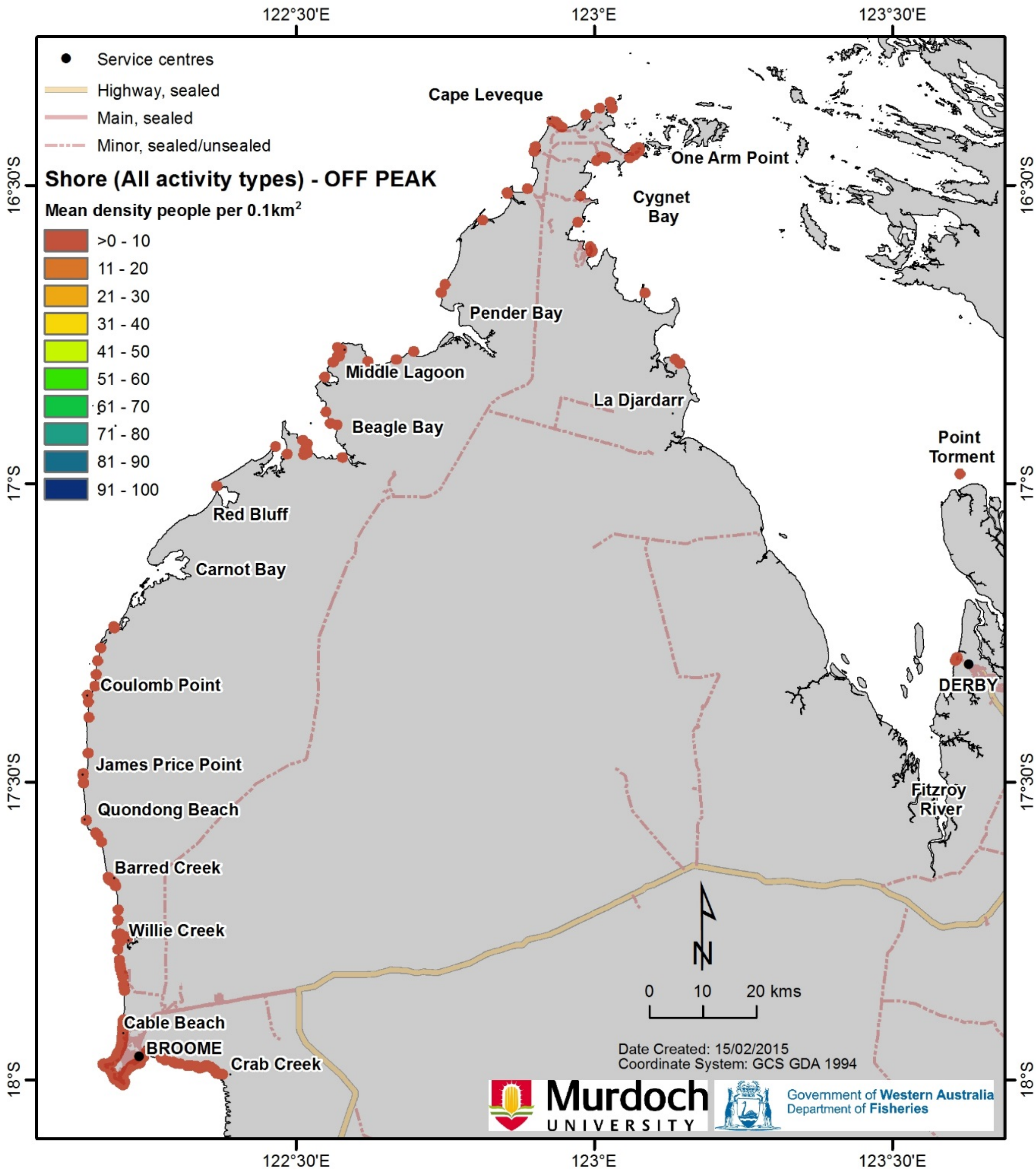

Figure 3. Mean density of people recorded along the shore between Crab Creek (Broome) and Point Torment (Derby) during the off-peak (wet) season (November 2012 – April 2013; n= 12 survey flights).

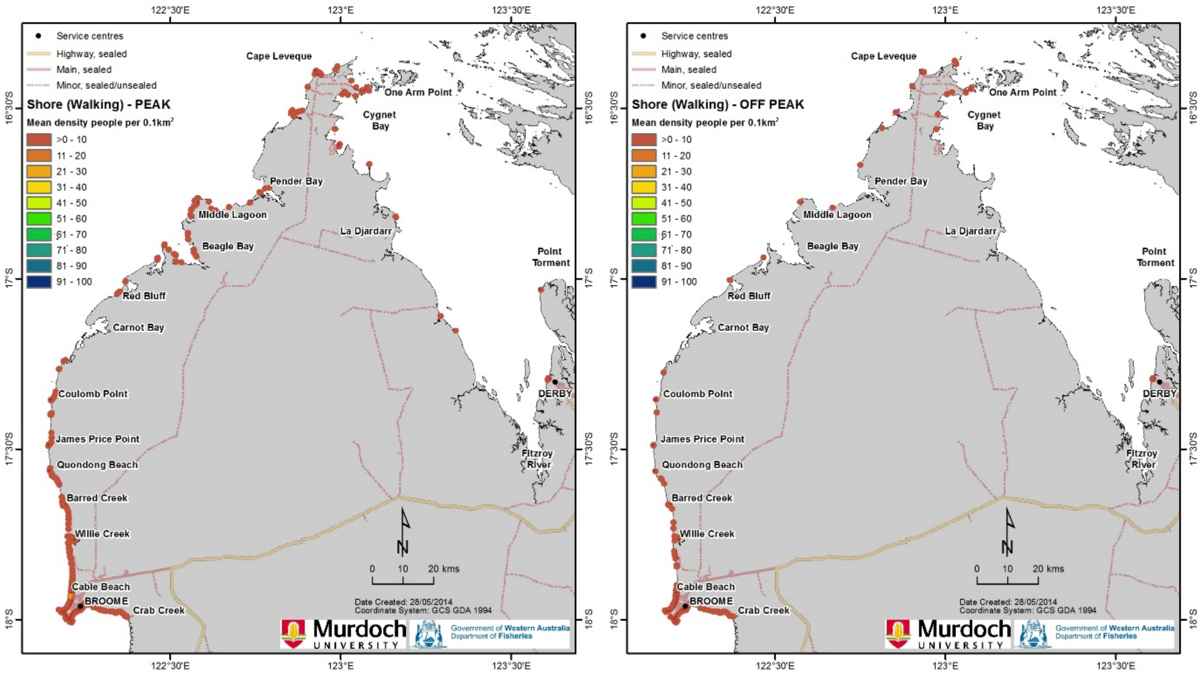

Figure 4. Mean density of people recorded as walking along the shore between Crab Creek (Broome) and Point Torment (Derby) during the peak (dry) and off-peak (wet) seasons (November 2012 – October 2013; n = 12 survey flights per season).

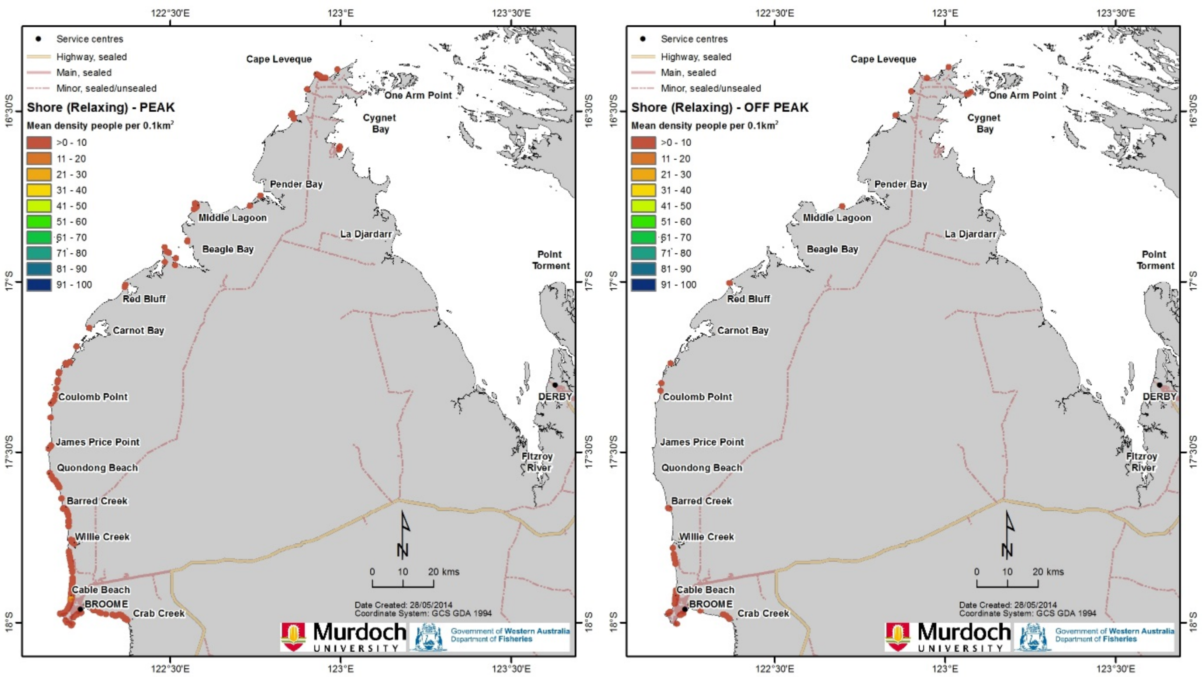

Figure 5. Mean density of people recorded as relaxing along the shore between Crab Creek (Broome) and Point Torment (Derby) during the peak (dry) and off peak (wet) seasons (November 2012 – October 2013; n = 12 survey flights per season).

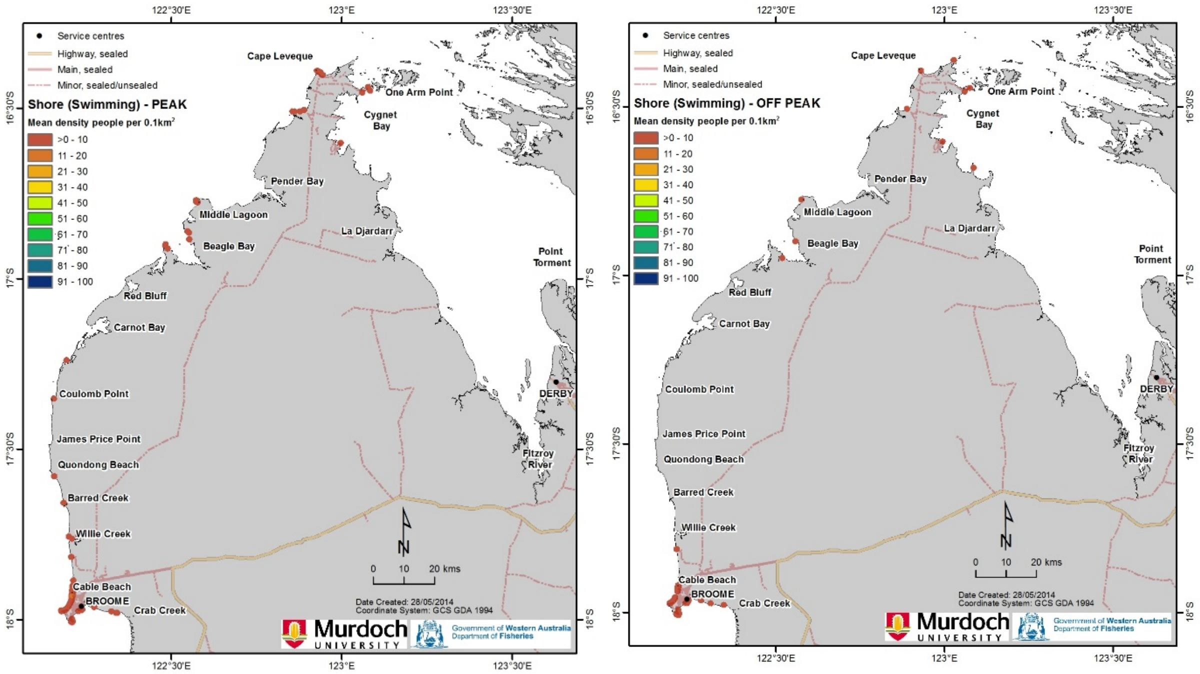

Figure 6. Mean density of people recorded as swimming from the shore between Crab Creek (Broome) and Point Torment (Derby) during the peak (dry) and off-peak (wet) seasons (November 2012 – October 2013; n = 12 survey flights per season).

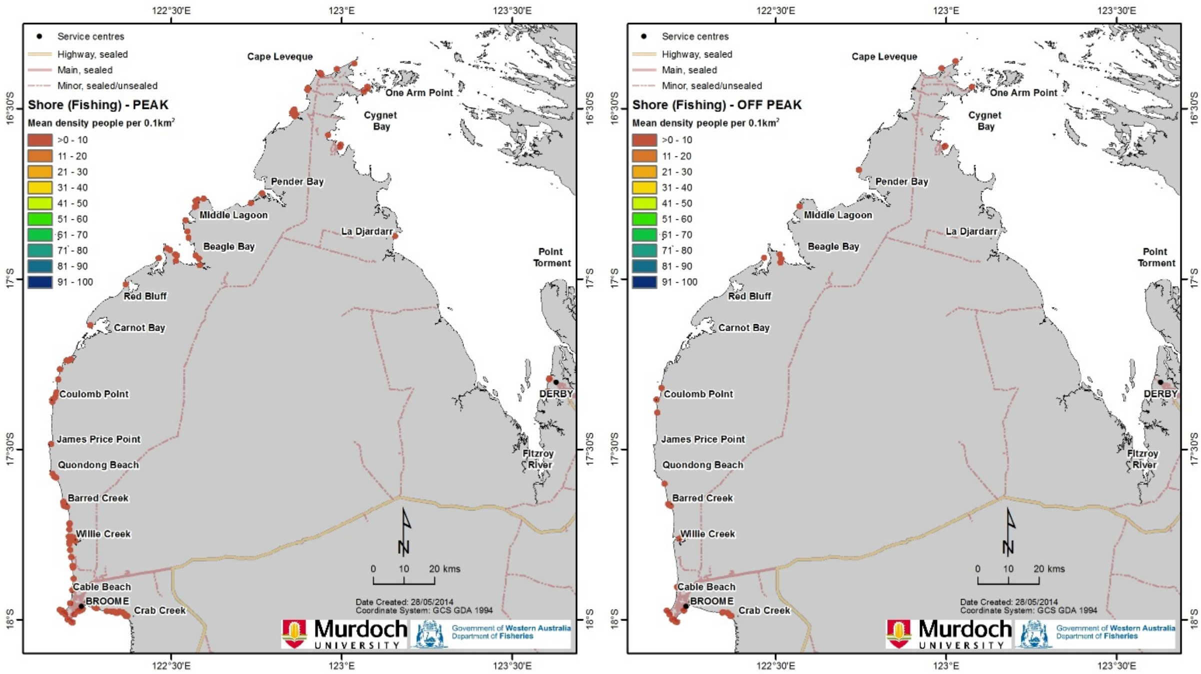

Figure 7. Mean density of people recorded as fishing from the shore between Crab Creek (Broome) and Point Torment (Derby) during the peak (dry) and off-peak (wet) seasons (November 2012 – October 2013; n = 12 survey flights per season).

In total, 5673 vehicles were counted along the coast during the 24 surveys. Although widely distributed, a large number of these (33%) were parked on, or adjacent to, Cable Beach from Cosy Corner southwards to Gantheaume Point. Figure 8 shows the mean distribution of vehicles by season and by weekday and weekend around the Dampier Peninsula. In general, during both seasons, there was a greater spatial extent for vehicles on weekends.

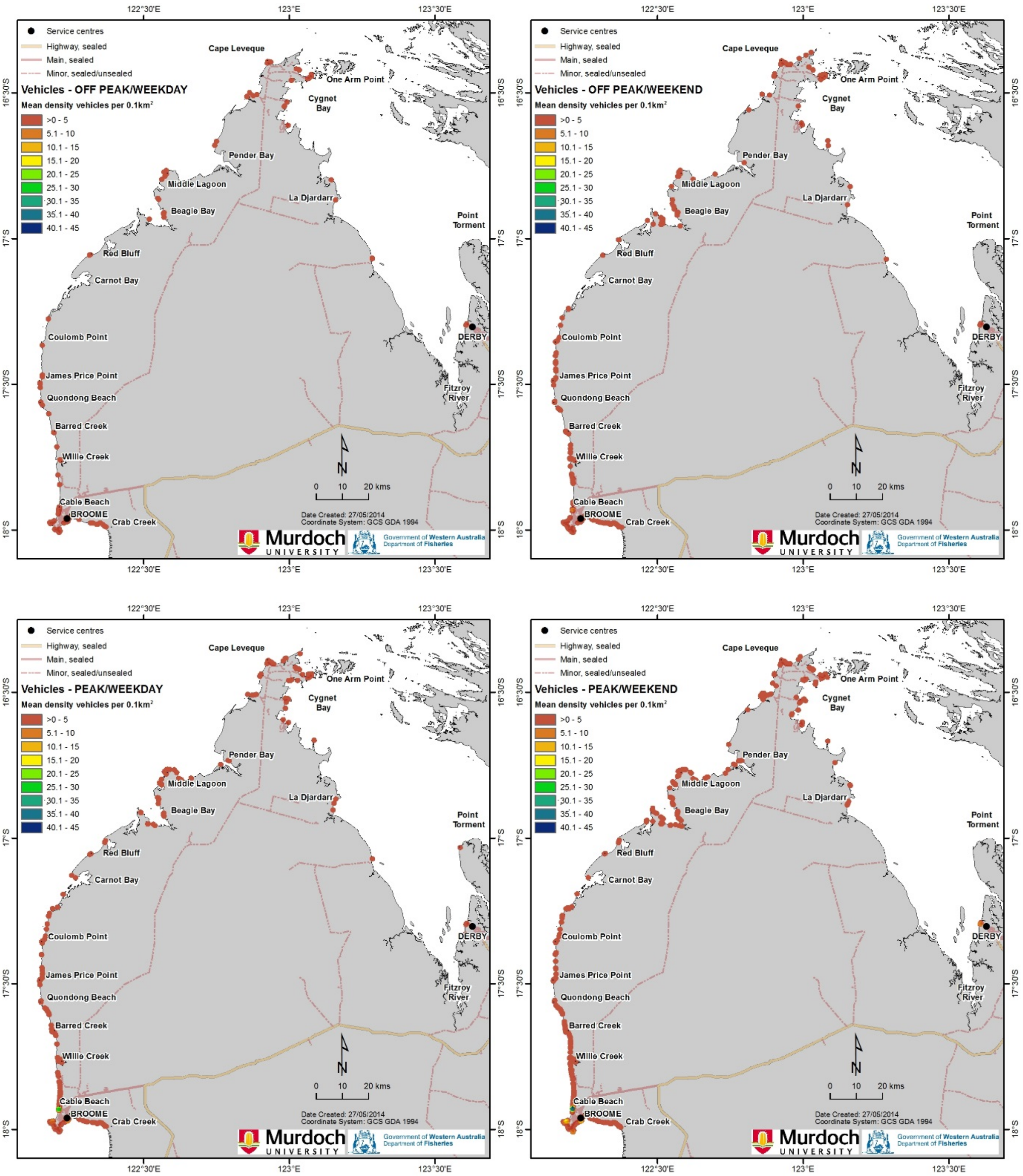

Figure 8. Mean density of vehicles recorded along the shore between Crab Creek (Broome) and Point Torment (Derby) during weekdays and weekends in the off-peak (wet) and peak (dry) seasons (November 2012 – October 2013; n= 6 survey flights per type of day per season).

The mean distributions of boat trailers left at boat ramps or along the beach relative to the peak and off-peak seasons and by day-type around the Dampier Peninsula are shown in Figure 9. High numbers of boat trailers were recorded at the Entrance Point boat ramp at Broome on weekends throughout the year and also on weekdays in the peak season. During the peak season there were also many boat trailers at the southern end of Cable Beach (adjacent to Gantheaume Point and the Minyirr Coastal Park) as many boats were launched from the beach here during easterly wind conditions.

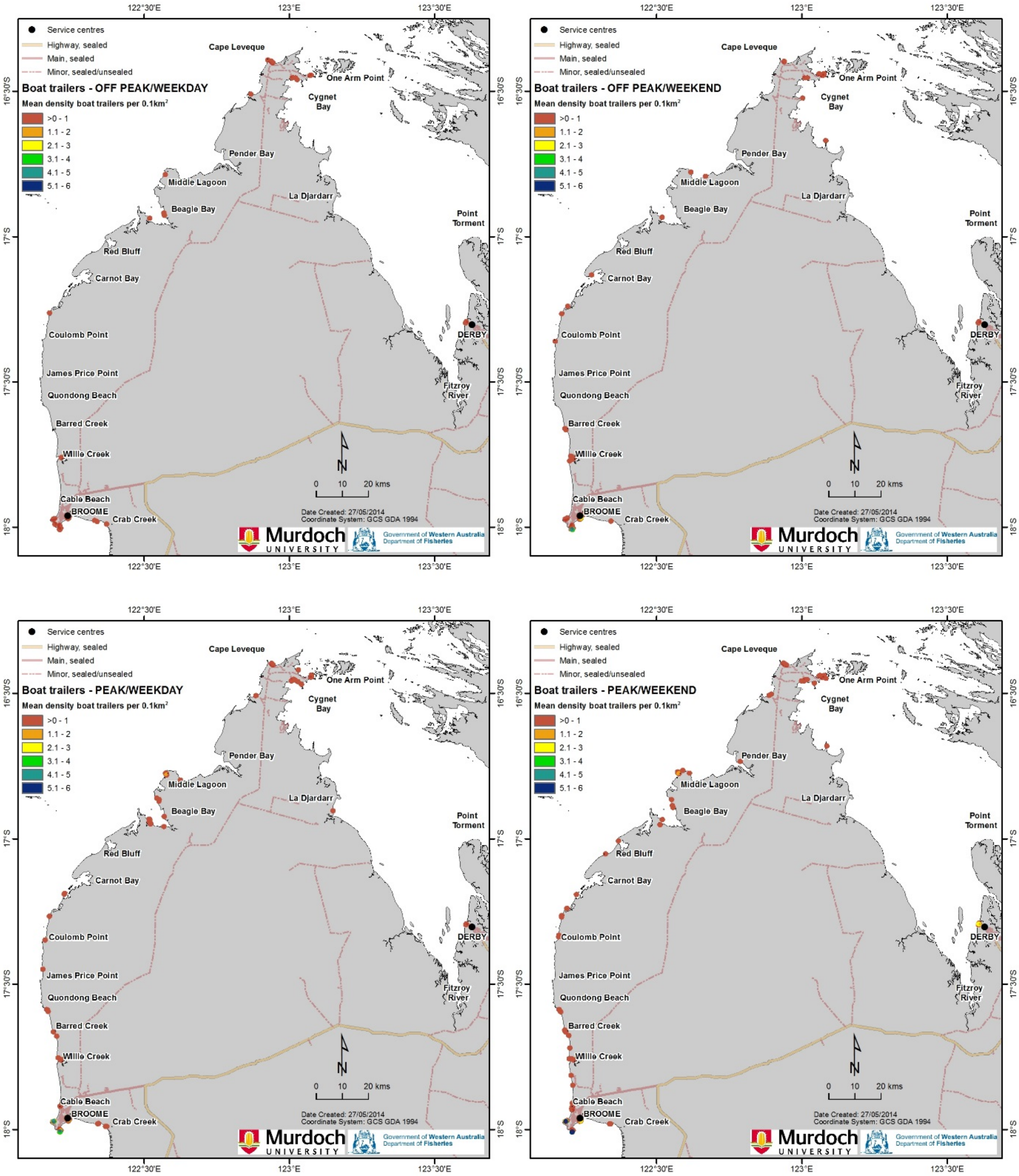

Figure 9. Mean density of boat trailers recorded along the shore between Crab Creek (Broome) and Point Torment (Derby) during weekdays and weekends in the off-peak (wet) and peak (dry) seasons (November 2012 – October 2013; n= 6 survey flights per type of day per season).

Camping along the coast of the Dampier Peninsula was limited in the wet season but increased during the dry season. The coast near Quondong Point was particularly popular for camping during the dry season and there was also an increased density of camps at Middle Lagoon at this time (Figure 10). There was little difference in the spatial distribution of camps relative to day-type in either season.

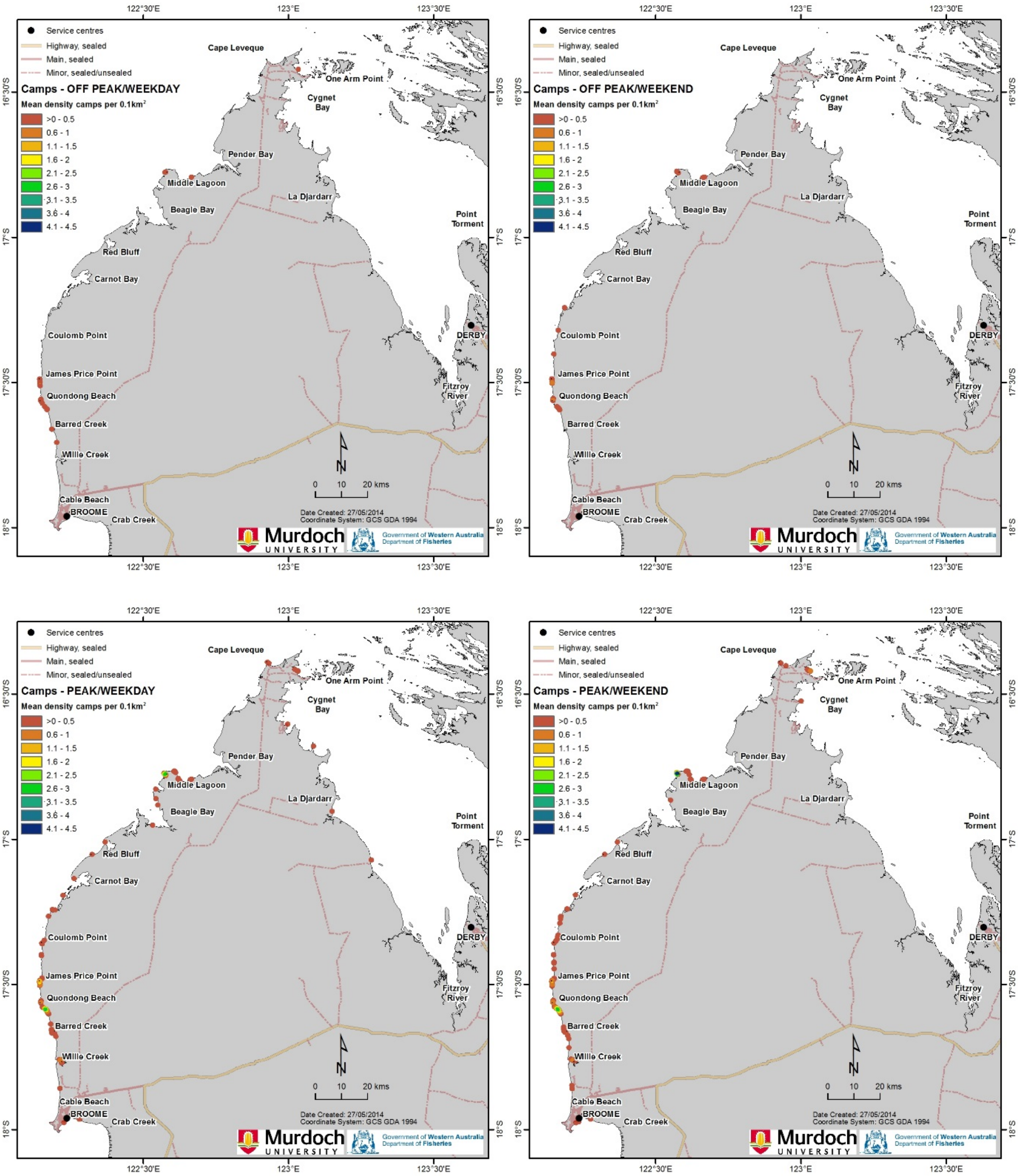

Figure 10. Mean density of camps recorded along the coast between Crab Creek (Broome) and Point Torment (Derby) during weekdays and weekends in the off-peak (wet) and peak (dry) seasons (November 2012 – October 2013; n= 6 survey flights per type of day per season).

3.3 Boat-based activities

Boat-based activities were largely concentrated in the south-western part of the study area in both seasons, particularly around the port of Broome (Figures 11 and 12). Boats were also more frequent in Beagle Bay, at

Middle Lagoon, around the northern tip of the Peninsula and near Derby during the peak season (Figure 11). Variance was fairly high and the standard deviations around the mean densities are shown in Appendix 2. Vessels observed to be engaged in recreational fishing within the 5 km offshore extent of the survey were surprisingly few and generally around Broome and Middle Lagoon in the peak season (Figure 13). However, during the surveys, many recreational fishing boats were observed to be motoring and were more widespread in the peak season extending north from Broome, off Middle Lagoon, around the north of the Peninsula and near Derby (Figure 14). During the peak season there were also many vessels in the sheltered anchorage at the southern end of Cable Beach adjacent to Gantheaume Point (Figure 15). Vessels engaged in pearling operations were largely concentrated around Cygnet Bay and, during the peak season, pearling vessels were also observed to be operating offshore of Quondong Point.

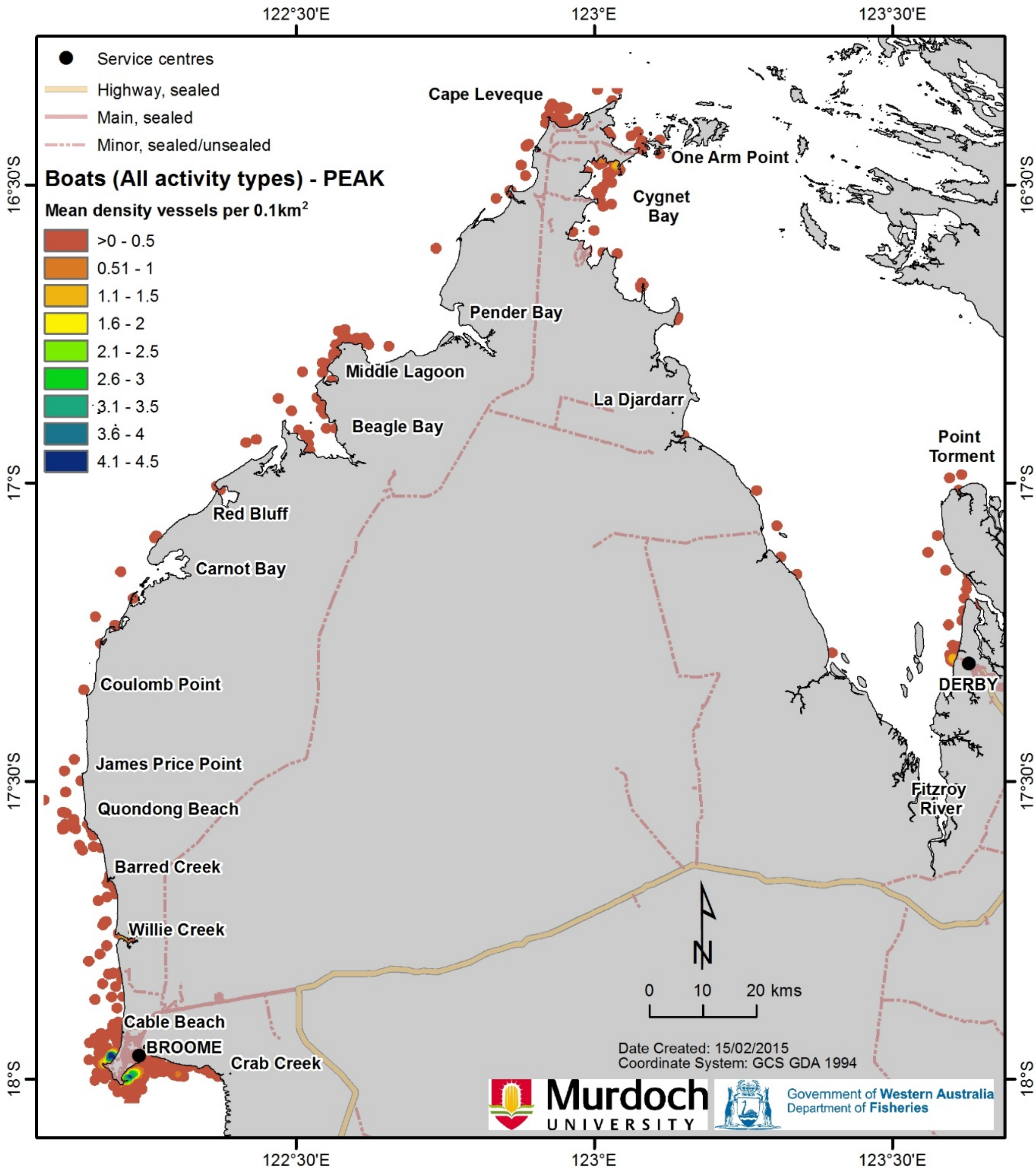

Figure 11. Mean density of all vessels recorded between Crab Creek (Broome) and Point Torment (Derby) during the peak (dry) season (May 2013 – October 2013; n=12 survey flights).

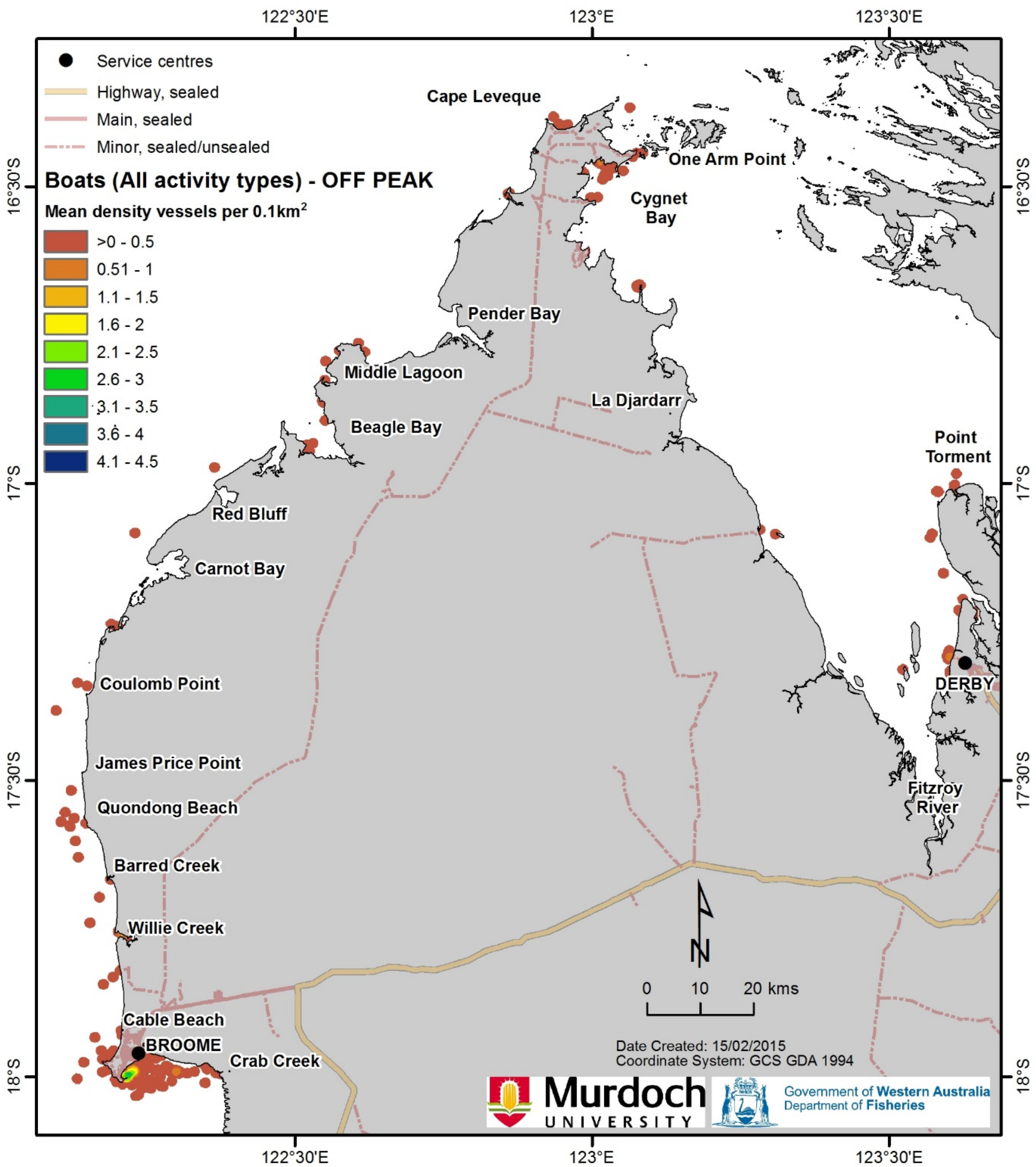

Figure 11. Mean density of all vessels recorded between Crab Creek (Broome) and Point Torment (Derby) during the off-peak off-peak (wet) season (November 2012 – April 2013; n= 12 survey flights).

4 Discussion and Conclusions

The aerial surveys of the Dampier Peninsula provided an effective way to examine the spatial distribution and density of human use along the coast and boat-based activity in adjacent coastal waters. The technique used was similar to that used for ascertaining recreational activity in Ningaloo Marine Park (Smallwood et al. 2011a). Aerial surveys have been used in several other places worldwide for surveying recreational fishing (Mann et al. 2003, Veiga et al. 2010, Hartill et al. 2011), beach use (Coombes et al. 2009), coastal camping (Hockings & Twyford 1997) and boat-based activity (Sidman & Flamm 2001, Volstad et al. 2006) and are particularly useful when covering large, remote areas or where road access is limited.

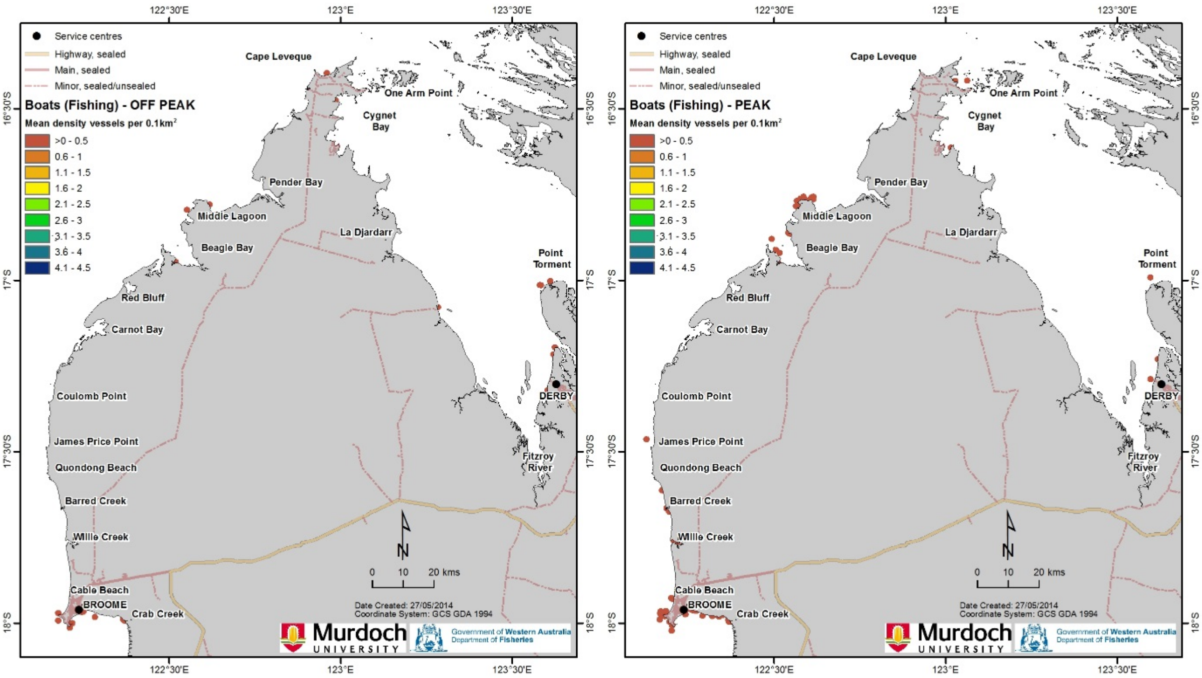

Figure 13. Mean density of vessels engaged in recreational fishing near the coast between Crab Creek (Broome) and Point Torment (Derby) during the off-peak (wet) and peak (dry) seasons (November 2012 – October 2013; n=12 survey flights per season).

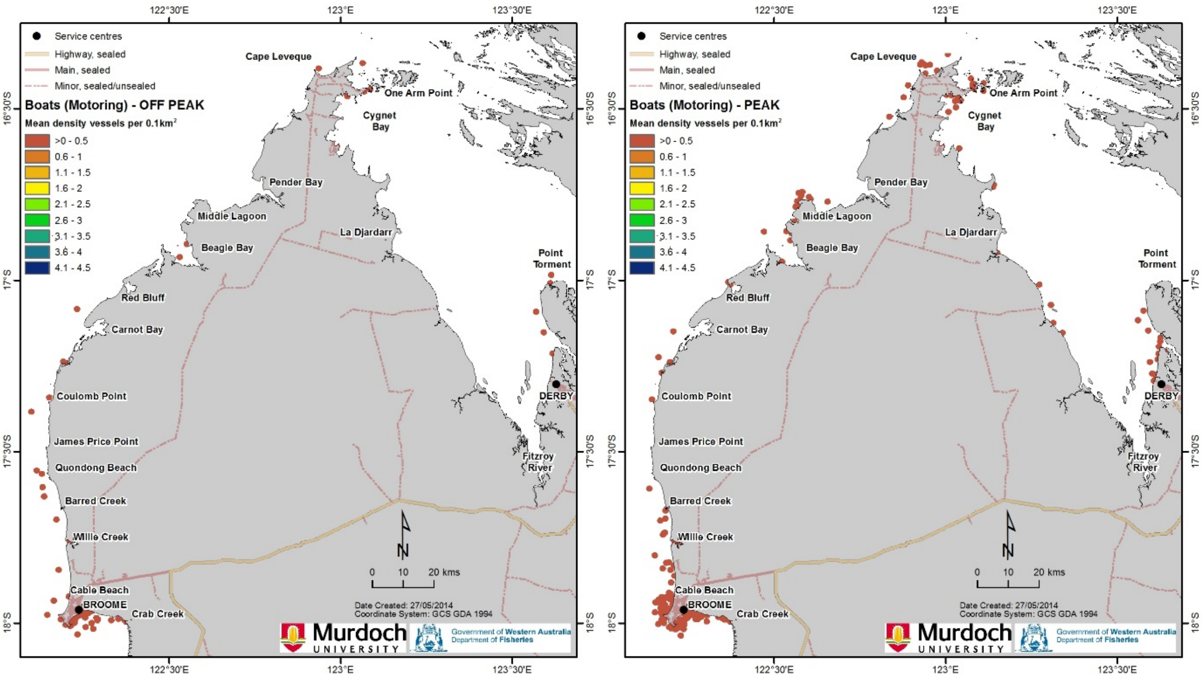

Figure 14. Mean density of vessels motoring along the coast between Crab Creek (Broome) and Point Torment (Derby) during the off-peak (wet) and peak (dry) seasons (November 2012 – October 2013; n=12 survey flights per season).

As expected, there were more people recorded along the shores of the Dampier Peninsula during the dry, winter season than the wet, summer season. The pattern of more activity during the winter months was similar to that found for the Ningaloo Marine Park near Exmouth which experiences a comparable climate (Smallwood et al. 2011a). Although the high temperatures, humidity, rain and cyclonic activity of the wet season generally deter Australian visitors to the Kimberley, the surveys indicated that, nevertheless, the local residents of Broome and Peninsula communities continue to engage in recreational activities during that time, particularly over weekends, though in lesser numbers than during the peak tourist season. Although not distinguishable in the aerial surveys, it is also possible that international visitors travelling to Australia to escape the boreal winter may be included in these off-peak observations as noted for Ningaloo (Smallwood et al. 2012b).

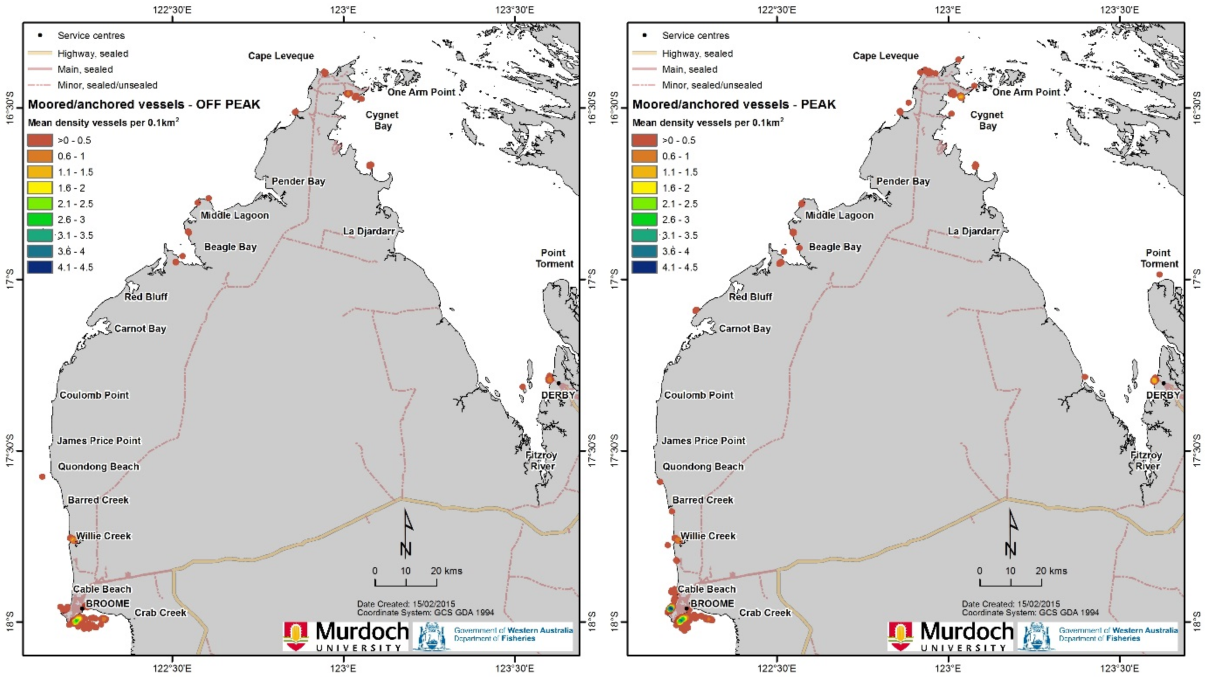

Figure 15. Mean density of vessels moored or anchored along the coast between Crab Creek (Broome) and Point Torment (Derby) during the off-peak (wet) and peak (dry) seasons (n=12 survey flights per season).

More people were observed on the western side of the Peninsula (particularly around Broome) than the eastern side. In addition to being further away from Broome, road and track access to the eastern side of the Peninsula is more limited (Gibbons 2012) and the extensive areas of mangroves lining the shore and creeks of King Sound (Zell 2007, Cresswell et al. 2011) also preclude four-wheel drive vehicles from approaching much of it. In contrast, long stretches of sandy beach on the western shores of the Peninsula, as well as numerous coastal tracks (Gibbons 2012), enable four-wheel drive vehicles to range widely from Cable Beach and other access points. There were more vehicles recorded along the coast in the peak season; stratification into weekdays and weekends indicated a wider spatial distribution over the weekends in both the peak and off-peak seasons indicative of residents travelling along the coast on weekends.

Mean densities of people recorded along the shore were generally low at all sites except for the well-advertised, tourist attraction of Cable Beach where, in the peak season, high numbers of people (>90 per 0.1 km^2) were engaged in activities such as walking, relaxing and swimming. In general, standard deviations were high because, except for Cable Beach, people were recorded in low numbers (<10 per 0.1 km^2) and were seldom observed in exactly the same geographic locations because of the wide-ranging mobility imparted by driving four-wheel drive vehicles along beaches and tracks. For the Dampier Peninsula, walking was the dominant activity (40%) followed by relaxing (27%), swimming (10%) and fishing (6%). This contrasts with Ningaloo Marine Park, where Smallwood et al. (2012b) found relaxing on the beach was the dominant activity (38%) followed by walking (19%), snorkelling (12%) and fishing (9%). It also contrasts strongly with the Eighty Mile Beach area where shore-based fishing (44%) was the dominant activity followed by walking (33%) and relaxing (8%) (Beckley et al. this report).

Four-wheel drive vehicles were mainly used to access the coast along the Dampier Peninsula and driving along the beach north of Cable Beach was particularly popular. A section of the central part of Cable Beach is closed to driving and Foster-Smith et al. (2007) contrasted the biological impacts of four-wheel driving on these areas.

There is also a ban on driving on Cable Beach at night over the summer months when flat back turtles are nesting (Shire of Broome 2014). Camping along the coast (with its associated issues of solid waste and sewage) was very limited in the wet season but expanded in the dry season particularly around Quondong Point (which is easily accessed from Broome via Manari Road), and Middle Lagoon, located further north. Proposed sealing of the road from Broome to Cape Leveque would dramatically change access to the north of the Dampier Peninsula and increased camping would be expected. It should be noted that camping within the confines of the caravan parks in Broome and Kooljaman at Cape Leveque was not monitored during this study.

Most of the boat trailers were observed at the boat ramps around Broome, particularly at Entrance Point (maximum numbers observed during the surveys were 48 trailers on 14 July and 45 trailers on 10 August). However, the southern end of Cable Beach was also used extensively for launching of boats in the dry season with the vehicles and trailers left above the high tide mark (maximum numbers recorded at this location were 66 trailers on 16 June and 54 on 14 July). Boat launching at Entrance Point has been previously investigated by Ryan et al. (2013) and Desfosses & Beckley (this report) using a remote camera system and the greater numbers of trailers observed in the dry season concurs with their findings of more launches during this period. During the dry season, boat trailers were also recorded regularly at Crab Creek, in Broome near Catalina Point, Town Beach and the Port boat ramps, and at Willie Creek, Barred Creek, Beagle Bay, Middle Lagoon, Cape Leveque, One Arm Point (three areas) and Derby. Most of these sites have constructed concrete boat ramps but launching of boats at Crab Creek, Middle Lagoon, Cape Leveque and two areas at One Arm Point was done from the beach. It is recommended that monitoring of boat launching is undertaken at One Arm Point prior to, and after, construction of the proposed sealed road from Broome as this will allow more boats to access the Buccaneer Archipelago, located to the east of King Sound.

Vessels were recorded in highest densities during both seasons near the port of Broome where commercial vessels use the jetty and occupy moorings to the east of it. In the dry season, there was also a higher density of vessels recorded at the southern end of Cable Beach as yachts, cabin cruisers and some charter vessels moor or anchor there to seek shelter from the prevailing easterly winds. There are several known anchorages along the Dampier Peninsula such as Cape Leveque and Beagle Bay (Putt 2014) where yachts were observed during the peak season; during 2013 several were returning south after the Fremantle to Bali yacht race (L.E. Beckley pers. obs.). Several boats, including charter vessels, occupied moorings adjacent to the Derby jetty, particularly in the dry season. Generally, boat-based activity increased and expanded in spatial extent during the dry season with more vessels around Beagle Bay, Middle Lagoon, Cape Leveque, One Arm Point, Cygnet Bay and Derby at that time. Relatively few boats were observed to be engaged in fishing though many recreational boats were observed to be motoring. It is likely that many of the boats that launched from Broome travelled further offshore to fish than the survey extent (about 5 km from the shore), particularly if they were involved in fishing for demersal species further south in Roebuck Bay or for pelagic species like sailfish at sites offshore of Quondong Point (Pepperell et al. 2011).

Although there are 15 state-managed commercial fisheries operating in the waters around the Dampier Peninsula, targeting predominantly tropical finfish species (Fletcher & Santoro 2014), there were relatively few observations of their vessels except for those of the pearl oyster fishery observed to be working west of James Price Point (Zone 3). This lack of other observations of commercial fishing is likely to be because of the closure of most coastal waters to trawling of finfish. During the study period, pearl aquaculture operations were observed at Cygnet Bay and at Tooker Point near Beagle Bay although facilities at Deep Water Point in King Sound did not appear to be fully operational.

The south-eastern part of the study area encompassed the northern shores of Roebuck Bay where a marine protected area is planned (Government of Western Australia 2011). This part of the coast was regularly used by people for various activities as there is relatively easy vehicle access from Broome via the unsealed road located close to the coast which passes the Broome Bird Observatory and terminates at Crab Creek. Numerous tracks and paths lead to the shore and a wide range of both shore-based and boat-based activities occurred in this area throughout the year.

A limitation of this study was that, for logistical and financial reasons, only 12 flights were conducted per season. Further, as generally low numbers of people and boats were observed, and they were seldom in exactly the same geographic location, variability was high. Also, the study was conducted at high tide, so any observations of gleaning or subsistence harvesting of intertidal biota would have been precluded. Nevertheless, a clear pattern of maximum use around Broome extending northward along the beach and via coastal tracks on the western side of the Dampier Peninsula was evident. In the north, there were nodes of use around Beagle Bay, Middle Lagoon, Cape Leveque, One Arm Point and Cygnet Bay. Although there is well-known seasonality in the numbers of tourists to the region (Collins 2008, Scherrer et al. 2011), it is apparent that local residents from Broome and communities along the Dampier Peninsula to use the coastal environment for recreational activities throughout the year.

This survey provides spatially explicit, quantitative data on the extent of human use, particularly recreational activities and boating, around the Dampier Peninsula within state waters during both the off-peak (wet) and peak (dry) seasons. For the traditional owners, residents, managers and planners in the western Kimberley, this study provides a bench mark of use prior to major coastal development such as the proposed construction of a sealed road northward to Cape Leveque, tourist infrastructure such as hotels, or marinas and larger boat ramps on the Dampier Peninsula.

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6 Appendices

APPENDIX 1

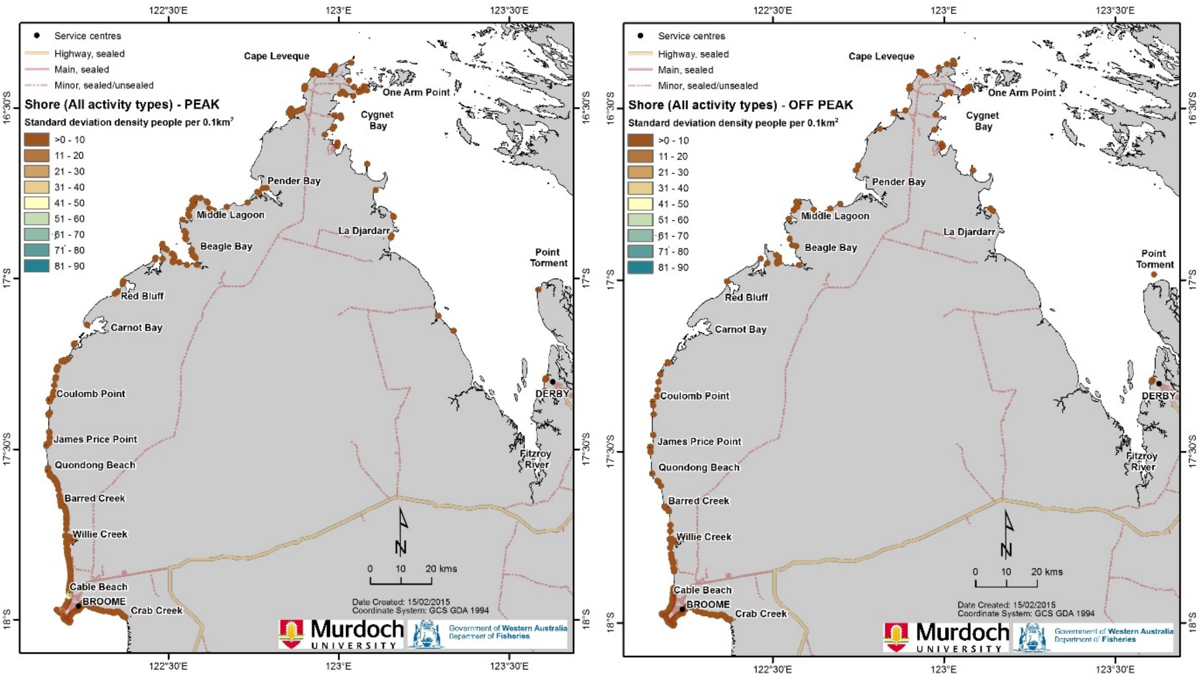

Figure 16. Standard deviations of the mean densities of people recorded along the shore between Crab Creek (Broome) and Point Torment (Derby) during peak (dry) season (12 survey flights) and the off-peak (wet) season (n= 12 survey flights).

APPENDIX 2

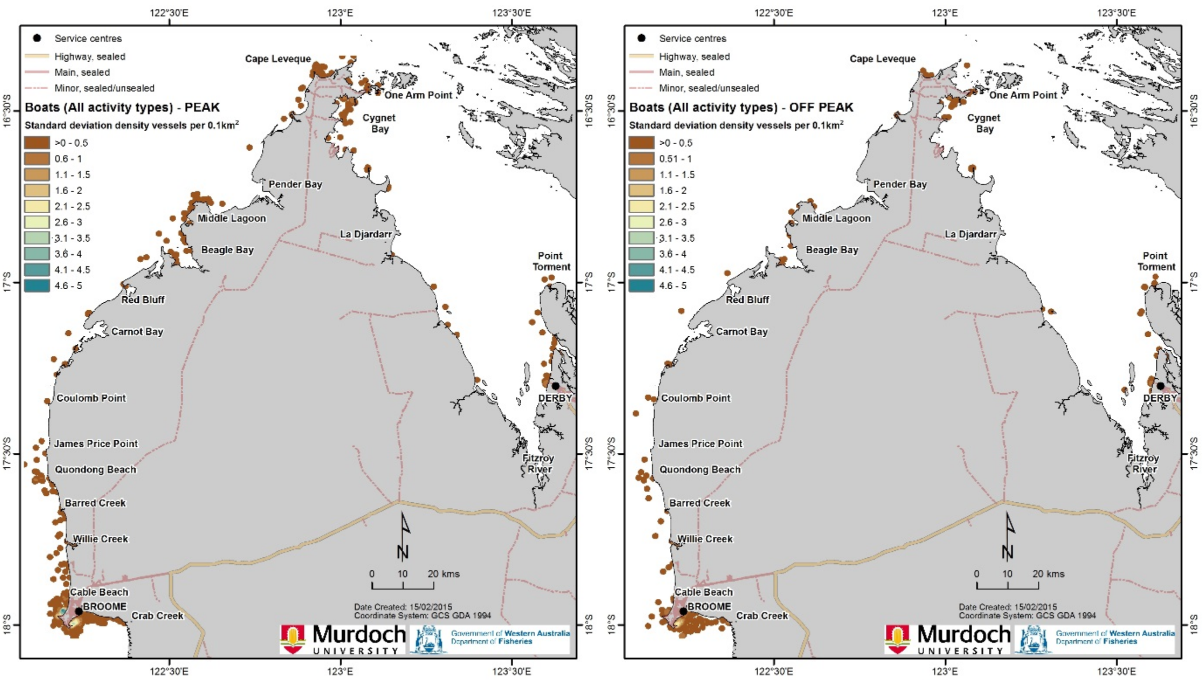

Figure 17. Mean densities of all vessels recorded in coastal waters between Crab Creek (Broome) and Point Torment (Derby) during the peak (dry) season (n=12 survey flights) and off-peak (wet) season (12 survey flights).

Chapter 3: Exploratory aerial surveys for assessment of human use in the Horizontal Falls, Lalang-garram Camden Sound and North Kimberley Marine Parks

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Summary

Exploratory aerial surveys were undertaken along the central and eastern Kimberley coast to examine spatial distribution of human use during the peak tourist season. Four surveys of human use were conducted between Camden Harbour (south of Augustus Island) and Point Torment (north of Derby) and included the Lalang-garram Camden Sound Marine Park and proposed Horizontal Falls Marine Park. A single survey over two days was conducted from Wyndham via Kalumburu to Camden Harbour along the eastern Kimberley coast. Very few (n=82) people were observed along the remote shores of the central and eastern Kimberley coast during the aerial surveys, with the majority observed in the vicinity of popular tourist destinations such as the Horizontal Falls, or close to camping areas at Kalumburu. Other isolated individuals or small groups of people were observed walking along the shore and were usually associated with small boats that were drawn up on the beach. Boat-based activity was limited but widely distributed in the central and eastern Kimberley with nodes around Cone Bay, Koolan Island, Horizontal Falls, Kuri Bay, Bougainville Peninsula, Kalumburu and Wyndham. Observed vessels ranged from small tenders to cruise and commercial vessels, with 26% engaged in activities and the remainder moored or anchored. At Horizontal Falls, the vessels were generally involved with tourism activities whilst, at Koolan Island, most were commercial vessels associated with the iron-ore loading jetty. In Cone Bay, most of the vessels were linked with the barramundi mariculture facilities whilst, along the Bougainville Peninsula, most vessels were associated with pearl culture. The aerial surveys provide preliminary information for tradition owners, managers and planners on key locations of human use along the central and eastern Kimberley coast. In addition, they inform about the logistics and design required for future, temporally-appropriate, surveys for monitoring the Lalang-garram Camden Sound, Horizontal Falls and North Kimberley Marine Parks.

1 Introduction

The Kimberley region of northern Australia is renowned for its Indigenous heritage, spectacular scenery and abundant wildlife (McGonigal 2003, Guélho 2007, Zell 2007). The traditional owners (particularly Dambimangari, Unguu and Wunambal Gaambera) and the Government of Western Australia are currently engaged in substantial efforts to protect the biodiversity of the central and eastern Kimberley coasts and three marine parks covering state waters in this region were announced in October 2010 (Government of Western Australia 2010). The management plan for the Lalang-garram Camden Sound Marine Park was published in October 2013. This park is extremely large (673,000 hectares), zoned for multiple-use and extends from the coast to the limit of state coastal waters (Department of Parks & Wildlife, Western Australia 2013). It includes Montgomery Reef in the south, the Champagny Islands in the north and Prince Regent River in the east (Figure 1). Development of the management plan for the Horizontal Falls Marine Park is underway and this park will also be a multiple-use park and extend from the Horizontal Falls in Talbot Bay eastwards to Collier Bay, Walcott Inlet and Doubtful Bay. The proposed North Kimberley Marine Park will extend from the eastern boundary of the Lalang-garram Camden Sound Marine Park to the Western Australia/Northern Territory border.

The remote coast of the central and eastern Kimberley is usually reached by boat or air (float planes and helicopters). Roads are limited to a single unsealed road that forks to provide access to the coast at Kalumburu and at Port Warrender near Mitchell Plateau (Figure 1). Despite its remoteness, iron-ore mining, fisheries and mariculture (pearl oysters and barramundi) contribute to the economy of the region (McGonigal 2003, Fletcher & Santoro 2014). Tourism is another important economic activity and expedition cruising is favoured with vessels traversing the region during the dry winter months (Scherrer et al. 2008, Beckley et al. this report). Other vessels, including sailing yachts, cabin cruisers and fishing charter vessels, also visit the coastal waters during the dry season, occupying a range of anchorages (Zell 2007, Putt 2014).

There have been no prior attempts to survey human use along this remote extent of coast. The aim of this study was to undertake exploratory aerial surveys along the coast from Derby to Camden Harbour to examine spatial distribution of human use during the peak tourist season. In addition, the study aimed to conduct a reconnaissance survey from Wyndham to Camden Harbour during the peak season to obtain an indication of human use in this eastern part of the Kimberley. These surveys were associated with concurrent, aerial surveys of human use of the Dampier Peninsula and 80 Mile Beach (Beckley et al. this report) and were designed to obtain preliminary information to assist with the logistics and design of future, temporally-appropriate, monitoring of the Lalang-garram Camden Sound, Horizontal Falls and North Kimberley Marine Parks. Nevertheless, the 2013 surveys do provide a synoptic indication of locations of human use and distribution of boats which should be useful for planning in the region.

2 Materials and Methods

2.1 Study area

The study area for the four aerial surveys of human use were conducted along the central Kimberley coast extended from Camden Harbour (south of Augustus Island) to Point Torment (north of Derby) and included the Lalang-garram Camden Sound Marine Park and proposed Horizontal Falls Marine Park (Figure 1). The single aerial survey of the eastern Kimberley extended from Wyndham to Camden Harbour, and encompassed most of the proposed North Kimberley Marine Park (Figure 2).

2.2 Survey design

The design of the aerial surveys was based upon the maximum count method often used in studies of recreational fishing where flights are conducted during periods of maximum recreational activity (Volstad et al. 2006, Veiga et al. 2010, Smallwood et al. 2012a). As there is a large tidal range in the region, surveys were standardised around high water when vessels can access coastal creeks and estuaries (Fletcher & Santoro 2012). Tidal information for Yampi Sound, Cape Voltaire and Wyndham was used to schedule the survey flights.

Surveys of the central (Table 1) and eastern Kimberley (Table 2) were limited because of their remote location, especially with respect to distance from airports with refuelling facilities. Although it was possible to conduct one survey during favourable conditions in April 2013, surveys were temporally restricted to the dry season because of the very severe thunderstorm activity in this region during the wet season (McGonigal 2003, Zell 2007). As other areas of the western Kimberley were also surveyed during the field trips, days could not be randomly selected and surveys were grouped into consecutive days (i.e., a five-day trip to the Kimberley may include several aerial surveys). In the case of extreme weather conditions (i.e., thunderstorms, strong winds or rain), illness or plane malfunction, a replacement day was incorporated into the end of each trip to allow for re-scheduling of flights.

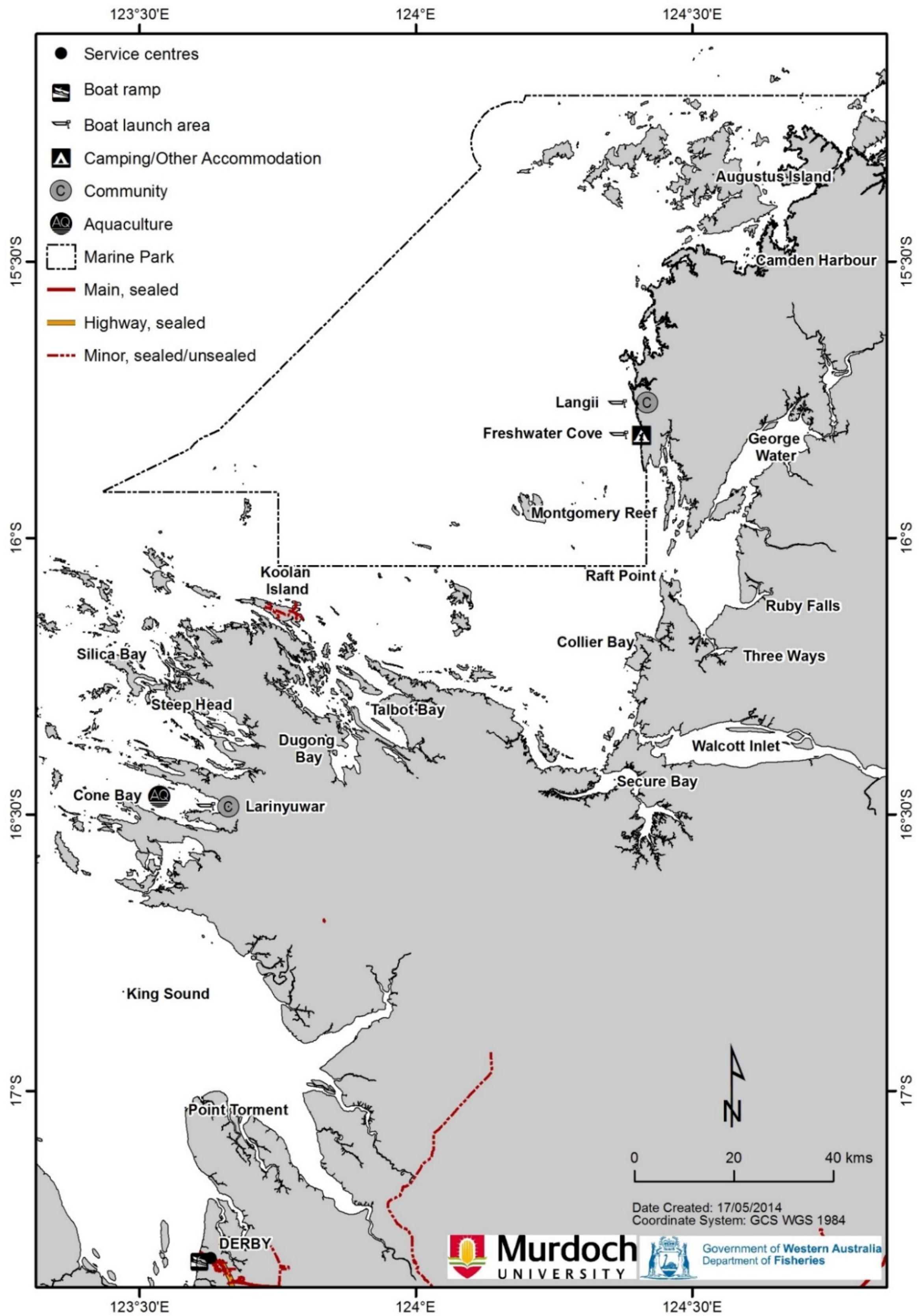

Figure 1. Study area for the central Kimberley survey flights from Camden Harbour to Point Torment, including the coast of the Lalang-garram Camden Sound Marine Park and the proposed Horizontal Falls Marine Park from Talbot Bay to George Water (April – August 2013).

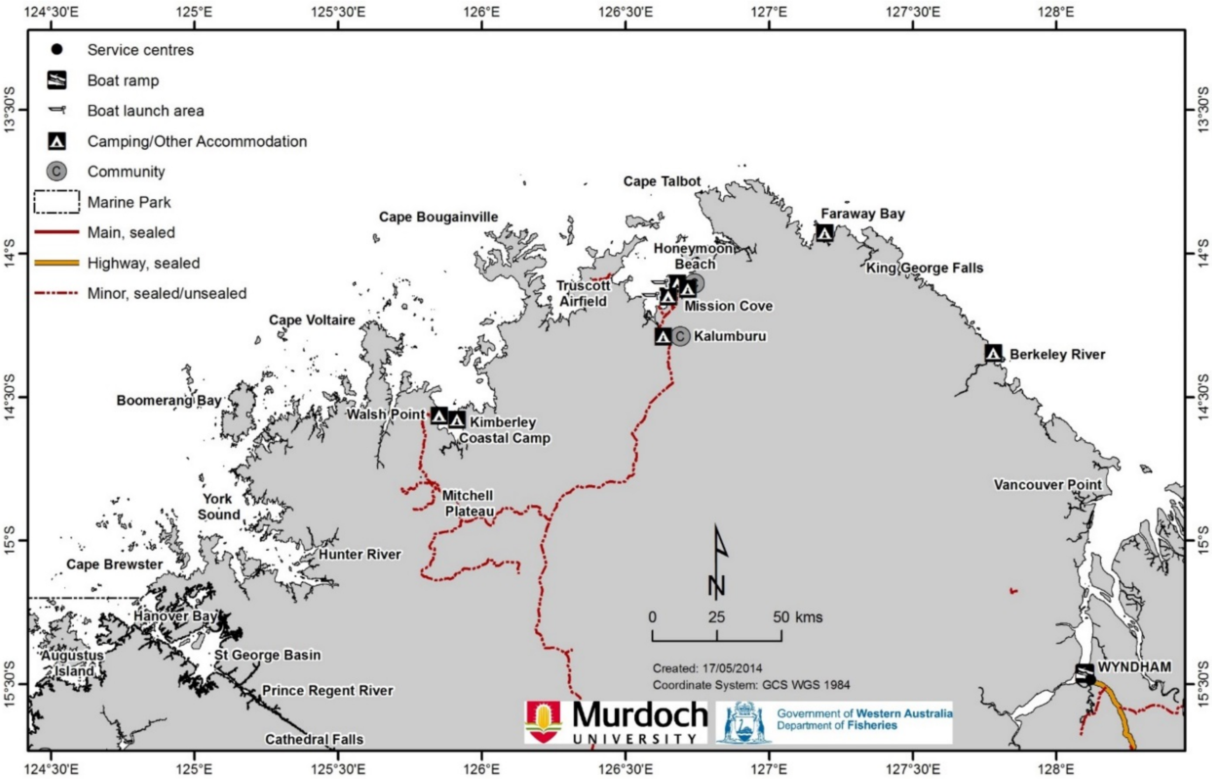

Figure 2. Study area for the aerial survey of the eastern Kimberley coast from Wyndham to Camden Harbour (Augustus Island) via Kalumburu (July 2013).

Table 1. Design features of the exploratory aerial surveys along the central Kimberley coast including the Lalang-garram Camden Sound Marine Park and the proposed Horizontal Falls Marine Park (April to August 2013). All flights conducted from Camden Harbour to Point Torment.

Design aspect	Design details
Extent	Point Torment (Derby) to Camden Harbour
Length of coast	~500 km
Study period	April 2013 – August 2013
Number of survey days (n)	4 (3 peak; 1 off peak)
Approximate day length	Peak (dry season): 6 am – 5 pm; Off peak (wet season): 5.30 am – 6 pm
Survey duration	2.5 hours and 1.5 hours to study area, 1 hour return plus refuelling stop

Table 2. Design features of the exploratory aerial survey along the eastern Kimberley coast from Wyndham to Camden Harbour via Kalumburu.

Design aspect	Design details
Extent	Wyndham to Camden Harbour
Length of coast	~1300 km
Study period	July 2013
Number of survey days (n)	2
Approximate day length	Peak (dry season): 6 am – 5 pm
Survey duration	6 hours and 3 hours to study area, 2 hours return plus four refuelling stops

The flight path for the survey followed the coastline with the plane generally positioned about 300 m offshore to enable the best viewing of activities along the shore. For small creeks and inlets, it was possible to obtain good coverage without deviating from the flight path. However, for larger inlets (e.g., George Water and Walcott Inlet) the entire perimeter of the inlet could not be covered because of constraints with respect to sufficient fuel to complete the entire survey. Generally, the flight would proceed to about half way into the inlet and then cross to the opposite shore and continue following the coastline. For the eastern Kimberley, all inlets were surveyed including Prince Regent River as far inland as Cathedral Falls.

There can be a reduction in the quality of data if the plane moves too fast for the observers to record all activity at a specific location, or parts of the plane obscure the observer's view while turning. To avoid such situations, the pilot was instructed to slow down or complete a loop in order to provide a second opportunity to capture the information. Awareness of the features of the coastline, visual inspection forward along the flight path, and open communication with the pilot also ensured that the plane was not turning at a time when a clear view of the coastline was required. These actions also assisted with reducing the effect of poor sightings of objects close to the aircraft because of obstruction of downward visibility (Leatherwood et al. 1982, Quang & Becker 1997). It is also difficult to observe recreational activity in poor light conditions and thus no surveys were scheduled to start before an hour after sunrise or finish within an hour prior to sunset.

Visibility issues can be a concern during aerial surveys (Pollock & Kendall 1987, Bayliss & Yeomans 1989, Marsh & Sinclair 1989) and it can sometimes be difficult to distinguish people on rocky shores unless they are wearing bright clothing. To assist with minimising such issues, photographs were taken so they could be examined post-flight to identify all recreational activity. Following the method applied by Smallwood et al. (2011a), boat-based activity was recorded at the 'boat' rather than the 'person' level to address difficulties in identifying the actual number of people on vessels with cabins and sun canopies.

2.3 Data collection

Aerial surveys were conducted by two observers in a Cessna 210 plane (4-seater with high wing configuration) with a cruising speed of 120 knots, which could be slowed to 100 knots for sites which required more time for observation. Surveys were flown at a height of 300 m (1000 ft).

Data on shore-based activities were collected by the observer in the rear seat and data on boat-based activities were collected by the observer in the front seat. Each observer had a Canon EOS 600D digital camera to document all observations and a datasheet for recording the time of observation, activity type, vessel type (if a boat-based activity) and number of people (if a shore-based activity). Shore-based activities within 500 m of the water's edge were recorded and vessels were observed out to about 5 km seaward of the flight path. A track of each survey was loaded onto a Garmin GPS, along with every known location along the route, to ensure consistency between surveys. A data logger that recorded geographical co-ordinates at one second intervals along the track of each flight was also mounted on the dashboard of the plane.

Aerial Survey Assistant (ASA) software was used to merge track logs and photographs from each survey and enable the observers to identify shore-based and boat-based activities to specific geographic co-ordinates (Ocean Vision Environmental Research 2010). This technique has been successfully utilised in previous aerial surveys of recreational shore-based activity in Western Australia (Smallwood et al. 2011a, Smallwood et al. 2011b, Smallwood & Gaughan 2013). For this project, the ASA software was further developed to capture information for boat-based activities.

2.4 Categories for coastal activities

Categories for activity types were based on previous research conducted in Western Australia (Smallwood & Beckley 2008, Smallwood 2010, Smallwood et al 2011c, Smallwood et al. 2012b) and elsewhere (Horneman et al. 2002). After considering some of the unique activity types in the Kimberley (i.e., commercial pearling) a total of 17 shore-based activity and 18 boat-based activity categories were utilised in the study (Table 3).

Boat type categories were also based on previous research conducted in Western Australia (Smallwood & Beckley 2008, Smallwood et al. 2011c) and elsewhere (Adams et al. 1992, Widmer & Underwood 2004, Warnken & Leon 2006) resulting in 11 categories of motorised vessels and six categories of non-motorised vessels being available for selection (Table 4).

Other indicators of recreational use, including counts of camps, boat trailers, anchored or moored boats, boats on the beach and vehicles along the shore were also made during the aerial surveys. This was similar to previous research conducted in Western Australia (Hughes & Mau 2006, Smallwood 2010, Smallwood et al. 2011c, Smallwood & Gaughan 2013) and elsewhere (Hockings & Twyford 1997). Standard definitions of each of these indicators are provided in Table 5. It should be noted that vehicles were only counted at day-use sites, and not if they were associated with a coastal campsite.

Table 3. Categories for shore-based and boat-based activities ascribed to observations during aerial surveys of coastal waters of the central and eastern Kimberley in 2013.

Activity type	**Characteristics**
Shore-based	
Beach games	Sporting activities conducted on the beach (i.e., frisbee, beach cricket, skim-boarding)
Boating	Loading or unloading charter passengers
Crabbing	Use of drop nets or scoops
Exercise	Jogging, yoga
Commercial	People involved in commercial or industry activity (may be in high visibility gear)
Line fishing	Extraction of marine organisms using a hook and line, includes fly fishing
Netting	Using a cast, haul or set net of mesh to collect marine organisms
Relaxing	Sunbaking, standing, sitting or resting along the shore and includes sitting under a shelter
Riding	Includes camel tours on Cable Beach
Snorkelling	Viewing of marine organisms using a face mask
Spearfishing	People targeting aquatic organisms with a spear-gun
Spectating/sightseeing	Looking at features of interest in the natural environment (or people participating in recreational activities), includes photographers and videographers
Surfing/paddle-boarding	Use of a board or stand-up paddleboard to ride waves
Swimming	Partial or full immersion in water, includes wading
Unknown	Activity of the person could not be ascertained
Walking	People travelling on foot along the shoreline, includes walking the dog and reef walking
Other	All other activity types
Boat-based	
Crabbing	Use of drop nets or scoops
Diving	Use of compressed air (SCUBA) by private or commercial groups from a boat.
Jet-skiing	Use of jet propelled craft, also known as Personal Water Craft (PWC)
Kayaking	Vessel powered by paddles, includes private and commercial kayaks
Kite surfing	Wind driven sport using a kite, includes people rigging a kite
Line fishing	Extraction of marine organisms using a hook and line, includes fly fishing
Motoring	Vessel transiting at high speed
Netting	Using a cast, haul or set net of mesh to collect marine organisms
Pearling/aquaculture	Vessels involved in pearling or aquaculture activity
Research	Research activities from an identified research vessel
Sailing	Yacht or dinghy under sail power
Spearfishing	People targeting aquatic organisms with a spear-gun
Towing sports	Activity where people are towed behind a vessel (e.g., knee-boarding, skiing and tubing)
Unknown	Activity of vessel could not be ascertained
Wildlife interaction	People view wildlife from close proximity (e.g., swimming with manta rays)
Wildlife viewing	People view wildlife from a distance (e.g., whale watching, turtle watching)
Windsurfing	Wind driven sport using a windsurfer, includes people rigging or setting up a windsurfer
Other	All other activity types

Table 4. Categories of vessels ascribed to observations made during aerial surveys of the coastal waters of the central and eastern Kimberley in 2013.

Vessel type	Characteristics
Motorised vessels	
Cruise ship	Large vessel (>25m) taking paid passengers
Cabin cruiser	Vessel with sleeping accommodation, in-board engine (private vessel)
Charter	Vessel (<25 m) with paying passengers undertaking recreational activities or live-aboard trip
Commercial	Vessel used for commercial purposes (e.g., fishing, research, rig tender, pearling)
Open >5 m	No sleeping accommodation, out-board engine (>5 m), includes cruise ship tenders
Open <5 m	No sleeping accommodation, out-board engine (<5 m), includes cruise ship tenders
Tinnie	Small aluminium vessel with out-board engine, generally <5 m
Jetski	Jet propelled craft also known as Personal Water Craft (PWC)
Tender	Small vessel powered by oars or motor, used for transport to or from a larger vessel/shore
Other	Includes other vessels such as a float plane or hydrofoil
Unknown	Unknown motorised vessel type
Non-motorised vessels	
Yacht	Vessel (>7 m) powered by sail
Dinghy	Vessel (<7 m) powered by sail
Kayak	Vessel powered by paddles, can carry one or two passengers
Windsurfer	Single person vessel consisting of a board and one sail
Kite surfer	Small surfboard with sail harnessing wind power
Unknown	Unknown non-motorised vessel type

Table 5. Categories for other indicators of human use recorded during aerial surveys of the central and eastern Kimberley coast in 2013.

Indicator	Characteristics
Camp	One (or more) tents, caravans or camper trailers with a shared communal area in an identifiable clearing (which may have associated vehicles)
Vehicle	Vehicle with four wheels
Motorbike	Motorbike or quad-bike
Boat trailer	Empty boat trailer, either attached to a vehicle or not, at a boat ramp or boat launching area
Anchored boat	Boat not being used for an activity but anchored (or tied to a mooring), often near a campsite or boat ramp but outside of an 'authorised' mooring area.
Boat on beach	Boat dragged up on the beach, often near a campsite

2.5 Analysis

After processing with Aerial Survey Assistant (ASA) software, the data points were imported into ArcGIS 10.2 for analysis. Data were collected in WGS84, which approximates GDA94, and was sufficient for presentation of raw data points using graduated symbols to represent the number of vessels, boats or other indicators of recreational activity. For these limited number of surveys all observations were included on the summary maps.

3 Results

3.1 Aerial surveys

Four survey flights were flown between Camden Harbour and Point Torment near Derby during the study period (Table 6). A single survey over two days of flying from Wyndham via Kalumburu to Camden Harbour was conducted along the eastern Kimberley coast in July 2013 (Table 7).

Table 6. Dates, times, start and finish locations for the aerial surveys of the central Kimberley coast (April to August 2013).

Date	Survey start time	Survey finish time	Survey start	Survey finish
12/04/2013	08:48	11:09	Camden Harbour	Point Torment
15/06/2013	12:24	14:37	Camden Harbour	Point Torment
16/07/2013	12:37	15:00	Camden Harbour	Point Torment
11/08/2013	12:01	14:29	Camden Harbour	Point Torment

Table 7. Dates, times, start and finish locations for the aerial survey of the eastern Kimberley (July 2013).

Date	Survey start time	Survey finish time	Survey start	Survey finish
18/07/2013	11:24	13:15	Wyndham	Kalumburu
18/07/2013	14:12	16:02	Kalumburu	Mitchell River
19/07/2013	07:19	09:24	Mitchell River	Camden Harbour

3.2 Shore-based activities

Very few people were observed along the shores of the central Kimberley coast during the four aerial surveys (Figure 3). In total, only 57 people were recorded and this included a large group of people (n=35) on the pontoon for float planes at Horizontal Falls in Talbot Bay. Other isolated individuals or small groups of people were observed walking along the shore and were usually associated with small boats that were drawn up on the beach. Two coastal camps were observed, one near Freshwater Cove and the other near Steep Head. Only one vehicle was observed and was located on the shore of Cone Bay near Larinyuwar commumity.

In the eastern Kimberley, only 25 people were recorded along the shore. They were mainly located in the vicinity of the camping areas near Kalumburu and also at the Kimberley Coastal Camp (Figure 4). The other isolated groups of people were generally associated with small tenders that were drawn up on the beach. With respect to activities, most people were walking, although a few were swimming and fishing near Kalumburu. Along the eastern Kimberley coast, very little camping was evident and that observed was mainly near Kalumburu at Beauty Point, Honeymoon Beach, Bluff Point and Mission Cove (Figure 5). Vehicles were observed on the shore at Wyndham, Berkeley River, Kalumburu and Port Warrender near the Mitchell Plateau (Figure 6). A few boat trailers were observed on the shore at Wyndham, at West Bay near Kalumburu, and at Port Warrender (Figure 7).

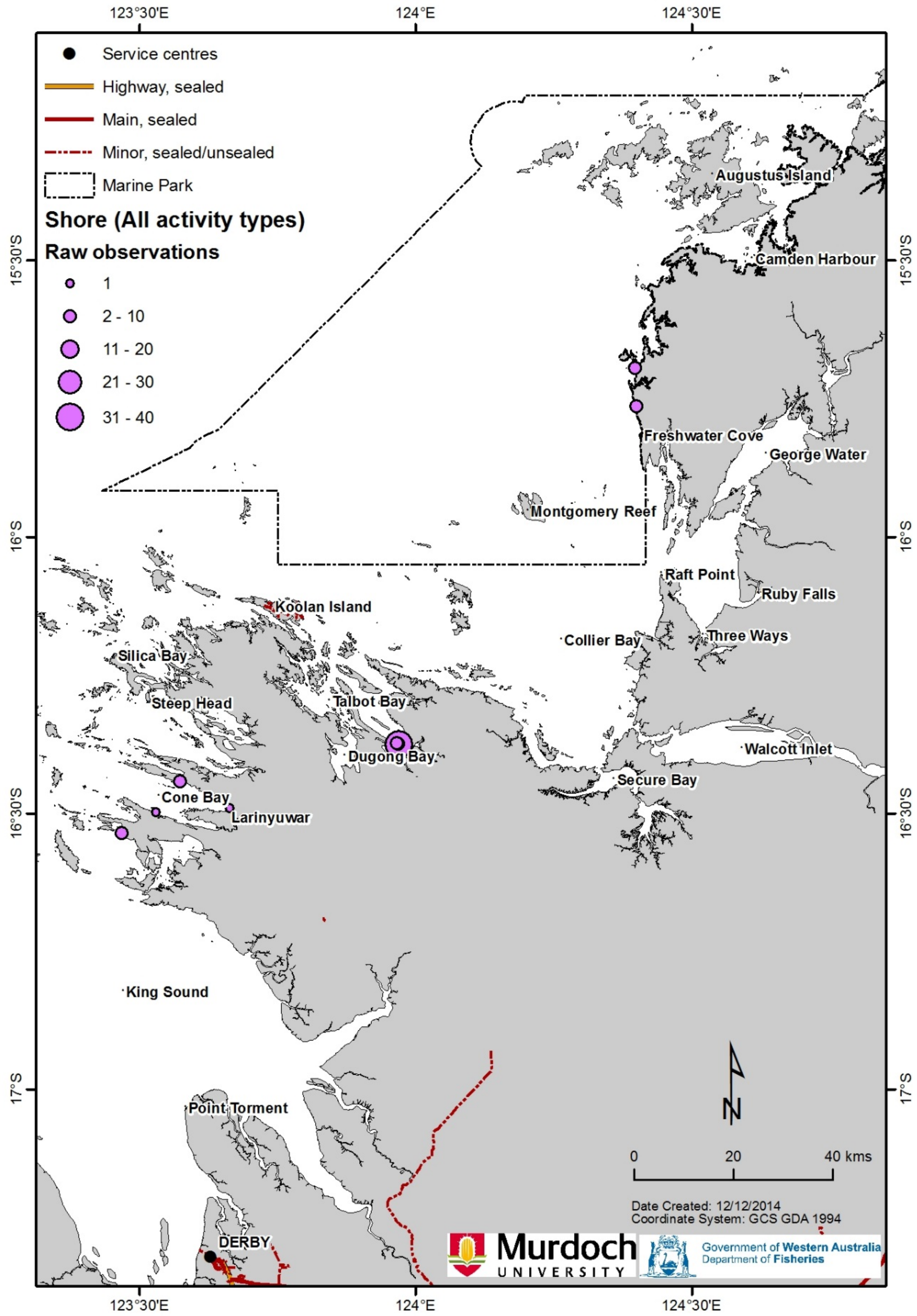

Figure 3. Locations and numbers of people recorded along the central Kimberley coast between Camden Harbour and Point Torment (Derby) during four survey flights (April to August 2013). This survey encompassed the shores of the Lalang-garram Camden Sound Marine Park and the proposed Horizontal Falls Marine Park.

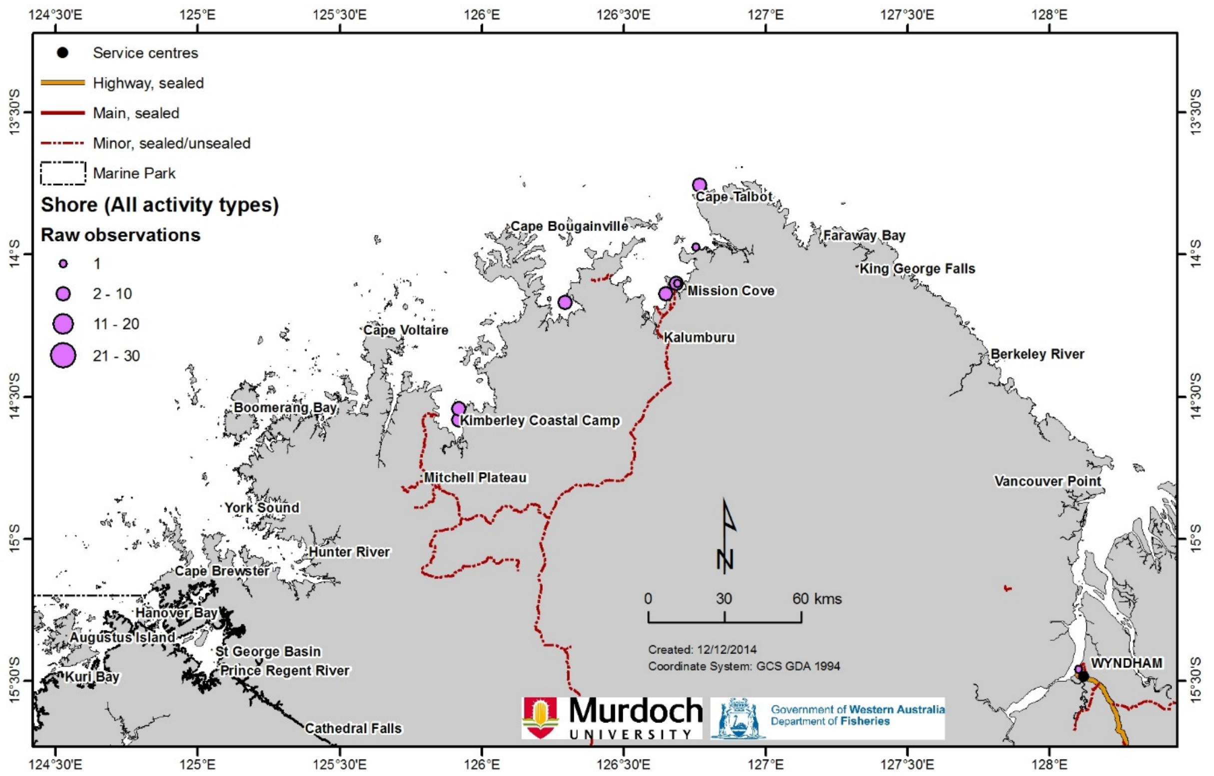

Figure 4. Locations and numbers of people recorded along the shore between Wyndham and Camden Harbour (Augustus Island) during an aerial survey of coastal waters of the eastern Kimberley (18-19 July 2013).

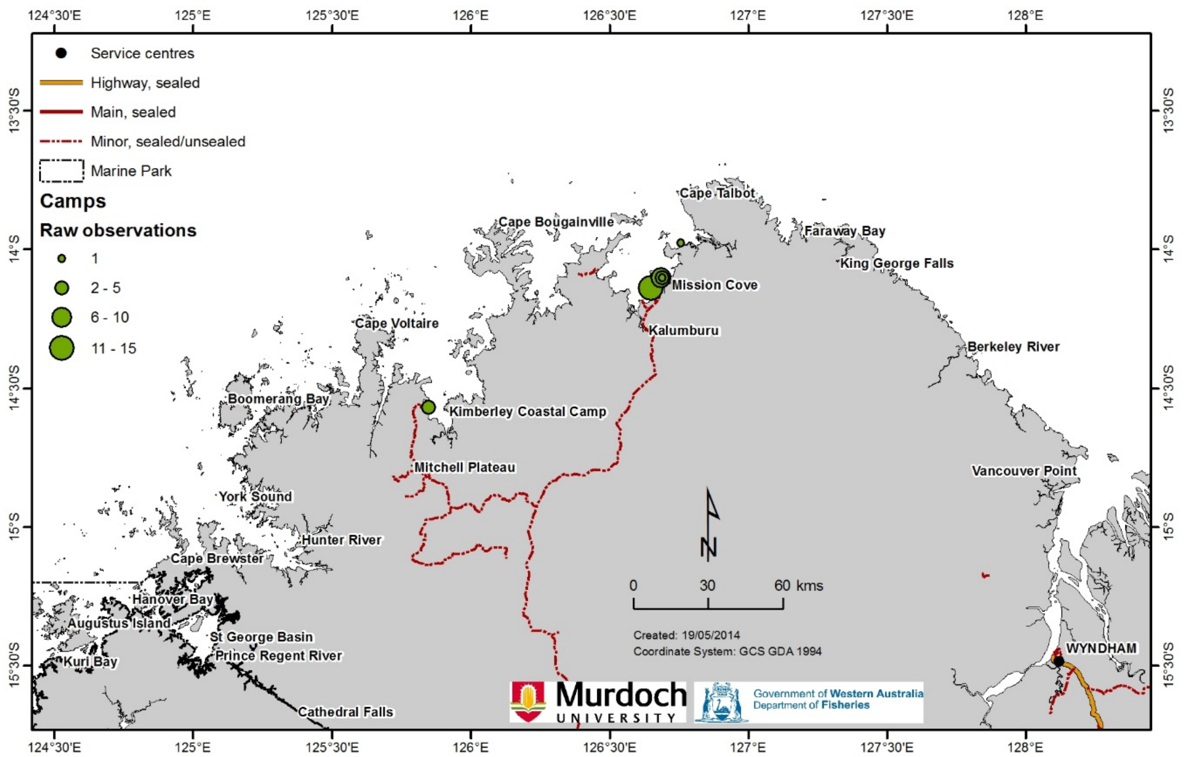

Figure 5. Locations and numbers of coastal camps recorded along the shore between Wyndham and Camden Harbour during an aerial survey of the eastern Kimberley coast (18-19 July 2013).

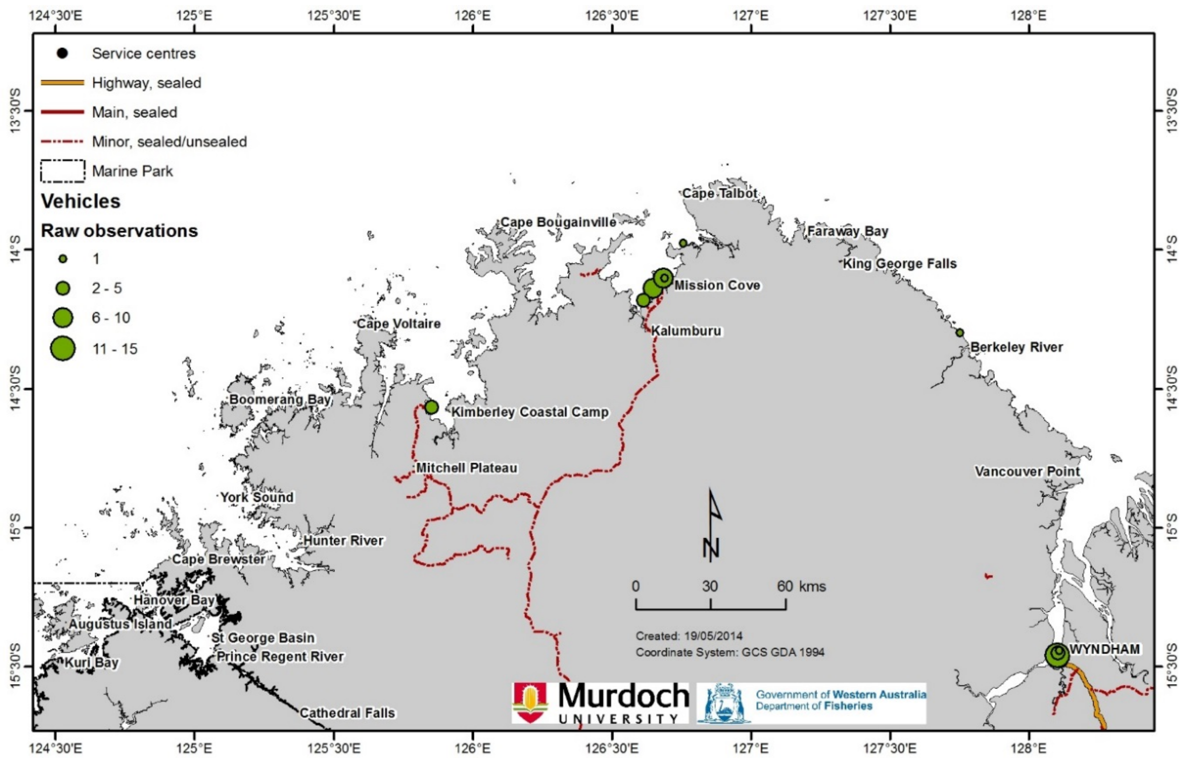

Figure 6. Locations and numbers of vehicles recorded along the shore between Wyndham and Camden Harbour during an aerial survey of the eastern Kimberley coast (18-19 July 2013).

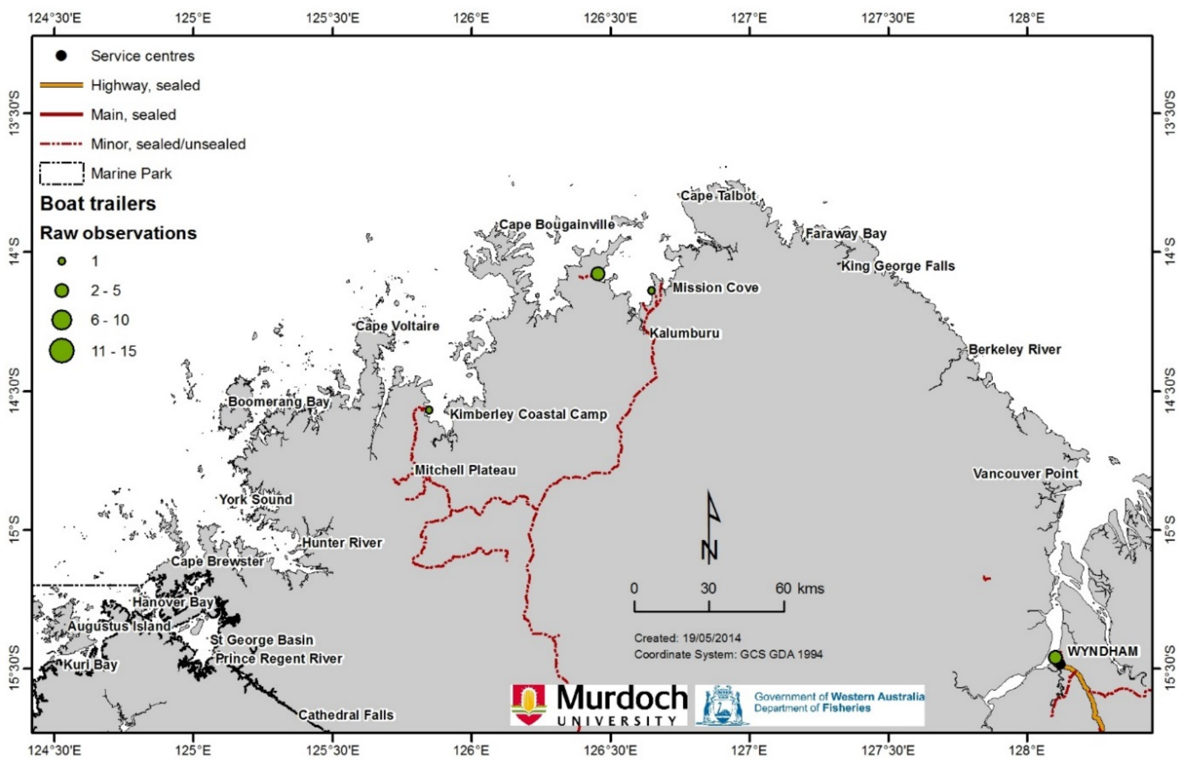

Figure 7. Locations and numbers of boat trailers recorded along the shore between Wyndham and Camden Harbour during an aerial survey of the eastern Kimberley coast (18-19 July 2013).

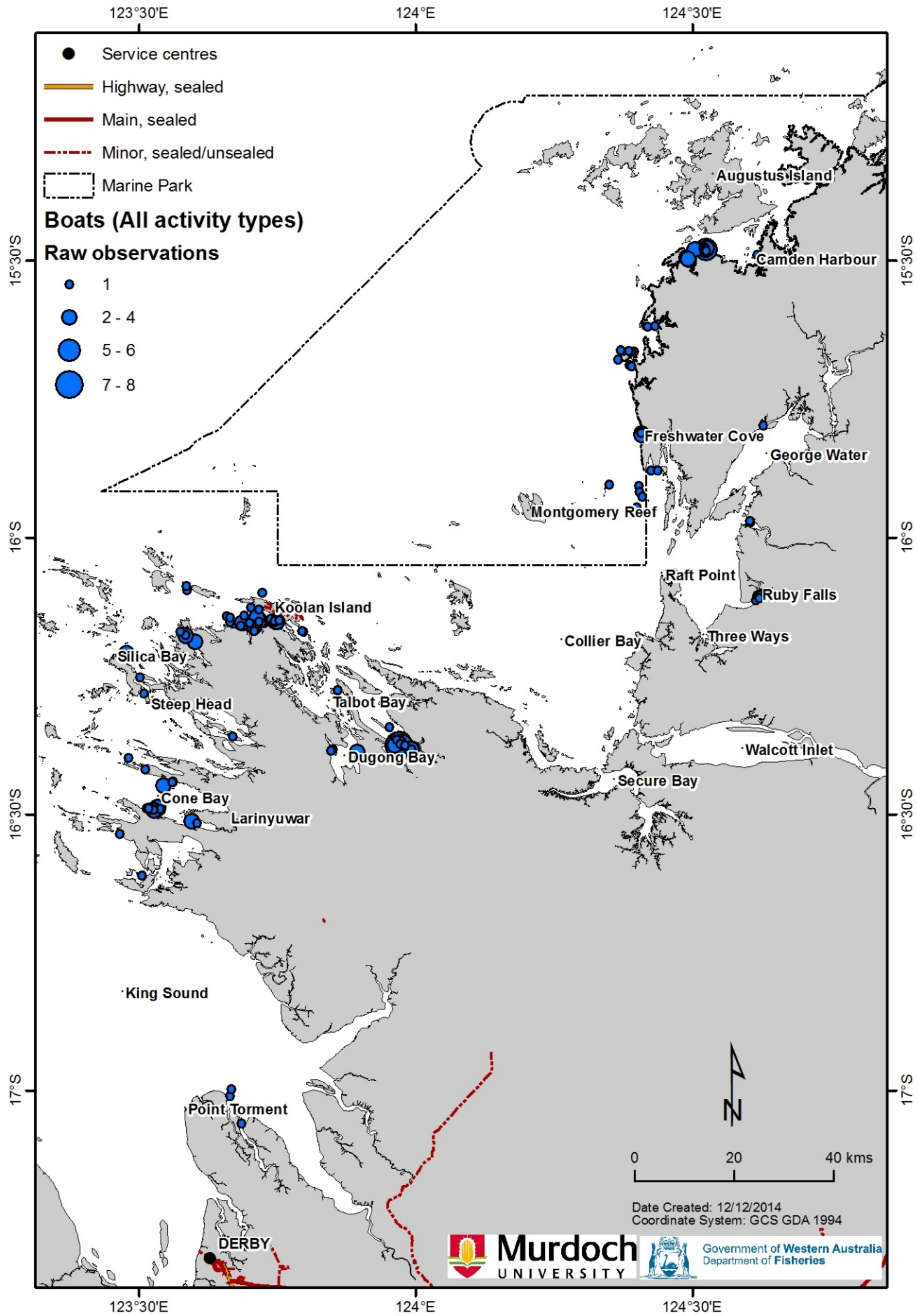

Figure 8. Locations and numbers of vessels recorded between Point Torment (near Derby) and Camden Harbour during four survey flights of coastal waters of the Lalang-garram Camden Sound Marine Park and proposed Horizontal Falls Marine Park (April to August 2013).

3.3 Boat-based activities

Boat-based activity was limited but widely distributed in the central Kimberley with nodes around Kuri Bay, Horizontal Falls (Talbot Bay), Koolan Island and Cone Bay (Figure 8). During the four surveys, the 53 vessels engaged in activities, and the 149 vessels that were moored or anchored ranged from commercial and cruise vessels to small tenders (<5m). At Horizontal Falls, the vessels were generally involved with tourism activities whilst, at Koolan Island, most were commercial vessels associated with the iron-ore loading jetty. In Cone Bay, most of the vessels were linked with the barramundi mariculture facility. Yachts were recorded in many anchorages including Samson Inlet and Sale River as well as some south of Koolan Island such as Silver Gull Creek and Crocodile Creek. Cruise vessels were recorded near Red Cone Creek, Raft Point, Horizontal Falls, Freshwater Cove, Koolan Island and Talbot Bay. Only three boats engaged in recreational fishing were observed and these were all in King Sound near Point Torment.

Vessels were widespread across the eastern Kimberley and observations comprised 82 vessels engaged in activities and 55 that were moored or anchored. The vessels included commercial shipping, vessels involved in pearling operations, cruise vessels, yachts, cabin cruisers and small tenders (Figure 9). Pearling activities were concentrated east and south-west of the Bougainville Peninsula at the Paspaley lease areas. Expedition cruise vessels were observed at Vansittart Bay and near Cathedral Falls in the Prince Regent River.

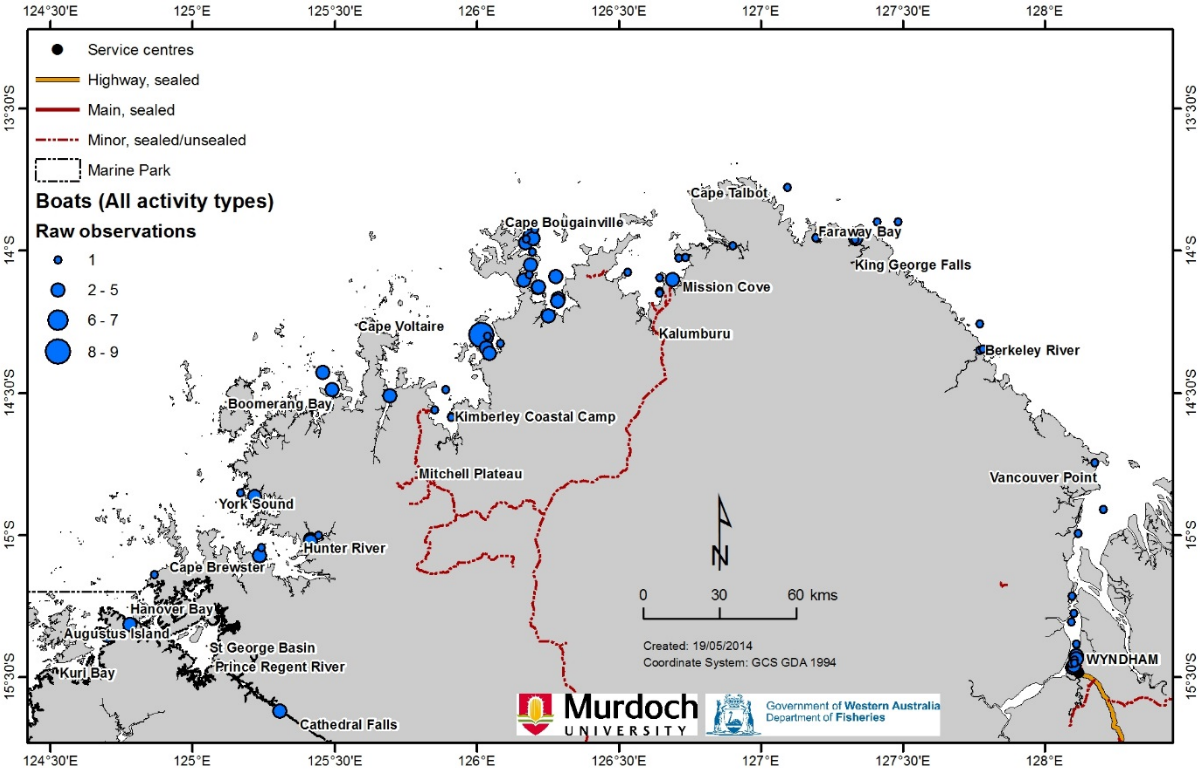

Figure 9. Locations and numbers of vessels recorded between Wyndham and Camden Harbour (Augustus Island) during an aerial survey of coastal waters of the eastern Kimberley (18-19 July 2013).

4 Discussion and Conclusions

4.1 Central Kimberley coast (Lalang-garram Camden Sound and Horizontal Falls Marine Parks)

The exploratory aerial surveys to the Lalang-garram Camden Sound Marine Park and the proposed Horizontal Falls Marine Park were restricted to one flight in April 2013 and three flights during the dry season (June, July and August 2013); each required refuelling at Derby before returning to Broome. Limited numbers of people were observed along the shore during these surveys as there are no access roads and very few tracks to the convoluted coast (Gibbons 2012). Horizontal Falls is a popular tourist destination with float planes flying people in from Broome or Derby to experience powerboat rides through the narrow gaps of cascading water (McGonigal 2003, Zell 2007). The planes and boats involved with this activity moor to a floating pontoon anchored nearby; the majority of people recorded during the survey were located on this pontoon. The few other people observed on the shore elsewhere were usually associated with a boat tender pulled up on the beach nearby. Interestingly, no groups of tourists from cruise vessels were observed on the shore during the surveys although these vessels are equipped with small boats to transfer the passengers to on-shore locations (Scherrer et al. 2008).

During the four survey flights, 53 vessels were observed to be conducting activities and a further 149 were either moored or anchored at sites in the study area. Commercial shipping activities at Koolan Island and vessels associated with barramundi mariculture in Cone Bay were dominant during all surveys. Some expedition cruise vessels were observed and these were either motoring between locations or anchored. These cruise vessels operate mainly in the peak season and have busy schedules visiting a range of anchorages and tourist sites (Scherrer et al. 2008; Beckley et al. this report). Private yachts that were sailing in coastal waters, or at anchor, were also observed; many of them were returning to Western Australia after the 2013 Fremantle to Bali yacht race. The Kimberley coast is a well-known cruising ground for yachts and the attributes of the many anchorages in the region are well-documented (Putt 2014, Kimberley Coast Cruising Yacht Club 2015).

With respect to the coastal waters of the Lalang-Garram Camden Sound Marine Park, there was relatively little shore-based and boat-based activity though it should be noted that the survey only followed the mainland coast; Montgomery Reef and other offshore islands were not included in the study area. The full extent of the proposed Horizontal Falls Marine Park has not yet been made publicly available but is expected to extend from the Horizontal Falls eastwards to Collier Bay, Walcott Inlet and Doubtful Bay. As such, Horizontal Falls itself was the only node of activity though several vessels were observed at sites within Doubtful Bay.

The four exploratory surveys of the Lalang-garram Camden Sound Marine Park and the proposed Horizontal Falls Marine Park have provided an indication of where use is located in the region as well as valuable information with respect to logistics for surveys in this area. This will be particularly useful for designing future, temporally-appropriate, surveys for benchmarking and monitoring of the proposed Horizontal Ralls Marine Park and the western extent of the Lalang-garram Camden Sound Marine Park.

4.2 Eastern Kimberley coast

Only one aerial survey of the eastern Kimberley was undertaken over two days during the peak tourist season in July 2013. Logistics were complicated with refuelling required at Kununnurra, Kalumburu (twice) and Derby to complete the long survey. As expected, very few people were observed along the shore during the survey and those were mainly at coastal camping sites near Kalumburu and at the Kimberley Coastal Camp near to Port Warrender. No groups of tourists from cruise vessels were observed on the shore.

Vessels were distributed throughout the area and comprised commercial shipping, vessels associated with pearl mariculture, cruise vessels, yachts, cabin cruisers and tenders. Many pearling leases are distributed in the bays of the eastern Kimberley and, during the survey, vessel activity associated with Paspaley pearl mariculture was recorded in Zone 4 both east and south-west of the Bougainville Peninsula (Fletcher & Santoro 2014). Vessels associated with the pearl mariculture industry were the most numerous of all vessels recorded in the eastern Kimberley and many of the bays were filled with floating lines bearing the cages of pearl oysters as well as their attendant vessels and floating accommodation. Cruise vessels were recorded in Vansittart Bay and in Prince Regent River near Cathedral Falls. A number of cruise vessels undertake busy itineraries visiting a host of sites in the eastern Kimberley during the dry winter season (Scherrer et al. 2008; Beckley et al. this report). Yachts and cabin cruisers were distributed throughout the region and were observed in many of the known anchorages (Putt 2014). Numbers appear to be relatively few and there is a strong network amongst the people who enjoy cruising along the Kimberley coast (Kimberley Coast Cruising Yacht Club 2015).

The exploratory survey of the eastern Kimberley has provided an indication of where use is located in the region and valuable information with respect to logistics for aerial surveys in the region. This will be particularly useful for designing future, temporally-appropriate, surveys for benchmarking and monitoring of the proposed North Kimberley Marine Park and the eastern extent of the Lalang-garram Camden Sound Marine Park.

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Chapter 4: Cumulative visitation by expedition cruise vessels along the remote Kimberley coast, northern Australia

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Summary

Adequate management of the coastal waters of the remote Kimberley requires knowledge of the spatial and temporal extent of human use (commercial, recreational and traditional). Vessel-based expedition cruising is popular along the central and eastern Kimberley coast where road access is extremely limited. A desk-top study was undertaken to quantify the number and passenger capacity of expedition cruise vessels advertising trips along the Kimberley coast during 2013. These vessels operate mainly from April to September between Broome and Wyndham with some offering excursions to islands further offshore. Detailed itineraries and types of activities offered at the sites visited were analysed. Eighteen cruise vessels (12-103 m in length) that advertised itineraries operated in the Kimberley in 2013 and 60% of these vessels carried <20 passengers. More than 110 sites were reported in the itineraries and, excluding the port of Broome, Montgomery Reef (275 vessel visits with 7382 passengers), Horizontal Falls (260 vessels visits with 7068 passengers), Raft Point (250 vessel visits with 6786 passengers), Prince Regent River (235 vessel visits with 6308 passengers) and Talbot Bay (211 vessel visits with 6176 passengers) were the most frequented sites. Activities at the sites usually included tender (small boat) excursions ashore for scenic visits to waterfalls, historical and rock art sites as well as walking, swimming and fishing. The entire Kimberley coastline was also surveyed during four consecutive days in July 2013 by two observers in a light aircraft (Cessna 210) to provide a snapshot of the actual locations and activities of expedition cruise vessels in the region during the peak tourist period. Despite the many limitations of this desk-top study, the cumulative estimates provide managers with an indication of where potential impacts may occur and where monitoring might be necessary along the Kimberley coast.

1 Introduction

The Kimberley coast with its remarkable geology, biodiversity and indigenous cultural assets is a prime destination for expedition cruise vessels (Zell 2007, Collins 2008, Sherrer et al. 2008, 2011a). These vessels ply the Kimberley coast during the dry season visiting anchorages where passengers are usually taken ashore in tenders and small boats to explore features such as waterfalls, Aboriginal art or historical sites.

The cruise industry began in the Kimberley in the 1980s and, by 2006, there were about 30 vessels involved, of which 14 were motor cruise vessels, nine were vessels engaged in fishing tours and seven were sailing yachts (Sherrer et al. 2008). The advertised itineraries of these vessels indicated that about 90 coastal sites were visited with several, such as Montgomery Reef, Horizontal Falls and Prince Regent River, highlighted as very popular destinations. Visitor management practices, operational, cultural and environmental sustainability as well as tourism access without the permission of the traditional owners have been examined for the Kimberley region (Hercock 1999, Smith et al. 2009, Sherrer & Doohan 2011, Sherrer et al. 2011a, 2011b).

The Lalang-gurram Camden Sound Marine Park and the designated Horizontal Falls and Northern Kimberley Marine Parks extend over much of the area frequented by the expedition cruise vessels. As management of marine parks requires an understanding of the extent of human use, information on visitation by passengers from cruise vessels is desirable. This study aimed to estimate cumulative visitation by cruise vessels and their passengers to the Kimberley coast by examining their advertised itineraries and activities during the 2013 season.

2 Materials and Methods

2.1 Desktop study

A desktop study was undertaken to examine the advertised itineraries of expedition cruise vessels operating during 2013 along the Kimberley coast. These vessels operate mainly in coastal waters between Broome and Wyndham though some include visits to Darwin and neighbouring countries such as East Timor or Indonesia. The study focused on vessels that offered frequent stops and small boat/tender excursions to enable passengers to visit sites of interest along the Kimberley coast. It thus excluded any cruise ships that traversed the area without stopping, or vessels that only offered day excursions and/or fishing charters out of Broome, Derby or Wyndham.

Information available on the websites of companies offering cruises (e.g., www.kimberleycruises.com) was examined to summarise the types and sizes of vessels operating in the Kimberley. Data were also gathered on the number of passengers and crew accommodated by each vessel, the number of small boats/tenders used for excursions to land-based sites and for fishing, and whether a helicopter was available for passengers to access scenic sights in the region. For each of the vessels which listed detailed cruise itineraries online, an Excel spread sheet was populated with the calendar dates of visits to each site during the 2013 cruise season.

The total number of vessel visits to each site was estimated by adding up the number of days when all vessels visited each site during the year. For each of the sites, the total number of potential visitors was calculated in a two-step process. Firstly, the total number of visits to each site by each vessel was multiplied by the maximum number of passengers accommodated by the respective vessel. Then, for each site, the estimated cumulative number of potential visitors was calculated by adding together the total visitors from all vessels visiting the site during the season. Quantitative data on the number of scheduled vessel visits and potential number of visitors during 2013 were collated for all sites in the Kimberley. Arc GIS software was used to map the sites and plot the numbers of vessel visits and visitors.

Estimation of vessel and passenger visits to the ports of Broome and Derby were problematic as sometimes the itineraries indicated that the vessels spent several days in these locations. In these cases, a maximum of two days was allocated to the port and the number of visits reduced accordingly so that the numbers of passengers visiting Broome and Derby were not over-estimated. For vessels that indicated a turnaround of passengers on the same day in either of the ports, the additional passengers were added to the total number of visitors to the port on those days.

Passenger transfers to or from vessels at the start or end of cruises can sometimes take place by helicopter, particularly at places like Mitchell Plateau. Incorporation of such transfers into the calculations proved difficult and estimates for the number of visitors to the Mitchell Plateau should be regarded as an underestimate.

To determine the total number of times each activity was offered by each vessel during 2013, the type of activities offered to passengers in the itineraries for each site were entered into an Excel spread sheet and multiplied by the number of times the vessel visited that site during the year. The data for all vessels were then added together to calculate the total amount of times the activity was offered in the 2013 itineraries. It is important to note that as passenger preferences were not available, it was not possible to estimate how many people actually undertook each activity.

2.2 Aerial survey of cruise activity along the Kimberley coast

The entire Kimberley coastline (excluding the many offshore islands) from Wyndham to Broome was surveyed during four consecutive days from 16-19 July 2013 by two observers in a Cessna 210 aircraft (see Chapters 2 & 3 for full details). The geo-referenced digital photographs taken of vessels during the survey were examined to identify cruise vessels and their locations were plotted using Arc GIS. These were then compared with the advertised itineraries of cruise vessels for each day during this period to establish extent of congruence between advertised itineraries and actual location of cruise vessels.

3 Results

3.1 Desktop study

At the time that the desktop study was undertaken in early 2013, there were 18 vessels advertising their itineraries online for cruises along the Kimberley coast between March and November 2013 (Table 1). Five other vessels indicated that they operated in the Kimberley but no itineraries were available for 2013 and, together with other vessels offering day trips or fishing charters, were not included in the analysis. Although the vessels ranged widely in size, the majority (81%) were <40 m in length (Figure 1a). Broadly, the vessels could be described as being cruise ships (two vessels of 90 m and 106 m in length), expedition cruisers (14 motor-powered vessels of 15 – 63 m length) or sailing yachts (two vessels of 12 m and 22 m length). The maximum number of passengers accommodated on board ranged from four, on one of the sailing yachts, up to 114 for one of the cruise ships operating in the region. For 61% of the vessels, the maximum number of passengers listed was < 20 (Figure 1b). The vessels operated in the Kimberley mainly during the months of April to September though some had slightly longer seasons and one, MS Caledonian Sky, only visited the Kimberley once during September (Figure 2).

Table 1. Details of cruise vessels operating in the Kimberley during the 2013 season. * indicates that some cruise itineraries were incomplete on websites and NS that information was not supplied.

Vessel name	Length (m)	Number of passengers	Number of crew	Number of tenders	Helicopter	Kimberley cruise season (2013)
MV Orion	103	106	75	12	No	May – Sep
MS Caledonian Sky	90	114	74	10	No	Sep
Oceanic Discoverer	63	72	NS	3	No	Apr – Sep
True North	50	36	19	6	Yes	Mar – Sep
Coral Princess	35	50	NS	3	No	Apr – Oct
Lady M*	31	10	8	2	No	Apr – Oct
MV Oceania	27	20	6	NS	No	Apr – Dec
K2O	23	12	5	3	No	Apr – Dec
MV Great Escape	26	14	6	3	Yes	Mar – Nov
Kimberley Quest II	25	18	6	4	Yes	Mar – Nov
Odyssey*	24	20	5	1	No	Apr – Nov
Discovery One	25	24	6	2	No	Mar – Oct
MV Diversity II	20	12	NS	3	No	Apr – Nov
Mahalo II*	19	12	4	1	No	May – Nov
Kimberley King Tide*	16	10	NS	1	No	Apr – Sep
Kimberley Explorer*	15	12	3	2	No	Apr – Sep
Yacht Starsand*	20	10	NS	NS	No	May – Sep
Yacht Escapade*	12	4	2	NS	No	Apr – Oct

Analysis of the listed itineraries revealed that vessels visited 114 different localities in the Kimberley (Appendix 1). The cumulative number of visits by all vessels to each locality showed that, in addition to the port of Broome, most vessel visits were concentrated in the area from the Buccaneer Archipelago through to Prince Regent River. The most vessel visits were to Montgomery Reef (275), Horizontal Falls (260), Raft Point (250), Prince Regent River (235) and Talbot Bay (211) (Figure 3, Appendix 1). Estimates of the number of potential passengers visiting each site during the season, based on the number of vessel visits and the maximum passenger capacity of each vessel, indicated that Montgomery Reef could have been visited by 7382 passengers, Horizontal Falls by 7062, Raft Point by 6786, Prince Regent by 6308 and Talbot Bay by 6176 during 2013 (Figure 4, Appendix 1).

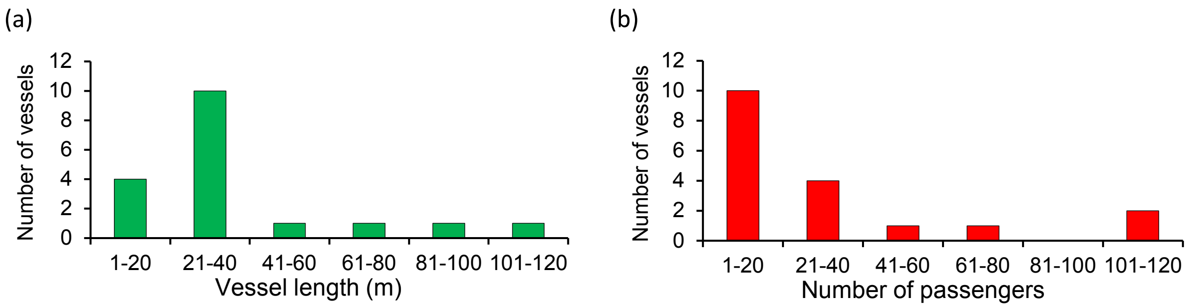

Figure 1. Size of cruise vessels (a) operating in the Kimberley in 2013 and their advertised number of passengers (b).

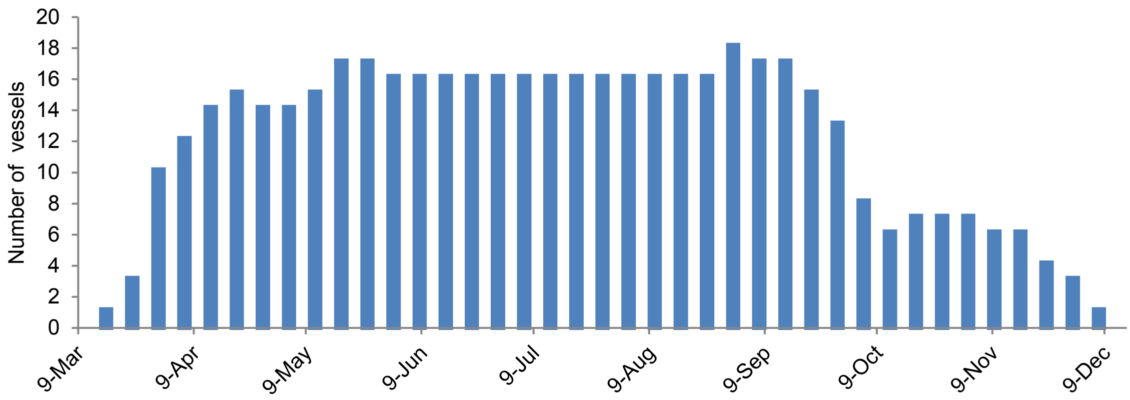

Figure 2. Number of cruise vessels operating each week along the Kimberley coast during 2013 (excluding fishing charter vessels).

The itineraries of the cruise vessels operating in the Kimberley highlighted many scenic features such as waterfalls and a range of activities that passengers could engage in. After taking into account all the visits by each vessel to each site during the scheduled cruises in 2013, boating/tender excursions were found to be the most advertised activity in the itineraries (1410 times). This was followed by swimming (1281 times), walking (1124 times), fishing (1068 times) and wildlife spotting (907 times) (Figure 5). These calculations do not take into passenger preferences.

3.2 Aerial survey of cruise vessel activity along the Kimberley coast

The flights covering the Kimberley coast from Broome to Wyndham over four days in July 2013 identified eight cruise vessels at various locations and these coincided with where the itineraries indicated they would be for all except MV Great Escape and Oceanic Discoverer (Figure 6). The former appeared to still be en route to its advertised destination whilst the latter appeared to be proceeding towards the next destination in their schedule. As the flights followed the mainland coastline, it was unlikely that vessels visiting offshore islands (Kimberley King Tide, MV Diversity) or transiting King Sound (Mahalo II) would have been observed on 16 July 2013. On 19 July 2013, Discovery One was not observed at Prince Regent River where the itinerary indicated it would be on that day.

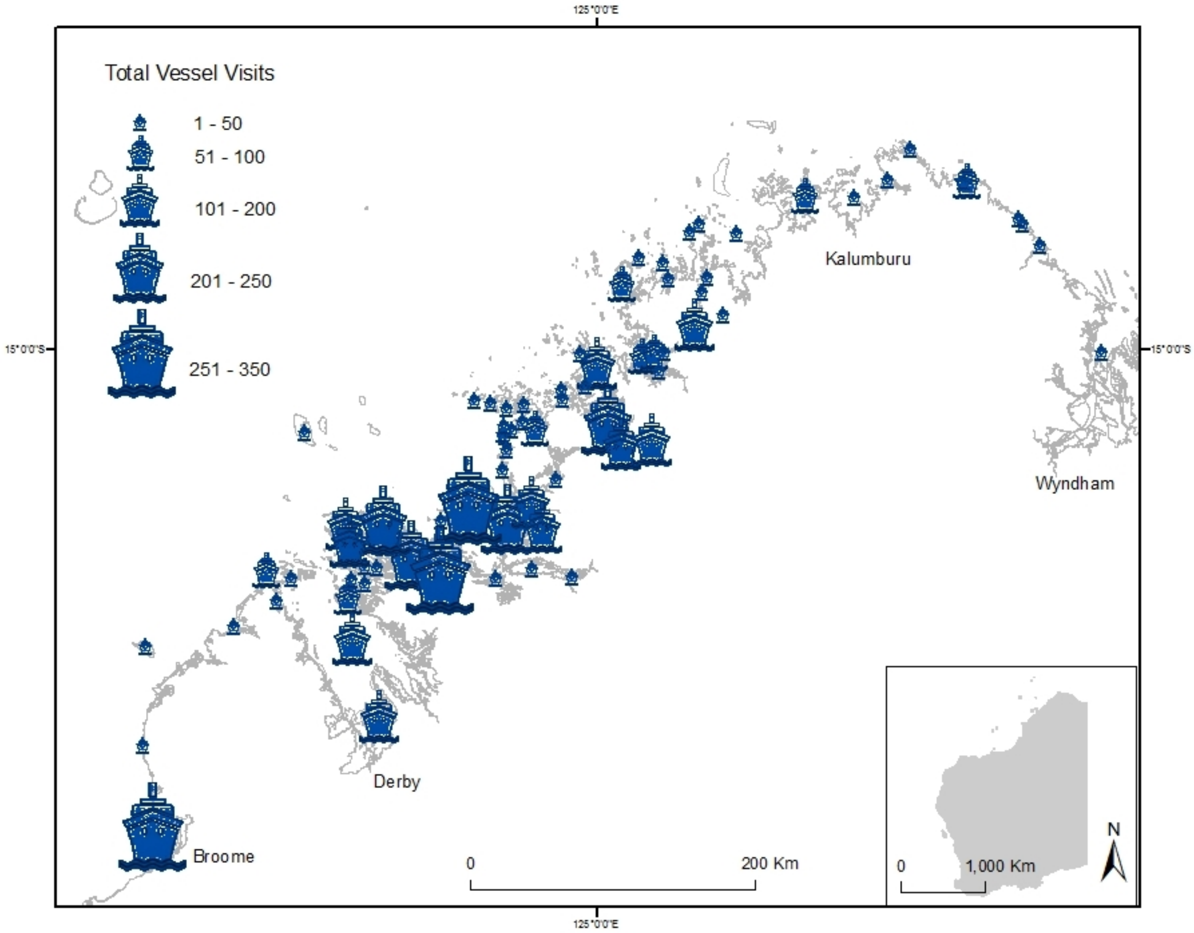

Figure 3. Total number of visits to each site by vessels engaged in expedition cruising in the Kimberley during the 2013 season. Note that for Broome and Derby, a maximum of two days per visit was included if stay in port exceeded this period to avoid over-estimation of passenger numbers.

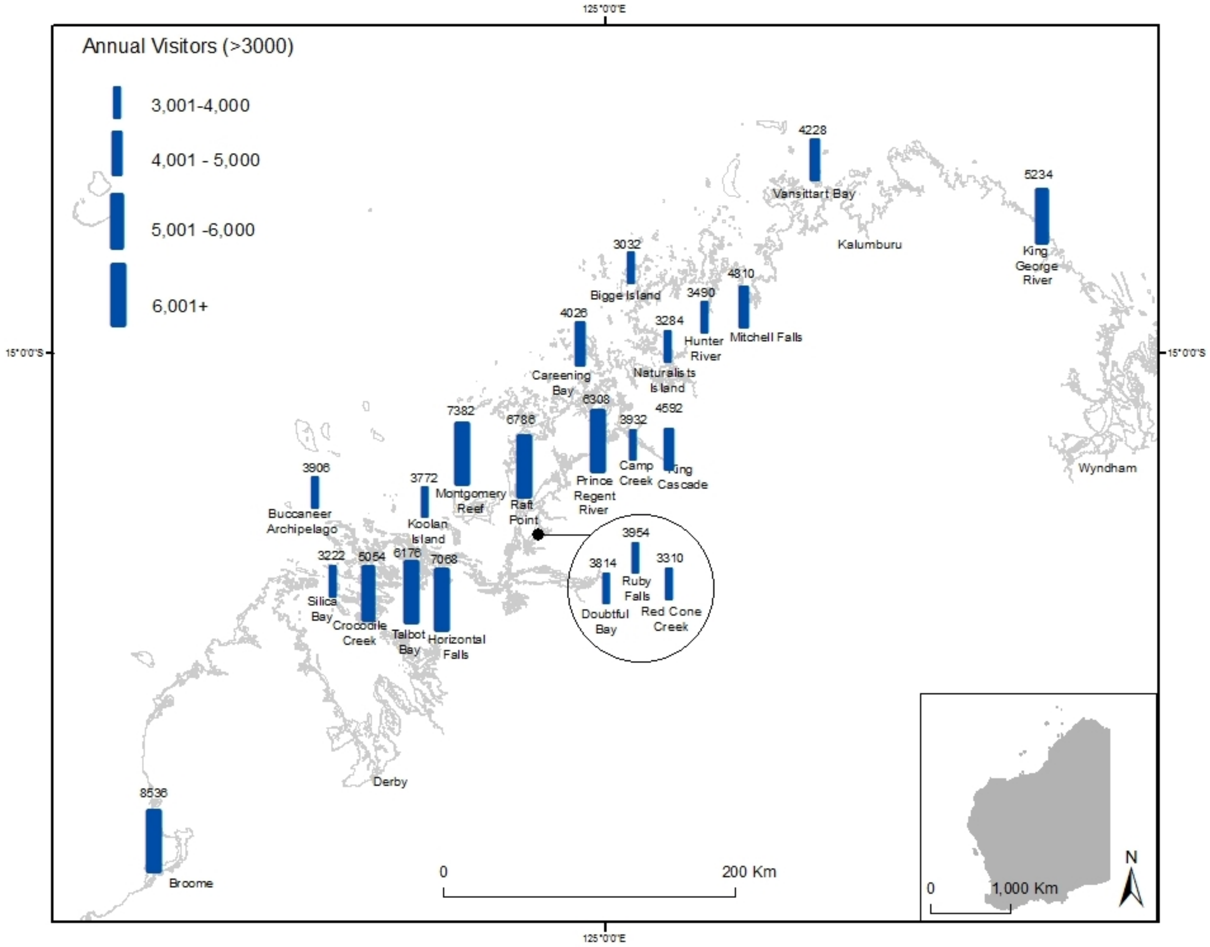

Figure 4. Estimated cumulative number of visits by cruise vessel passengers at the major sites along the Kimberley coast during 2013. Note that numbers assume full occupancy of the vessels, exclude crew members and do not imply that all passengers go ashore. The figure only includes sites with >3000 potential visitors.

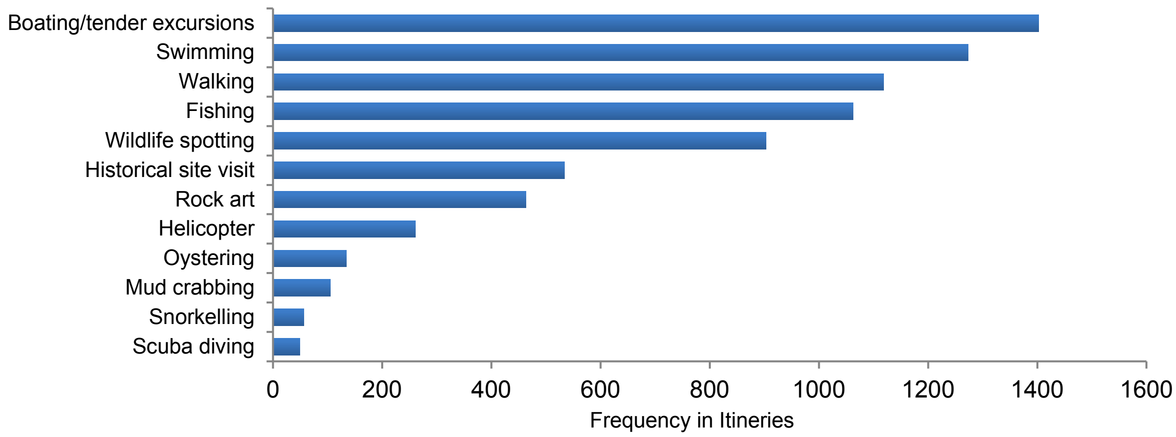

Figure 5. Cumulative frequency of times activities appeared in the advertised itineraries of all scheduled cruises in the Kimberley during 2013.

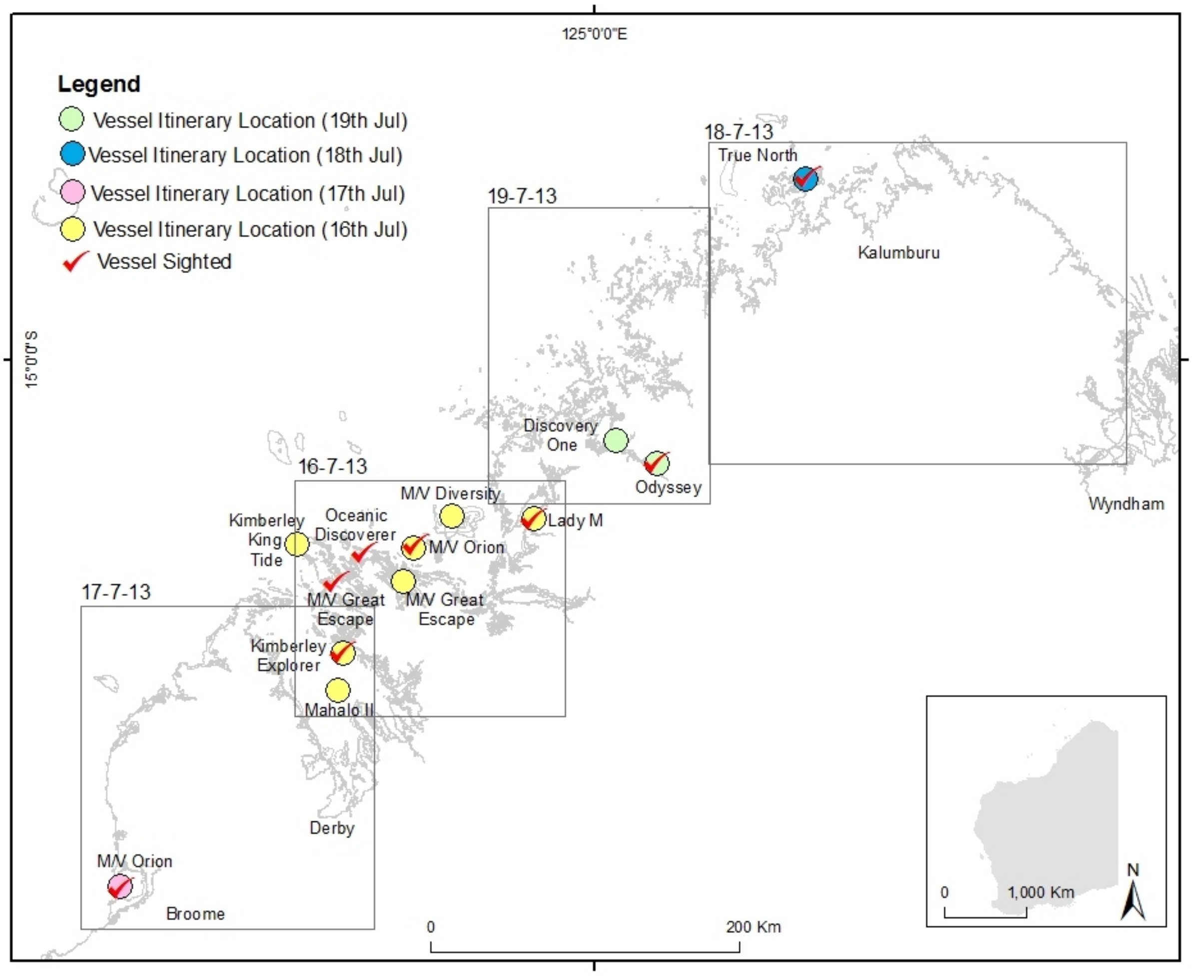

Figure 6. Aerial survey observations of cruise vessels along the Kimberley coast and their expected locations from their advertised itineraries for each of the days when flights took place (16-19 July 2013).

4 Discussion and Conclusions

Eighteen vessels (including two sailing yachts) were advertising cruising itineraries online for their Kimberley voyages in 2013. While this would appear to be considerably less than the 30 vessels recorded as operating in 2006 (Sherrer et al. 2008), that total included 14 motor cruise vessels, nine vessels engaged in fishing tours as well as seven yachts. As vessels engaged in fishing tours were not included in this study, it appears that the cruising fleet is fairly similar to that of 2006 but with a few more motor cruise vessels and less sailing yachts advertising itineraries. The majority of the cruise vessels operating in 2006 were still operating in 2013 but there had been some turnover. Although most vessels were still relatively small, a second vessel carrying >100 passengers had joined the fleet but it only operated on one trip through the Kimberley during the 2013 season.

In total, 114 sites were listed in the itineraries of cruise vessels in the Kimberley which is more than the 96 sites indicated by Sherrer et al. (2008). However, one third of the listed sites were visited <20 times during the season and then only by the smaller vessels. Besides Broome, Montgomery Reef, Horizontal Falls, Raft Point, Prince Regent River and Talbot Bay had the most vessel visits (>210) and these places were also identified by Sherrer et al. (2008, 2011a) as appearing on most vessel itineraries. As expected, these sites also had the most visitors during the 2013 season with >6000 estimated for each of these locations. The influence of passenger capacity of the vessels was clearly evident for some sites such as King George Falls which ranked next in terms of visitors (5234) although it only had 115 vessel visits. It should be noted that all visitors are potential visitors as calculations assume that the vessels were carrying their full complement of passengers but could not take into account whether passengers actually went ashore at the site or not. Further, the estimates do not include any calculations for crew of the vessels. It is recommended that this detail is explored further.

Of the sites where the most cumulative visitation was estimated to take place, Montgomery Reef and Prince Regent River are located in the newly declared Lalang-garram Camdem Sound Marine Park. Horizontal Falls, Talbot Bay and Raft Point are within the designated Horizontal Falls Marine Park. The host of environmental and cultural impacts from activities associated with shore-based excursions undertaken by visitors have been examined for the Kimberley (Sherrer et al. 2008, 2010, 2011, Smith et al. 2010) and were not investigated again in this study. Nevertheless, the estimates of total potential visitors to the various sites within the new Kimberley parks provide managers and traditional owners, particularly the Dambimangari people, with an indication of where any such impacts would be more likely to occur. Further, it would be worth examining the possibility of boat strikes on whales by vessels traversing the area at speed (Bezamat et al. 2014) as the calving season for humpback whales in the Kimberley coincides with the peak season for expedition tourism (Jenner et al. 2001).

Boat/tender excursions, swimming and walking were the advertised activities with the highest cumulative frequency in itineraries offered throughout the 2013 season. At the most popular sites, visiting vessels typically offer similar activities to their passengers. For example, most vessels stopping at Montgomery Reef offer tender excursions on a falling tide to witness the water cascading off the reef and a few of these offer opportunities for reef walking, snorkelling and fishing at this site. Boat excursions to the scenic Horizontal Falls also represent a commonly featured activity on most cruise itineraries, with some vessels also offering speed boat rides through the falls. At Raft Point, the majority of visiting vessels use tenders to transfer passengers to the shore, where they are guided on a short walk along a scenic track up to a secluded Aboriginal rock art gallery. Prince Regent River is most often mentioned in itineraries as a waterway through which vessels transit on their way to the nearby King Cascades waterfalls, though approximately half of the vessels visiting the area also offer passengers the chance to do some fishing in the river.

The aerial survey flights along the Kimberley mainland coast over four days in July 2013 recorded eight of the 12 cruise vessels that were expected to be in the respective survey areas although two were travelling between their scheduled destinations. For three of the vessels that were not sighted, their itineraries would have resulted in them being beyond observation range and the absence of one at Prince Regent River would be explained by the early hour of the survey flight and the offshore island location of the vessel the previous night.

Passengers on cruise vessels are not the only visitors to this coast and private motor vessels and sailing yachts as well as fishing charter vessels also access the remote Kimberley coast. The WA Department of Fisheries maintains records of fishing charter vessel activity (Telfer 2010), but the total numbers of people visiting sites on these and private vessels remain to be determined. Nevertheless, as these vessels would generally carry less people, it would be expected that the expedition cruise vessels provide the bulk of the visitors to sites along the central and eastern Kimberley coast. A notable exception to this would be at Horizontal Falls where float planes bring visitors from Broome and Derby to experience the spectacular effects of the tides. Similarly, as there are airstrips and road access to Mitchell Plateau and Kalumburu, there will also be additional visitors there.

From on-line advertised itineraries, this study has estimated the cumulative visitation by cruise vessels and the total number of potential visitors to >100 sites along the Kimberley coast during the 2013 season. Despite the many limitations of the study, these estimates provide managers and traditional owners with an indication of where potential impacts may occur and where monitoring might be necessary along the Kimberley coast. It is recommended that information on passenger preferences be garnered as this might further narrow down where cultural and environmental impacts may occur.

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6 Appendices

APPENDIX 1

Table 2. Cumulative number of visits by cruise vessels and the potential number of visitors to sites along the Kimberley coast calculated from published itineraries during 2013. The number of potential visitors was derived from the passenger capacities of vessels and does not imply that the passengers went ashore at these sites. * indicates inland sites with helicopter flights involved.

Site	Vessel visits	Potential visitors
Broome	340	8536
Montgomery Reef	275	7382
Horizontal Falls	260	7068
Raft Point	250	6786
Prince Regent River	235	6308
Talbot Bay	211	6176
Crocodile Creek	209	5054
Doubtful Bay	188	3814
Ruby Falls	181	3954
King Cascades	170	4592
Buccaneer Archipelago	151	3906
Red Cone Creek	147	3310
Careening Bay/Mermaid Boab Tree	142	4026
Silica Beach	139	3222
Camp Creek	137	3932
Sale River	136	2388
Derby	132	1620
Yampi Sound	123	2430
Koolan Island	120	3772
King George River and Falls	115	5234
Mitchell Falls*	110*	4810
King Sound	108	2132
Hunter River	106	3490
St George Basin	103	1882
Cockatoo Island	96	2350
Three Ways	96	1804
Vansittart Bay & Jar Island	89	4228
Rowley Shoals	86	1696
Silvergull Creek	84	1074
Bigge Island	81	3032
Cyclone Creek	77	1290
Kuri Bay	75	2574
Hidden Island	74	2232
DC3 crash site	73	2618
Camden Harbour	68	994
Naturalist Island	62	3284
Koolama Bay	62	2852
Prince Fredrick Harbour	55	2788
Cape Leveque	52	682
Cascade Bay	51	586
Hells Gate	51	586
Dugong Bay	51	622
Strickland Bay	50	556
Cone Bay	49	562
Langgi	48	818
Mitchell Plateau*	48*	856
Berkley River	47	932
Cambridge Gulf	44	1506
Wyndham	44	2296
Whirlpool Passage	43	524
Camden Sound	43	860
Sheep Island	43	688
Lacepede Islands	38	2226

Site	Vessel visits	Potential visitors
Kingfisher Islands	35	414
Tranquil Bay	34	2052
Collier Bay	32	488
Jackson Falls	31	756
Myridi Bay	29	346
Porosus Creek	29	564
Leadline Creek	28	720
Nares Point	28	1840
Pender Bay	27	1590
Winyalkan Bay	27	1590
Hathaway's Hideaway	27	1590
Surveyors Creek	25	534
Hanover Beach	21	468
Hanover Bay	21	346
Roe River	21	412
Coppermine Creek	20	216
Walcott Inlet	20	264
Mitchell River	20	302
Cape Londonderry	20	456
Cathedral Falls	19	376
Drysdale River	19	458
Glenelg River	18	190
Cape Voltaire	18	708
Secure Bay	16	200
Augustus Island	16	318
Eagle Falls	16	576
Bungle Bungle Ranges*	15*	1590
Crawford Bay	14	168
Turtle Reef	14	166
Deception Bay	13	222
One Arm Point	12	154
Bonaparte Archipelago	12	288
Sampson Inlet	9	180
Montague Sound	9	308
No Name Creek	8	288
Cygnet Bay	8	32
Low Rocks	8	576
Voltaire Passage	8	288
Adele Island	7	136
Sisters Island	7	84
Spitfire Creek	6	72
Admiralty Gulf	6	110
James Price Point	5	84
Shark Alley	5	60
Slate (Wailgwin) Islands	5	76
Slade Island	4	48
Brecknock Harbour	4	48
Prudhoe Islands	4	48
Napier Broome Bay	4	72
Casuarina Falls	4	40
Joseph Bonaparte Gulf	4	72
Edeline Islands	3	36
Munster Waters	3	36
Heywood & Champagny Islands	2	36
Butterfly Gorge	2	40
Wilson Point	2	40
Rice Rocks	2	40
Rothsay Water	2	36
Isdell River	1	12
High Cliffy Island	1	20
Atlantis Bay & Whiskey Creek	1	14

Chapter 5: Temporal and environmental factors affecting the launching of recreational boats at Entrance Point boat ramp, Broome, Western Australia

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Summary

The study examined recreational boat launches at Entrance Point boat ramp, Broome over 12 months using remote camera surveillance and investigated temporal and environmental factors that could influence the frequency of launches from this site. There were 6057 recreational boat launches during the study period and the highest number of launches was observed in August 2013 (882) and the highest number of launches in a single day (79) took place on 16 June 2013. In general though, for 69% of the days there were <20 boat launches per day. Although 60 % of all launches at Entrance Point boat ramp took place during the dry season, there was no significant difference in the mean number of launches per hour between the wet (0.56 h^{-1}) and dry (0.83 h^{-1}) seasons. There were, however, significant differences between the number of launches h^{-1} for day type, school holidays, time of day, wind direction and wind speed. When considering the temporal and environmental variables on an hourly timeframe, number of launches h^{-1} showed a low correlation with wind speed and wind gust and no correlation with season, school holidays, air temperature and wind direction. On a daily timeframe, wind speed, wind gust, day type and minimum temperature had the strongest correlations. Periods of greater than normal activity at the boat ramp (> 4 launches .h^{-1}) occurred during 322 hours of the study period (3.7% of the total time). At these times, the launches were predominantly between 8 am and noon on weekends during the dry season when there were no school holidays and the wind was <3 m.s^{-1} ESE. Time series modelling on the hourly launch data using the factors retained from the correlation analysis showed that day type, time of day, school holidays, and tidal height were the significant predictors that together described the most variation in launches on a daily cycle. For the weekly cycle, only day type and wind speed were significant predictors. Use of remote camera footage allowed cost-effective analysis for the entire study period and required fewer resources and man-hours than traditional surveys. The method did not impact on the activity of the boaters, delivered almost continuous observations, was able to monitor boat ramp use after hours and enabled trends over days and weeks to be defined.

1 Introduction

Several studies have examined the spatial patterns in use of recreational boats in Western Australia (Sumner & Williamson 1999, Sumner et al. 2002, Prior & Beckley 2006, Smallwood et al. 2006, Williamson et al. 2006, Prior & Beckley 2007, Sumner et al. 2008, Smallwood et al. 2011, Smallwood & Beckley 2012, Smallwood et al. 2012). Most of these studies have also examined broad temporal distribution of recreational boating particularly with respect to fishing. Recently, fine scale temporal patterns in recreational boat use have also been examined by using remote video cameras at boat ramps to monitor boat launches at several sites around the Western Australia including at Broome (Ryan et al. 2013, Wise & Fletcher 2013).

There are more than 85,000 registered recreational powerboats in Western Australia (Cripps, 2010). Of these, about 1800 are registered in the town of Broome, a regional centre in the Kimberley region of north-western Australia. Broome has several boat ramps from where these vessels can launch in order to take part in marine activities such as recreational fishing. There were 3300 recreational boat fishing licences issued for the Kimberley region in 2010/11 out of a total of 116,256 for the whole state of Western Australia (Ryan et al. 2013).

A range of factors affect water-based recreational activities and these include time of day, day type (weekdays, weekends, public holidays), school holiday periods, seasons and weather conditions (Widmer & Underwood

2004, Leon & Warnken 2008, Dalton et al. 2010, Sunger et al. 2012). As the climate of Broome has a wet season (November to April) and a dry season (May to October) when there is an annual influx of tourists to the region (Collins 2008), it would be expected that there would be some seasonality in the launching of boats from boat ramps in the town.

The aim of this study was to examine boat launches at Entrance Point boat ramp at Broome over 12 months using remote camera surveillance and investigate temporal and environmental factors that could influence the frequency of launches of recreational boats from this site. This study coincided with aerial surveys that were conducted to quantify human use of the Kimberley (Beckley et al. this report).

2 Materials and Methods

2.1 Remote camera data

The boat ramp at Entrance Point (18.008°S 122.208°E) in Broome has a south-easterly aspect and is adjacent to the Broome Fishing Club (Western Australian Department of Transport 2013). Remote video footage was obtained from a camera placed by the Western Australian Department of Fisheries at the Broome Fishing Club to monitor activity at Entrance Point boat ramp. Video footage from November 2012 to October 2013 was analysed as this coincided with the aerial surveys of human use of the Dampier Peninsula coast and adjacent waters (Beckley et al. this report).

The camera was a Mobotix m12s with a 43 mm lens and a 5 megapixel image capture. Vision was streamed to an Apple Mac mini-computer where a frame was captured every 8 seconds and combined into a QuickTime.mov file for each hour. Security Spy software (Bensoft) was used to compile and record all of the data which were then transferred hourly to the Hillarys laboratories of the Western Australian Department of Fisheries for storage (Wise & Fletcher 2013; S. Blight, Western Australian Department of Fisheries, pers. comm.).

Boat launches and retrievals were recorded to the nearest minute, but were aggregated to hourly periods for analyses. Launches were only recorded when the boat departed the shore and retrievals were only recorded when the boat was pulled from the water (i.e. not for dropping off people). Both launches and retrievals were classified according to vessel type (commercial, powerboat, jet-ski, kayak, other, unknown) and only powerboat data were used for analyses in this study. Data from the camera were missing for some periods (Appendix 1) and were estimated by imputing data from similar strata (hour, day type, month, school holidays) of adjacent time periods (Wise & Fletcher 2013).

2.2 Factors influencing boat launching

Various temporal and environmental factors that may influence the launching of boats were examined. Time of day, day type and season were the temporal factors investigated. Day type was classified into weekdays and weekends/public holidays. Time of day was classified into four-hour blocks, while seasons were classified into wet season (Nov -Apr) and dry season (May-Oct). School holidays were another factor that could influence the number of boat launches and the Western Australian school holidays and public holidays in the study period are given in Appendix 2.

Environmental factors considered in the study included temperature, rainfall, tides, winds and sea surface temperature. Daily maximum and minimum air temperatures and rainfall data were obtained from the Bureau of Meteorology (2014a). Monthly averages and variance (temperature) or totals (rainfall) were calculated and compared to the thirty year average by related samples Wilcoxon signed rank test. Data were categorised into wet season and dry season and statistical analyses on the hourly data were carried out by two-sample t-test.

Hourly data on tidal heights (m above tide gauge zero), surface seawater temperature (°C), wind speed ($m.s^{-1}$), wind gust ($m.s^{-1}$), wind direction (° true), and barometric pressure (hPa) were obtained from the Australian Baseline Sea Level Monitoring Project (Bureau of Meteorology 2014b). The data were obtained from station number 003102 (18.0°S 122.2°E), located at the Broome deep-water port approximately 1km north-east of the Entrance Point boat ramp (Bureau of Meteorology, 2010). Surface seawater temperatures were averaged over each month to statistically compare data between the wet and dry seasons.

Wind direction was measured as degrees true and was an average of the last six, one-minute measurements recorded in the previous hour (Bureau of Meteorology 2014c). Wind speed was an average of the last six, one-minute measurements recorded in the previous hour, while wind gust was a maximum of the 60, one-minute measurements taken in the previous hour (Bureau of Meteorology 2014a). The data were isolated for 9 am and 3 pm AWST and categorised into frequency tables according to the secondary inter-cardinal directions (N, NNE, NE, ENE, etc.) and $1 m.s^{-1}$ speed intervals. Lakes Environmental WRPlot View (v.7.0.0) software was used to construct wind roses for the wet and dry seasons. The difference in wind speed and direction at 9 am and 3 pm between the wet and dry seasons was analysed using two-sample t-tests. Barometric pressure data were averaged over individual days and over each month and analysis of differences in pressure between the wet and dry seasons were undertaken using two-sample t-tests.

Values missing from the environmental data (Appendix 1) were imputed to enable time series analysis. For any missing tidal values, the mean of the values for the 24th and 25th hours previous to the missing value were used. Missing values for all other variables were estimated as a linear trend of the previous 24 h.

T-tests were used to analyse variables where all of the raw data were available. Where the distribution was not normal, or the number of values being compared was too small, Wilcoxon signed-rank tests (SPSS v.21.0.0.1) were used. Monthly means from the study period were compared to the monthly means for the 30-year climatic data for the two seasons and the year using Wilcoxon signed rank tests.

Various time series models were also run on the imputed data set (SPSS v.21.0.0.1). Both daily and weekly cycles were used to test different seasonal trends. For the weekly cycle, hourly data were aggregated to give daily values. Boat launches were added together for each day, a daily range was calculated for the tidal data, daily means were calculated for surface seawater temperature, air temperature, air pressure, wind direction, and wind speed data, and a maximum value was taken for the wind gust data.

3 Results

3.1 Boat launches

There were 6057 boat launches during the study period when estimated figures for the missing values were included (Table 1). The highest number of launches per month was observed in August 2013 (882) and the highest number of launches in a single day (79) took place on 16 June 2013. In general though, for 69% of the days there were <20 boat launches per day (Figure 1a). When considering all hours of the day, there were zero launches per hour for 70% of the time (Figure 1b).

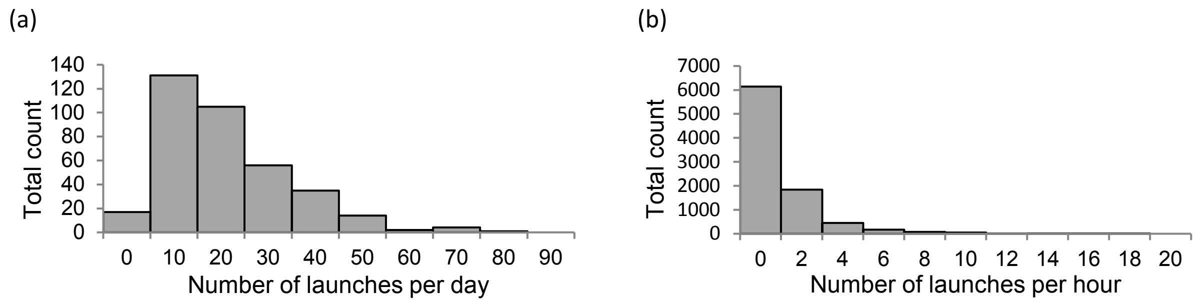

Figure 1. (a) Number of launches per day and (b) number of launches per hour from November 2012 to October 2013 at Entrance Point boat ramp, Broome.

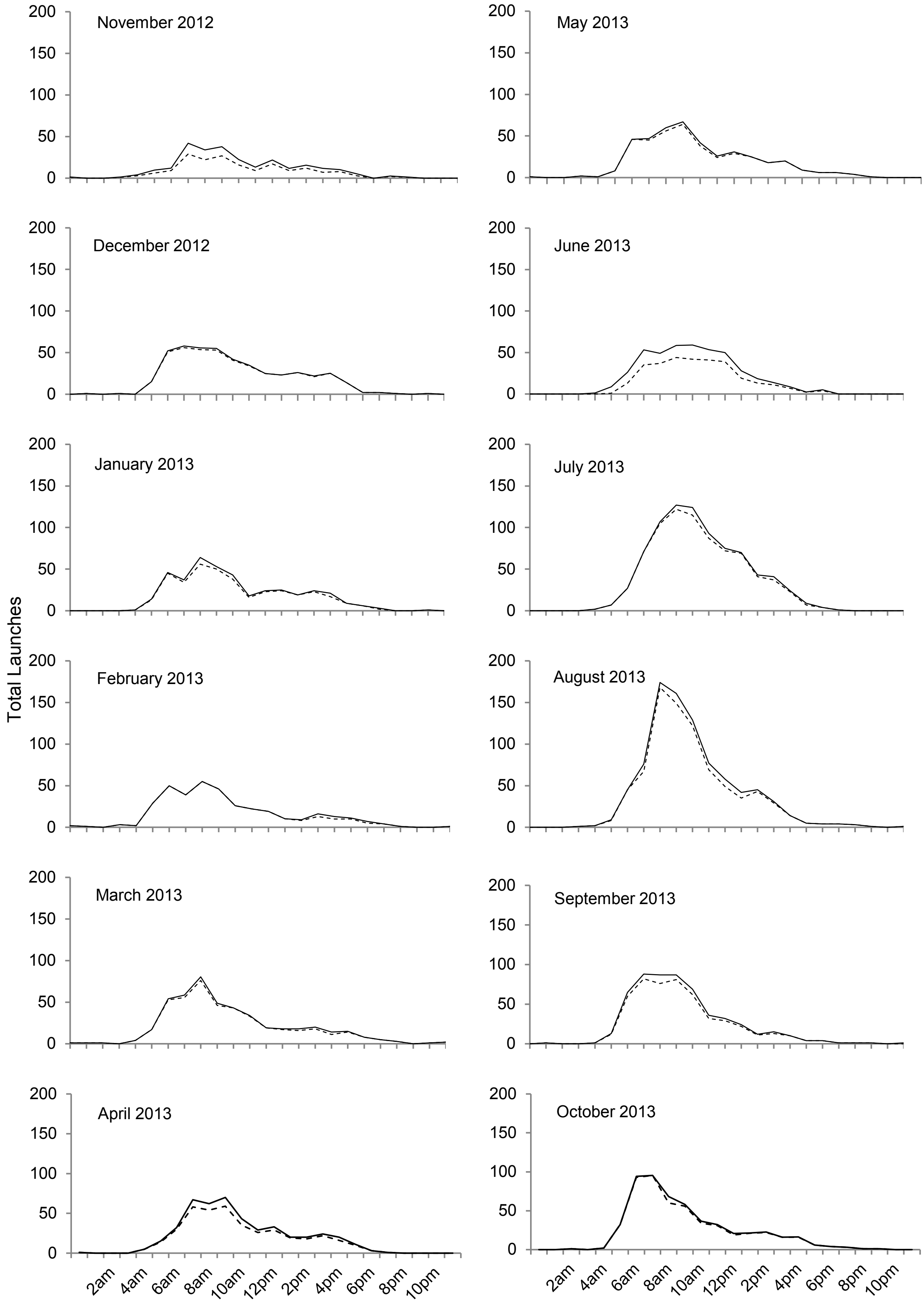

Figure 2. Total number of power-boat launches (y-axis) per hour for each month at the Entrance Point boat ramp in Broome from November 2012 to October 2013. Dashed lines indicate raw data and solid lines include estimated data used in statistical analyses.

The mean imputed number of launches for each day of the week clearly showed the increase on weekend days though from July to September there were higher mean numbers of launches on weekdays (Figure 4). Most launches (96%) took place between 4 am and 8 pm. The peak in launches occurred between 6 am and 10 am in all months though tended to be slightly later during the winter months (Figure 2). The mean hourly launch rate ranged from 1 - 6 .h^{-1} (Figure 3).

Table 1. The total number of boat launches per month (with maximum number of launches per day) during the November 2012 to October 2013 study period. The data of Ryan et al. (2013) for March 2011 to February 2012 at the same boat ramp are included for comparison. * indicates missing data and value estimated using method of Wise & Fletcher (2013).

Month	Launches 2012-13	Max. number per day	Launches 2011-12 (Ryan et al. 2013)
November	258.5*	29	446
December	456	35	400
January	408	38	447
February	366.3*	46	322.3
March	465.8*	38	475
April	456.3*	50	620
May	420	38	318
June	436.1*	79	535
July	825	67	817
August	882	69	663
September	552	40	511
October	531.3*	44	672
TOTAL	6057		6226

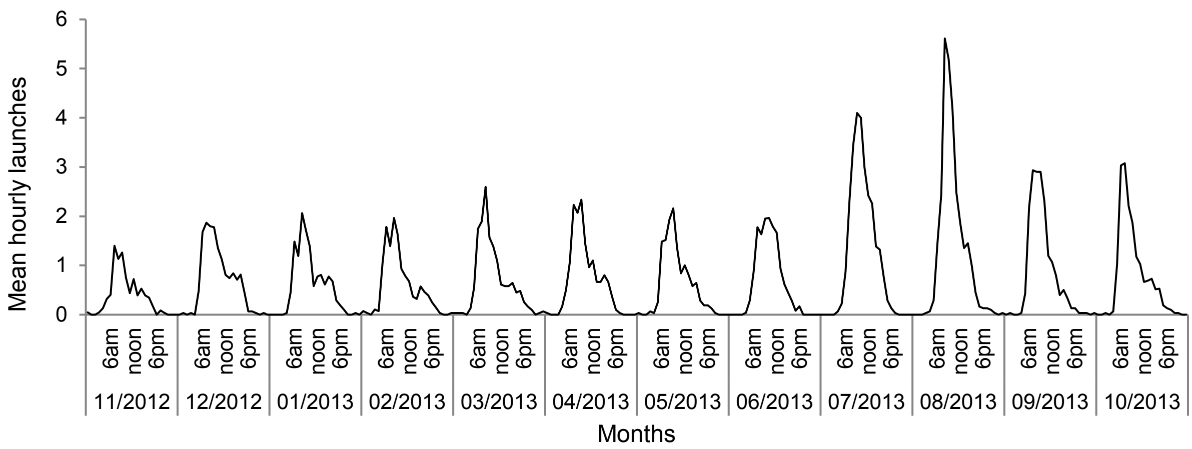

Figure 3. Mean hourly boat launch rate per month at Entrance Point boat ramp, Broome, from November 2012 to October 2013.

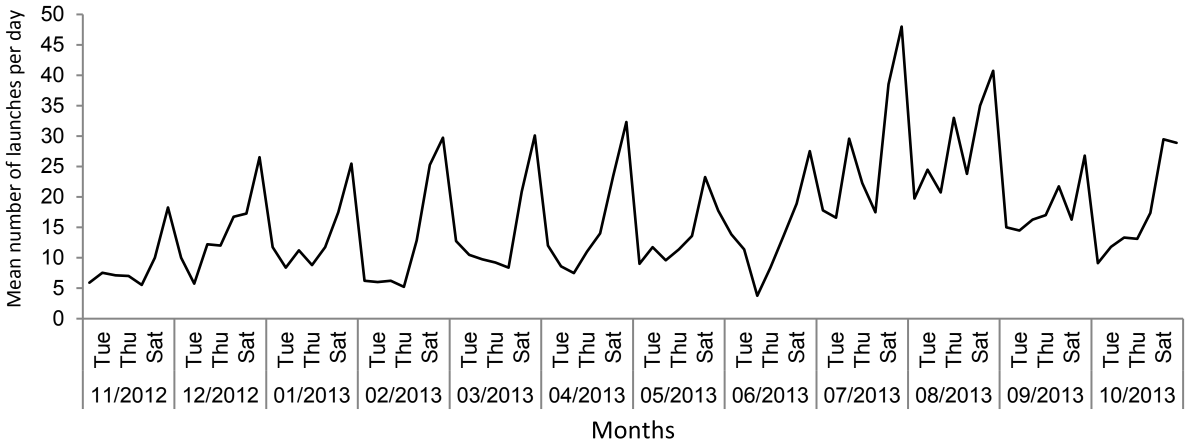

Figure 4. Imputed mean number of launches for each day of the week per month at the Entrance Point boat ramp, Broome, from November 2012 to October 2013.

3.2 Environmental variables

During the study period, daily maximum air temperatures ranged from 20.3°C to 43.0°C, while minimum temperatures ranged from 8.8°C to 30.5°C (Table 2). Maximum ($t=11.99$, $p<0.001$) and minimum air temperatures ($t=20.16$, $p<0.001$) showed significant differences between wet and dry seasons for the study period (Figure 5). There was no significant difference between median monthly maximum temperatures for the study period compared to the 30 year median ($p\leq0.158$), though there was a significant difference for the minimum temperatures ($p\leq0.005$).

Rainfall per day ranged from 0 mm to 146.4 mm during the study period (Table 2). Somewhat surprisingly, there was no significant difference in average rainfall between wet and dry seasons ($t=0.633$, $p\leq0.527$) or between the 30 year median rainfall and that of the study period ($p\leq0.754$). Examination of cumulative rainfall per month showed that there was considerable late rain in May and June 2013 (Figure 6).

Sea surface temperatures ranged from 20.7°C to 29.7°C during the study period (Figure 7) and there were significant differences in sea surface temperature between the wet and dry seasons ($t=143.66$, $p\leq0.001$). Barometric pressure varied greatly in February 2013 when cyclone Rusty crossed the coast at Pardoo Station, located about 400 km south of Broome (Figure 8). There were significant differences in barometric pressure between the wet and dry seasons ($t=-84.482$, $p\leq0.001$).

For the study period, there was no significant difference in average wind speed at 9 am between the wet season and dry season ($t=-0.91$, $p\leq0.363$) but there was a significant difference in the mean wind direction at 9 am between seasons ($t=4.43$, $p\leq0.001$) (Figure 9). There were significant differences for both wind speed ($t=3.20$, $p\leq0.001$) and wind direction ($t=2.89$, $p\leq0.004$) at 3 pm between the wet and dry seasons (Figure 10). When comparing the study period to the 30 year mean, there were significant differences in median monthly wind speeds for both 9 am ($p\leq0.005$) and 3 pm ($p\leq0.006$) over the year, as well as at 3 pm ($p\leq0.031$) for the wet season. However, there were no significant differences in median monthly wind speeds for 9 am ($p\leq0.219$) and 3 pm ($p\leq0.219$) for the dry season and 9 am ($p\leq0.219$) for the wet season, based on the same comparison.

Table 2. Descriptive statistics for the environmental variables considered to influence the number of boat launches per hour at the Entrance Point boat ramp, Broome (November 2012 to October 2013).

Variable	Dry Season (May-Oct)			Wet Season (Nov-Apr)			Year
	Min.	Max.	Mean (SD)	Min.	Max.	Mean (SD)	Mean (SD)
Daily Data							
Maximum Temperature (°C)	20.3	41.0	34.7 (2.30)	27.2	43.0	31.0 (3.43)	32.84 (3.45)
Minimum Temperature (°C)	8.8	28.6	18.6 (4.34)	16.0	30.5	26.1 (2.52)	22.33 (5.18)
Rainfall (mm)	0.0	146.4	1.7 (12.06)	0.0	50.2	2.4 (8.02)	2.06 (10.26)
Hourly Data							
Tide (m)	0.67	9.99	5.50 (2.02)	0.71	10.21	5.59 (2.09)	5.54 (2.06)
Sea Surface Temperature (°C)	20.7	29.7	24.7 (2.53)	28.8	32.4	30.7 (0.88)	27.68 (3.53)
Air Temperature (°C)	15.8	36.2	24.8 (3.03)	21.3	38.5	29.5 (1.72)	27.09 (3.42)
Barometric Pressure (hPa)	1004.4	1019.7	1011.7 (2.37)	993.6	1015.0	1006.6 (3.13)	1009.16 (3.76)
Wind Direction (° true)	0	360	199.6 (80.86)	0	360	232.6 (93.90)	215.96 (89.09)
Wind Speed ($m.s^{-1}$)	0	16.7	5.25 (2.64)	0.0	18.2	5.4 (2.58)	5.33 (2.61)
Wind Gust ($m.s^{-1}$)	0.8	22.6	7.2 (3.08)	1.2	29.0	7.8 (3.40)	7.46 (3.26)

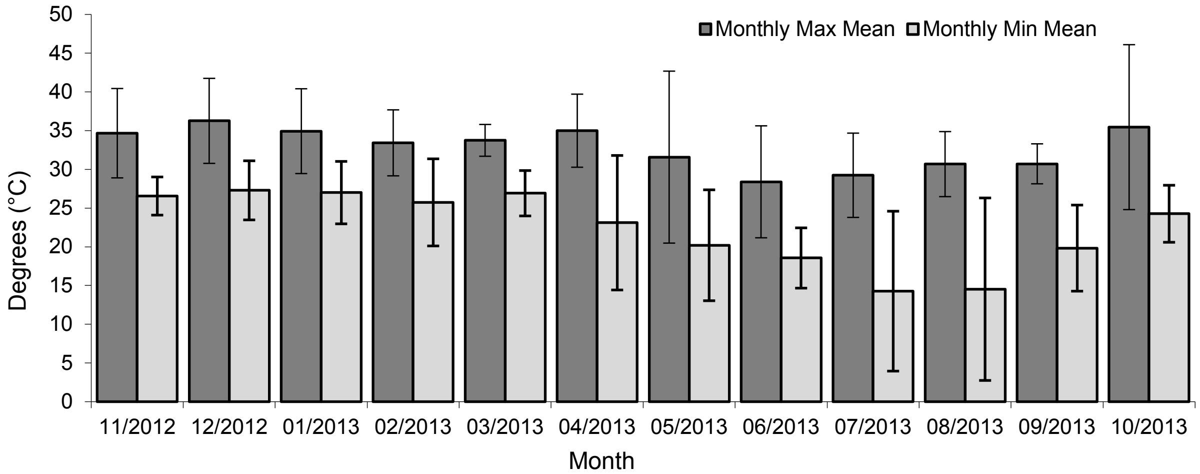

Figure 5. Mean air temperature and variance for Broome Bureau of Meteorology station 003102 during each month of the study period.

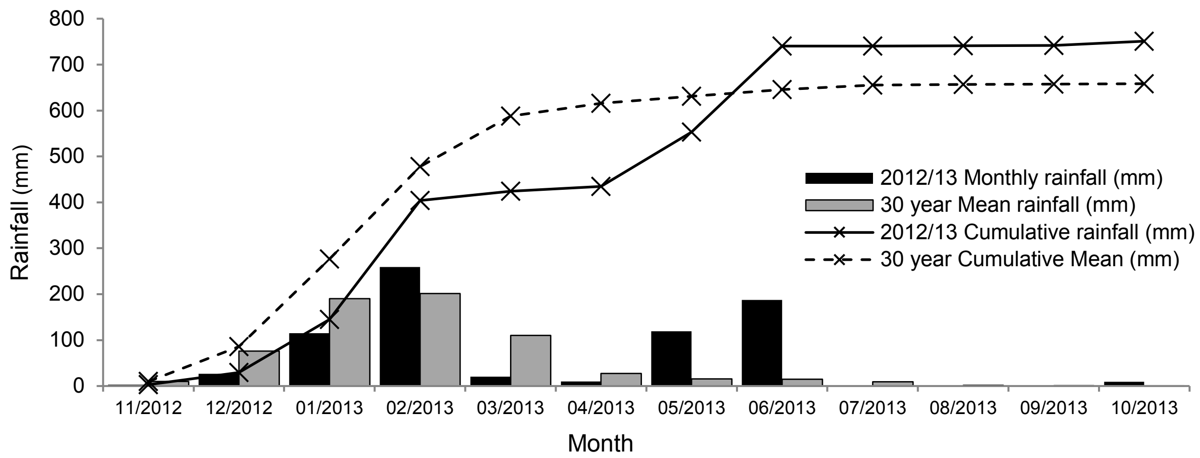

Figure 6. Monthly and cumulative rainfall for Broome (Bureau of Meteorology station 003102) over the study period and the comparison with the 30 year mean monthly rainfall.

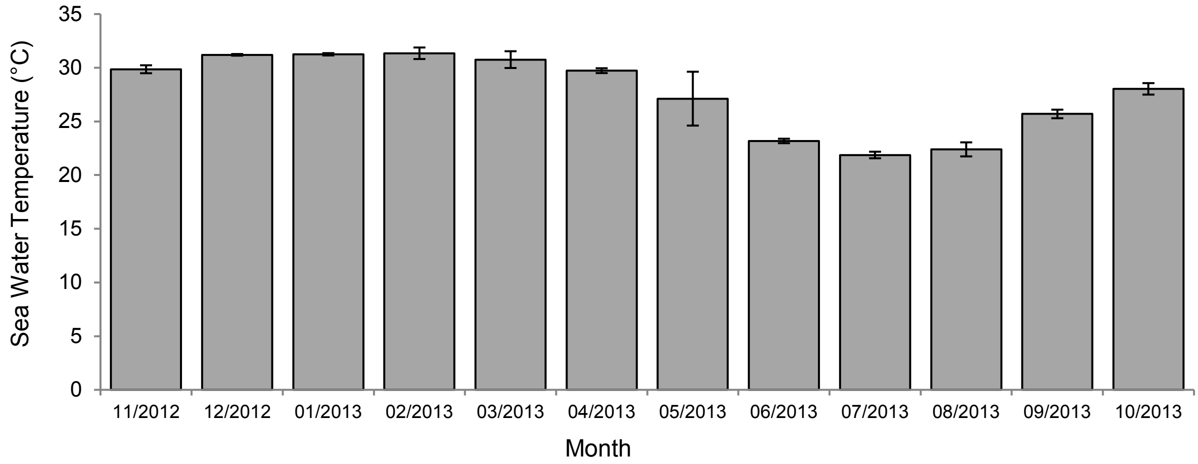

Figure 7. Monthly means and variance for sea surface temperature at Broome (Bureau of Meteorology station 003102) during each month of the study period.

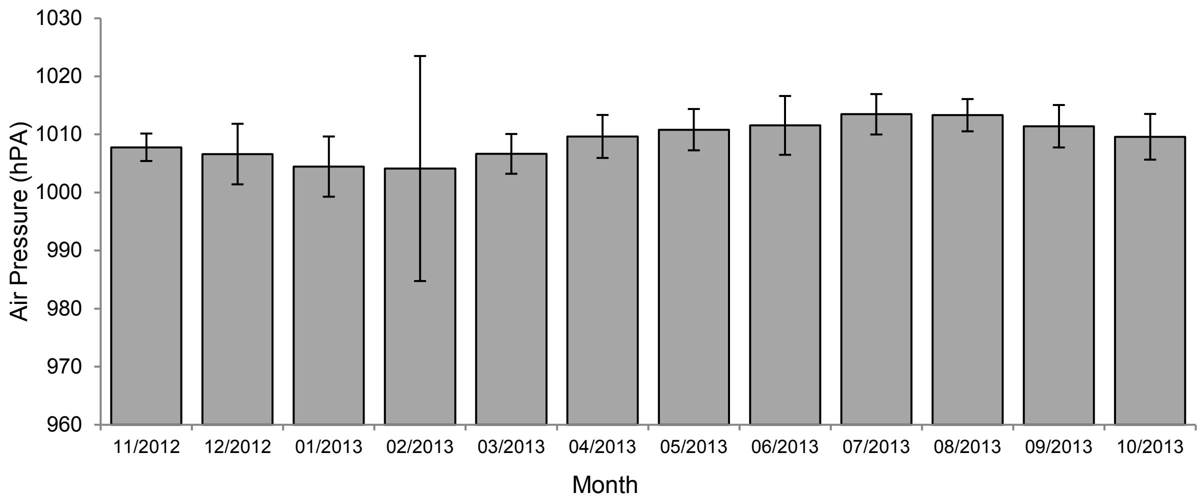

Figure 8. Monthly mean and variance for barometric pressure at Broome (Bureau of Meteorology station 003102) during each month of the study period.

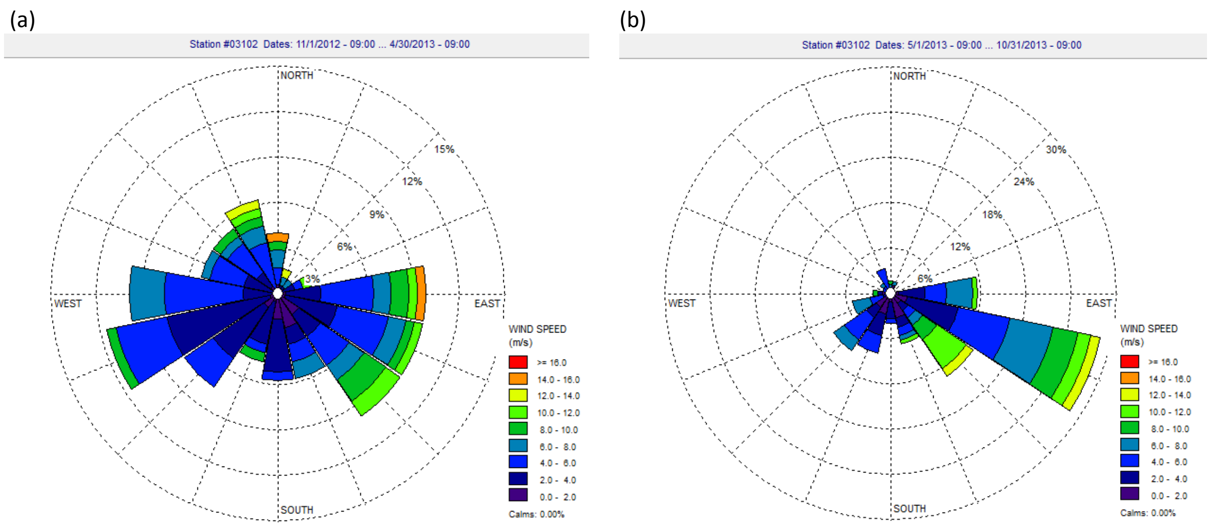

Figure 9. a) Wind rose at 9am for the wet season (Nov 2012 – Apr 2013) and b) dry season (May 2013 – Oct 2013) at Broome (Bureau of Meteorology station 003102).

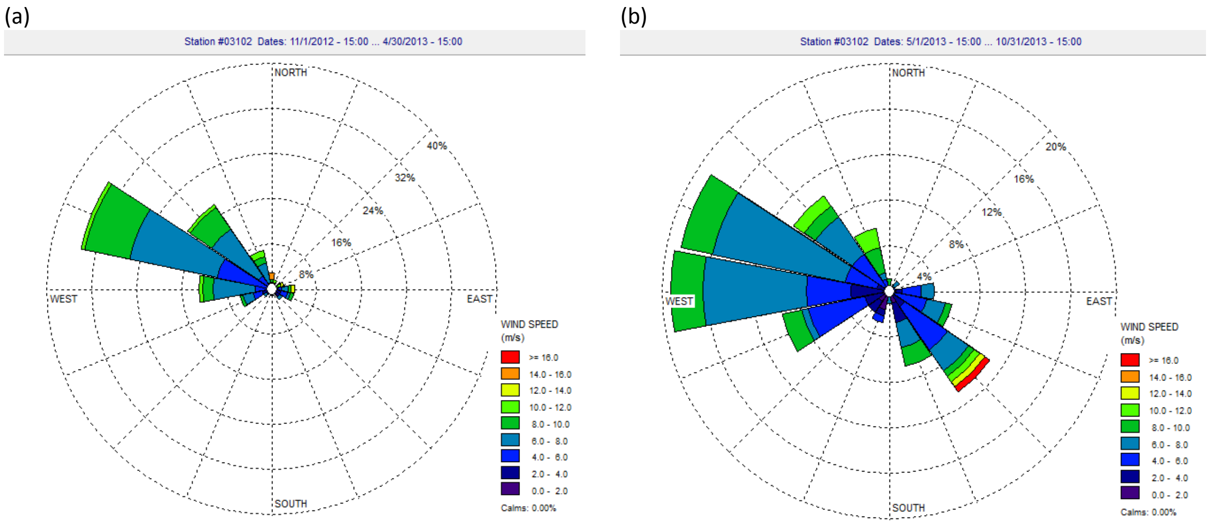

Figure 10. a) Wind rose at 3pm for the wet season (Nov 2012 – Apr 2013) and b) for the dry season (May 2013 – Oct 2013) at the Broome (Bureau of Meteorology station 003102).

3.3 Influence of temporal and environmental variables on boat launches

Although 60% of all launches at Entrance Point boat ramp took place during the dry season, there was no significant difference in the mean number of launches per hour ($p \leq 0.144$) between the wet (0.56 h^{-1}) and dry (0.83 h^{-1}) seasons (Table 3). There were, however, significant differences between the number of launches h-1 for day type and school holidays. For time of day, wind direction and wind speed, all categories had significantly different numbers of launches h^{-1} (Table 3).

When considering the temporal and environmental variables on an hourly time frame, number of launches correlated mainly with wind speed and wind gust although the correlation was low (Table 4). There were weak correlations with other variables but the number of launches h-1 had no correlation (<0.100) with season, school holidays, air temperature and wind direction. When the hours of darkness between 8 pm and 4 am were removed from the analysis, wind speed and wind gust still had the strongest correlation with number of launches h^{-1}, but time of day became more strongly correlated (Table 4). On a daily timeframe, wind speed, wind gust, day type and minimum temperature had the strongest correlations (Table 4).

Periods of higher than normal activity at the boat ramp (> 4 launches .h^{-1}) occurred during 322 hours of the study period (3.7% of the total time). At these times, the launches were predominantly between 8 am and noon on weekends during the dry season when there were no school holidays and the wind was <3 m.s^{-1} ESE (Table 5).

Table 3 Temporal and environmental variables considered as co-variates influencing the number of boat launches and retrievals per hour at the Entrance Point boat ramp, Broome.

Variable	Classification[a]	N (hours)	Mean no. of launches h^{-1} (SD)[b, c]	Sig.[d]	Mean no. of retrievals h^{-1} (SD)[b, c]	Sig[d]
Season	0 = Wet season (Nov-Apr)	4344	0.56 (1.25)	0.144	0.53 (1.32)	0.144
	1 = Dry season (May-Oct)	4416	0.83 (1.88)		0.82 (1.95)	
Day type	0 = Weekday (Mon-Fri)	6024	0.53 (1.22)	0.000	0.52 (1.26)	0.000
	1 = Weekends/Public holidays	2736	1.06 (2.18)		1.03 (2.29)	
Time of day (h)	0 = 0000-0359	1460	0.01 (0.12)	0.000	0.02 (0.14)	0.000
	1 = 0400-0759	1460	1.02 (1.78)		0.03 (0.19)	
	2 = 0800-1159	1460	2.00 (2.70)		0.57 (1.16)	
	3 = 1200-1559	1460	0.86 (1.30)		2.19 (2.85)	
	4 = 1600-1959	1460	0.25 (0.59)		1.12 (1.86)	
	5 = 2000-2359	1460	0.02 (0.13)		0.13 (0.39)	
School holidays	0 = Not school holidays	6504	0.64 (1.54)	0.039	0.63 (1.59)	0.039
	1 = WA school holidays	2256	0.83 (1.77)		0.83 (1.89)	
Wind direction (° true)	0 = N (0°±12.25°)	274	0.40 (1.09)	0.000	0.42 (1.01)	0.000
	1 = NNE (22.5°±12.25°)	165	0.56 (1.50)		0.18 (0.71)	
	2 = NE (45°±12.25°)	144	0.87 (2.05)		0.13 (0.55)	
	3 = ENE (67.5°±12.25°)	147	0.76 (1.86)		0.21 (0.65)	
	4 = E (90°±12.25°)	333	1.06 (2.13)		0.35 (1.01)	
	5 = ESE (112.5°±12.25°)	839	1.07 (2.08)		0.37 (1.17)	
	6 = SE (135°±12.25°)	785	0.63 (1.64)		0.33 (1.14)	
	7 = SSE (157.5°±12.25°)	504	0.59 (1.64)		0.34 (1.12)	
	8 = S (180°±12.25°)	351	1.06 (2.09)		0.42 (1.04)	
	9 = SSW (202.5°±12.25°)	363	1.13 (2.03)		0.56 (1.62)	
	10 = SW (225°±12.25°)	471	0.82 (1.67)		0.57 (1.52)	
	11 = WSW (247.5°±12.25°)	824	0.71 (1.62)		0.91 (2.13)	
	12 = W (270°±12.25°)	1063	0.51 (1.28)		0.95 (1.98)	
	13 = WNW (292.5°±12.25°)	1168	0.59 (1.20)		1.20 (2.20)	
	14 = NW (315°±12.25°)	818	0.48 (1.18)		0.90 (1.86)	
	15 = NNW (337.5°±12.25°)	511	0.44 (1.17)		0.72 (1.54)	
Wind speed (m.s-1)	0 = 0.0-2.9	1592	1.35 (2.49)	0.000	0.68 (1.71)	0.000
	1 = 3.0-5.9	3945	0.73 (1.54)		0.76 (1.83)	
	2 = 6.0-8.9	2428	0.39 (0.91)		0.68 (1.55)	
	3 = 9.0-11.9	656	0.14 (0.50)		0.31 (0.98)	
	4 = 12.0-14.9	115	0.03 (0.23)		0.11 (0.57)	
	5 = 15.0-17.9	23	0 (0)		0 (0)	
	6 = 18.0-20.9	1	0 (-)		0(-)	

[a] Numeric values indicate categories for nominal variables
[b] Mean and standard deviation (SD) for nominal data shows mean and standard deviations per category
[c] Mean and standard deviation (SD) for scalar data shows the mean & standard deviation for the variable
[d] Significance when comparing medians between categories with the Independent samples median test

3.4 Time series analyses

Wind gust and wind speed were highly inter-correlated (0.906) so only wind speed was used as a factor for the time series analyses. Sea surface temperature was also removed due to inter-correlation with season (-0.844) and air temperature (0.819). Other factors that were kept in the analyses, but were still moderately inter-correlated, were barometric pressure (correlated with season 0.676; air temperature -0.649; water temperature -0.734) and air temperature (correlated with season -0.692).

Time series modelling on the hourly launch data (including imputed data) using the factors retained from the correlation analysis showed that day type, time of day, school holidays, and tidal height were the significant predictors that together described the most variation in launches on a daily cycle (R^2=0.764; ARIMA [2, 0, 2][2, 0, 1]). For the weekly cycle only day type and wind speed were significant predictors (R^2=0.628; ARIMA [0, 0,][0, 0, 0]).

Table 4 Linear correlations of temporal and environmental variables with the number of launches.h^{-1} at Entrance Point boat ramp, Broome.

	Correlation to number of launches. h^{-1}		
Variable	Hourly	4 am to 8 pm	Daily
Season	0.084	0.109	0.238
Day type	0.153	0.198	0.434
Time of day	-0.104	-0.205	n/a
School holidays	0.050	0.066	0.142
Tide	-0.121	-0.078	-0.093
Water temperature	-0.114	-0.146	-0.300
Air temperature	-0.080	-0.131	-0.218
Maximum temperature	-	-	-0.060
Minimum temperature	-	-	-0.333
Barometric pressure	0.144	0.202	0.230
Wind direction	-0.083	-0.102	0.145
Wind gust	-0.227	-0.310	-0.522
Wind speed	-0.230	-0.316	-0.522
Daily rainfall	-	-	-0.141

Table 5 Conditions when higher than normal boat launching activity occurred (> 4 launches.h^{-1}) at the Entrance Point boat ramp in Broome (n = 322 h).

Variable	Classification[a]	N (h)	N (h) >4 launches h^{-1})	% of >4 launches h^{-1}	% of yearly total
Season	0 = Wet season (Nov-Apr)	4344	97	30.1	2.2
	1 = Dry season (May-Oct)	4416	225	69.9	5.1
Day type	0 = Weekday (Mon-Fri)	6024	122	37.9	2.0
	1 = Weekends/Public holidays	2736	200	62.1	7.3
Time of day	0 = 0000-0359	1460	0	0	0
	1 = 0400-0759	1460	84	26.1	5.8
	2 = 0800-1159	1460	204	63.4	14.0
	3 = 1200-1559	1460	33	10.3	2.3
	4 = 1600-1959	1460	1	0.3	0.1
	5 = 2000-2359	1460	0	0	0
School holidays	0 = Not school holidays	6504	206	64.0	3.2
	1 = WA school holidays	2256	116	36.0	5.1
Wind direction (° true)	0 = N (0°±12.25°)	274	5	1.6	1.8
	1 = NNE (22.5°±12.25°)	165	5	1.6	3.0
	2 = NE (45°±12.25°)	144	10	3.1	6.9
	3 = ENE (67.5°±12.25°)	147	80	2.5	5.4
	4 = E (90°±12.25°)	333	24	7.5	7.2
	5 = ESE (112.5°±12.25°)	839	49	15.2	5.8
	6 = SE (135°±12.25°)	785	26	8.1	3.3
	7 = SSE (157.5°±12.25°)	504	19	5.9	3.8
	8 = S (180°±12.25°)	351	31	9.6	8.8
	9 = SSW (202.5°±12.25°)	363	25	7.8	6.9
	10 = SW (225°±12.25°)	471	18	5.6	3.8
	11 = WSW (247.5°±12.25°)	824	31	9.6	3.8
	12 = W (270°±12.25°)	1063	26	8.1	2.5
	13 = WNW (292.5°±12.25°)	1168	20	6.2	1.7
	14 = NW (315°±12.25°)	818	16	5.0	2.0
	15 = NNW (337.5°±12.25°)	511	9	2.8	1.8
Wind speed (m.s^{-1})	0 = 0.0-2.9	1592	158	49.1	9.9
	1 = 3.0-5.9	3945	146	45.3	3.7
	2 = 6.0-8.9	2428	17	5.3	0.7
	3 = 9.0-11.9	656	1	0.3	0.2
	4 = 12.0-14.9	115	0	0	0
	5 = 15.0-17.9	23	0	0	0
	6 = 18.0-20.9	1	0	0	0

4 Discussion and Conclusions

The total number of 6057 boat launches recorded at Entrance Point boat ramp during the 12-month study period from November 2012 to October 2013 was slightly less than the figure of 6226 launches documented by Ryan et al. (2013) for 2011-2012 at the same boat ramp. Nevertheless, with respect to total number of launches, the months of July 2013 (825 launches) and August 2013 (882 launches) exceeded the maximum of 817 launches in a month recorded in July 2011 (Ryan et al. 2013). The 6057 launches at Entrance Point boat ramp during the study period would constitute about 13% of all boat launches estimated for the northern region of Western Australia in 2011/2012 (Ryan et al. 2013). The total of 79 launches in any one day was considerably more than the maximum instantaneous count of trailers at this site (47) during the concurrent aerial survey of the Dampier Peninsula (Beckley et al. this report) but as boats are launched and retrieved throughout the year, this would be expected.

The original hypothesis, that number of launches from the boat tramp would be significantly higher in the dry season than the wet season, was based on the expected influence of tourists to the Broome area at that time. However, despite more boat launches in the dry season, the difference in number of launches h^{-1} was not significantly different between the two seasons. This was surprising, but reflects the consistent launch rate throughout the wet season by local residents and the much greater variability in the launch rate during the dry season, possibly exacerbated by blustery conditions and considerable unseasonal rain in June 2013 (Hennessy 2013).

Most boat launches at Entrance Point took place between 6 am and 10am. This is consistent with the earlier results of Ryan et al. (2013) for Broome and also for the Hillarys boat ramp in the Perth metropolitan area (Fletcher & Wise 2013). Although the number of boat launches at Entrance Point is considerable (6057) this total constitutes only about 22% of the annual total number of launches at Hillarys, which is one of the busiest boat ramps in the Perth metropolitan area and Western Australia.

Tourism Western Australia (2014) estimated that only 47% of overnight visitors to Broome between 2011 and 2013 were from within Western Australia with 37% coming from inter-state and 16% from overseas. Broome is an attractive destination for both short-term and long-term holidays (sensu Herington et al. (2013). The estimated mean length of stay for Western Australian visitors to Broome was 6.1 nights, while it was 6.8 nights for visitors from inter-state (Tourism Western Australia 2014). With such large numbers of tourists (53%) coming from outside Western Australia, it is expected that the large distances from inter-state metropolitan centres would make it difficult to tow a boat to Broome. Unless anglers hired a boat while they were visiting Broome, they would not have an impact on the usage of the Entrance Point boat ramp. Even for intra-state tourists, towing a boat and trailer from the major regional centres in the south-west of the Western Australia would be prohibitive for short-term stays. This suggests that any increase in use of the boat ramp over weekends and public holidays is most likely to be driven by local boat users and long-term visitors.

Grey nomads are travelling retirees who travel to warmer Australian climates for extended periods during winter, and would make up a large component of the long-term visitors to Broome (Onyx & Leonard 2005, Davies 2011). Stoeckl et al. (2006) showed that for the Gulf of Carpentaria, a region in north-west tropical Queensland, >75% of retired couple visitors and >90% of retired single visitors rated fishing as an important draw card for their visit. It is likely that grey nomads contribute to the increased usage of the boat ramp in the dry season in Broome, but the base level throughout the year, particularly in the wet season, is due to the resident population, especially members of the Broome Fishing Club which has its clubhouse overlooking Entrance Point. This consistent use by residents during both seasons would have reduced the impact of tourists during school holidays and over the dry season.

The number of launches during school holidays was significantly different to that outside school holiday periods. However, in the time series analysis, this was only shown as a predictor on a daily trend, and not on the weekly trend. As mentioned previously, the distance of Broome from major inter-state population centres would make it difficult to tow a boat on a short-term holiday, but a two-week holiday may possibly be of sufficient length for holidaymakers from within Western Australia or from the Northern Territory. Barring this, the increase in ramp usage during school holidays would be driven by the local population, especially since the highest total number of launches occurred in August, when there were no school holidays.

When comparing environmental factors between the wet and dry seasons, there were significant differences in all variables except rainfall and wind speed at 9 am. The unseasonal rainfall events in May (119 mm) and June (187 mm) resulted in the median monthly rainfall not being significantly different between seasons. Likewise, the difference in the mean number of launches h^{-1} between wet and dry seasons was not statistically significant probably due to the inclement weather causing a lower than expected number of boat launches in these two months. This finding differs from that of Williamson et al. (2006) who observed much higher effort in the Pilbara region during the dry season than the wet season.

As expected, there were more launches on weekends and public holidays, and this was supported by the time series models. This is consistent with findings of Sunger et al. (2012) who found that there was greater water-based activity on weekends, and that it was more of a predictor than wet or dry weather. When separating the weekday launch figures from the weekend figures, the day before a weekend or public holiday also had substantially increased activity. This could be due to alternative work schedules (a large shift-based workforce or rostered days off), or a high incidence of paid holidays or avoidable sick leave to maximise the time off over the weekend (Pearson 1997, Lingard et al. 2012), which may have resulted in underestimation of the impact of day type as a category.

Due to the consistent peak number of launches between 6 am and 10 am, tide can be ruled out as a driving factor in its own right. The semi-diurnal nature of the tide on a 24.5 hour cycle meant that over each individual month, the tidal height at these times ranged between low tide and high tide. Analysis of the video footage, even though the tidal range exceeded 9 m and the boat ramp only extended several metres into the water, indicated that there was no impediment to the ability to launch or retrieve vessels. Although most launching was aided by four-wheel drive vehicles, even standard two-wheel drive cars were able to drive on the exposed substrate to access the water's edge.

The majority of launches occurred between 8am and noon when the wind speed was <6 $m.s^{-1}$, and the wind direction was from the E through to SW. The dominant wind direction at 9 am in the dry season was E to SE, while being more variable during the wet season. Since launches continually peak between 6am and 10 am irrespective of season, time of day was considered to be a stronger factor in influencing launches than wind direction. However, an interaction of strong wind speeds with onshore wind directions was noted to severely influence use of the boat ramp. The Entrance Point boat ramp has a south-easterly aspect with no shelter from prevailing, strong E to SE winds. Since interactions were not considered in the time series models, this was not shown as a significant predictor affecting use of the boat ramp. Use of generalised linear models with interactions between wind speed and wind direction may illustrate this better.

While the median number of launches was significantly different for categories of day type, time of day, school holidays, wind direction, and wind speed, correlation values showed that there was no individual factor that influenced the number of launches in its own right. This suggests interactions between variables as significant predictors rather than individual variables acting alone. Further, other boat ramps and the southern end of Cable Beach (Beckley et al. this report) provide alternative boat launching opportunities when conditions are not ideal at Entrance Point.

Even though the time series models showed that day type, time of day, school holidays, and tidal height were significant predictors on a daily basis, examination of the prevailing conditions when there was higher than normal use of the boat ramp, revealed other factors as strong drivers. Apart from school holidays not being a factor, they were consistent with our expectations and this reinforced the proposition that the resident population of Broome drives the higher use at the boat ramp. As the remote camera is located at the clubhouse of the Broome Fishing Club, it is also likely that their regular fishing competitions would have had an impact on peak days.

While many of the studies conducted on recreational fishing in Western Australia (Sumner & Williamson 1999, Sumner et al. 2002, Sumner et al. 2008, Smallwood et al. 2011, Smallwood & Beckley 2012, Smallwood et al. 2012, Ryan et al. 2013, Wise & Fletcher 2013) have noted the weather conditions when people engage in fishing from boats, these do not necessarily indicate which conditions actually influence frequency of use.

Using remote camera footage allowed cost-effective analysis over hourly periods for the entire study period and required fewer resources and man-hours than traditional surveys. The method did not impact on the activity of the boaters, delivered almost continuous observations, was able to monitor boat ramp use after hours and enabled trends over days and weeks to be defined.

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6 Appendices

APPENDIX 1

Table 6. Missing data from the Bureau of Meteorology station number 003102 and the remote camera at Entrance Point boat ramp, Broome, during the November 2012 to October 2013 study period. Times in AWST.

Month	Environmental Variable Data	Remote Camera Data
November 2012	0000-0700 01/11/12	0000 01/11/12 - 1000 08/11/12
	1600 07/11/12 - 0700 08/11/12	
	0600-1700 22/11/12	
December 2012	0000-1200 13/12/12	
	1400 17/12/12 - 1300 18/12/12	
January 2013	1300 27/01/13 - 1300 28/01/13	
February 2013	1500 02/02/13 - 0200 03/02/13	
	1100 07/02/13a	
	0700 08/02/13b	
	0300 10/02/13b	
	1300-1600 11/02/13	
	0500 20/02/13b	
	1000-2200 21/02/13	
	1000 25/02/13	
	0500 20/02/13b	
	1000-2200 21/02/13	
	1000 25/02/13	
March 2013	1100 10/03/13 - 1400 11/03/13	0700-1000 23/03/13
	0700-1100 23/03/13	
April 2013	1000-1800 08/04/13	1700 19/04/13
	0700 20/04/13 - 0600 21/04/13	
	1200 27/04/13 - 0800 28/04/13	
May 2013	0100-1700 28/05/13	
June 2013	0000-1500 09/06/13	1900 19/06/13 - 1400 26/06/13
	1800 18/06/13 - 1300 19/06/13	
July 2013	0800-2200 04/07/13	
	1400 19/07/13 - 1000 20/07/13	
	1100 20/07/13	
	0000-1300 25/07/13	
August 2013	0800 18/08/13 - 1000 19/08/13	
September 2013	1200 19/09/13 - 1800 20/09/13	0300 04/09/13
	0400-2300 27/09/13	
October 2013	1800 01/10/13a	1800 09/10/13
	0100-1500 23/10/13	1000 16/10/13
		0800 & 1400 17/10/13
		1200 18/10/13
		0800 & 1800 20/10/13
		1200 21/10/13
		1000 23/10/13
		1000 & 1200-1500 29/10/13
		0800 & 1600 30/10/13
		2300 31/10/13

[a] data missing for surface seawater temperature, air temperature, barometric pressure

[b] data missing for wind direction, wind speed, wind gust

APPENDIX 2

Table 8. Dates of Western Australian school holidays and public holidays during the study period (November 2012 to October 2013).

Season	School holidays	Public holidays
Summer	20/12/12-03/02/13	Christmas day 25/12/12
		Boxing Day 26/12/12
		New Year's Day 01/01/13
		Australia Day 28/01/13
Autumn	20/04/13-05/05/13	Labour Day 04/03/13
		Good Friday 29/03/13
		Easter Monday 01/04/13
		ANZAC Day 25/04/13
Winter	06/07/13-21/07/13	Foundation Day 03/06/13
Spring	28/09/13-13/10/13	Queen's Birthday Holiday 30/09/13

Chapter 6: A review of the potential impacts of human use on the coastal habitats of the Kimberley, north-western Australia

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Summary

The Kimberley has an energetic oceanographic environment, with large tides, seasonal monsoons, El Niño-Southern Oscillation influences and high incidences of tropical cyclones. The convoluted, drowned ria coastline of the Kimberley is predominantly rugged and bedrock dominated, with erosion causing a vast array of landscape features including cliffs, gorges, valleys and islands. Other notable marine and coastal features include sandy beaches, dune systems, tidal flats, inlets, bays and mangrove-lined estuaries. Tourism is a significant contributor to the Kimberley economy at 36% or around $275 million per annum and it relies heavily on visitation to the natural environment. An increase in visitor numbers and other anthropogenic uses could cause an escalation of impacts to the natural and cultural assets which make the Kimberley unique. In this review, the main anthropogenic uses from recreation and tourism that have the potential to impact Kimberley marine habitats, were examined using a spatial and temporal conceptual model. This was applied to the six main habitats found along the Kimberley coastline, namely sandy beaches, rocky shores, coral reefs, coastal wetlands, islands and coastal waters (pelagic). Coastal track formation, litter and rubbish, pollution, and impacts of boating, fishing and other recreational activities were considered to be the most likely environmental impacts from tourism and recreation in the Kimberley.

1 Introduction

The Kimberley region of north-western Australia is one of the most unique places on earth and there are many natural and cultural assets that make this region suitable for tourism and recreational uses. These comprise spectacular land- and seascapes including gorges, waterfalls and reefs (McGonigal 2003, Guélho 2007, Zell 2007, Scherrer et al. 2011a, Scherrer et al. 2011b, Putt 2014) as well as dugongs, humpback whales, dolphins, seabirds, turtles and numerous species of fishes (Fletcher & Santoro 2014, Rogers et al. 2011, Waayers et al. 2011, Fox & Beckley 2005). Culturally, the Kimberley region is home to some of the best examples of Indigenous rock art (Morwood 2002, Scherrer et al. 2008). Humans have occupied the region for at least 30,000 years (O'Connor 1999) and the Indigenous rock art provides some of the best evidence for this long occupation, with clear differences in the painting types, subjects and styles among the surviving pieces (Morwood 2002). There is also historical evidence of Indonesian fishermen visiting these northern Australian waters to fish for Trochus and trepang (sea-cucumber) (Morwood 2002, Zell 2007, Scherrer et al. 2008). Other more recent human activities include pastoralism, mining, pearling, commercial fishing and oil and gas exploration (Scherrer et al. 2008, Davies & Cammell 2009, WA Department of Regional Development 2011).

Tourism is a significant contributor to the Kimberley economy at 36% or around $275 million per annum (KPP Business Development 2009, WA Department of Regional Development 2011). In the eight years up to 2009, there was a 109% increase in passenger numbers through Broome airport (KPP Business Development 2009), although this could reflect the increase in oil, gas and mining operations in the region as well as an increase in visitor numbers. Recent estimates have indicated a total of between 274,200 and 348,000 visitors per annum (Collins 2008, KPP Business Development 2009). The numbers of domestic and international tourists to each of the local government authorities in the Kimberley region averaged over the years 2011-2013 are given in Table 1.

Table 1: Visitors numbers to Kimberley local government areas averaged over three years (2011-2013).

Type of tourist	Broome	Derby-West Kimberley	Kununurra	Total
Domestic	151,400	55,300	69,700	276,400
International	29,100	8,900	14,300	52,300
Total	180,500	64, 200	84,000	328,700

Source: Tourism Western Australia Fact Sheets for Broome, Derby-West Kimberley and Kununurra 2013.

The greatest proportion of tourists visit during the dry season from May to October as the conditions are more favourable with minimal risk of flooding of roads and cooler day-time temperatures (25-34°C) (BOM 2013a, 2013b). The majority of visitors stay in Broome although accommodation is also available at Derby and Wyndham and there are a number of more remote campsites (Hercock 1999, Davies & Cammell 2009). Some pastoralists also provide visitor accommodation including campsites, cabins and chalets (e.g., Drysdale River Station and El Questro Station) (Hercock 1999, Davies & Cammell 2009). The growth of four-wheel drive vehicle ownership in Australia has also resulted in an increase in the number of visitors willing, and able, to access more remote destinations along the coast (Hercock 1999, Greiner & Larson 2004).

More remote marine and coastal areas of the Kimberley are accessed from the regional centres by light aircraft, sea planes, helicopters and boats (Collins 2008). These often link up with expedition cruises, where visitors stay on board vessels while they cruise the Kimberley coastline (Davies & Cammell 2009, Scherrer et al. 2008). The drawcard for these expedition cruises is being able to visit unspoilt locations that have strong natural or cultural appeal (Maher 2012). The vessels mostly follow similar itineraries and regularly visit natural attractions such as waterfalls and gorges and cultural sites on Aboriginal lands (Collins 2008, Scherrer et al. 2011a, Scherrer et al. 2011b, Beckley et al. this report). There are also fishing charters, whale watching cruises and single-day plane and boat trips from regional centres to sites such as the Horizontal Falls in Talbot Bay and pearl farms in Cygnet Bay (Davies & Cammell 2009, Curtin Sustainable Tourism Centre 2010).

Recognising this growing tourism base, Tourism Western Australia released a document in 2010 entitled "Tourism development priorities – Australia's north west" which listed a number of projects that would improve tourism access in the region. This included sealing of a number of the coastal access routes around Broome, including Willie Creek Road and Crab Creek Road, development of a marina, harbour and other recreational boat facilities within Broome, and upgrading of the port facilities at Wyndham (Tourism Western Australia, 2010). The development of a dedicated cruise ship terminal in Broome is also being investigated (Cordingley 2013a). Additionally, an examination of the potential impacts to tourism of the proposed liquefied natural gas project estimated that tourist numbers could increase to 623,300 in 2025 and 876,931 in 2045 based on current visitation patterns (KPP Business Development 2009). Discussions are still on-going regarding moving the Broome Airport to a location outside of the town in order to allow it to expand to cope with this increased visitation. However, when this would occur is uncertain given the recent announcement of $14 million upgrade of the current airport's terminals and runways (Cordingley 2013b).

The town of Broome is the largest centre in the region and is the major service centre for the region's tourism, mining, aquaculture and pastoral industries. The Shire of Broome has a population of approximately 15,000 people of which 12,766 people live in the town (ABS 2013). Other coastal population centres in the region are Derby (3261 people) and Wyndham (787 people) (Davies & Cammell 2009, ABS 2013). Indigenous people make up 40% of the permanent population of the Kimberley region, of which 32% reside in the urban centres of Broome, Derby and Wyndham (Australian Bureau of Statistics, 2013). There are also a number of Indigenous communities scattered along the Kimberley coast, from the larger Bidyadanga and Kalumburu communities, to smaller ones that are only used seasonally.

One of the first industries in the region was pastoralism in the early 1900s (Holmes 2004, Scherrer et al. 2008). A number of these pastoral stations still remain and some have diversified their income base to include tourism and camping opportunities (Hercock 1999). Pearling began along the coast in the early 1900s, with nearly 400 luggers and 3500 people in the industry by 1910; this dropped off during World War II before re-establishing itself again after the war (Wells & Jernakoff 2006). The fishing and mariculture industries have since expanded to include prawn and gillnet fisheries and there has also been increase in the number of commercial cultured pearl operations (Davies & Cammell 2009, Fletcher & Santoro 2014).

Mining and resource extractions currently occurs inland, along the coast and offshore of the Kimberley. The total value of resource commodities was estimated at $838 million in 2009-10, $1.02 billion in 2010-11 and $1.12 billion in 2012-13 with iron ore, diamonds, crude oil and heavy metals the main contributors (Manning 2011, Kimberley Development Commission 2013, Chamber of Mines and Energy Western Australia 2015). There are proven offshore hydrocarbon reserves (Collins 2011) with an estimated 31 trillion cubic feet of gas within the Browse Basin (KPP Business Development 2009). Businesses with interests in the Basin include Woodside, BHP Billiton, BP, Chevron, INPEX and Shell. Iron ore mining activities are generally concentrated at inland sites, however, two mines operate on Koolan and Cockatoo Islands off the Kimberley coast (Environmental Protection Agency 2005, WA Department of Environment and Conservation 2012).

To maintain the regional centres, mining and pastoral activities, ports exist at Broome, Derby and Wyndham. The port of Broome predominantly handles imports and exports associated with livestock, oil and gas supplies and general cargo (Broome Port Authority 2013). The port of Derby has been used for lead and zinc concentrate exports and now predominantly services supply barges as well as recreational and tourist vessels (Shire of Derby West Kimberley 2013). Wyndham port imports fuel, chemicals and general cargo to support the surrounding agricultural, mining and pastoral industries while also exporting commodities from these industries, including nickel and livestock (Davies & Cammell 2009).

2 Kimberley coastal ecosystems

The Kimberley has an energetic oceanographic environment, with large tides, seasonal monsoons, El Niño-Southern Oscillation influences and high incidences of tropical cyclones (Condie & Andrewartha 2008). Tides can range to over 10 m during spring tides (Cresswell & Badcock 2000). The Kimberley coastline is predominantly rugged and bedrock dominated, with erosion causing a vast array of landscape features including honeycomb weathering, chasms, cliffs, gorges, islands and valleys (Zell 2007, Short 2011, Scott 2012). Other notable marine and coastal features include sandy beaches, dune systems, tidal flats, embayments and mangrove-lined estuaries (Cresswell et al. 2011).

The convoluted drowned ria coastline of the Kimberley is over 13,000 km in length with sandy beaches only occupying 16% of the open coast (Short 2011). The beaches predominantly consist of thin strips of sand between land and sea which experience low wave action and high tides (Short 2011). Almost one quarter of these beaches consist of high-tide beaches with fronting fringing reefs or inter-tidal rock flats (Short 2011). While having some of the shortest beaches in Australia (average beach length is 0.52 km), the Kimberley also has some long stretches of sandy beach including Cape Baskerville (14 km), Cable Beach (12 km) and 80 Mile Beach south of Broome (Short 2011).

Rocky shores comprise the remainder of the Kimberley coastline and predominantly consist of steep cliffs up to 200 m high in some areas. The rocky coastline is interspersed by short rivers and creeks which have cut deep valleys into the cliffs, which are largely sandstone, with basalt formations around the northern coast as well as siltstones and stromatolitic dolomites (Brocx & Semeniuk 2011, Collins 2011, Short 2011, Scott 2012). Bedrock headlands, inter-tidal and fringing reefs and rocky shores are also common features that make up the rocky coast (McGonigal 2003, Cresswell et al. 2011, Short 2011). The intertidal zone is generally steep and narrow and has a highly irregular profile. Macro-algae are abundant and there is a rich diversity of highly cryptic intertidal fauna (Wilson 2013).

Mangroves, mudflats, estuaries and tidal lagoons constitute the numerous coastal wetlands in this region (Semeniuk 2013). Large tracts of mangroves are found at Walcott Inlet, Ord and Fitzroy River mouths and the largest stand is in St George Basin (Semeniuk 2013). Along the ria section of the Kimberley coast, the mangrove habitats are well developed with the mangrove vegetation commonly growing to the edge of the terrestrial vegetation (Wilson 2013). The extremely large tidal range in the Kimberley combined with seasonal monsoonal rainfall greatly influences the estuaries along the coast (Wilson 2013).

There are generally two reef types along the Kimberley coast – fringing reefs adjacent to coastal islands and mainland shores, and large platform reefs, banks and shelf-edge atolls located further offshore (Short 2011, Wilson 2013). Within these reef types, the communities are diverse due to the large variation in the types of substrates and their location, but they can be categorised as algal-dominated or coral-dominated reefs (Zell 2007, Brocx & Semeniuk 2011).

There are over 2000 islands off the Kimberley coast, with the majority concentrated in the Buccaneer and Bonaparte Archipelagos. Many lie close to the Kimberley coast and though primarily rocky, many have small sandy beaches (Zell 2007, Short 2011, Vigilante et al. 2013). They are important areas for marine turtles and seabird rookeries (Clarke et al. 2011, Waayers et al. 2011).

3 Anthropogenic impacts

An increase in visitor numbers and other anthropogenic uses could cause an escalation of impacts to the natural and cultural assets which make the Kimberley unique. The Kimberley coastline has a range of habitats and these are likely to be impacted in different ways. Here, the main anthropogenic uses that have the potential to impact Kimberley marine habitats, predominantly from recreational and tourism use, pollution and exploitation will be reviewed. This is based on the application of a spatial and temporal conceptual model of potential anthropogenic impacts for beaches presented by Defeo et al. (2009), to the six main habitats found along the Kimberley coastline (Figure 1).

The threats that apply to the marine habitats in the Kimberley region are identified in Table 2. Data on the impacts of these threats are very limited for the Kimberley region (Appendix 1) and, as a result, this review mainly consists of studies from similar habitats and climates (where possible).

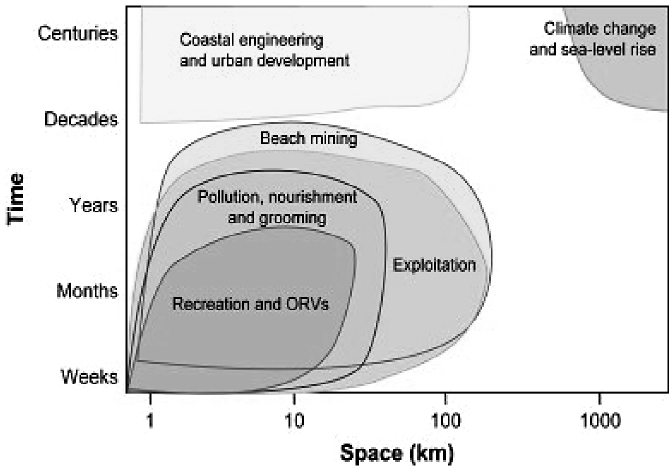

Figure 1. Spatial and temporal representation of differing anthropogenic uses on coastal habitats, (Source: Defeo et al. 2009).

3.1 Sandy beaches

Numerous comprehensive reviews have been undertaken of the anthropogenic threats to sandy beaches (Brown & McLachlan 2002, Defeo et al. 2009, McLachlan et al. 2013), particularly in relation to recreation (Davenport & Davenport 2006, Hardiman & Burgin 2010). Recreational use of beaches often results in impacts associated with the means of access, particularly four-wheel drive vehicles and access tracks, as well as accumulation of litter and waste. Common damage reported by studies on the impacts of four-wheel drive vehicles include disturbance of the physical attributes of dune systems through rutting, damaging or denuding dune vegetation, disturbance, injuring or even the killing of beach fauna including shore-birds, turtles and invertebrates (Brown & McLachlan 2002, Davenport & Davenport 2006, Defeo et al. 2009, Schlacher & Thompson 2008).

Table 2. Some applicable impacts from anthropogenic uses of marine and coastal ecosystems along the Kimberley coastline

Habitat type/Impact	Litter and rubbish	Tracks and trampling	Vessels	Recreational fishing	Marine recreational activities	Pollution	Large-scale commercial uses
Sandy beaches	Campers Marine debris Fishing-related waste	4WDs Accessing camp sites	Boat landings Oil and fuel Disturbance of fauna	4WDs Access Targeted species By-catch Litter Bait collection	4WDs on beaches and dunes Access Trampling Disturbance of fauna	Sewage Food waste Detergents	Development of ports, jetties & groins Oil & gas
Rocky shores	Visitors accessing sites Marine debris Fishing-related waste	Visitors accessing sites	Boat landings Oil and fuel Anchor damage Disturbance of fauna	Access Targeted species By-catch Litter Bait collection	Access Trampling of biota Disturbance of fauna	Sewage Fishing offal Visitor waste	Development of ports, jetties & groins Oil & gas
Coral reefs	Fishing-related waste Marine debris	Visitors accessing sites	Anchor damage Oil and fuel Boat strikes Disturbance of fauna	Access Targeted species By-catch Litter Bait collection	Damage from snorkelers & divers Disturbance of fauna Access	Sewage Sediment runoff Provisioning of fish Waste from boats	Development of ports, jetties & floating pontoons Oil & gas
Coastal wetlands	Visitors accessing sites Fishing-related waste Marine debris	4WDs Visitors accessing sites	Boat wash Oil and fuel Anchor damage Disturbance of fauna Damage to flora	4WDs Access Bait collection Targeted species By-catch Litter	4WDs Access Disturbance of fauna Trampling of flora	Sewage Visitor waste Waste from boats	Development of ports, jetties & groins Oil & gas
Coastal waters (pelagic)	Marine debris Fluvial debris Fishing-related waste	NA	Oil and fuel Disturbance of fauna Noise Boat strikes	Targeted species By-catch Noise Boat-strikes	Disturbance of fauna Noise Fauna strikes	Sewage Waste from boats Fuel lead and spills	Aquaculture Pearling Commercial fishing Oil & gas
Islands	Visitors accessing sites Fishing-related waste Marine debris	Visitors accessing sites	Boat landings Oil and fuel Anchor damage Disturbance of fauna	Access Targeted species By-catch Disturbance of fauna	Access Disturbance of fauna Noise	Sewage Waste from boats	Iron ore mining Development of ports & jetties Oil & gas

Areas of Cable Beach at Broome where four-wheel drive access is permitted have been found to have a greater accumulation of litter, predominantly food-related plastics and paper, than areas where vehicle access is not permitted (Foster-Smith et al. 2007). Vehicles can also lead to sand displacement with beach traffic on Main and Flinders Beaches on North Stradbroke Island in Queensland (up to 500 cars per day) found to disrupt 5.8% and 9.4% of the top 30 cm of beach sand per day during peak season (Schlacher & Thompson 2008). Driving on sandy beaches has been found to compact and pulverise seaweed wrack that accumulates along the Texas coast, which reduces dune crest elevation and affects the response of beaches to storm surges (Houser et al. 2013).

Networks of access tracks can form over time, and tend to be fan-shaped through spreading out from central inland areas to coastal access points (Priskin 2003). Sandy soils are often the most sensitive to recreation-based disturbance as compaction of the soil is a likely outcome of the reduction of vegetation cover (Priskin 2003). A study of coastal tracks in the west Kimberley, from Broome to east of Derby, identified 1647 km of coastal access tracks within the 525,272 ha study area which was considered to have a disturbance footprint of 2665 ha or 0.5% of the study area (Gibbons 2012). Within this track network, the density was higher west of King Sound than east of the Sound. Additionally, fewer tracks were found in the nature conservation reserves. Beach foredunes contained a relatively high density of coastal access tracks, with the location of these heavily influenced by the presence of nearby formal road networks or accommodation infrastructure (Gibbons 2012).

People walking through coastal dunes can also cause impacts. In a comparison between vegetated dune systems in France, the dunes that received lower visitor pressure exhibited short narrow paths, with small areas of bare sand among the dune vegetation (Curr et al. 2000). The areas of dunes receiving higher visitor pressure exhibited many interlinked paths, widening and extension of existing paths and enlargement of path nodes. In addition to direct damage to vegetation, fauna can be disturbed or crushed. The main factors that influence the level of impact from walking or driving on dunes are soil moisture, run-off, erosion and the type of vegetation and micro-organisms (Brown & McLachlan 2002).

Despite the popularity of beachside camping in Australia, there are limited data available as to possible ecological impacts (Thompson & Schlacher 2008). Camping on beaches and fore dunes can lead to a reduction in dune vegetation generally associated with vehicles accessing camping locations (Schlacher et al. 2011). This is especially important in the Kimberley due to the presence of the monsoon vine thickets which are listed as a “threatened ecological community” under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999 (Government of Australia, Department of Environment 2013a). These thickets are mainly confined to the dune systems and other Holocene coastal landforms along the Dampier Peninsula, and represent the most southern occurrence of rainforest type vegetation in Western Australia. Clearing and disturbance, as a result of camping or access to camping sites, can further fragment, degrade and isolate the already fragmented distribution of these thickets (Government of Australia, Department of Environment 2013a).

Fixed camping locations and associated vehicle access can also cause scalloping of the dune-beach interface and breaching of fore dunes allowing swash and wave surges to penetrate behind these dunes, potentially increasing beach erosion. Fore dunes are generally more sensitive to low levels of use but do recover from disturbances quicker than stabilised secondary dunes, although these dunes are more able to tolerate sustained use than fore dunes (Hockings & Twyford 1997). Vine thickets and other dune vegetation may also be adversely affected by vehicles accessing beaches to launch boats from trailers.

Roebuck Bay and 80 Mile Beach are internationally important areas for a number of migratory and resident shore-bird species with the northern shores of Roebuck Bay providing important roosting sites for these birds (Rogers et al. 2006, 2011). It has been identified that the presence of people simply walking along the shore caused disturbance to these shore-birds (Rogers et al. 2006). Fortunately, the study identified that highest disturbance levels were when the migrant and resident shore-bird population numbers where naturally low, decreasing the potential long-term impacts on these species (Rogers et al. 2006). However, shore-bird numbers on the northern beaches of Roebuck Bay do appear to be declining, probably as a result of increasing numbers of people and birds of prey as well as probable degradation of habitats in the northern hemisphere. Interestingly, the increase in the number of birds of prey is hypothesised to be related to the increasing numbers of fishers and the additional food source from their fishing scraps (Rogers et al. 2011). This disturbance could also extend to marine turtles that frequent the Kimberley beaches as they can be easily disturbed in nesting areas (Defeo et al. 2009). Trampling can also lead to compacted sand which can be difficult for the turtles to dig into during egg-laying, with established nests vulnerable to trampling and damage (Davenport & Davenport 2006).

Pollution on sandy beaches can range from molecules to large debris and often enter the beach systems through two main sources – terrestrial run-off or washing up as a result of marine debris and dumping (Crain et al. 2009, Defeo et al. 2009). The impacts from pollution can be acute and temporary (e.g., litter) but can also be more chronic and long lasting (e.g., oil, hydrocarbons, petrol lead). Food wastes and human waste from campers can increase nutrient levels, while the use of detergents and soaps for cleaning can cause changes in water tension and dissolved oxygen levels (Hadwen et al. 2008). The persistence and breakdown of pollution is dependent on the physical properties of the beach systems such as sand particle size, wave energy and temperature (Defeo et al., 2009).

Data from the 2012 annual Western Australian Beach Cleanup identified 7226 items of rubbish along the Gascoyne, North West and Kimberley coastlines with cigarette butts and filters, metal bottle caps, lids and pull-tabs, and hard and soft plastics the major items (Smith et al. 2012). From Broome Town Beach, 52.5 kg of rubbish was collected, of which 35% was plastic and 84% came from land-based sources. From around the Wyndham jetty, a total of 25 kg of rubbish was collected with 61% being comprised of plastics (Smith et al. 2012). Litter is likely to be an increasing problem with any potential increase of visitor use along the Kimberley coastline given the remoteness of some of the visitor nodes, small size of current facilities, limited municipal rubbish collection outside of the regional centres and absence of recycling facilities.

Organic pollution can result from discharge of raw, or partially treated, sewage from boats or beach-based campsites (Burgin & Hardiman 2011, Schlacher et al. 2011). While this sewage contains few toxic substances, there is the potential for nutrient enrichment which can lead to the lowering of oxygen tensions and the upward movement of anoxic layers within the sand profile (Brown & McLachlan 2002, Defeo et al. 2009). An increase in visitor numbers and camping along the Kimberley coastline could potentially result in increases in the amount of sewage which may not be appropriately disposed of or treated. A study of regional groundwater around Roebuck Bay and sediments collected from Town Beach at Broome has shown elevated levels of nutrients (Estrella 2013). These increased nutrient loads and the shallow waters found along the Kimberley coast enhance the production of fast-growing cyanobacteria which can compete with seagrass for light and space and could eventually lead to the smothering of the seagrass communities (Estrella 2013).

Fishing is a popular activity along the Kimberley coast (Davies & Cammell 2009, Fletcher & Santoro 2012). However, recreational and commercial fishing have been acknowledged as sources of depletion of fish stocks off beaches as well as adjacent to large population centres or tourist destinations (McPhee et al. 2002). This is both in terms of catch, and by-catch, direct physical damage or disturbance to habitat characteristics (Brown & McLachlan 2002, Defeo et al. 2009). Studies of fishers along Broome beaches have indicated that they predominantly target threadfin salmon, whiting and trevallies (Williamson et al. 2006). The spatial extent of recreational fishing along beaches has also intensified given the increased ownership and use of four-wheel vehicles (McPhee et al. 2002). A comprehensive suite of regulations pertaining to recreational fishing is in place (WA Department of Fisheries 2014a).

A study of tourists to Karumba in the Gulf of Carpentaria in Queensland identified three different types of tourist anglers based on motivation for fishing, namely those that fished for food, those that fished as an outdoor recreational activity and those that fished for trophy fish (Greiner et al. 2013). The three angler types had different characteristics with those fishing for food tending to be older, travelling in smaller parties, staying longer and were more often repeat visitors. The trophy fish anglers were younger and tended to be travelling in larger family groups and had higher incomes. The angler types also differed in their fishing habits and there was a significant positive correlation between those fishing for food and the number of targeted species caught and kept per person. Additionally, this type was positively correlated with a higher frequency of freezing of caught fishes to eat when they returned home or to share with others (Greiner et al. 2013). Those fishing for trophy fish demonstrated a negative correlation with keeping of the fish caught and frequency of freezing fish caught. This is important to note given the number of “grey nomad” tourists who visit the Kimberley each year who often fish for food as well as those seeking the trophy fish experience.

3.2 Rocky coasts

Intertidal platforms and rocky shores receive a number of impacts common to fringing reef systems and sandy beaches (Table 2). Most studies on the impacts of human use of rocky coasts have focused on trampling and its effects on macro-invertebrates (Smith et al. 2008, Hardiman & Burgin, 2010, Minchinton & Fels 2013). Studies of trampling of algae in Victoria have shown that a single instance of trampling can reduce the biomass by 20% (Keough & Quinn 1998, Addison et al. 2008). Fucoid algae are the most susceptible to trampling, with the rate of decline proportional to the intensity of trampling (Keough & Quinn 1998).

Along the California rocky coastline, heavily utilised areas showed reduced mussel population variables such as cover, bed thickness, biomass and abundance, with a shift in the size structure of populations to smaller individuals (Smith et al. 2008). Trampling was also found to increase the deposition of land and sub-tidal sourced sediments onto rock platforms in southern Australia to above natural levels, which had both positive and negative implications dependent of the functional group and species of macro-invertebrates (Minchinton & Fels 2013). For example, the increased sediment load negatively affected barnacles but had no significant effect on mussels (Minchinton & Fels 2013). Overall, it appears that most molluscs are resistant to trampling, while algae are less resistant and may suffer from reduced abundance and cover as a result of slower recovery rates (Hardiman & Burgin 2010).

Rocky platforms and cliffs are often accessed by visitors to the Kimberley in order to view the Indigenous rock art, and trails created to access these cultural sites have resulted in some vegetation loss through the widening of trails to avoid obstacles or from people walking side by side (Scherrer et al. 2011b). It has also resulted in the increase of litter (e.g., toilet paper), although this is often removed by tour operators and visitors (Scherrer et al. 2011b). Toilet paper and other litter are also concentrated in camping locations (Hercock 1999).

Pollution from oil, boat fuel or other sources can have impacts at all levels of rocky shore biota, from affecting cellular structures of organisms making them more susceptible to diseases, to shifts in abundance and composition of intertidal communities (Thompson et al. 2002). Some barnacle and mussel species have shown tolerance to oil spills, however, grazing molluscs appear to be most susceptible to pollution (Thompson et al. 2002). Nutrient enrichment has been shown to affect intertidal and rocky coast communities including declines in the abundance of perennial algae and an increase in the cover of ephemeral algae and such changes can affect the abundance and composition of mollusc communities (Thompson et al. 2002, Atalah & Crowe 2012).

While collection of marine living resources from intertidal platforms and rocky coasts has occurred for thousands of years, use of non-traditional equipment to harvest, transport and store species has seen the impacts associated with collecting increase. Targeted species are generally the most affected with declining populations and reduced sizes of the remaining populations (Thompson et al. 2002). While species are generally not removed through visitors fossicking, species can still be disrupted when boulders or stones are overturned and not replaced (Addison et al. 2013).

3.3 Coral reefs

The main impacts on coral reefs from human use are generally considered to be increases in sediment loading, organic and inorganic pollution and over-exploitation of reef resources (Table 2, Wilkinson 1999). The threats and impacts to coral reefs increase proportionally to population size and economic growth and usually there are diminishing radii of impact spreading away from human population centres (Wilkinson 1999). Coral damage indices have been used to examine the impacts of recreational activities such as reef-walking, snorkelling and diving (Hardiman & Burgin 2010, Juhasz et al. 2010, Hannak et al. 2011) which are at the lower end of the temporal and spatial impact spectrum.

Most of the impacts from diving or snorkelling are as a result of physical damage to the substrate caused by kicking with fins or inadvertent contact from hands or equipment (Meyer & Holland 2008). The anchoring of boats on coral reefs causes physical damage through the anchors and their chains (Chabanet et al. 2005, Davenport & Davenport 2006, Claudet et al. 2010, Hardiman & Burgin 2010). Additionally, studies of reef walking have shown that corals, especially branching species, are susceptible to physical damage (Hardiman & Burgin 2010, Hannak et al. 2011). For example, the Napoleon Reef in Egypt has abundant coral rubble and broken branching colonies as a result of uncontrolled trampling by tourists and local net fishers (Hannak et al. 2011). Further, a study of five coral reef sites in French Polynesia with varying levels of use showed the site with the most utilization had the lowest percentage of coral cover, with almost no branching corals and massive corals less pronounced (Juhasz et al. 2010).

Often, the largest source of impact to coral reefs adjacent to landmasses and shallow continental shelves is increased sediment loads (Wilkinson 1999). These sediments can remain in suspension in the water column, stressing coral by reducing the ambient photosynthetically active radiation. Sediments can also settle on the reef itself, completely burying the corals and associated biota (Wilkinson 1999, Chabanet et al. 2005). Seasonal flushings during the “wet” season may carry increased sediment loads to fringing reef systems in the Kimberley because of anthropogenic disturbance of soil in catchments. However, this effect would decrease offshore with distance from the coast (Collins 2011).

Organic and inorganic pollution as a result of human activities near reef environments can affect coral reefs. Boats can become sources of oil, other hydrocarbons, litter and sewage, which can also enter reef environments from run-off from terrestrial environments (Wilkinson 1999, Baker et al. 2013). Organic pollutants favour the growth and development of benthic algae or disrupt coral symbiosis and reef community structure (Chabanet et al. 2005, Baker et al. 2013). While the effect of pollutants has largely been unexplored, it is understood that the pollutants can act as a stimulus for increasing the bio-erosion of corals therefore reducing their structural strength (Wilkinson 1999, Chabanet et al. 2005). These pollutants may also have longer term repercussions due to persistence in sediments and waters (Wilkinson 1999).

Fishing around coral reefs can result in the removal of predatory and herbivorous fishes from the reef system and the latter can result in proliferation of macro-algae to the detriment of coral communities (Wilkinson 1999). There can also be considerable incidental damage to reefs from fishing activities including damage from anchors, discarded nets and vessels striking the reefs (Wilkinson 1999, Chabanet et al. 2005, Ban & Alder 2008). Further, in Madagascar, reef gleaning has been shown to degrade and cause losses of habitat on the Grand Recif of Toliara (Andrefouet et al. 2013). The study concluded that coral reefs that were heavily used as a daily food and income source were less likely to recover compared to reefs subjected to only natural disturbances.

In the Kimberley, harvesting of reef invertebrate species is largely limited to sea cucumbers (12 tonnes in 2012) though recently there has been a decline in catch (Fletcher & Santoro 2014). In addition, the Bardi Jawi and Mayala Native Title holders of One Arm Point have an exemption under the *Fisheries Resources Management Act 1994* to commercially harvest trochus (*Trochus niloticus*). This is a small fishery whereby the trochus is collected by hand off the reefs near the Dampier Peninsula and Buccaneer Archipelago at low tide. A recent risk assessment, undertaken as part of ecologically sustainable development certification under the *Environment Protection and Biodiversity Conservation Act 1999* indicated that the current method of selection (i.e. minimal by-catch due to hand picking) and the amount of trochus collected is being conducted in a manner that minimises impacts on the ecosystem (Australian Government, Department of Sustainability, Environment, Water, Population and Communities 2010). The limited number of collectors and the use of dinghies to access the reefs were also considered to have minimal damage on the reefs.

Reefs systems along the Kimberley coast have demonstrated their ability to recover from disturbance events. Scott Reef was affected by the mass coral bleaching event in 1988 and permanent transects on the reef revealed a decline in live coral cover of between 80–90% on the reef crest and reef slope (Gilmour et al. 2013). Recovery was initially slow as the atoll is largely isolated from coral larvae derived from other shelf-edge coral atolls. However, within 12 years, coral cover, recruitment, diversity and community structure were similar to that found prior to the bleaching event. The absence of chronic human disturbances appear to have allowed Scott Reef to recover relatively quickly, as studies have shown that there was very low mortality of recruits derived from remnant corals (Gilmour et al. 2013).

3.4 Coastal wetlands

Coastal wetlands are important nurseries for fish and other marine organisms, so any impacts are likely to have repercussions in the wider marine ecosystems (Contessa & Bird 2004). Additionally, coastal wetlands are also areas likely to be cleared, dredged or developed for the building of coastal infrastructure (Paling et al. 2003, Contessa & Bird 2004).

Modest trampling of mangrove habitats has been shown to cause substantive changes in flora and fauna assemblages (Hardiman & Burgin 2010). An experimental study of trampling in temperate mangroves in New South Wales identified significant changes in micro-habitat features and macro-faunal assemblages (Ross 2006). Areas trampled exhibited a decrease in biomass of the *Bostrychia-Caloglossa* algal association, large numbers of bent and/or broken pneumatophores and a decrease in the number of gastropod species commonly associated with pneumatophores. Other changes to the micro-habitat included alteration of the soil structure and the increase in the amount of pooled water on the mangrove forest floor (Ross 2006).

Tidal flats are often trampled or disturbed as a result of fishing or collecting activities (Hardiman & Burgin 2010). Collection of bait species by pumping with a hand-operated suction pump has been found to have a marked effect on ghost shrimp density, porosity, organic carbon content and redox potential of the inter-tidal sediments of a tidal flat in Victoria (Contessa & Bird 2004). Further, the harvesting of such species can have flow on effects through potentially impacting the foraging success of shore-birds (McPhee et al. 2002).

Boat use is common in estuaries and often concentrated in the shallows and/or narrow channels (Hardiman & Burgin 2010). This has become more prominent with the introduction of jet-skis which has provided the ability to access very shallow waters at high speed (Burgin & Hardiman 2011). A study of seagrass scarring in the Florida Bay area of the Everglades National Park showed the densest concentration of propeller scars was associated with the level of boating activity and areas of shallow water depth and in close proximity to channels and shorelines (Hallac et al. 2012). Other impacts from boating in estuaries include bank soil erosion from waves and wash, physical damage to emergent and floating plants, and erosion of littoral plant roots, or trampling and compaction of plants to access and launch small boats or dinghies, all of which have the potential to change the distribution of aquatic vegetation (Burgin & Hardiman 2011).

Mangroves and saltmarshes often can accumulate heavy metals in their sediments due to them acting as nutrient and pollution traps (Burgin & Hardiman 2011). They are generally more robust and able to tolerate higher accumulation levels than other coastal ecosystems before showing any visible signs of impact (Burgin & Hardiman 2011). However, one of the characteristics of the Kimberley region is the tropical monsoonal weather pattern, resulting in increases of water flow, which could potentially increase heavy metal contamination from run-off from ports or mining areas (e.g., Koolan and Cockatoo Islands). A study of the Cross River Estuary in Nigeria, which has a similar monsoonal climate, indicated that sediments collected in the wet season had the highest mean concentration values for a number of heavy metals (Essien et al. 2009).

3.5 Coastal waters (pelagic environment)

The main anthropogenic impacts on the coastal waters (pelagic environment) primarily come from vessels, exploitation of living resources, and from coastal activities or development of infrastructure along the coast (Table 2, Davenport & Davenport 2006, Scherrer et al. 2008, 2011a).

The large global growth in the use of private craft such as yachts and power boats has encouraged marina and jetty development (Davenport & Davenport 2006). A recently completed study on boating facility demand in Broome identified that at January 2012 there were 1704 recreational boats registered to owners in the greater Broome area (WA Department of Transport 2012). This recreational boat ownership has been increasing since 1990. Spot counts of boat trailers at launching sites in Broome recorded a maximum of 140 boats in 2011 with an estimation of 52% of these being locals and 48% tourists (WA Department of Tourism 2012). Cruise tourism has also seen a resurgence in the last 30 years (Davenport & Davenport 2006), with the Kimberley region showing growth in expedition cruising in recent years (Scherrer et al. 2011a). As of January 2012, there were

132 commercial vessels registered in Broome of which 83 were capable of carrying passengers (WA Department of Transport 2012).

Boats, including those for fishing charters, whale watching or personal leisure activities can directly affect marine fauna such as fish, invertebrates, mammals and birds through sound, propeller wash, turbulence, turbidity and direct or indirect propeller impact (Davenport & Davenport 2006, Burgin & Hardiman 2011). The behaviour of the fauna can also be affected by the presence of boats through disturbance or potentially avoiding areas frequented by boats (Davenport & Davenport, 2006, Hardiman & Burgin 2010, Burgin & Hardiman 2011). For example, a study of dolphins in Shark Bay showed that as the number of tour operators increased, there was a decline in the average dolphin abundance in the area frequented by tourist vessels (Bejder et al. 2006).

The Kimberley region is an important calving ground for humpback whales between June and November each year (Jenner et al. 2001) and several different tour operators offer whale watching experiences in the Kimberley (Curtin Sustainable Tourism Centre 2010). Continual exposure to noise or whale watching activities could cause stress responses in marine mammals which could interfere with breeding, feeding or general health of the animal (Wright et al. 2011). Wash and wake formation associated with boat movement can potentially cause visual and acoustic impacts, which could be especially harmful to dolphins (Davenport & Davenport 2006) given their reliance of acoustics for orientation, communication and predator/prey detection (Bejder et al. 2006, Harbrow et al. 2011).

Some boat-based tourism ventures may provide food for sharks or fish species in order to attract them to an area and increase opportunities for tourists to see these fauna up close (Laroche et al. 2007). While limited in its application in the Kimberley (Talbot Bay), the impacts of this practice still need to be considered. The artificial feeding of fish can alter their natural behaviour, create a reliance on the provided food source, increase aggression and competition, and cause health problems to the fish species (Feitosa et al. 2012). Ultimately, the effects of provisioning are influenced by the type and quantity of food, duration of feeding, population and community composition of species (Feitosa et al. 2012).

Boats are likely to be the major source of both organic and inorganic pollution in pelagic habitats. Fuel, oil and other chemicals discharged from boats can result in reduced water quality (Hardiman & Burgin 2010, Burgin & Hardiman 2011). However, vessels within Australian waters must comply with the MARPOL Discharge Standards regarding oil, waste disposal and sewage (Australian Marine Safety Authority 2013). Additionally, the Environmental Protection (Sea Dumping) Act 1981 (Cth) aims to minimise threats to the marine environment through prohibiting the ocean disposal of waste considered to be harmful and regulating permitted waste disposal (Australian Government, Department of the Environment 2013b). Sewage and/or chemical toilet discharge can lead to localised spikes in nutrients or eutrophication (Hardiman & Burgin 2010). Organic and inorganic pollution loads are likely to increase according to peaks in tourism (i.e. in the Kimberley, during the winter dry season) or periods with large numbers of vessel movements (Crain et al. 2009, Hardiman & Burgin 2010).

Plastics also dominate litter in the ocean as it is transported more easily that other more dense materials (Crain et al. 2009, Ryan et al. 2009). This characteristic also results in a greater proportion of plastics in litter with increasing distance from source areas (Ryan et al. 2009). Litter in the ocean is either sourced from rubbish dumped or unintentionally lost by vessels at sea or washed out from land-based sources (Edyvane et al. 2004, Ryan et al. 2009, Reisser et al. 2013). A study of marine plastic pollution around Australia identified high amounts of plastic near cities on the east coast, as well as at remote locations such as the west of Tasmania and the North West Shelf (Reisser et al. 2013). The high concentration off the North West Shelf could be from international sources as well as the high volume of marine operations in the region (Reisser et al., 2013).

Exploitation of marine resources in pelagic habitats can be split into recreational and commercial. With recreational fishing, there is a distinct seasonal peak in the winter months as a result of significant numbers of tourists (Williamson et al. 2006, Fletcher & Santoro 2014, Beckley et al. this report). Much of this fishing is boat-based due to the high tidal range with beach fishing usually limited to periods of flood tides or high water (Fletcher & Santoro, 2012). In addition to the targeting of a range of demersal species, pelagic species such as mackerel and sailfish are sought after (Williamson et al. 2006, Pepperell et al. 2010). Fishing can also be a key source of litter with nylon lines, sinkers, hooks and plastic bags discarded or dropped by anglers (Burgin & Hardiman 2011).

Commercial fishing can be a major threat to species and ecosystems as it can result in population depletions and impacts to marine food webs (Crain et al. 2009). Fishing operations not only affect the target species, but non-target species can also be impacted through by-catch or incidental catch (Crain et al. 2009). Extensive fishing closures over large areas of coastal waters have been introduced to manage prawn trawling and some finfish harvesting along the Kimberley coast (Fletcher & Santoro 2014).

Mariculture, especially the production of barramundi and pearls from pearl oysters, is an important commercial activity in the Kimberley region (Fletcher & Santoro 2014). The Western Australian state government recently announced the establishment of a Kimberley Development Aquaculture Zone. The 2000 ha zone, located in Cone Bay (215 km north-east of Broome) will allow for mariculture developments of marine finfish native to the north-coast region to be established in floating sea-cages (WA Department of Fisheries, 2014b).

There is a lack of research and consensus on the impacts of pearl farms on the biophysical environment and marine fauna (Watson-Capps & Mann 2005, Jelbart et al. 2011). Potential impacts could include the introduction and spread of disease into the ecosystem during the seeding or translocation of longlines, attraction of other fauna, perceived change in water quality, nutrient impacts in sediment and entanglement of fauna in longlines (Wells & Jernakoff 2006). However, a study of pearl farms in Cygnet Bay, Port George and Vansittart Bay identified no significant differences between the abundance and distribution of macro-benthic species or in the percentage concentrations of biochemical characteristics of sediments between pearl farm and reference sites (Jelbart et al. 2011).

3.6 Islands

There are over 2000 islands off the Kimberley coast, ranging from larger islands that are inhabited (e.g., Koolan and Cockatoo Islands) to smaller rocky outcrops. Most the islands are rocky though they often have small pocket beaches. As such, some of the impacts of anthropogenic use of islands are very similar to those documented above for sandy beaches and rocky coasts (Table 2).

Many of islands in the Kimberley are important roosting sites for birds and turtles nest on many of the island beaches (Clarke et al. 2011, Rogers et al. 2011, Waayers et al. 2011, Vigilante et al. 2013). Internationally significant numbers of both shore-bird and seabird species are found at Ashmore Reef, Adele Island and the Lacepede Islands. Shore-bird species include the Pacific Golden Plover, Grey Plover, Lesser Sand Plover and the Grey-tailed Tattler and common seabirds including the Wedge-tailed Shearwater, Brown Booby, Sooty Tern and Black Noddy (Clarke et al. 2011; Rogers et al. 2011). In addition to disturbing these species, increased human visitation to these islands could also result in the introduction of exotic flora and fauna, potentially outcompeting or reducing the quality of habitat available (WBM Oceanics Australia & Claridge 1997). Oil pollution from spills in the open ocean or from boats accessing the islands could also impact these seabird and turtle populations.

There is the potential with increasing anthropogenic use of boats along the Kimberley coastline for these seabird species to be disturbed by approaching boats and island landings. A study of boat approaches to colonies of Black skimmers on islands off New Jersey found that birds were more tolerant of boats moving tangentially to the colony and allowed them to approach closer than boats that approached the shore directly (Burger et al. 2010). The distance at which the birds responded to the presence of boats varied with reproductive stage, with birds responding when boats were further away during pre-egg laying periods (Burger et al. 2010).

Landing on the islands by helicopters/planes has the potential to impact the bird populations. The sudden sight and sound of aircraft can trigger a bird's flight or fight response, with the level of disturbance and response of the bird dependent on the species, breeding status and distance to aircraft (Harris 2005, Harbrow et al. 2011). Breeding birds are less likely to take flight than non-breeders, presumably due to the investment of energy in egg production (Harris 2005).

A number of islands along the Kimberley coast are known to be important nesting sites for green turtles (*Chelonia mydas*), flatback turtles (*Natator depressus*) and hawksbill turtles (*Eretmochelys imbricata*) (Pendoley 2005, Vigilante et al. 2013). Increasing human usage along the coast leads to an increase in the number and intensity of light sources. Artificial lighting from human-inhabited coastal areas or from resource extraction industries can impair the ability of hatchlings orientating themselves to the ocean (Berry et al. 2013). Research conducted on the Barrow-Lowendal-Montebello island chain as to the effects of lighting from offshore oil and gas operations demonstrated that hawksbill turtle hatchlings were disrupted from the most direct line to the ocean, while green and flatback turtles were significantly attracted to light sources (Pendoley 2005).

3.7 Cumulative impacts of marine and coastal tourism

In the Kimberley context, repeated visits by expedition cruise tourists, in addition to other human activities, could have cumulative effects on the marine environment. This has been documented from other cruise-based tourism destinations around the world. For example, expedition cruises to the Antarctic Peninsula have been growing steadily over the last 20-30 years (Lynch et al. 2010), with the most popular sites receiving a disproportionately high amount of use. A similar pattern is currently evident in the expedition cruise tours along the Kimberley coast. The majority of vessels cruise the central Kimberley with several key sites regularly visited (Scherrer et al. 2008). The most heavily visited sites include Horizontal Waterfalls, Montgomery Reef, Mitchell River and Falls, King George River and Falls, King Cascades and Crocodile Creek (Scherrer et al. 2008, Beckley et al. this report).

In addition to this is the cumulative use of four-wheel drive tracks to access coastal areas on the Dampier Peninsula for camping, recreation or launching of small boats leading to the widening of tracks, blowouts of dune vegetation or the collapsing of estuarine banks (Davenport & Davenport 2006, Schlacher & Thompson 2008).

4 Conclusions

Through this review of the anthropogenic uses of the Kimberley coast, mainly associated with recreation and tourism activities, it has become apparent that there are a number of activities which can impact coastal habitats. Litter and rubbish, both land or marine-derived, has the capacity to affect all habitats, especially given the lack of refuse collection outside of the regional centres. In addition, the impacts relating to access include the creation of coastal campsites, tracks through dunes and coastal vegetation to access sites to launch small boats, the potential damage to reefs from boats strikes and anchors, as well as the trampling of dune and intertidal biota. Fishing is another potential source of environmental impact along the Kimberley coast.

However, there are two major characteristics of the Kimberley region that currently constrain impacts. Firstly, the length and remoteness of the coast limits the areas that are adversely impacted. Often, impacting activities are concentrated at specific areas, either associated with regional centres or points of access to the coast. This allows for the more inaccessible areas to remain relatively impact-free. Secondly, the tropical monsoonal climate of the Kimberley region results in a seasonal visitation pattern with a considerable drop-off of visitor numbers during the wet season. During this season, much of the coast is relatively inaccessible due to heavy rains making the traversing of roads and tracks in the region difficult. This wet season may provide the coastal habitats an opportunity to recover from any impacts associated with tourism and recreational use. However, given the potential for increasing visitor numbers, impacts need to be monitored to ensure the Kimberley coast retains the cultural and natural assets that make this region so unique.

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6 Appendices

APPENDIX 1

Table 3: Estimation of level of impact and existence of data per impact and habitat type relative to the Kimberley coast.

Impact Category	Habitat	Level of impact	Existence of data
Litter	Sandy beaches	Moderate-high	Some
	Rocky shores	Moderate	Poor
	Coral reefs	Low	Poor
	Coastal wetlands	Moderate	Some
	Pelagic (open ocean)	Moderate	Some
	Islands	Low	Poor
Track formation/trampling	Sandy beaches	Moderate	Some
	Rocky shores	Moderate	Some
	Coral reefs	Low-moderate	Poor
	Coastal wetlands	Moderate-high	Poor
	Pelagic (open ocean)	NA	NA
	Islands	Moderate	Poor
Boat use	Sandy beaches	Moderate-high	Some
	Rocky shores	Moderate-high	Some
	Coral reefs	Low	Some
	Coastal wetlands	Moderate	Some
	Pelagic (open ocean)	Moderate	Some
	Islands	Moderate	Some
Recreational fishing	Sandy beaches	Moderate	Some
	Rocky shores	Moderate	Some
	Coral reefs	Moderate	Some
	Coastal wetlands	Moderate	Some
	Pelagic (open ocean)	Moderate	Some
	Islands	Moderate	Some
Marine recreational activities	Sandy beaches	Moderate	Some
	Rocky shores	Moderate	Some
	Coral reefs	Low-moderate	Some
	Coastal wetlands	Moderate	Some
	Pelagic (open ocean)	Low	Some
	Islands	Low	Poor
Pollution	Sandy beaches	Moderate	Poor
	Rocky shores	Moderate	Poor
	Coral reefs	Low-moderate	Poor
	Coastal wetlands	Moderate	Poor
	Pelagic (open ocean)	Low	Poor
	Islands	Low	Poor
Large-scale commercial uses	Sandy beaches	Unknown	Poor
	Rocky shores	Unknown	Poor
	Coral reefs	Low	Poor
	Coastal wetlands	Unknown	Poor
	Pelagic (open ocean)	Low	Some
	Islands	Low-moderate	Some