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Assessing patterns of recreational use in large marine parks: a case study from Ningaloo Marine Park, Australia.

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Abstract

Being able to accurately locate and describe recreational use within marine parks is essential for their sustainable management. Given the difficulty in accessing many marine parks, as well as their large size, the surveys to obtain these much-needed data are often logistically challenging and expensive. Aerial surveys are one potential method for obtaining accurate, timely data and this paper details the design for one such survey conducted in the Ningaloo Marine Park, off the north-western coast of Australia. Ningaloo has been nominated as a world heritage site and the fringing coral reef that forms the centrepiece of the Marine Park extends for 300 km along the coastline. The survey involved 34 temporally stratified flights conducted over a 12-month period. All vessels and people were geo-referenced and where possible, their activities were recorded, providing data that clearly illustrates dramatic expansions and contractions in recreational use. Not only does the spatial extent of use expand in the peak visitor season (April – October), the density of use correspondingly increases. High densities of recreational activity in the Park's waters were accompanied by increased numbers of vehicles, camps, boat trailers and boats on the adjacent shoreline. Aerial surveys proved to be an effective method for rapidly obtaining recreational data with high spatial accuracy. Such a method has broad applicability to marine parks as it provides comprehensive data to benchmark existing recreational use, as well as monitor future changes in activity patterns, which are essential for the informed management that must underpin sustainability efforts.

Keywords: aerial survey, multiple-use, monitoring, Ningaloo Reef, Geographic Information System

1. Introduction

Coastal and marine environments are highly valued for the range of recreational and tourism opportunities they provide to visitors (James, 2000). Marine protected areas (generally referred to as marine parks in Australia) are often focal points for people taking advantage of these opportunities as they are generally created in areas with unique biological or geomorphological features (Gurran et al., 2007), and can be easily accessible from the shore. Ningaloo Marine Park in north-western Australia (Fig. 1) exemplifies such characteristics. Recently nominated as a world heritage site, it is a coastal multiple-use marine park encompassing one of the largest fringing coral reefs in the world (Wilkinson, 2008), with a highly variable coastal geomorphology comprising intertidal reef platforms, cliffs and sandy beaches (Cassata and Collins, 2008). Even though isolated from large population centres, the unique attributes of the Marine Park attract 200 000 visitors annually, who undertake a wide variety of recreational activities such as fishing, swimming, snorkelling and sunbaking on the beach (CALM and MPRA, 2005).

Understanding patterns of recreational use by visitors to marine parks is necessary for implementing sustainable management practices as these data contribute to evaluations of management effectiveness, planning of infrastructure developments and resource allocation. Linkages with biological datasets to assist with monitoring human impacts are also important for sustainable management and conservation of resources. However, these outcomes are not often achieved because of *ad hoc* approaches to survey design which fail to capture spatial and temporal variability in recreational pressure, unresponsiveness of the data to management needs and inaccessibility of data for further analysis. Such issues are well-documented for visitor data in terrestrial areas (Hornback and Eagles, 1999; Horneman et al., 2002; Wardell and Moore, 2005), and are also relevant to marine parks (Pomeroy et al., 2004).

Further contributing to the lack of collection (and application) of data on patterns of recreational use are the difficulties associated with surveying coastal and marine environs. Numerous access points and dispersed travel networks combine with the dynamic and ephemeral nature of many activities to make it difficult to determine not only where they occur, but also hinders the use of surrogates (i.e. roads) to map their sphere of influence (Ban and Alder, 2008). Observation surveys (conducted from land, water and air) (Coombes et al., 2009; Dalton et al., 2010; Smallwood and Beckley, 2008), secondary data sources (Dwight et al., 2007), visitor interviews and mail or phone surveys (Sidman and Fik, 2005) as well as GPS trackers (Pelot et al., 2004) have all been used to assess recreational activity occurring from boats and the shore. Each technique has different limitations and biases. For example, self-reported data from interviews may lead to response biases but allow in-depth questioning of participants (Pollock et al., 1994) while observers conducting aerial surveys may experience visibility bias but are able to cover large tracts of land (Pollock and Kendall, 1987). Costs also escalate with increasing size of the study area and higher intensity of sampling.

A survey encompassing a longitudinal timeframe, and collecting geo-referenced data points, enables analysis at various spatio-temporal scales which clearly capture patterns of recreational use. Such scales must be selected carefully as, if summarised too broadly, they may inhibit the understanding of these activities (Eastwood et al., 2007). Selection of analysis units should consider the scale of previous research (Pederson et al., 2009), associated spatial accuracy (Hengl, 2006), current management and administrative boundaries (Lewis et al., 2003), practical limitations of data analysis and implementation of results (Shriner et al., 2006). The size of the study area is also important, with larger areas of the marine environment generally aggregated at broader scales, i.e. 10 x 10 (Leeworthy et al., 2005) or 2 x 2 (Eastwood et al., 2007) nautical mile blocks when compared to smaller areas, such as confined bays, i.e. 15 x 15 m (Sidman et al., 2000).

The aforementioned factors, combined with the traditional approach of designing marine parks based solely on biological criteria (Roberts et al., 2003), has led to social and economic elements (including data on recreational activities) being poorly represented in park planning and management (Dalton, 2004; St. Martin and Hall-Arber, 2008). Ningaloo Marine Park is no exception, with measurable long-term indicators (i.e. species diversity, abundance or biomass) for many biological characteristics, while those for social elements are not yet defined in such detail (CALM and MPRA, 2005). A holistic approach to park management (comprising social as well as biological elements) requires the collection of data on recreational activities to provide a complete understanding of pressures placed on protected areas (Wilkinson et al., 2003).

The aims of this study were to advance the understanding of recreational use patterns in marine parks, which has benefits for park planning and management of resources, as well as to showcase aerial surveys as a tool for collecting fine-scale, spatially explicit data on such use. Therefore, using Ningaloo Marine Park as a case study, aerial surveys were used to map boat- and shore-based recreational activities at various temporal scales to highlight spatio-temporal trends as well as the malleability of these data for meeting management requirements. Data on numbers of parked vehicles, camps and boat trailers along the shoreline of the Marine Park were also collected to investigate their links with changing densities of recreational use.

2. Methods

2.1 Study area

Ningaloo Marine Park (state waters) is 300 km in length and extends 3 nautical miles seaward from the coastline to the limit of Western Australian state waters, beyond which the Ningaloo Marine Park (Commonwealth waters) extends further offshore (Fig. 1). The fringing reef crest demarcates a shallow lagoon environment with a mean width of 2.5 km, providing a sheltered location for recreation from boats and the shore (CALM and MPRA, 2005). The remoteness of Ningaloo from major population centres has kept visitor numbers low when compared to other iconic coral reef destinations, such as the Great Barrier Reef and Florida Keys. The highest number of visitors occurs between April – October, coinciding with milder winter temperatures, while the remaining months are characterised by hotter temperatures and increased risk of cyclonic activity (BOM, 2010).

Main access routes to the coast are limited and comprise sealed and unsealed (gravel) roads (Fig. 1). A network of sandy tracks radiate from these main roads, providing access to beaches and along the remainder of the coast. Two coastal towns (Exmouth and Coral Bay) provide a range of accommodation types while coastal camping is also permitted adjacent to much of the Marine Park, and are sites where visitors are often able to launch small vessels directly off the beach. Larger vessels can launch from four constructed boat ramps (Fig. 1).

2.2 Sampling regime and survey design

From the air, observers were able to survey the entire shoreline and marine environment of Ningaloo Marine Park in a single transect. A total of 34 aerial flights were completed from January – December 2007 and were stratified by month. Higher sampling effort was allocated to peak visitor months (April – October; three to four flights per month) compared to off peak months (November – March; two flights per month), which have lower visitation. Within this broad temporal stratification, peak months with school holidays (April, July and October) had the highest sampling intensity (four flights per month).

Flights were allocated to randomly selected days within each month and departure times were standardised at 8 am to enable the best opportunities for viewing recreational use, similar to other surveys of boating in north America (Reed-Anderson et al., 2000) and Australia (Warnken and Leon, 2006). Wind patterns along the Ningaloo coast generally consist of lighter, mainly offshore conditions in the morning and stronger onshore seabreezes in the afternoon. Morning conditions were therefore more suited for boating and many beach-related activities, while reduced wind action on the water surface also improved visibility for observers (Marsh and Sinclair, 1989).

The 4-seat fixed (high) wing Cessna 172 was flown at an altitude of 500 ft and, with an average speed of 100 knots, it took ~4 hours for a return trip along the entire length of the Marine Park. All recreational activities occurring from boats and the shore were geo-referenced during this period. All flights commenced at Exmouth (Fig. 1), as the linear nature of the flight path along the coastline hindered randomisation of start location. Similar to surveys of recreational fishing in South Africa (Mann et al., 2003), the outbound (southbound) and return (northbound) flights were considered to be two separate counts of recreational activity. Duplicating observations within each flight direction was unlikely due to the rapid speed of air travel. However, duplication was likely between southbound and northbound flights, especially close to the turning point at the southern end of the Ningaloo (Red Bluff), where there may only be a few minutes between observations. Although this has implications for independence of data between flight directions, it allowed investigation of the levels of recreational activity occurring at different time periods.

Positional information (along with time and heading) was recorded every two seconds using a GPS linked to a PalmPilot for data storage. Digital cameras were also used to document shore and boating activity, especially in locations with high numbers of people or vessels. An offset measurement (i.e. distance of the object from an observation point) was estimated using calibrated markers taped to the wing strut, a technique adapted from wildlife research (Ottichilio and Khaemba, 2001). The fringing reef crest was an additional reference point used to improve distance estimation for boats, while the mean high water mark was used for shore activity. This offset distance, combined with the position of the plane, enabled the location of vessels and people on the shore to be calculated (Vincenty, 1975). The observers also recorded platform (i.e. shore or boat), group size and activity type. If an activity was boat-based, then boat type (Table 1) and the location of the vessel with respect to the reef crest (i.e. inside or outside), was documented.

2.3 Spatio-temporal mapping and statistical analysis

A selection of temporal scales was used to analyse and display the geo-referenced data obtained during the aerial surveys to demonstrate how such information can provide flexible outputs to inform management, which can be tailored to meet specific requirements. Boating activity data were aggregated to season (summer, autumn, winter and spring) while shore activities were analysed by month (January – December) as well as peak (April – October) and off peak (November – March) periods of tourist activity, which were defined using historical visitor data (CALM and MPRA, 2005).

Numerous spatial scales were also available to display boating activity and second-order nearest neighbour Euclidean distance determined the smallest grid size from which clustering of boat-based activity could be ascertained, similar to techniques used by (Hengl, 2006) and (Sidman et al., 2006). However, the 1 km^2 grid cells, which were the outcome of this analysis, were difficult to visualise over a large study area so a larger 9 km^2 (3 x 3 km) grid was created. Additionally, for 67% of vessels observed during the study (especially those with cabin accommodation) it was difficult to identify the number of people on board, as they were obscured from view of the observers. Boating data were therefore aggregated based on number of observations (where one observation represents one vessel).

Deciding on the dimensions of spatial units for aggregating activities which take place along the coastal strip can be complex as the coastline may be convoluted (Vafeidis et al., 2004) and is constantly shifting due to tidal effects (Tolvanen and Kalliola, 2008). Data points were aggregated into 3 km long coastal segments which extended 0.5 km inland and 0.5 km seaward of the mean high water mark. The horizontal boundaries of these segments corresponded to 9 km^2 grid cells. Although group size was underdetermined for less than 1% of observations of shore activity, it was not possible to distinguish separate groups of people at beaches with known high densities off visitors. A total count of people participating in specific recreational activities at these beaches was therefore linked to a central geo-referenced location (Fig. 1). Shore activity along the entire coast was displayed using number of people, as an observation could represent >50 people.

Effects of temporal factors on levels of recreational activity were investigated using analysis of variance (ANOVA). Data were tested for assumptions of normality and homogeneity and, if violated, were transformed or equivalent non-parametric tests were utilised. Multivariate analysis was also undertaken using PRIMER (Clarke and Warwick, 2001) to determine the significance, if any, of specific recreational activities in the temporal distribution of observed vessels and people on the shore. Data were standardised across samples to correct for differences in absolute abundances and square root transformed to adjust for the effect of dominant activity types. A Bray-Curtis similarity measure was used to create a data matrix on which analyses were performed. Analysis of similarity (ANOSIM) was able to detect statistical differences between temporal factors while similarity percentages (SIMPER) determined the specific recreational activities responsible for such differences (Clarke, 1993). ANOSIM generates values of R which fall between -1 and +1 (with a value of zero representing no difference between samples) as well as an associated ρ value which indicates significance at 0.05 level.

3. Results

3.1 Boat-based activities

A total of 2 906 aerial observations of boat activity was recorded, and significantly higher counts were obtained on later northbound flights (10 am – 12 noon) when compared to earlier southbound (8 am – 10 am) flights ($F_{(1,\,66)}=15.88$, $\rho<0.05$) (Fig. 2a). Boat-based activity was also distributed in 4.2% more grid cells during northbound flights. Higher numbers of vessels were present in peak months (April – October) for both flight directions ($F_{(1,\,66)}=33.42$, $\rho<0.05$) while significant differences in number of boats and composition of recreational activities were also revealed (ANOSIM, R=0.26, $\rho<0.05$). However, further investigation using SIMPER could not identify specific activities responsible for these differences, although a large number of motoring (transiting) vessels were observed on southbound flights throughout the year. Based on the greater spatial extent and greater number of observations during the later northbound flights, these were selected for further analysis.

Boat-based activity occurred at highest levels inside the lagoon (54.7%) with 29.6% outside and the remaining 15.7% adjacent to parts of the coast with no fringing reef crest (in the northern- and southern-most extent of the Marine Park). Tinnies (small aluminium vessels) (26.8%), open boats >5 m in length (20.3%) and charter vessels (16.5%) were the dominant boat types (Fig. 3). The largest boats (charter vessels and open boats >5 m in length) were in greatest numbers outside the lagoon whereas the smaller motorised vessels (comprising tinnies and tenders) and non-motorised vessels such as kayaks, kitesurfers and windsurfers, were found almost exclusively inside the lagoon.

Recreational activity from boats was concentrated adjacent to the coast and inside the lagoon environment in all seasons (Fig. 4a-d). Nevertheless, seasonal changes in boat-based activities were evident, with higher densities of vessels as well as expansion along the coast and outside the fringing reef crest in autumn and winter. The highest mean densities for all seasons were in the grid cells adjacent to Coral Bay and Tantabiddi where there are constructed boat ramps. However, there were also areas of Ningaloo were no boating activity was observed. Grid cells with a mean number of observations <0.75 had standard errors greater than their mean, indicating high levels of variability in observations.

3.2 Shore-based activities

There were 15 373 people observed undertaking recreational activities along the shoreline during aerial surveys, of which 71.1% were recorded on the later northbound flight, significantly greater than found on earlier southbound flights ($F_{(1,\,66)} = 22.71$, $\rho<0.05$) (Fig. 2b). A maximum count of 910 people was recorded on a northbound flight during the October school holidays. An ANOSIM test revealed a significant difference in number of people and composition of recreational activities undertaken during each flight direction (R=0.43, $\rho<0.05$). As with boat-based activities, a SIMPER test again could not clearly identify a specific activity which characterised these differences, with many types recorded during both flight directions. Northbound flight data were selected for further analysis based on the greater number of people observed and for consistency with analysis of boating activity.

Expansion of recreational activity along the shore, and increased densities of people, can be clearly identified in peak months (April – October), when compared to off peak months (Fig. 5Fig. a-l). However, activity was observed year-round in some 3 km segments along the northern extent of the Marine Park. Conversely, no shore-based recreation was observed near Jane Bay and Cape Farquhar, located further to the south. Coastal segments with a mean number of people <1.0 had standard errors greater than their mean, indicating high levels of variability in observations.

In addition to counts of people, 7 696 observations of camps, boat trailers and vehicles as well as boats that were not being used for recreation at the time of observation (i.e. on moorings, anchored, in marina pens or on the beach) were also made. Counts of vehicles and boat trailers showed significant differences between the two flight times, with higher mean counts on later northbound flights than earlier southbound flights (Table 2). Boats being launched were rarely observed, as the plane was travelling at high speed, thereby reducing the likelihood of capturing this activity. The observed number of anchored vessels was also low as people generally leave small vessels drawn up on the beach.

Vehicles were recorded along the coast all year-round, especially in the northern extent of Ningaloo where there are many coastal carparks from which people can walk to the beach (Fig. 6a). However, the vehicles were observed in double the number of coastal segments during peak months when compared to off peak months. Coastal segments with a mean of <5.0 vehicles had standard errors greater than their mean, indicating high levels of variability in observations, a pattern also found for number of camps, boat trailers and boats on the beach.

Camps were distributed over a greater number of coastal segments in peak periods (Fig. 6b). However, relatively high densities of camps were also observed in off-peak months. The finite number of camps in Cape Range National Park allowed for occupancy to be calculated, unlike for the majority of coastal camping areas further to the south, with undesignated sites and no appointed maximum capacity. The National Park had a mean occupancy >80% for June – September, while the remaining peak months had a mean >50%. Mean occupancy dropped to <15% for all off peak months (November – March). Camps in the towns of Coral Bay and Exmouth were not recorded as they were located within caravan parks containing overhanging trees, rendering it impossible to accurately survey these sites from the air.

Boat trailers were observed within fewer coastal segments than camps or vehicles (Fig. 6c). Highest numbers were obtained in peak months within parking areas associated with constructed boat ramps at Tantabiddi and Exmouth. During most of the study period, trailers associated with boats launched off the beach in Coral Bay were required to be parked in the caravan parks so could not be accurately counted. A new boat launching facility was opened in late 2007 and subsequent to this, the associated boat trailers were counted.

Boats on the beach comprised those vessels not being used for recreation at the time of observation. These generally consisted of tinnies that were pulled up on the beach adjacent to coastal camping areas and also charter boats at Coral Bay (Fig. 6Fig. d). Boats on the beach were recorded at more coastal segments in peak months, with the highest numbers adjacent to coastal camping areas (e.g. Lefroy Bay and 14 Mile).

3.3 Spatial accuracy

Known landmarks, which had previously been geo-referenced via land-based surveys, were used for 22% of data points, and therefore had no sampling error. Horizontal positional error (extracted from the GPS) and sampling error associated with the remaining data points was 6.1 m (*SD*=6.4) for each vessel and 4.3 m (*SD*=2.4 m) for each group observed on the shore. These errors were different for boat and shore-based activities as the co-ordinates were computed using different distance estimation techniques. Markers on the wing struts were calibrated to a maximum distance of 1 500 m from the plane, and 24.8% of vessels (and 0% of shore groups) were observed beyond this distance, thereby being exposed to greater error, which was difficult to quantify.

4. Discussion

4.1 Effectiveness of aerial flights for quantifying recreational activity

Aerial surveys were an effective technique for obtaining data on recreational use occurring from boats or the shore throughout the entire extent of Ningaloo Marine Park. Similar techniques have been implemented on four continents, including North America, for surveying beach use (Coombes et al., 2009), recreational fishing (Mann et al., 2003; Veiga et al., 2010), coastal camping (Hockings and Twyford, 1997) and boating activity (Sidman and Flamm, 2001; Volstad et al., 2006) occurring along the shoreline and in nearshore marine environments, although few have obtained the fine-scale resolution, longitudinal timeframe or spatial accuracy of this current study. Such an approach has application to marine parks worldwide, especially those encompassing a large geographic extent and situated adjacent to the coast, so that data can be simultaneously collected on shore and boat-based activities.

Widespread availability and affordability of handheld GPS units and GIS software supports the collection of geo-referenced point data by researchers and management agencies. Spatially, such outputs can be readily adjusted to inform management (i.e. ascertaining areas of high recreational use occurring within different management zones or at localised sites of a marine park which can be used to identify future infrastructure requirements). The malleability of fine-scale temporal data was also demonstrated by using months, seasons and peak/off-peak periods to display patterns of recreational use which can be adjusted to meet management needs. A within-week comparison may also be beneficial, especially in areas adjacent to large population centres where it would be expected that use on weekends would be higher than on weekdays, as shown in populous parts of California (Dwight et al., 2007) and Spain (Roca and Villares, 2008). In this study, stratification by day type was not incorporated into the survey design due to the small permanent population residing within 50 km of the Marine Park (~2 000 people).

Limitations of aerial flights have traditionally been that they are expensive and it can be challenging to accurately record data from a fast moving platform, resulting in sampling errors due to duplicate sightings and difficulties with ascertaining perpendicular distance from the flight path (Logan and Smith, 1997; Pollock and Kendall, 1987). Although a ‘per hour’ rate to hire light aircraft may be expensive, aerial surveys are cost-effective when balanced against the staff costs and time required to cover a large area by water (via boat) or by land (via vehicle). For example, it took 2 hours to survey the full extent of the Marine Park from the air, when compared to 3 days by off-road vehicle (Smallwood, 2010). Although both methods required two staff, salaries and other expenses (i.e. accommodation, food) were reduced during aerial surveys because of their shorter duration.

Issues of capturing and processing data at high speed have been mitigated by ongoing improvements in equipment. This includes an increasing tendency to move towards automated data systems that eliminate the need for manual data entry or transcription

(Butler et al., 1995; Logan and Smith, 1997), and also contribute towards increased spatial accuracy of data points. In this study, data loggers automatically obtained time and positional information so that researchers only recorded time of observation, thereby increasing their availability for documenting other information (i.e. boat type, number of people). Watches and digital cameras were also synchronised prior to the start of each flight for consistency across equipment. Where possible, landmarks were geo-referenced prior to aerial flights to provide a known position that could be recorded, which virtually eliminated sampling errors associated with activity occurring at these points.

Accuracy assessments are a common validation method for spatial classifications of habitats and other features (Lunetta and Lyon, 2004), but are rarely conducted for surveys of recreational activity. The mean spatial error for data points in this study was ~30 m (including 25 m for inherent GPS biases); substantially less than the 300 m reported during observational aerial surveys in Alaska (Soiseth et al., 2007). The small error supports the use of fine-scale grids for analysis of shore and boat data, as did the strong clustering of geo-referenced points. It was difficult to visually interpret data over the entire geographic extent of Ningaloo at these finer-scales, therefore 9 km^2 grid cells and 3 km coastal segments were selected to explore synoptic patterns of recreational activity. However, if analysis must be focused on a localised site, then geo-referenced data points provide useful insights into the relationships between recreational activity and features such as the fringing reef crest, management boundaries and boat launching locations (Smallwood, 2010). Such variations in spatial scales of analysis should be determined on a park-by-park basis to best highlight the patterns of recreational use within that area.

Collecting data on both north and southbound flights enabled a decision to be made regarding the usefulness of each dataset for future research or monitoring of recreational use; similar to the maximum count method applied to recreational fishing surveys in North America (Lockwood et al., 2001; Volstad et al., 2006). At Ningaloo, northbound flights were completed later in the morning (10 – 12 noon), and obtained more observations, which complemented findings of previous research in which the majority of vessels had launched by around 11 am (Neiman, 2007; Worley Parsons, 2006). These northbound flights were therefore likely to obtain maximum counts of boat trailers and boat-based recreation occurring in the Marine Park. However, earlier southbound flights recorded higher numbers of camps and may provide a more realistic maximum count of occupancy for the previous night.

4.2 Spatio-temporal patterns of recreational use

Using aerial surveys has advanced the knowledge of recreational use patterns at Ningaloo by providing a method of rapidly collecting data throughout the entire Marine Park. The highly seasonal patterns of use are explained by the very high temperatures and extreme weather events (such as cyclones) which occur in this part of the world during spring and summer, particularly December – March. Therefore, the highest levels of visitation to Ningaloo (in terms of greater spatial extent and density of recreational use from boats and the shore) occur in autumn and winter, which have lower wind speeds and cooler temperatures. This is in contrast to many other countries (and the southern parts of Australia) where the highest levels of beach visitation occur during summer and the associated school holiday break (Dwight et al., 2007; Lim and McAleer, 2001). These results do, however, accord with other research where broad temporal factors such as seasons are well-known to affect the distribution and density of recreational use (Higham and Hinch, 2002; Jang, 2004).

The value of this extended temporal approach to surveying recreational use is emphasised in the data showing that, even in the off peak months with their extreme weather conditions, people were still observed undertaking recreational activities. These months were rarely considered in earlier research as anecdotal evidence suggested that little visitation occurred during this time. Such a finding could indicate expansion beyond the traditional peak tourism season, especially for international visitors from the northern hemisphere escaping their cold winter months (Smallwood, 2010). Economic benefit to local communities is likely to result from such expansion, although environmental impacts from these activities are also likely to increase in concert, which has implications for the conservation of biodiversity and allocation of management resources.

The fine-grained spatial approach possible with these aerial surveys provided not only changes in numbers over the year, but also where these changes occurred. In peak months boating activity not only increased in density at favoured sites, it also expanded along the coast and outside the sheltered lagoon environment. Such information enables managers to understand the simultaneously changing temporal and spatial nature of recreational use in marine parks such as Ningaloo. Shore activities also exhibited a similar pattern to boating, with greater spatial extent and density of use in peak months.

The expansion of activity from boats and along shore coincided with increased number of camps, parked vehicles, boat trailers and boats on the beach. These facilities provide points from which visitors can access, and therefore impact, on coastal and marine resources. Although this is a complex relationship, it can be generalised that visitor impacts are likely to be greatest closest to such facilities (Sanderson et al., 2002). Prior research (2006) asked respondents to identify the general region they would be travelling to, by boat, for recreation. Although distribution was evenly split inside and outside the lagoon, the majority of respondents planned to only travel short distances from the boat launching site, similar to patterns of boating activity reported in Florida (Sidman et al., 2004).

4.3 Implications for management

Improved management of marine protected areas depends upon accurate spatio-temporal data on the social and ecological values of the area(s) of interest. Important social datasets are those relating to visitors and their management. Information on visitor numbers has been recently identified as the core, first tier set of data required for managing protected areas, with all other visitor data regarded as second tier (Griffin et al., 2010). As such, the ability of aerial surveys to provide a synoptic overview of recreational use is critical for sustainable park management. Their contribution lies in providing decision support for management (Ban and Alder, 2008; Halpern et al., 2008), while also being used to complement and focus the collection of additional visitor data using other methods as required.

Details on visitor numbers, where they are going and what they are doing have value for two key components of information acquisition for protected area management, namely, benchmarking and ongoing monitoring programs. Collection of benchmark data on recreational use, such as described in this paper, is the first critical step in gathering the data needed to understand current visitor use and then incorporate such knowledge in planning and management efforts (Newsome et al., 2002). An intensive sampling regime, such as that applied in this study, seems essential for important marine protected areas, such as this proposed world heritage site. This study has also emphasised the benefits of taking a broad temporal approach, with the resultant benchmarking able to reflect changes in the extent and densities of recreational use throughout the year.

Declaration of Ningaloo as a world heritage site can be expected to increase visitor numbers, similar to experiences in other parts of the world (Buckley, 2004; Yang et al., 2010). People are also more likely to be attracted to sites where they expect to find high abundances and diversity of marine life (Davenport and Davenport, 2006; Hawkins et al., 2005). Such increases are likely to affect the patterns of behaviour exhibited by people participating in recreational activities. The approach to aerial surveying detailed in this paper provides protocols for future monitoring, for which the key features should be that it occurs year-round and throughout the whole park to capture the variability in usage patterns across space and time.

Monitoring year-round will not only identify changes in numbers of people, but will also uncover any expanding temporal distribution which may be the result of greater recreational pressure (i.e. as visitors seek to avoid overcrowding or obtain access to limited accommodation (Arnberger and Brandenburg, 2007)). However, it is important to ensure maximum levels of recreational activity are quantified by sampling during the busiest visitor months, as these periods have the greatest potential to impact on coastal and marine ecosystems (i.e. damage to marine habitats from anchors or snorkelers (Davenport and Davenport, 2006)). Data from these periods also enables managers to determine the occupancy of carparks and camping areas, and if capacity is being exceeded, consider an appropriate management response, such as the expansion of existing facilities or creation of new ones at alternative recreational sites.

Monitoring will be of greatest benefit if it occurs throughout an entire marine park, especially where there is a high diversity of coastal geomorphology and infrastructure, as patterns of recreational use are likely to vary with these features. For example, snorkelers and divers are often attracted to areas with coral habitats and high rugosity (Davenport and Davenport, 2006) while sunbathers prefer sandy beaches (Schlacher and Thompson, 2008). Findings can then be used to compare changes in recreational use at specific sites which are the result of introduced management initiatives (i.e. to measure the success of dispersing visitors from a single high-use site to a number of other sites to reduce congestion) or new infrastructure, such as boat ramps or camping sites. Although spatially explicit data are being incorporated into conservation and management of marine resources from a fisheries perspective (Costello et al., 2010), the current study illustrates the benefits of such data to all recreational activities occurring within marine parks.

An important part of monitoring, as distinct from research, is optimising survey effort so that repeat data collection efforts are cost-effective and efficient, while also maintaining an acceptable level of accuracy. Indicators, or surrogates, are another means of achieving these outcomes, as they utilise a known relationship between variables to reduce the number that need to be measured. Such approaches are often used for measuring environmental variables (Marion et al., 2006; Parnell et al., 2006), but are rarely applied to assess the level of pressure from human activities (Rogers and Greenaway, 2005). In this study, counts of vessels and people undertaking recreational activities were found to increase in concert with numbers of camps, boat trailers, parked vehicles and boats on the adjacent shoreline. It is envisaged that such relationships (although probably site specific) can be used to develop indicators for measuring recreational activities at Ningaloo and elsewhere.

5. Conclusions

Marine parks provide a repository for much of the world's biodiversity while, at the same time, attracting rapidly increasing numbers of visitors, especially those interested in recreational activities. This paper has explored, through application to Ningaloo Marine Park, aerial surveys as an effective approach for obtaining temporal data at fine-scales with high spatial accuracy, on patterns of recreational use. A great strength of the data, and associated survey technique, is their ability to be analysed at different spatio-temporal scales. Benefits include being able to compare current recreational activity and management arrangements at the site through to regional scales, and similarly being able to evaluate the possible effects of changes in management practices or infrastructure (i.e. construction of a new boat ramp) on the distribution and intensity of recreational activities. Through its contributions to benchmarking and ongoing monitoring programs, the aerial survey technique described in this paper is clearly a critical component of the array of data collection approaches required if sustainable development and conservation is to become a reality in coastal environments.

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Table 1 Categories of vessel types recorded during aerial surveys [adapted from Adams et al., (1992), Warnken and Leon (2006), Widmer and Underwood (2004)].

Table 2 Mean, standard error and significance of variables (one-way ANOVA) on southbound and northbound aerial flights.

Fig. 1 Ningaloo Marine Park with main access roads, constructed boat ramps, fringing reef crest and settlements.

Fig. 2 The (a) mean number of boats observed and (b) mean number of people counted on the shore during southbound and northbound aerial surveys in 2007 (±SE) (number of flights = 34).

Fig. 3 Total number of observations for each boat type during northbound aerial flights in 2007 (number of observations = 1 718).

Fig. 4 Seasonal spatial variation in boats observed during northbound aerial surveys throughout Ningaloo Marine Park in (a) summer, (b) autumn, (c) winter and (d) spring (number of flights = 34).

Fig. 5 Monthly spatial variation in shore-based activity obtained from northbound aerial surveys throughout Ningaloo Marine Park from January – December 2007 using number of observed people (number of flights = 34).

Fig. 6 Spatial variation recorded in (a) vehicles (b) camps (c) boat trailers and (d) boats on the beach during off-peak and peak months, during northbound aerial flights throughout 2007.

- aerial surveys are a powerful method for obtaining accurate data on patterns of recreational use
- spatial extent of recreational use expanded in the peak visitor season while density increased
- high densities of recreational use were accompanied by increased numbers of vehicles, camps and boat trailers

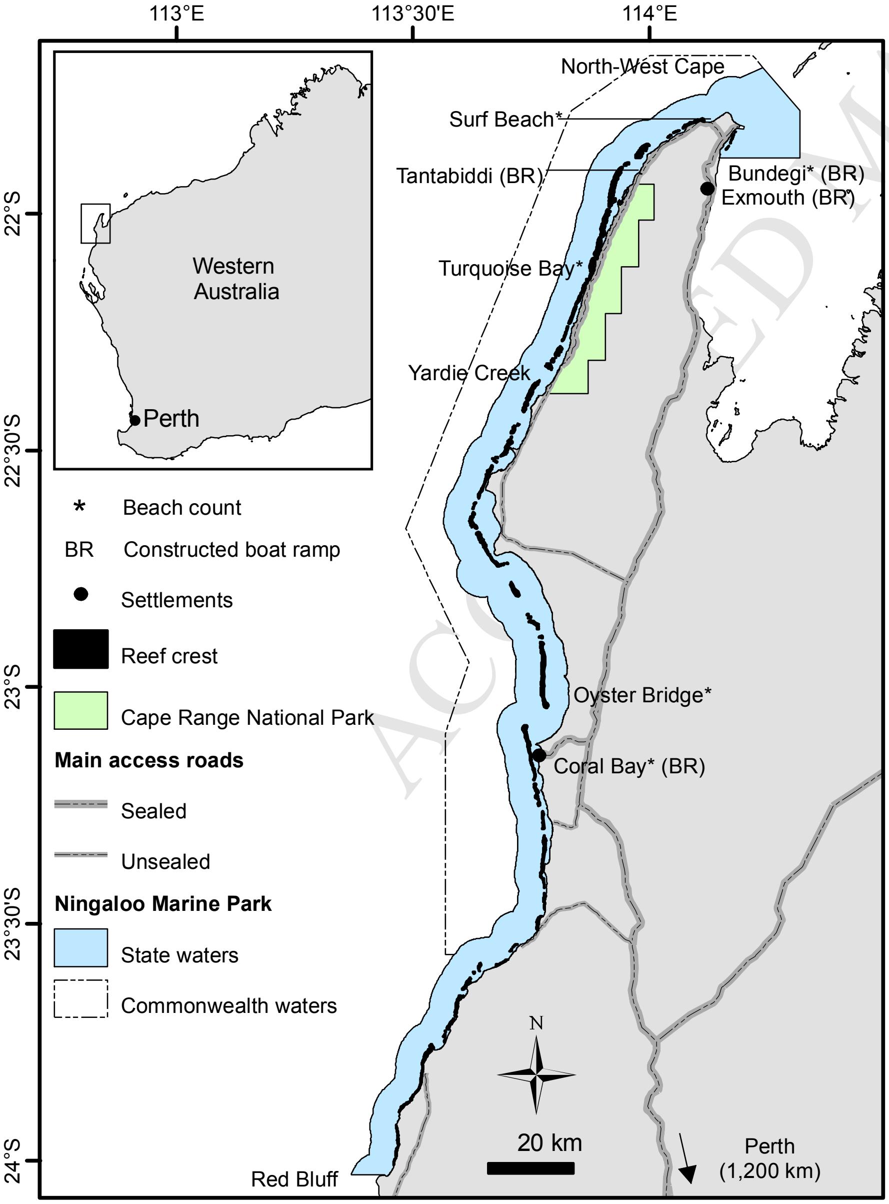
Table 1

Vessel type	**Characteristics**
Motorised vessels	
Cabin cruiser	Sleeping accommodation, in-board engine.
Charter	Paid passengers undertaking recreational activities.
Commercial	Used for commercial purposes (i.e. fishing, research, rig tender).
Open >5 m	No sleeping accommodation, out-board engine, >5 m in length.
Open <5 m	No sleeping accommodation, out-board engine, <5 m in length.
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.
Non-motorised vessels	
Yacht	Vessel >7 m 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.

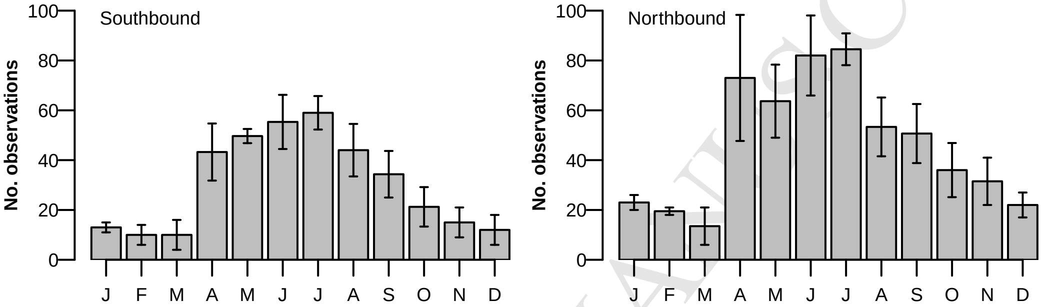
Table 2

Variable	**Southbound**		**Northbound**		**ρ value**
	Mean	**± SE**	**Mean**	**± SE**	
Vehicles	96.6	7.9	202.0	16.3	$F_{(1, 66)} = 33.74, \rho<0.05$*
Camps	193.1	22.0	183.1	22.0	$F_{(1, 66)} = 0.10, \rho>0.05$
Boat trailers	21.1	2.4	40.5	5.2	$F_{(1, 66)} = 11.23, \rho<0.05$*
Boat on beach	64.1	7.7	55.3	7.0	$F_{(1, 66)} = 0.70, \rho>0.05$
Boats launching	4.4	0.5	3.9	0.8	$F_{(1, 66)} = 0.33, \rho>0.05$
Moored boats	21.0	0.8	21.2	0.9	$F_{(1, 66)} = 0.03, \rho>0.05$
Boats in pens	27.8	0.9	24.9	0.7	$F_{(1, 66)} = 3.30, \rho>0.05$
Anchored boats	1.3	0.4	1.2	0.5	$F_{(1, 66)} = 0.002, \rho>0.05$

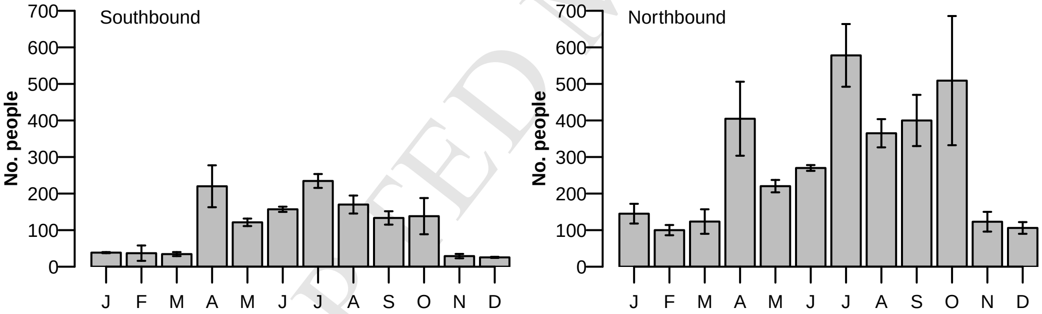
* significant value

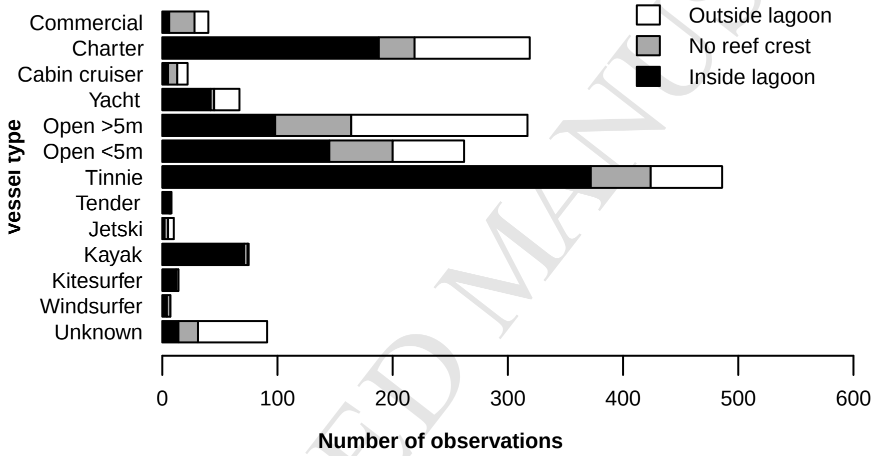

113°E
113°30'E
114°E
22°S
22°30'S
23°S
23°30'S
24°S
Western Australia
Perth
North-West Cape
Surf Beach*
Tantabiddi (BR)
Bundegi* (BR)
Exmouth (BR)
Turquoise Bay*
Yardie Creek
Oyster Bridge*
Coral Bay* (BR)
Red Bluff
Perth (1,200 km)
N
20 km
* Beach count
BR Constructed boat ramp
● Settlements
Reef crest
Cape Range National Park
Main access roads
Sealed
Unsealed
Ningaloo Marine Park
State waters
Commonwealth waters

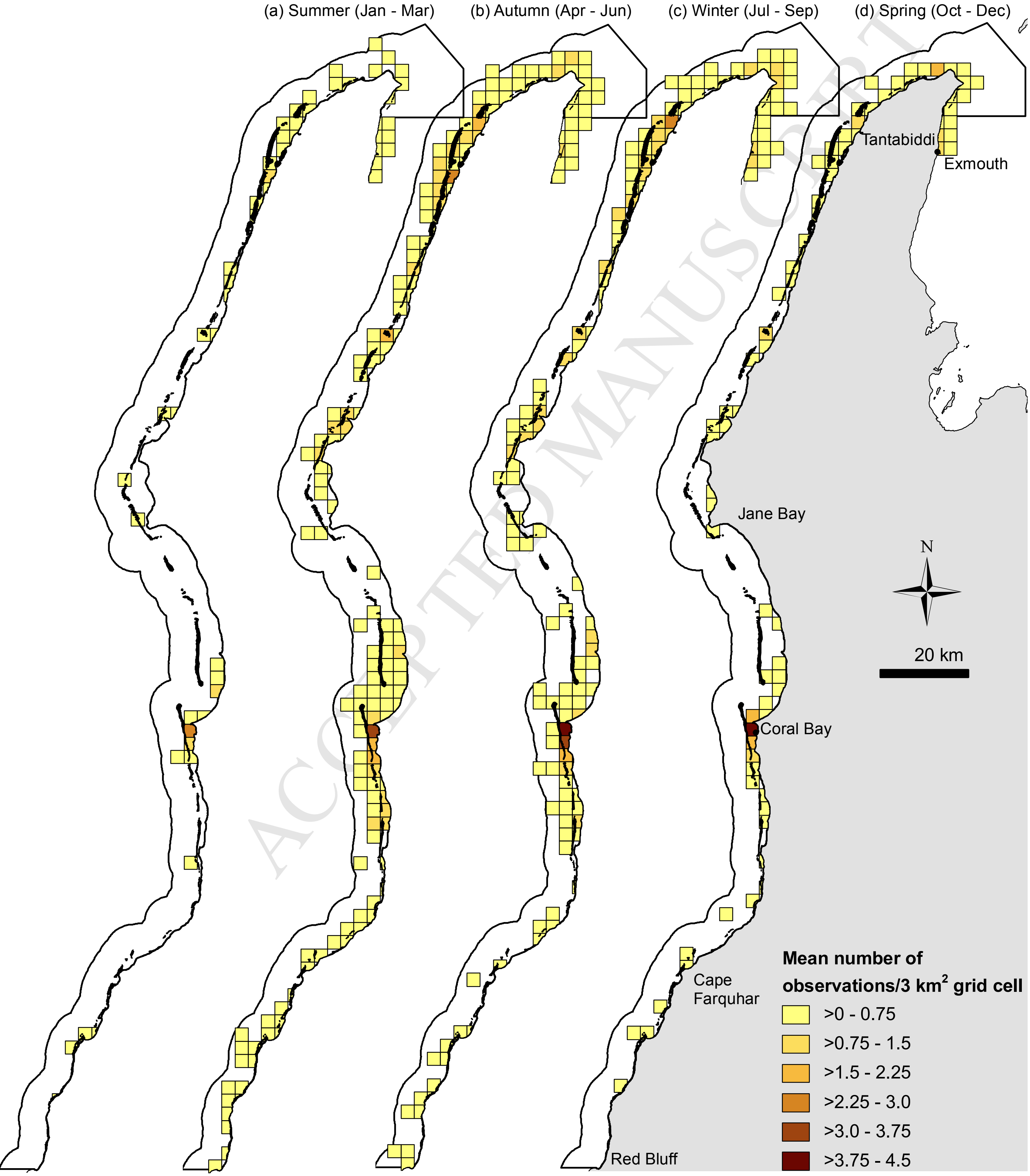
(a) Boat−based activity

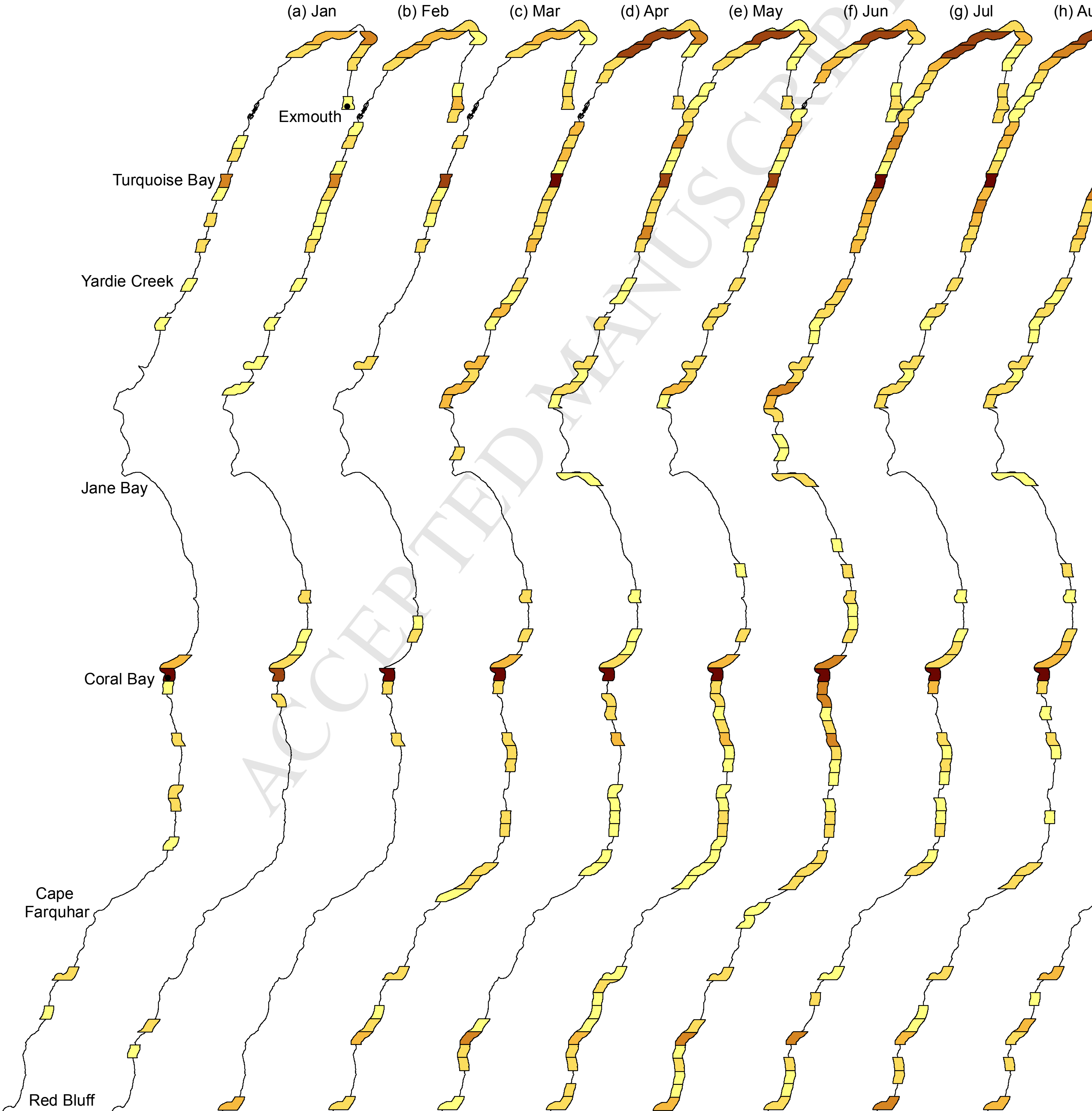


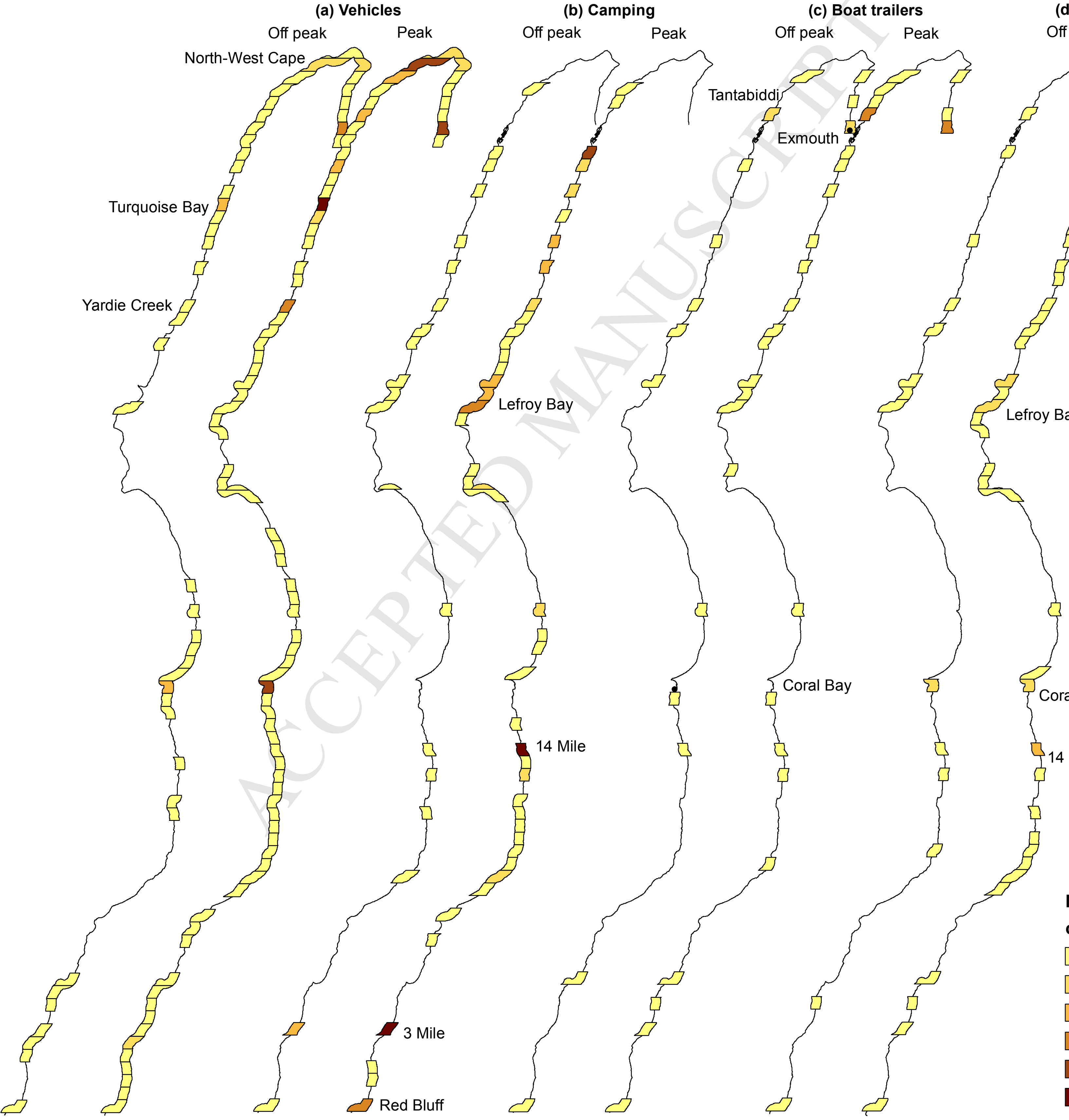
(b) Shore−based activity




Commercial
Charter
Cabin cruiser
Yacht
Open >5m
Open <5m
Tinnie
Tender
Jetski
Kayak
Kitesurfer
Windsurfer
Unknown
vessel type
0
100
200
300
400
500
600
Number of observations
☐ Outside lagoon
▨ No reef crest
■ Inside lagoon


(a) Summer (Jan - Mar)
(b) Autumn (Apr - Jun)
(c) Winter (Jul - Sep)
(d) Spring (Oct - Dec)
Tantabiddi
Exmouth
Jane Bay
N
20 km
Coral Bay
Cape Farquhar
Red Bluff
Mean number of observations/3 km² grid cell
>0 - 0.75
>0.75 - 1.5
>1.5 - 2.25
>2.25 - 3.0
>3.0 - 3.75
>3.75 - 4.5


(a) Jan
(b) Feb
(c) Mar
(d) Apr
(e) May
(f) Jun
(g) Jul
(h) Au
Exmouth
Turquoise Bay
Yardie Creek
Jane Bay
Coral Bay
Cape Farquhar
Red Bluff


(a) Vehicles
Off peak
Peak
North-West Cape
Turquoise Bay
Yardie Creek
(b) Camping
Off peak
Peak
Lefroy Bay
14 Mile
3 Mile
Red Bluff
(c) Boat trailers
Off peak
Peak
Tantabiddi
Exmouth
Coral Bay
(d
Off
Lefroy Ba
Cora
14