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Aerial surveys of shore-based recreational fishing in Carnarvon and Shark Bay: June to August 2012

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1.0 Executive summary

Aerial surveys are a useful tool for obtaining data on the spatial distribution of recreational fishing and estimating fishing effort. Following the successful application of this method in the Perth Metropolitan area, aerial surveys were conducted around Carnarvon and Shark Bay from June to August 2012. Recreational shore-based fishers were identified by fishing method (*i.e.,* line fishing, ballooning, netting and spearfishing) and their location geo-referenced. Additional information on non-fishers, camps, boat trailers, vehicles and boats anchored or on the beach was also recorded. A combination of systematic random and stratified random sampling was employed, providing good estimates of fishing effort when conducting 6 and 9 surveys per month in Shark Bay and Carnarvon, respectively.

A total of 683 and 305 recreational shore-based fishers were counted during aerial surveys in Carnarvon and Shark Bay, respectively. The majority of fishers were participating in line fishing, followed by ballooning (a specialised form of line fishing) and netting. Analysis of temporal factors revealed some significant differences between month, day type (weekday, weekends/public holidays) and time of day (morning, midday and afternoon) when considering numbers of camps and boat trailers. However, the number of recreational fishers was not influenced by these factors. This is likely to be due to the small resident population, and high numbers of tourists, during the winter months.

The spatial distribution of recreational shore-based fishers varied throughout the study area, with the Quobba coastline, 1 Mile Jetty and Steep Point having the highest density of recreational fishers. Line fishers were observed on a variety of platforms (*i.e.,* beaches, cliffs and jetties) while ballooning was located almost exclusively on cliffs. Netting was only observed on beaches and in, or near, mangroves. Non-fishers, camps, boat trailers and boats anchored or on the beach were heterogeneously distributed throughout the study area.

The successful implementation of this current study indicates that similar designs would be suitable for surveying other regional sites. The data provided can contribute to the management of nearshore (<20 m depth) and pelagic fish stocks, and marine ecosystems, while also complementing land-based surveys from which detailed catch information can be obtained for estimation of catch rate and total catch.

2.0 Introduction

Western Australia has the fastest growing population of all states in Australia, with the northern regions in particular experiencing rapid growth and development due to the influence of the resource sector (ABS, 2010). The remarkable natural features and high level of biodiversity along much of the northern coastline are also the focus of many marine-orientated tourism activities, including recreational fishing activity from boats and the shore (Carlsen and Wood, 2004; Collins, 2008). Such activity has been identified as a possible risk to fish stocks and the environment in the Gascoyne Coast and North Coast bioregions (Shaw, 2000; Human and McDonald, 2009). This is of particular concern as participation in recreational fishing is likely to increase in line with population growth (Wise *et al.*, 2007).

State-wide estimates of recreational boat-based catch and fishing effort have been generated in northern Western Australia during a recent survey undertaken in 2011/12 by the Department of Fisheries (DoF) (DoF, 2012). Roving creel and bus route surveys have also been implemented in the Gascoyne Coast and North Coast bioregions to provide estimates of boat-based catch and fishing effort within these areas (Williamson *et al.*, 2006; Wise *et al.*, 2012).

Recreational shore-based fishing has often comprised a small component of these surveys undertaken in the north of Western Australia, with data on catch and effort provided at broad spatial scales [see Sumner *et al.* (2002) and Williamson *et al.* (2006)]. However, the collection of such data is difficult as many sites have limited coastal access (often along sandy tracks accessible by 4WD only) and accommodation options (predominantly coastal campsites that require visitors to be self-sufficient).

Aerial surveys are a useful tool for estimating fishing effort and ascertaining the spatial distribution of shore-based recreational fishing over large areas which may be difficult to access by vehicle (Pollock *et al.*, 1994; Smallwood *et al.*, 2011a; Smallwood *et al.*, 2011b). These data can then be used in the allocation of sampling effort for future on-site surveys where catch information may be obtained. The successful implementation of a series of aerial surveys of recreational shore-based fishing in the Perth Metropolitan area in 2010 and 2011 (Smallwood *et al.*, 2011b; Smallwood *et al.*, 2012b), led to this project to conduct a survey in a regional area in northern Western Australia.

3.0 Objectives

The objectives of this project were to:

1. Evaluate and identify a site for aerial surveys of recreational shore-based fishing in northern Western Australia;
2. Determine the most appropriate method of data collection and analysis for aerial surveys at this site, including calculation of fishing effort;
3. Determine the spatial and temporal distribution of shore-based recreational fishers; and
4. Provide data that can be used by managers and stakeholders when considering management of nearshore (<20 m depth) fish stocks in regional Western Australia.

4.0 Site selection

Several factors were considered when selecting the site for aerial surveys of recreational shore-based fishing in northern Western Australia including;

1. the level of shore-based recreational fishing activity and existing knowledge (which may also be used to compare results across surveys),
2. feasibility (*i.e.*, logistics, access to the accommodation and services) and,
3. preferences of management agencies and stakeholders.

Broome, Karratha and Port Hedland in the North Coast bioregion, and Exmouth, Carnarvon and Shark Bay in the Gascoyne Coast bioregion were the sites evaluated in this process (Figure 1).

Recreational shore-based fishing is a popular activity along much of the coastline of northern Western Australia, although few surveys of recreational shore-based fishing have been undertaken in recent years (Table 1). The most recent surveys have been conducted in Exmouth (along the Ningaloo Marine Park) in 2007, and an aerial survey is currently underway between Port Hedland and Derby, as a component of Western Australian Marine Science Institute 2 (WAMSI 2). While Shark Bay, Carnarvon and Karratha are also popular with recreational shore-based fishers (Shaw, 2000; Sumner *et al.*, 2002), surveys have not be completed in these areas since the early 2000s.

Shark Bay and Carnarvon were highlighted as areas of interest by management. These data will provide an understanding of recreational shore-based fishing in the Point Quobba Fish Habitat Protection Area (FHPA), Miaboolya Beach FHPA, Shark Bay World Heritage area and Shark Bay Marine Park, which is beneficial for several management agencies. Long-term monitoring of boat-based recreational fishing has been undertaken in Shark Bay in response to recreational fishing of the iconic snapper (*Pagrus auratus*) (Jackson and Moran, 2012; Wise *et al.*, 2012), while data collection of shore-based recreational fishing activity has been more intermittent.

It would be possible to conduct aerial surveys in each of the six sites available for selection, and assessing the benefits and limitations of each has provided useful information for any future aerial surveys in northern Western Australia. After consideration of all the factors, Shark Bay and Carnarvon were selected as the preferred sites, as their close proximity allowed them both to be incorporated into a single survey, with field staff based in Carnarvon.

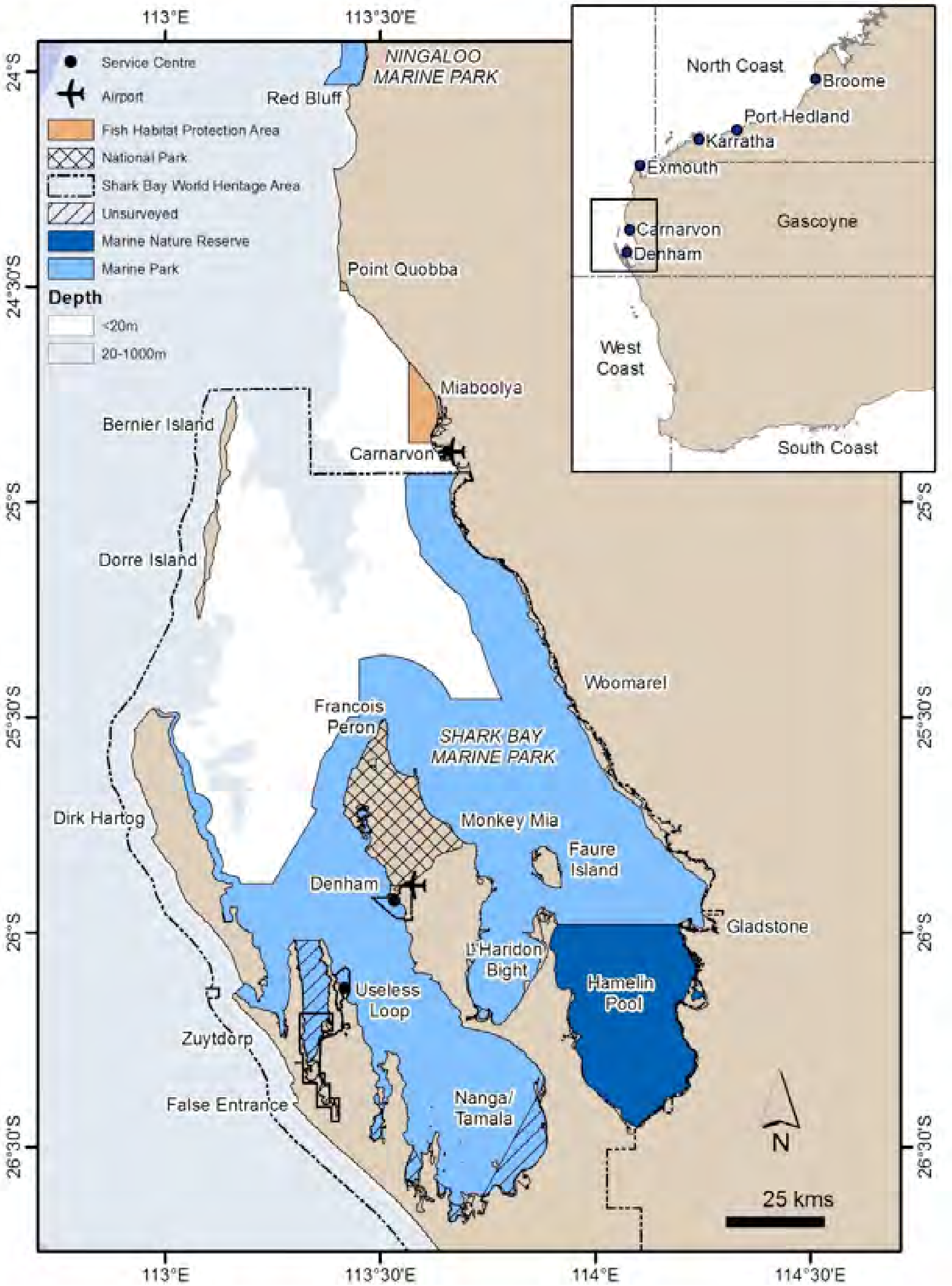

Figure 1. Location of all sites considered in northern Western Australia (inset) and details of the selected study area in Carnarvon and Shark Bay.

Table 1. Timeline of previous research on shore-based recreational fishing in northern Western Australia.

Year	Survey type	Duration	North Coast			Gascoyne		
			Broome	Port Hedland	Karratha	Exmouth	Carnarvon	Shark Bay
1983	Aerial survey (Moran, unpublished data, DoF)	10 months (Feb – Nov 1983)						
1984								
1985								
1986								
1987								
1988								
1989								
1990								
1991								
1992								
1993								
1994								
1995								
1996	Roving creel survey (Sumner and Steckis, 1999)	1 month (July 1996)						
1997								
1998	Access point & roving creel survey (Sumner et al., 2002)	12 months (Apr 1998 – Mar 1999)						
	Aerial survey (Sumner, unpublished data, DoF)	3 months (Jun – Aug 1998)						
1999	Access point & roving survey (Williamson et al., 2006)	12 months (Dec 1999 – Nov 2000)						
2000	Phone/diary survey (Henry and Lyle, 2003)	12 months (May 2000 – Apr 2001)						
2001	Tamala creel survey (Sumner and Malseed, 2002)	12 months (May – Oct 2001)						
2002	Tamala creel survey (DoF, unpublished data)	6 months (May – Oct 2002)						
2003	Tamala creel survey (DoF, unpublished data)	6 months (Apr – Aug 2003)						
2004								
2005								
2006								
2007	Aerial and land-based observation surveys, roving creel survey (Smallwood and Beckley, 2012)	12 months (Jan – Dec 2007)						
2008								
2009								
2010								
2011								

5.0 Study area

Carnarvon and Shark Bay are located in the southern part of the Gascoyne Coast bioregion and, for the purposes of this study, are defined as geographically distinct locations extending from Red Bluff to Gladstone and L'Haridon Bight to False Entrance, respectively (Figure 1). This separation is due to the location of Hamelin Pool Marine Nature Reserve in between the two sites, and also corresponds to the boundaries used in previous recreational fishing surveys. A number of discrete survey areas were defined within each site using information from prior studies as well as natural features and management boundaries (Table 2). These survey areas not only provide a useful broad spatial scale for analyses, but also assist with defining the start and finish locations that were randomly selected for each aerial survey.

Table 2. Extent of survey areas within each site.

Site Name	Area Name	Extent		Approx. length of coastline
Carnarvon	Quobba	Red Bluff -24.0333, 113.4415	Gascoyne River -24.8643, 113.6203	100 km
	Carnarvon	Gascoyne River -24.8643, 113.6203	Oyster Creek -24.9293, 113.6860	10 km
	Woomarel	Oyster Creek -24.9293, 113.6860	Gladstone -25.9535, 114.2501	140 km
Shark Bay	L'Haridon Bight	Point Petit -25.9518, 113.8706	Monkey Mia -25.7944, 113.7191	90 km
	Francois Peron	Monkey Mia -25.7944, 113.7191	Lagoon Point -25.9186, 113.5182	100 km
	Denham	Lagoon Point -25.9186, 113.5182	Goulet Bluff -26.2160, 113.6907	40 km
	Nanga/Tamala	Goulet Bluff -26.2160, 113.6907	Steep Point -26.1495, 113.1608	200 km
	Dirk Hartog	Dirk Hartog Island		140 km
	Zuytdorp	Steep Point -26.1495, 113.1608	False Entrance -26.3932, 113.3082	40 km

Recreational fishing from boats and the shore is a popular activity around Carnarvon and Shark Bay due to the diversity of coastal geomorphology and habitats which provide for a range of aquatic organisms to be targeted (DEC, 2008; DoF, 2012). Along much of the coastline, shallow and/or sheltered waters combine with mangroves, sandy beaches, creek systems and salt marshes to enable shore-based fishers to catch a wide variety of nearshore species such as mullet (Muglidae), tailor (*Pomatomus saltatrix*) and whiting (Sillaginidae) (Sumner *et al.*, 2002; DoF, 2003). The remainder of the coastline (*i.e.,* Steep Point, Dirk Hartog Island and Quobba) is more exposed, and deeper waters (up to 20 m) often abut cliffs where shore-based fishers can catch species such as snapper (*Pagrus auratus*), Spanish mackerel (*Scomberomorus commerson*) and golden trevally (*Gnathanodon speciosus*) (Sumner *et al.*, 2002; DoF, 2004). Tailor and whiting are indicator species for the nearshore ecological suite (<20 m) while Spanish mackerel and grey mackerel (*Scomberomorus semifasciatus*) are indicators for the pelagic suite (DoF, 2011). Line fishing is the dominant type of recreational fishing from boats and the shore, although netting, spearfishing and targeting of rock lobster using pots or snares is also undertaken (CALM, 1996; DoF, 2004). In addition, ballooning is a common method for targeting pelagic species such as Spanish mackerel from cliffs; whereby an offshore breeze and gas-filled balloon is used to position a line and bait on the water surface out to sea (Cusack and Roennfeldt, 2003).

Carnarvon (population ~6,000) and Denham (population ~1,000) are the only service centres located within the study area and, along with Monkey Mia, have constructed public ramps for launching vessels. Tourism is an important industry in the region, with many visitors travelling to the region during the mild winter months from April to October (Marriott *et al.*, 2012). Camping is permitted at many sites along the coast, especially in Shark Bay where there are numerous access tracks in some areas. Boats can also be launched directly off the beach at many of these sites.

Locations in the study area that were excluded from the survey include Faure Island, Bernier Island and Dorre Island. Access to these islands by the general public is restricted or prohibited, and shore-based fishing was therefore not expected to occur in any large numbers. Due to the offshore location of these islands they were also difficult to survey safely in a single engine plane. Hamelin Pool Marine Nature Reserve was also excluded as it is a no-take area, and 100% compliance was assumed. In addition, several narrow convoluted loops or embayments that were difficult to survey or had no vehicle access, were also excluded (Figure 1). It was assumed that no shore-based recreational fishing activity occurred in these areas. These exclusions assisted with reducing flight times, which had benefits in terms of minimising observer fatigue and enabling the entire flight to be conducted without refuelling.

6.0 Survey design

This study aimed to provide information on recreational shore-based fishing activity in Carnarvon and Shark Bay. Fishing activity was divided into several sub-categories including line fishing, ballooning, netting and spearfishing. Only people actively participating in any of these types of recreational fishing were counted. Actively participating was defined as having those people with lines or nets in the water, or fishing equipment (such as rods or catch bucket) present. Unless these criteria were met, observed individuals were recorded as non-fishers.

During each flight, observers made instantaneous counts of shore-based fishers along the survey route, to provide an overall progressive survey count (Pollock *et al.*, 1994). All observations were geo-referenced and associated attributes such as number of people, fishing method (*i.e.,* line fishing, netting) and platform (*i.e.,* beach, cliff, jetty or groyne) were recorded. This was similar to aerial surveys conducted previously in the West Coast bioregion (Smallwood *et al.*, 2011b; Smallwood *et al.*, 2011c). Data from digital cameras and data loggers were processed using Aerial Survey Assistant Software [see Smallwood *et al.* (2011c)]. Geo-referenced data on number of camps, vehicles, anchored boats and boat trailers were also collected, as this information can assist with understanding the distribution of shore and boat-based fishing activity. It should also be noted that vehicles were only counted at day use sites, and not at campsites. A day use site is a location where camping is not permitted and visitors generally only utilise the area for short periods of time within a day, while a single tent or caravan is generally counted as one campsite. However, a group of tents or caravans is classed as a single camp if they are sharing a single communal area. Training with observers prior to the start of the survey attempted to ensure that standard data collection techniques were employed. Flights were conducted at a height of 300 metres, and at a speed of 100 knots.

6.1 Sampling regime

To minimise the costs associated with conducting surveys at a site remote from Perth, a combination of systematic random and stratified random sampling was employed, whereby surveys were grouped into 'trips' of several consecutive days and were completed twice per month. Grouping flights in this way is a limitation of the survey design that may result in an underestimate of variance associated with estimates of effort. To minimise this, a number of randomisation techniques were used when allocating the dates of these trips across each month so that, as far as possible, each day had an equal probability of being selected (Table 3). This reflects a modified systematic random sampling regime as there was no standard number of days allocated between trips. A minimum period between trips was not required as staff alternated between trips and they could be performed back-to-back if necessary. Flights within each trip were allocated using stratified random sampling, with Shark Bay and Carnarvon treated as two separate survey sites.

The winter months from June to August were selected for the aerial surveys as previous recreational fishing surveys in the Gascoyne Coast bioregion identified these months as a peak time for shore-based recreational fishing activity (Sumner *et al.*, 2002). However, it is acknowledged that the summer months are popular for shore-based fishers targeting pelagic species, such as Spanish mackerel, especially around Steep Point (Sumner *et al.*, 2002; Cusack and Roennfeldt, 2003).

Tides are another factor which can influence fishing activity, although this was not incorporated into the current survey design as a stratum. The number of flights and their distribution within the survey months should have ensured that sampling occurred across low, mid and high tides.

Day type (weekday, weekends/public holidays) was not believed to have a significant effect in Shark Bay and Carnarvon when compared to other survey sites, due to the small permanent populations located in these service centres and the large number of visitors who holiday in the region, often for extended periods. Stratification by day type was incorporated unequally into the survey design (1WE:2WD) and *post hoc* analyses used to determine if these strata could be collapsed for calculation of fishing effort. Although the July school holidays occurred within the study period, in line with other studies of shore-based fishing in Western Australia, they were not treated as weekends.

Shark Bay had two time of day strata (morning, afternoon) while, due to its shorter coastline and therefore shorter flight time, Carnarvon had three time of day strata (morning, midday, afternoon) (Table 3). Although surveys of shore-based fishing in the Perth Metropolitan area showed less fishing activity in the middle of the day (Smallwood *et al.*, 2011b), this current study was undertaken in a remote, tourism-dependent economy and it is unclear if the same pattern would be evident. Therefore, these strata were allocated equally within month. Allocating flights across an entire day also allowed for fishing effort to be calculated.

Table 3. Summary of the survey design for each site.

Site	**Carnarvon**	**Shark Bay**
Extent	Red Bluff – Gladstone	Point Petit – False Entrance
Length of coast	~250 km	~600 km
Study period	June – August 2012	June – August 2012
No. days (N)	92	92
No. survey days (n)	27	18
Length of fishing day	8 am – 5 pm	8 am – 5 pm
Survey length	3 hours	4.5 hours
Flight times	Morning (8 am – 11 am) Midday (11 am – 2 pm) Afternoon (2 pm – 5 pm)	Morning (8 am – 12.30 pm) Afternoon (12.30 pm – 5 pm)
Mode of travel	Plane (Cessna 172RG)	Plane (Cessna 172RG)
Cruising speed	100 knots	100 knots
Stratification & randomisation		
Month	Stratified by month, with each sampled at the same intensity.	
Trip allocation	Each trip was allocated using a series of steps to maximise the equal probability of each day being selected. A random number of days were selected between each trip and each day within a trip was sampled.	
Site	Random selection was used to determine which site was allocated flights first within a trip.	
Tide	No stratification.	
Day type	Random allocation of days, non-uniform probability (1WE/PH:2WD).	
Time of Day	Random allocation across each time-of-day stratum with uniform probability.	
Starting location	Randomly selected from locations listed in Table 2.	
Direction of travel	Randomly selected.	

Visibility issues are a common concern during aerial surveys as it may be difficult to identify shore-based fishers on cliffs or groynes (Pollock and Kendall, 1987; Pollock *et al.*, 1994). Photos were taken of fishing locations, especially if a vehicle was present, so they could be examined during post-processing. Where required, the pilot was also instructed to slow down or complete a loop to provide a second opportunity to capture photos or additional information. The convoluted coastline around Shark Bay may hinder observations of shore-based fishers (*i.e.,* the plane will often be turning). Being aware of upcoming turns and open communication with the pilot generally ensured that the plane was not turning at a time when a clear view of the coastline was required. It is difficult to see shore-based fishers due to bad light conditions and therefore surveys were scheduled to depart and arrive approximately 1 hour after sunrise and prior to sunset, respectively.

Although the weather conditions (*i.e.,* strong winds and rain) expected in Carnarvon and Shark Bay during the winter months are milder than further south in Western Australia, the majority of rain events do occur during this time (BOM, 2012). Such weather conditions, along with other factors such as illness or plane malfunction that may cause cancellation of a flight and rescheduling options were considered in the survey design. Two flights were cancelled during the survey of which one (a Shark Bay survey in June) could not be re-scheduled while the other survey (a Carnarvon survey in July) was rescheduled for the end of that particular trip on a similar day type and time of day. Additionally, a replacement plane was required on four surveys due to engine problems, although this did not impact on the survey schedule.

6.2 Calculation of fishing effort

The maximum count aerial survey design is often used to estimate fishing effort for recreational shore-based fishers (Volstad *et al.*, 2006; Veiga *et al.*, 2010; Smallwood *et al.*, 2012b). For this technique to be successful, it is necessary to obtain information on the distribution of fishing activity occurring across a day (*i.e.,* using access point surveys, roving creel surveys or remotely operated cameras). However, these other survey techniques were difficult and expensive to implement in this remote area. Flight times were therefore randomly selected with equal probability across a day so that only data from the aerial surveys were required to calculate fishing effort (Pollock *et al.*, 1994; Volstad *et al.*, 2006; Veiga *et al.*, 2010). For variance calculations it was assumed that days were randomly selected.

Fishing effort (in hours) was calculated separately for Carnarvon and Shark Bay, as they are geographically distinct locations, for line fishing and ballooning only. It was not possible to calculating fishing effort for netting due to the low number of observations. The length of the survey day was 9 hours (8 am – 5 pm) and fishing effort could only be calculated for this period. Time of day was sampled with uniform probability, although this differed between Carnarvon (0.33) and Shark Bay (0.5) due to the differing flight times. Day type was initially incorporated into the survey design but these were collapsed based on *post-hoc* analyses that indicated fishing activity was not statistically different between weekdays and weekends/public holidays. Fishers were counted as individuals, rather than fishing parties, therefore effort was calculated as fisher hours.

Following Pollock *et al.* (1994) effort for fishing day i was estimated in fisher hours for stratum s and fishing period j as

$$e_{sij} = I_{sij}T,$$

where I_{sij} is the instantaneous count of fishers and T is the length of the fishing period j. Daily effort for stratum s was estimated as

$$\hat{E}_{si} = \frac{e_{sij}}{\pi},$$

where π is the total probability that the daily effort occurred in fishing period j. Mean daily effort was calculated as

$$\hat{\bar{E}}_s = \frac{1}{n_s} \sum_{n_s} \hat{E}_{si} \quad ,$$

where n_s is the number of days sampled in stratum s. Estimated variance for the mean daily effort within stratum s was calculated as

$$var(\hat{\bar{E}}_s) = \frac{\delta_s^2}{n_s} \quad ,$$

where the numerator was represented as

$$\delta_s^2 = \frac{1}{n_s - 1} \sum_{s=1}^{n_s} (\hat{E}_{si} - \hat{\bar{E}}_s)^2 \quad .$$

The total effort in each stratum s was estimated by extrapolating the mean daily effort to the total number of days N as

$$\hat{E}_s = N_s \hat{\bar{E}}_s \ ,$$

for which variance was calculated as

$$var\,(\hat{E}_s) = N_s^2\, var\,(\hat{\bar{E}}_s) \quad .$$

Total effort was then estimated by summing the effort estimates across the number of strata L

$$\hat{E} = \sum_{s=1}^{L} \hat{E}_s \quad .$$

Variance of the total effort was calculated using the sum of individual variance estimates for each stratum s as

$$var\,(\hat{E}) = \sum_{s=1}^{L} var\,(\hat{E}_s) \quad .$$

Standard error was calculated by taking the square root of the variance while Relative Standard Error (RSE) was calculated by dividing the standard error by the estimate of fishing effort to indicate the uncertainty expressed as a percentage of the estimate.

6.3 Validation of aerial counts

A standard process of data validation was undertaken prior to analysis to check for data entry errors and consistency of data collection between observers. In addition to this standard validation, paired-observer counts were completed on 10 flights to provide some understanding of visibility bias. This technique has been widely implemented in wildlife surveys to derive correction factors to adjust observed numbers to absolute estimates (Cook and Jacobson, 1979; Bayliss and Yeomans, 1989; Graham and Bell, 1989; Pollock *et al.*, 2006; Koneff *et al.*, 2008) and enable the probability of a fisher being detected to be determined (but not the probability of a fisher being available for detection). It was only aimed to complete this analysis at a preliminary level to investigate the correlation of counts between observers, as it was outside the scope of this report.

Land-based counts were also conducted at Steep Point on six days that corresponded to approximate times of the aerial surveys. These counts were completed by staff from the Department of Environment and Conservation and DoF Fisheries and Marine Officers, who followed a predetermined route between the cliffs at Steep Point (-21.1495, 113.1608) and eastwards along the beach to the mangroves (-26.1853, 113.2447). Five of these land-based counts corresponded with paired-observer counts. Due to the direction of the survey (*i.e.,* the paired-observers could only be used on 'clockwise' surveys) and staff availability, the sixth land-based count occurred on a flight with a single observer. The number of camps and shore-based fishers were counted during the land-based counts and this data provided some understanding of the number of fishers available for detection by aerial observers at this location.

6.4 Statistical analyses and mapping

Only counts obtained by the primary observer were used for the analysis techniques described below.

The existence of statistically significant differences in counts of variables (*i.e.,* fishers, non-fishers, camps and boat trailers) with respect to month, day type and time of day strata were tested for each site using analysis of variance (ANOVA). There was insufficient data to conduct this analysis for each fishing method. Data were tested for assumptions of normality and homogeneity and, if required, were transformed.

Linear regression models were fitted to the paired-observer counts to compare the total counts obtained from each observer during the flights, for all variables (*i.e.,* fishers, non-fishers, camps). The various components of the regression were presented (coefficient, r^2 value and p-value). A similar analysis was used to compare observations from aerial surveys with the six land-based counts at Steep Point during the Shark Bay surveys.

The spatial distribution of observations (*i.e.,* fishers, non-fishers, camps and boat trailers) was summarised across the entire 3-month study period using the point density tool in ArcGIS 10.1. This tool calculates the density of point features in a grid cell by counting the total number of point features within a specified search radius (or neighbourhood), 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 0.1 km^2 was specified, along with a search radius of 1 km. This analysis was completed separately for Carnarvon and Shark Bay. The survey design was also taken into consideration by dividing each density layer by the number of flights undertaken at each site. Similar techniques have been used in studies of recreational use in Australia (Smallwood *et al.*, 2012a) and elsewhere (Dalton *et al.*, 2010; Thompson and Dalton, 2010).

7.0 Results

A total of 683 and 305 recreational shore-based fishers were counted during aerial surveys conducted in Carnarvon and Shark Bay from June to August 2012, respectively. At both sites, the majority of these fishers were involved in line fishing (87.7 – 94.1%) followed by ballooning (3.3 – 10.5%) and netting (1.8 – 2.6%) (Table 4). No spear fishers were recorded during the study, although this is likely due to the difficulty in observing this activity.

Table 4. Number of people observed undertaking different types of shore-based recreational fishing and non-fishing activity in Carnarvon and Shark Bay, where n = number of flights.

Activity type	Carnarvon n = 27	Shark Bay n = 17
Recreational fishing	683	305
Line fishing	599 (87.7%)	287 (94.1%)
Ballooning	72 (10.5%)	10 (3.3%)
Netting	12 (1.8%)	9 (2.6%)
Spear fishing	0	0
Non fishing	703	999

7.1 Temporal distribution

7.1.1 Shore-based recreational fishing and non-fishing activity

The effect of month on the mean number of recreational shore-based fishers (all types) counted during the aerial surveys was non-significant for both Carnarvon ($F_{(1,25)}$=1.28, p=0.267) and Shark Bay ($F_{(1,15)}$=0.63, p=0.438). Subsequent analysis of this activity type was therefore combined across the entire 3-month survey period.

The mean numbers of recreational shore-based fishers varied by time of day and day type during aerial surveys for Carnarvon and Shark Bay (Figure 2). A two-way ANOVA found the mean number of fishers in Carnarvon and Shark Bay was non-significant when compared to day type and time of day (Table 5).

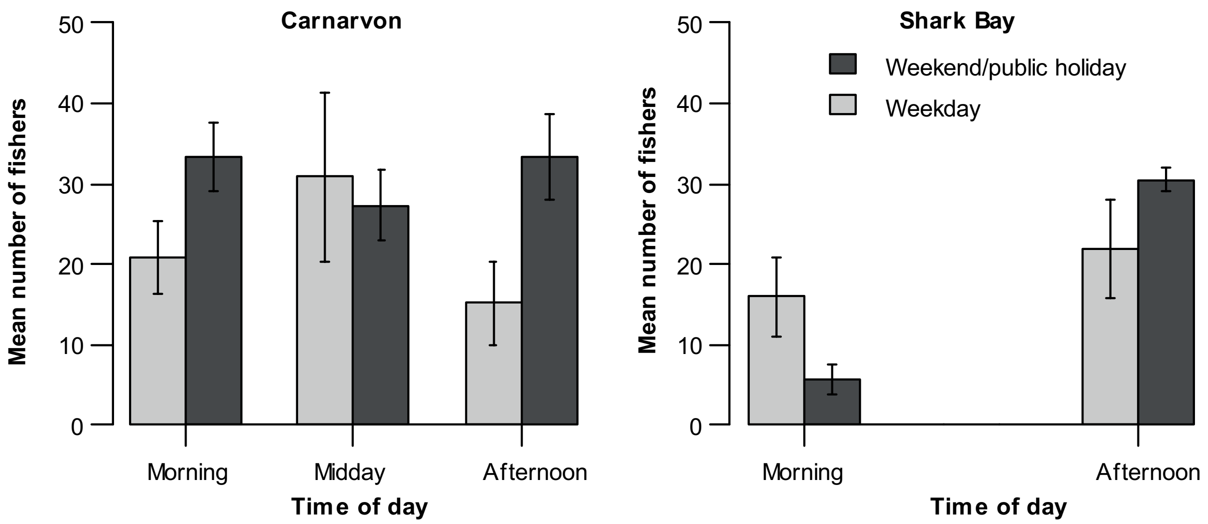

Figure 2. Mean number (±SE) of recreational shore-based fishers (all types) counted per flight during the (a) Carnarvon (n = 27) and (b) Shark Bay (n = 17) surveys.

Table 5. Effects of time of day and day type on the mean number of recreational shore-based fishers (all types) observed during aerial surveys in Carnarvon and Shark Bay where df = degrees of freedom, SS = Sum of Squares, MS = Mean Squares. Bold font denotes significance at levels <0.05.

Source of variation	df	SS	MS	F-value	p
Carnarvon					
Day type	1	2.56	2.56	3.82	0.065
Time of day	2	1.55	0.78	1.16	0.334
Day type x time of day	2	1.34	0.67	0.99	0.387
Residuals	21	14.11	0.67		
Shark Bay					
Day type	1	0.45	0.46	0.72	0.413
Time of day	1	2.51	2.51	3.94	0.069
Day type x time of day	1	1.92	1.92	3.02	0.105
Residuals	13	8.28	0.64		

The number of recreational shore-based fishers observed adjacent to the population centres of Carnarvon and Denham was also investigated with respect to day type. Carnarvon was the only area where mean number of fishers was consistently greater on weekends/public holidays than weekdays. This most likely indicates the effects of the adjacent population centre. However, it was not a statistically significant difference ($F_{(1,25)}$=3.44, p=0.076). Denham is the largest population centre in Shark Bay, and the effect day type on the number of fishers was also non-significant in this area ($F_{(1,25)}$=0.12, p=0.737).

The effect of month on the mean number of non-fishers counted during the aerial surveys was non-significant for Carnarvon ($F_{(1,25)}$=3.73, p=0.065) and Shark Bay ($F_{(1,15)}$=1.44, p=0.248). Subsequent analysis of this activity type was therefore combined across the entire 3-month survey period.

The mean numbers of non-fishers counted during the aerial surveys in Carnarvon were very similar for all times of day and day types (Figure 3). A two-way ANOVA found that time of day and day type had no significant effect on the number of non-fishers in Shark Bay and Carnarvon (Table 6).

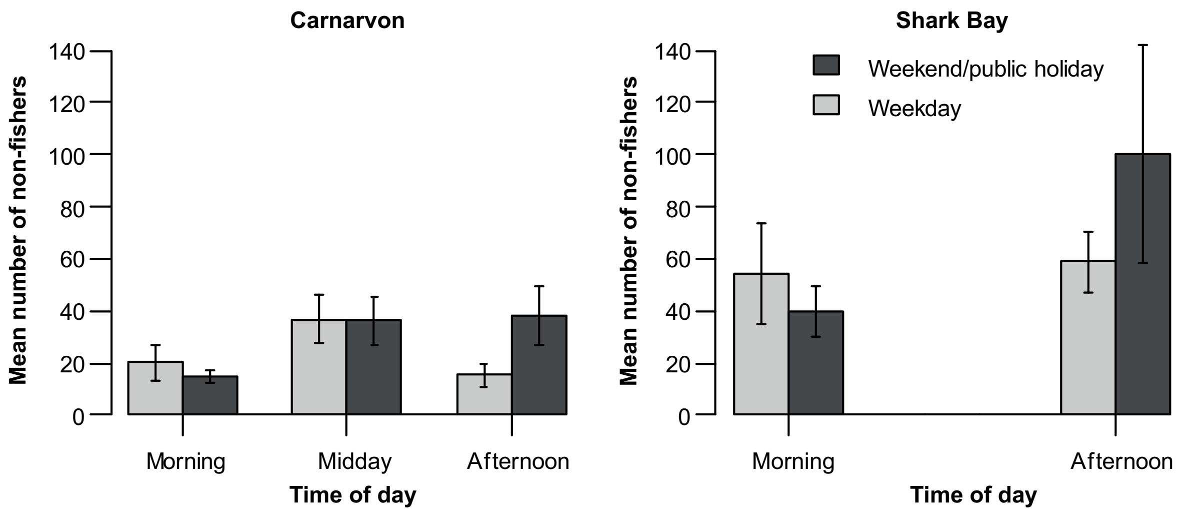

Figure 3. Mean number (±SE) of non-fishers counted per flight during the (a) Carnarvon (n = 27) and (b) Shark Bay (n = 17) surveys.

Table 6. Effects of time of day and day type on the mean number of non-fishers observed during aerial surveys in Carnarvon and Shark Bay where df = degrees of freedom, SS = Sum of Squares, MS = Mean Squares. Bold font denotes significance at levels <0.05.

Source of variation	df	SS	MS	F-value	p
Carnarvon					
Day type	1	189	189	0.66	0.426
Time of day	2	1646	823	2.87	0.079
Day type x time of day	2	893	446	1.56	0.233
Residuals	21	6014	286		
Shark Bay					
Day type	1	180	180	0.12	0.735
Time of day	1	1777	1777	1.18	0.296
Day type x time of day	1	2656	2656	1.77	0.206
Residuals	13	19512	1501		

7.1.2 Camping and vehicles

The effect of month on the mean number of camps counted during the aerial surveys was significant in Carnarvon ($F_{(1,25)}$=8.12, p=0.008) and non-significant for Shark Bay ($F_{(1,15)}$=0.15, p=0.701). The significant difference for Carnarvon was the result of fewer camps observed in June when compared to July and, to a lesser extent, August.

The mean numbers of camps does not show great variation between time of day and day type, as people tend to camp across multiple days (Figure 4). Accordingly, a two-way ANOVA showed no significant effect of these variables on the number of camps in Shark Bay (Table 7). A three-way ANOVA for Carnarvon, which included the additional 'month' variable, showed there was no interactive effect, with the only significant difference for the main effect of month.

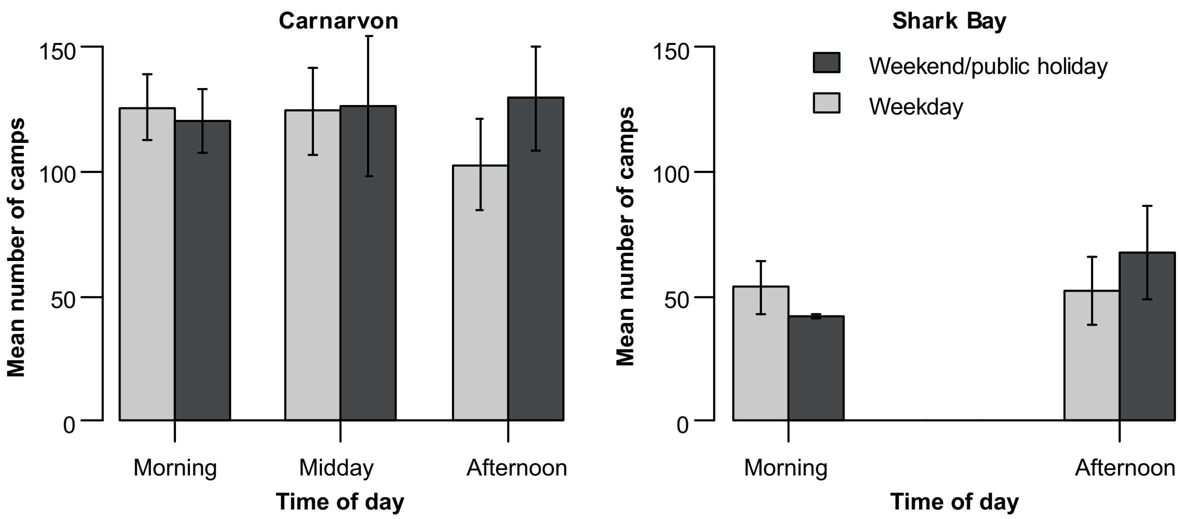

Figure 4. Mean number (±SE) of camps counted per flight during the (a) Carnarvon (n = 27) and (b) Shark Bay (n = 17) surveys.

Table 7. Effects of time of day and day type on the mean number of camps observed during aerial surveys in Carnarvon and Shark Bay where df = degrees of freedom, SS = Sum of Squares, MS = Mean Squares. Bold font denotes significance at levels <0.05.

Source of variation	df	SS	MS	F-value	p
Carnarvon					
Month	1	8537	8537	5.80	**0.029**
Day type	1	353	353	0.24	0.631
Time of day	2	966	483	0.33	0.725
Month x day type	1	3	3	<0.01	0.962
Month x time of day	2	786	393	0.27	0.769
Day type x time of day	2	1115	558	0.38	0.691
Month x day type x time of day	2	993	496	0.34	0.718
Residuals	15	22067	1471		
Shark Bay					
Day type	1	2	2	<0.01	0.956
Time of day	1	168	168	0.24	0.633
Day type x time of day	1	617	617	0.87	0.367
Residuals	13	9189	707		

The effect of month on the mean number of vehicles counted during the aerial surveys was non-significant for Carnarvon ($F_{(1,25)}$=3.83, p=0.062) and Shark Bay ($F_{(1,15)}$=0.75, p=0.4). Subsequent analysis of was therefore combined across the entire 3-month survey period. The mean numbers of vehicles counted during the aerial surveys in Carnarvon was similar for all times of day and day types, as reflected in the two-way ANOVA which found no significant effects (Figure 5; Table 8).

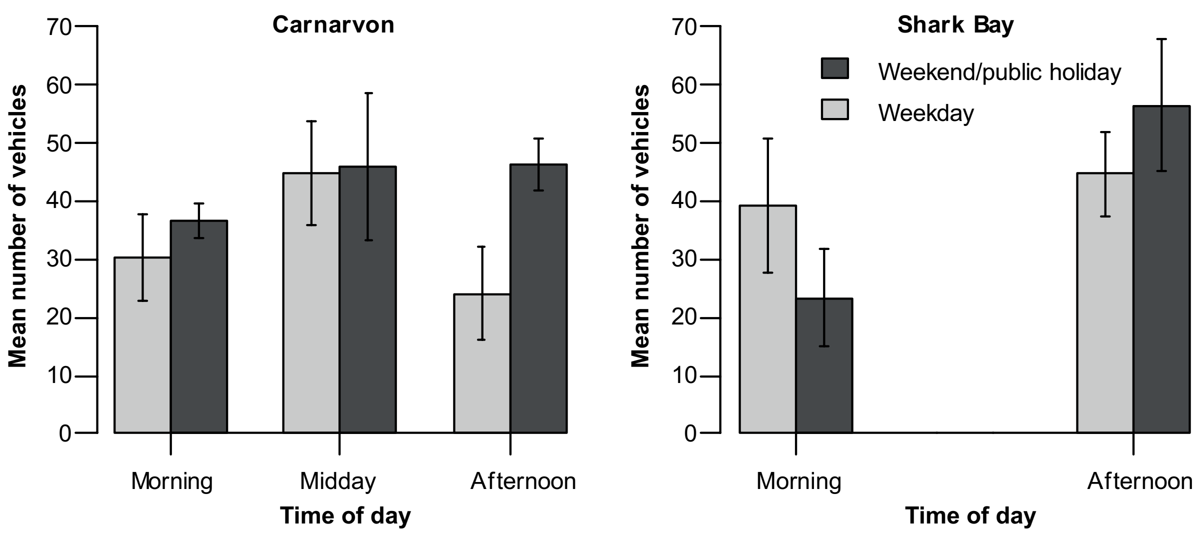

Figure 5. Mean number (±SE) of vehicles counted per flight during the (a) Carnarvon (n = 27) and (b) Shark Bay (n = 17) surveys.

Table 8. Effects of time of day and day type on the mean number of vehicles observed during aerial surveys in Carnarvon and Shark Bay where df = degrees of freedom, SS = Sum of Squares, MS = Mean Squares. Bold font denotes significance at levels <0.05.

Source of variation	df	SS	MS	F-value	p
Carnarvon					
Day type	1	593	594	1.76	0.198
Time of day	2	1035	517	1.54	0.238
Day type x time of day	2	473	237	0.70	0.506
Residuals	21	7063	336		
Shark Bay					
Day type	1	100	100	0.21	0.656
Time of day	1	755	755	1.57	0.233
Day type x time of day	1	656	656	1.36	0.264
Residuals	13	6259	481		

7.1.3 Boat trailers, boats on beach and anchored boats

The effect of month on the mean number of vehicles counted during the aerial surveys was non-significant for Carnarvon ($F_{(1,25)}$=1.61, *p*=0.216) and Shark Bay ($F_{(1,15)}$=0.122, *p*=0.286). Subsequent analysis of was therefore combined across the entire 3-month survey period.

The mean numbers of boat trailers varied by time of day and day type in Carnarvon, with weekends/public holidays having greater numbers than weekdays (Figure 6). In Shark Bay, greater numbers of boat trailers were recorded during the afternoons. The two-way ANOVA found that the mean number of boat trailers was statistically significant with respect to time of day in Carnarvon, and for day type in Shark Bay (Table 9).

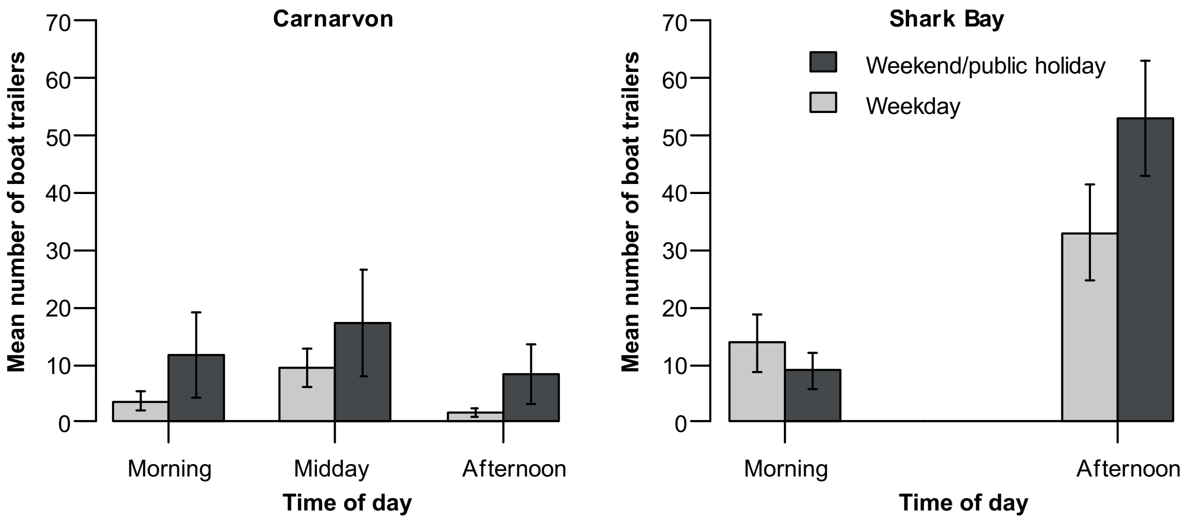

Figure 6. Mean number (±SE) of boat trailers counted per flight during the (a) Carnarvon (n = 27) and (b) Shark Bay (n = 17) surveys.

Table 9. Effects of time of day and day type on the mean number of boat trailers observed during aerial surveys in Carnarvon and Shark Bay where df = degrees of freedom, SS = Sum of Squares, MS = Mean Squares. Bold font denotes significance at levels <0.05.

Source of variation	df	SS	MS	F-value	p
Carnarvon					
Day type	1	342	342	4.93	**0.037**
Time of day	2	312	156	2.24	0.131
Day type x time of day	2	2	1	0.17	0.983
Residuals	21	1458	69		
Shark Bay					
Day type	1	36	36	0.15	0.705
Time of day	1	2897	2897	12.10	**0.004**
Day type x time of day	1	529	529	2.21	0.151
Residuals	13	3113	239		

The effect of month on the mean number of boats anchored or on the beach counted during the aerial surveys was non-significant for Carnarvon ($F_{(1,25)}$=1.13, *p*=0.298) and Shark Bay ($F_{(1,15)}$=0.19, *p*=0.672). Subsequent analysis of was therefore combined across the entire 3-month survey period. The mean numbers of boats anchored or on the beach was much lower for Carnarvon than Shark Bay (Figure 7). However, at both sites there were no significant effects of time of day and day type (Table 10).

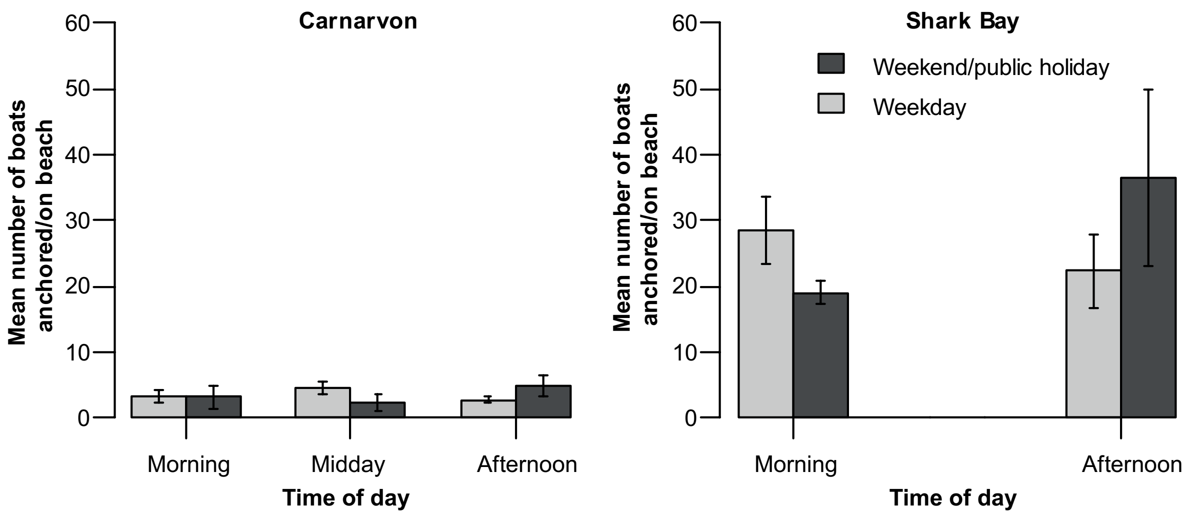

Figure 7. Mean number (±SE) of boats on beach or anchored counted per flight during the (a) Carnarvon (n = 27) and (b) Shark Bay (n = 17) surveys.

Table 10. Effects of time of day and day type on the mean number of boats on beach or anchored observed during aerial surveys in Carnarvon and Shark Bay where df = degrees of freedom, SS = Sum of Squares, MS = Mean Squares. Bold font denotes significance at levels <0.05.

Source of variation	df	SS	MS	F-value	p
Carnarvon					
Day type	1	<0.01	<0.01	<0.01	0.953
Time of day	2	1	1	0.14	0.872
Day type x time of day	2	20	10	2.0	0.161
Residuals	21	106	5		
Shark Bay					
Day type	1	1	1	<0.01	0.931
Time of day	1	1	1	<0.01	0.924
Day type x time of day	1	480	480	3.07	0.103
Residuals	13	2033	156		

7.2 Spatial distribution

7.2.1 Shore-based recreational fishing and non-fishing activity

The spatial distribution of activities varied during the Carnarvon surveys. Line fishing was distributed predominantly on beaches, followed by rock platforms and cliffs. This activity had the highest densities around the Blowholes, Carnarvon (especially 1 Mile Jetty and Pelican Point), Bush Bay and New Beach (Figure 8a). Ballooning was only recorded along the rock platforms and cliffs of the Quobba coastline (Figure 8b). Netting was only recorded at a few locations in low densities between Carnarvon and Bush Bay, which were predominately sandy beaches, followed by in, or near, mangrove systems (Figure 9a). Non-fishers were also recorded during aerial surveys and were found to occur in highest densities at the Blowholes, Carnarvon and Bush Bay (Figure 9b). No people were recorded participating in recreational shore-based fishing (or non-fishing activities) between New Beach and Gladstone.

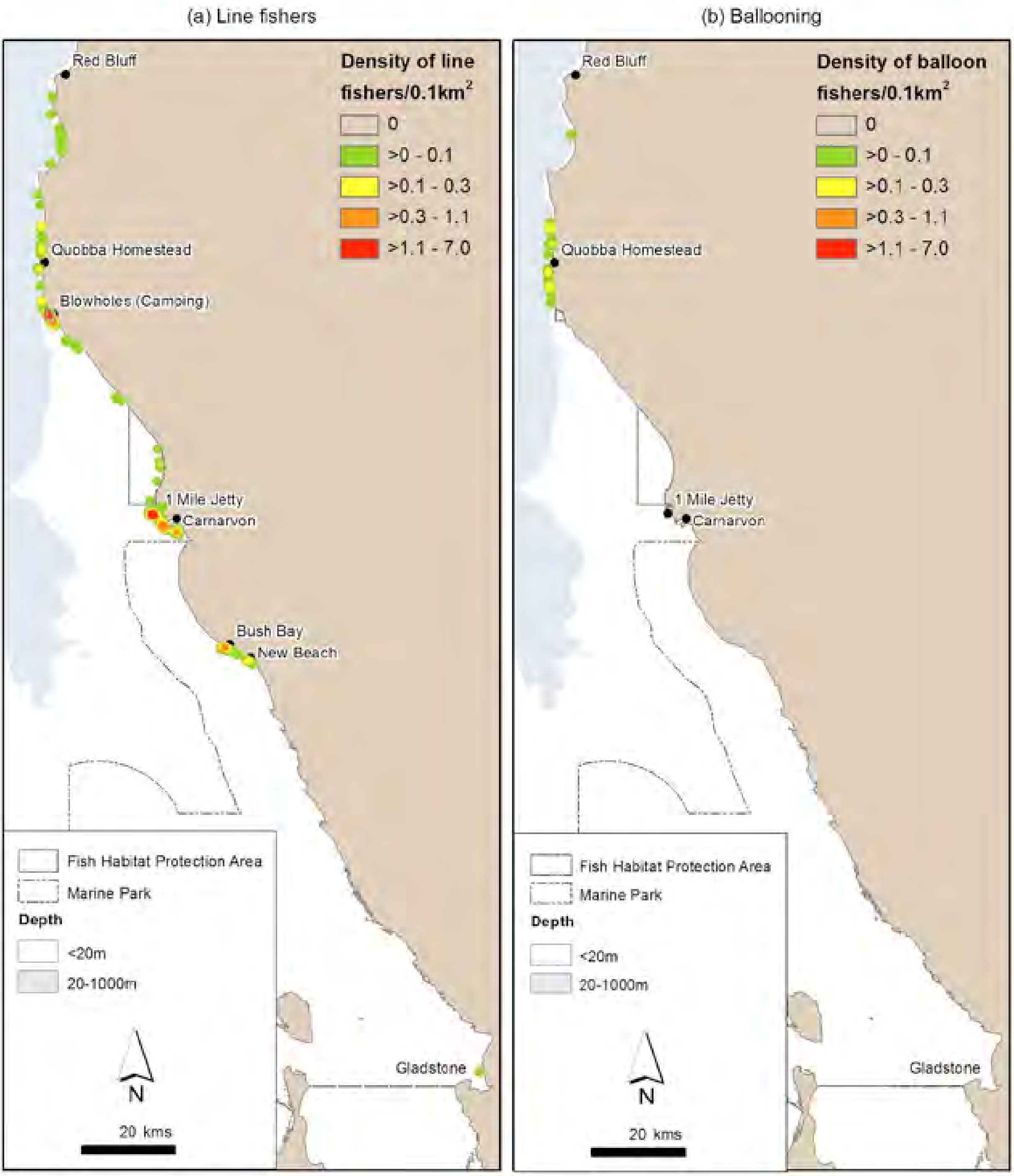

Figure 8. Density of people fishing recreationally using (a) lines and (b) balloons during Carnarvon aerial surveys.

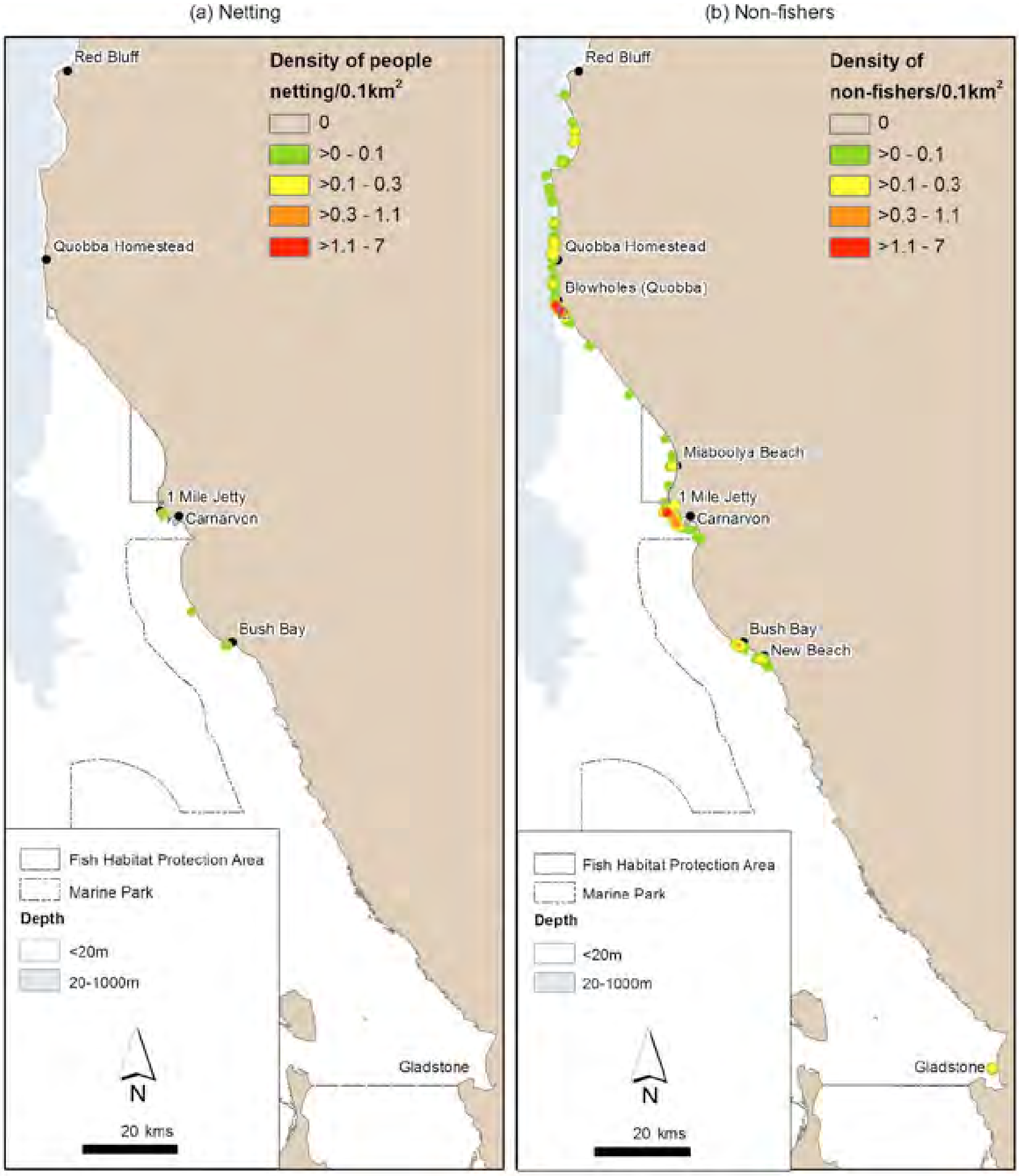

Figure 9. Density of people (a) fishing recreationally using nets and (b) non fishing during Carnarvon aerial surveys.

Line fishing was the only type of recreational shore-based fishing activity observed in the Quobba FHPA and Miaboolya FHPA during the survey. The mean number of fishers observed in the Quobba FHPA was 4.7 (±0.11) per survey. This was lower for the Miaboolya FHPA with a mean of 0.8 (±0.04) fishers per survey.

The spatial distribution of different of activities also varied during the Shark Bay aerial surveys. Line fishing was the most widely distributed and had the highest densities of people, especially around beaches at Monkey Mia, Bottle Bay and Cattle Well, to the north of Denham (Figure 10a). Line fishing was also observed on the cliffs and beaches at Steep Point and Shelter Bay.

Ballooning was only observed on the cliffs at Urchin Point, on Dirk Hartog Island and at Steep Point (Figure 10b). Netting was also only observed at a few locations around Denham and to the south of Monkey Mia which are dominated by sandy beaches and mangroves (Figure 11a). Non-fishers were widely distributed throughout the Shark Bay surveys, with the highest densities recorded at Monkey Mia, Cape Peron, Denham, Eagle Bluff and Steep Point (Figure 11b).

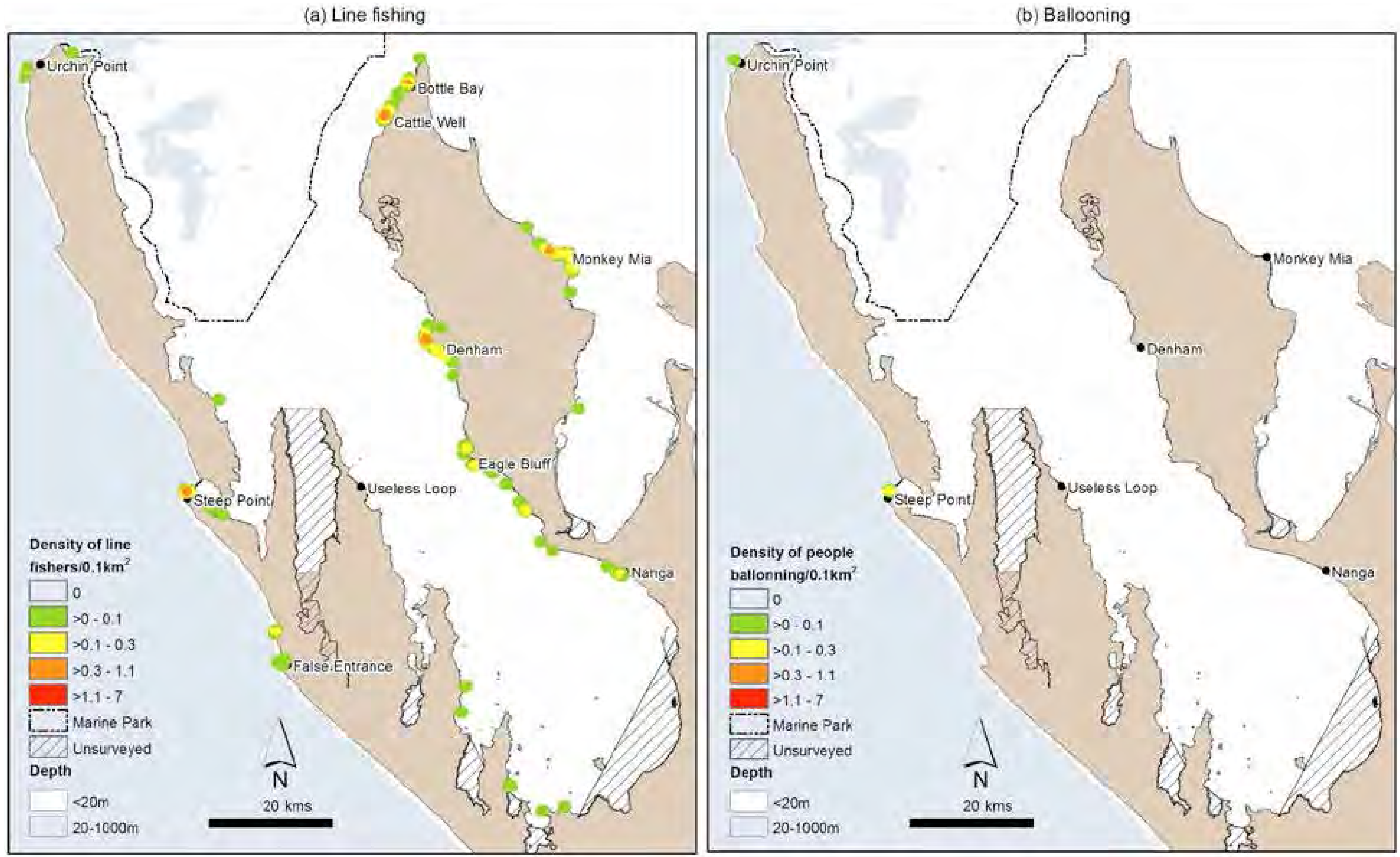

Figure 10. Density of people fishing recreationally using (a) lines and (b) balloons during Shark Bay aerial surveys.

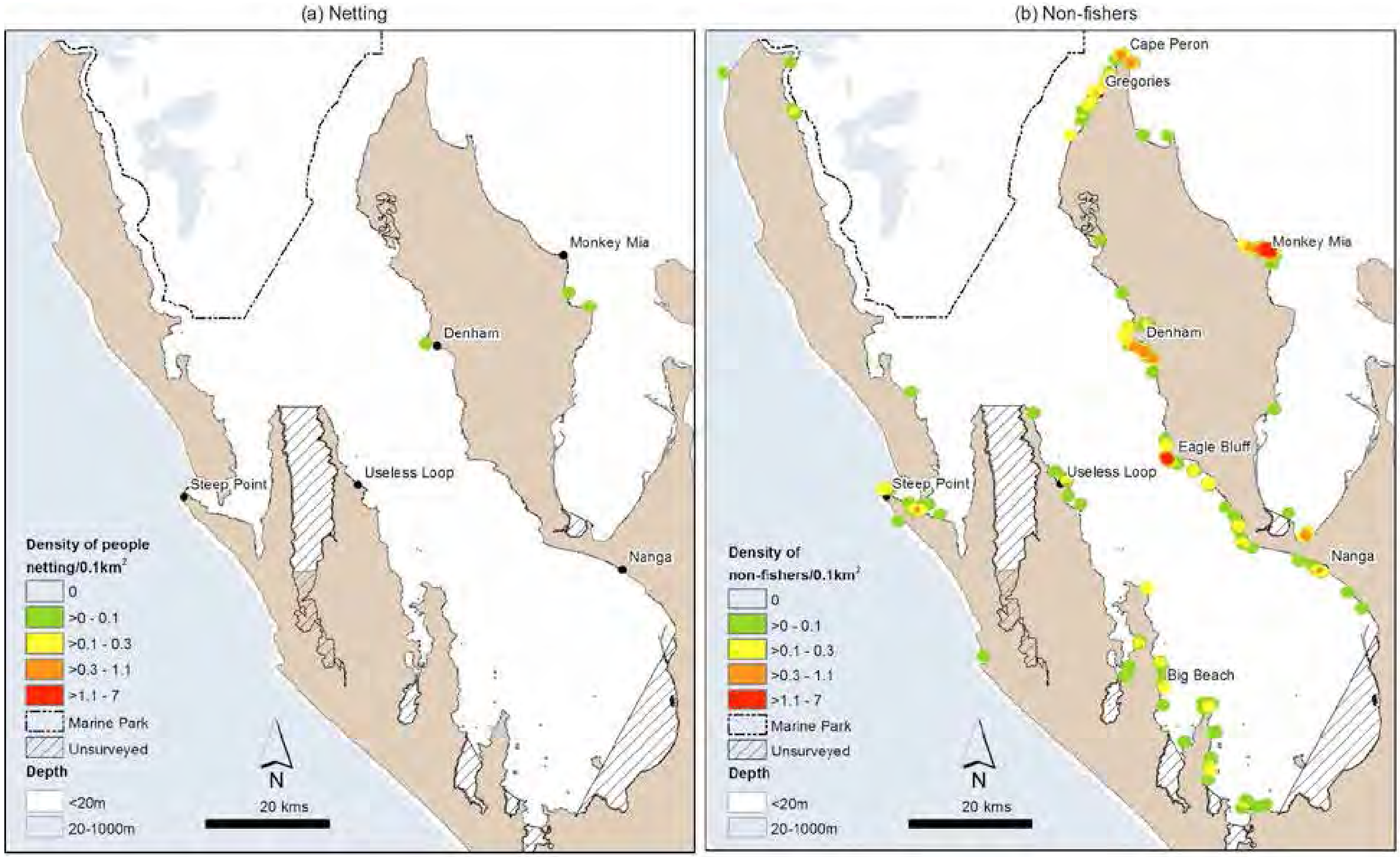

Figure 11. Density of people (a) fishing recreationally using nets and (b) non fishing during Shark Bay aerial surveys.

7.2.2 Camping and vehicles

The highest numbers of camps along the Carnarvon coast were at the Blowholes, Bush Bay and New Beach (Figure 12a). It should be noted that only those camps with caravans, campervans or tents were counted at the Blowholes (*i.e.,* no attempt was made to count or determine occupancy at the beach shacks located in this area). Vehicles were also counted at day use sites, with the highest numbers occurring at the Blowholes and Pelican Point near Carnarvon (Figure 12b). Due to the Quobba access road following the coastline, vehicles were widely distributed throughout this area.

The highest numbers of camps in Shark Bay were at Bottle Bay, Steep Point, Tent Landing, Boorabuggata and around Big Beach (Figure 13a). It should be noted that camps in caravan parks at places such as Nanga or Denham were not counted. Vehicles in day-use areas were counted and were at highest densities at Monkey Mia, Denham, Ocean Park and Eagle Bluff (Figure 13b).

7.2.3 Boat trailers, boats on beach and anchored boats

Boat trailers and boats anchored or on the beach were also counted during the aerial surveys. Anchored boats are those not currently being used (*i.e.*, are anchored off a campsite), which along with boats on the beach, can provide an understanding of potential boating activity. The highest density of boat trailers during the Carnarvon surveys was within the town site, at the only formal boat ramp along this survey route (Figure 14a). Boat trailers were also observed at several other locations, indicating boats had launched from the beach. Boats on the beach or anchored were also only evident in a few locations, with the highest numbers observed at the Blowholes (Figure 14b).

The highest density of boat trailers for the Shark Bay surveys was observed at Denham and Monkey Mia, the only two public boat ramps along this survey route (Figure 15a). Boat trailers were observed at numerous other locations including the caravan park at Nanga, indicating that boats were beach launched from the beach. Boats on the beach or anchored also occurred at numerous locations along the Shark Bay survey route, with the highest numbers observed at Monkey Mia, Steep Point and Boorabuggata (Figure 15b).

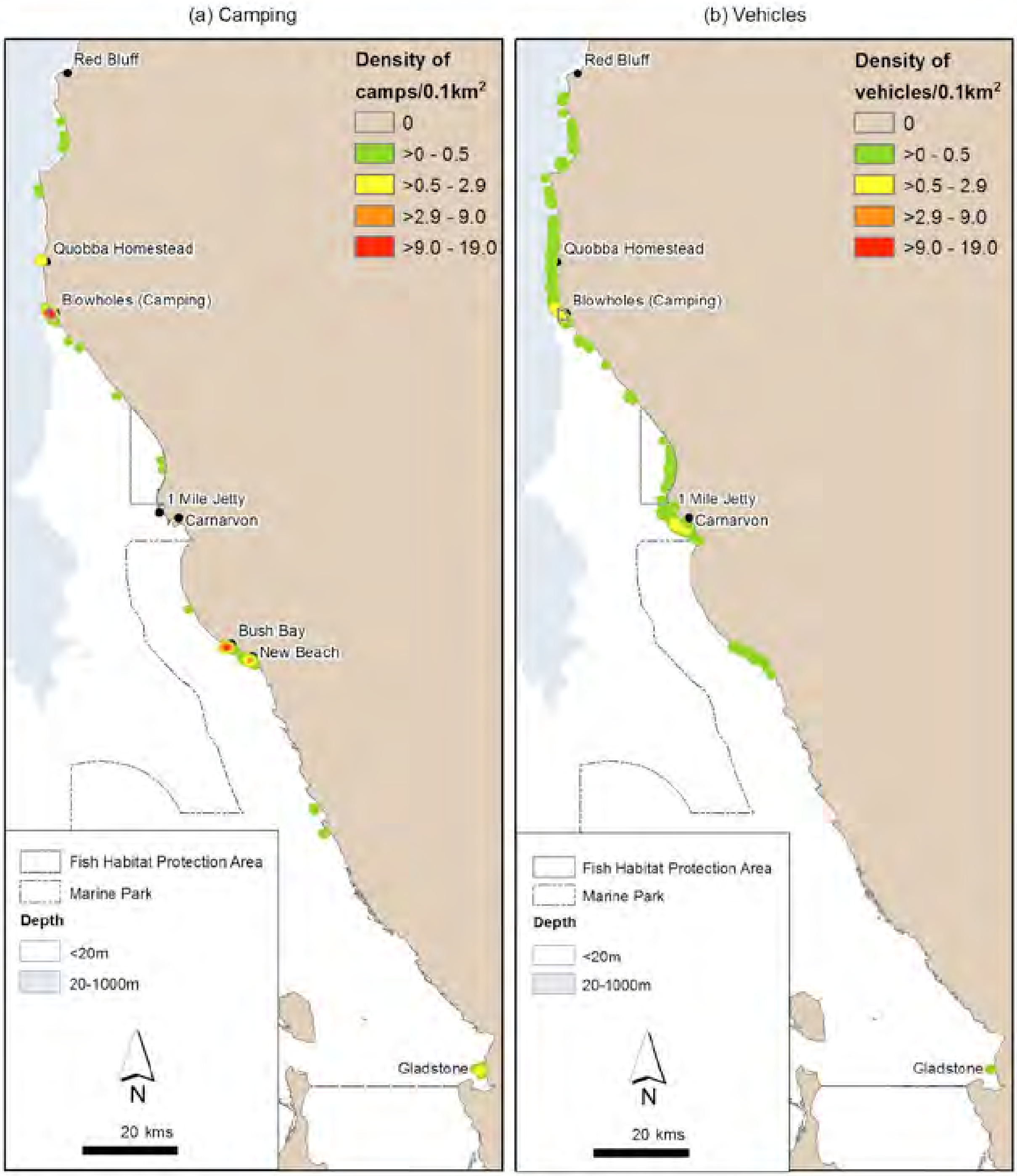

Figure 12. Density of (a) camps and (b) vehicles during Carnarvon aerial surveys.

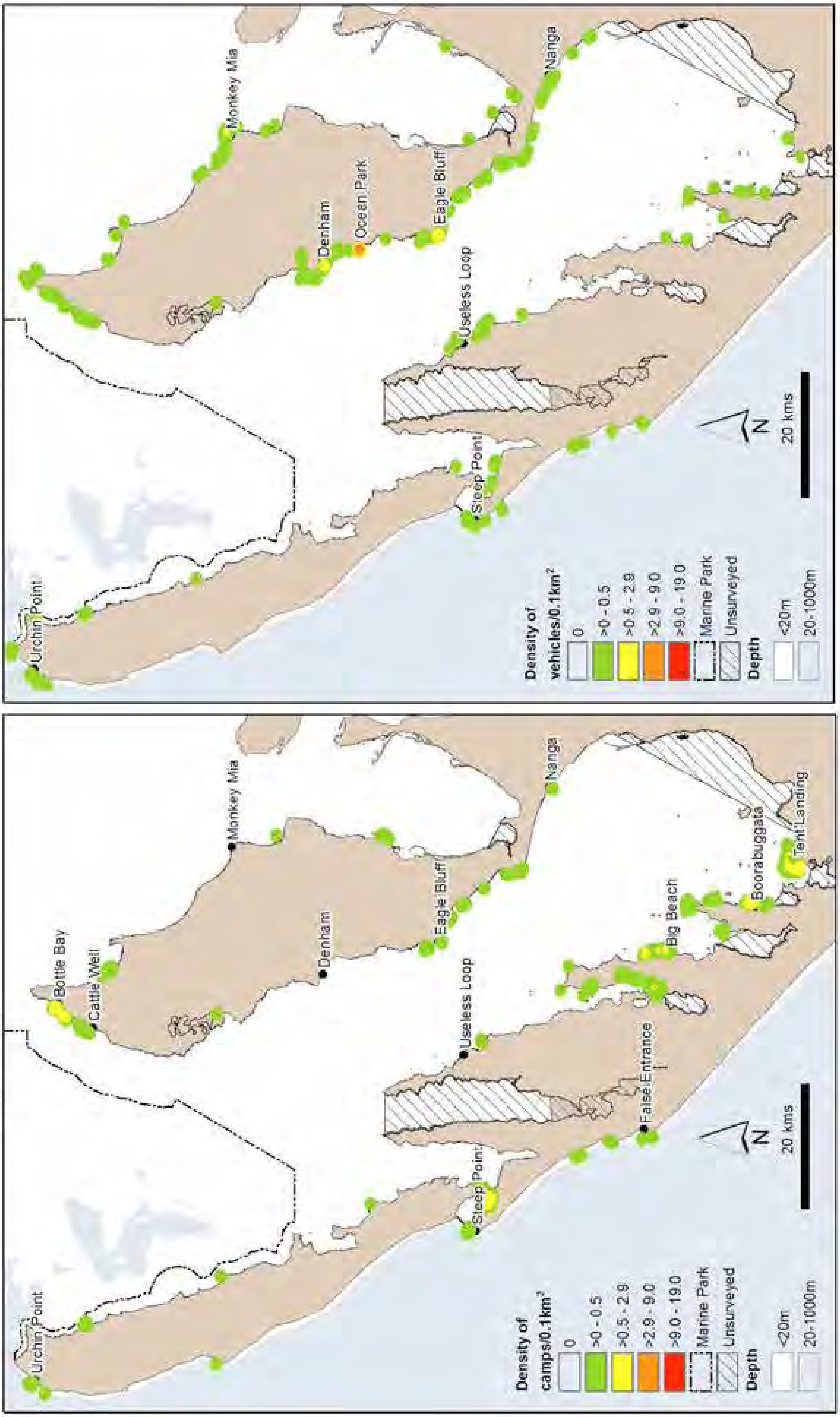

Figure 13. Density of (a) camps and (b) vehicles during Shark Bay aerial surveys.

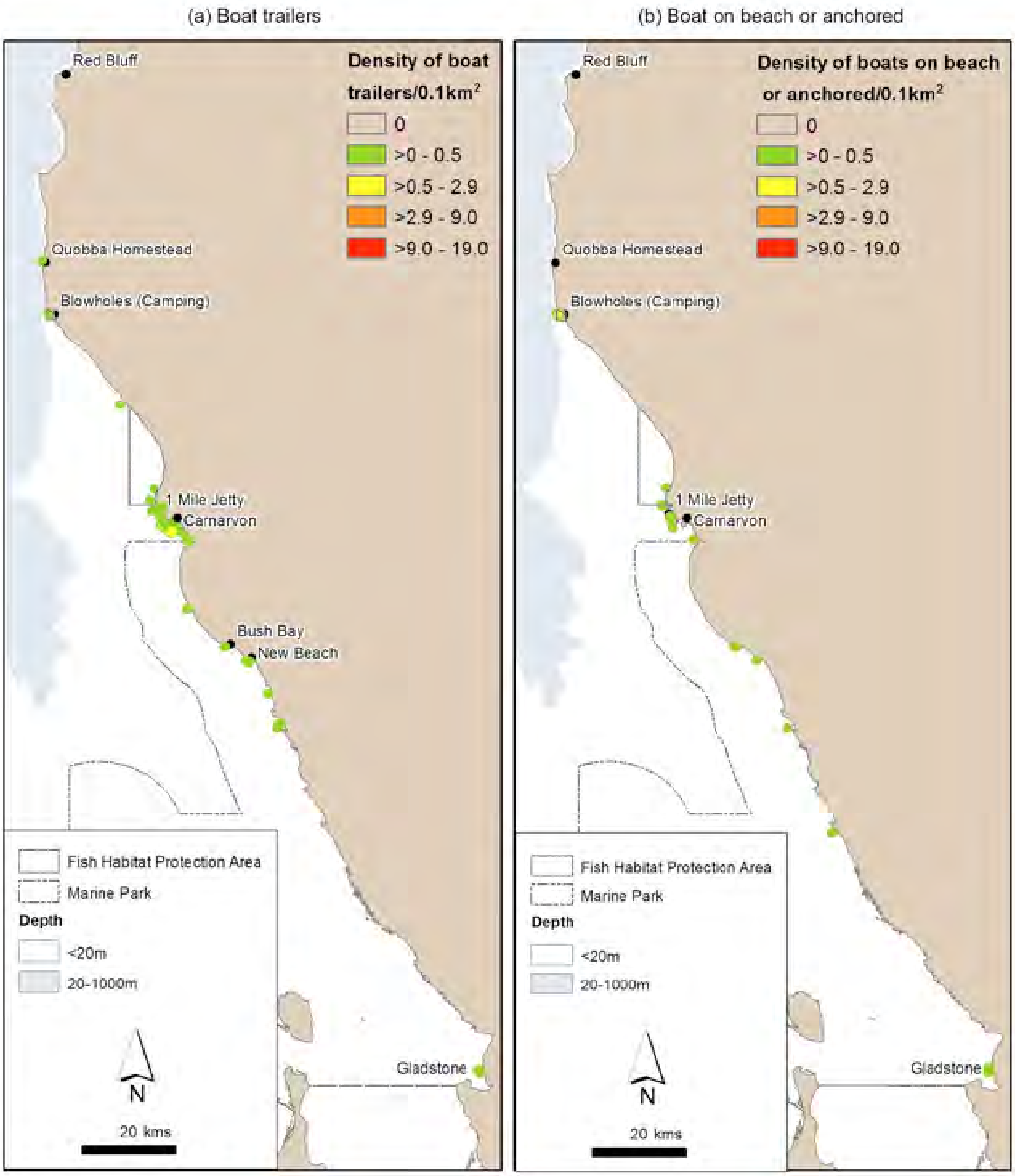

Figure 14. Density of (a) boat trailers and (b) boats on beach or anchored during Carnarvon aerial surveys.

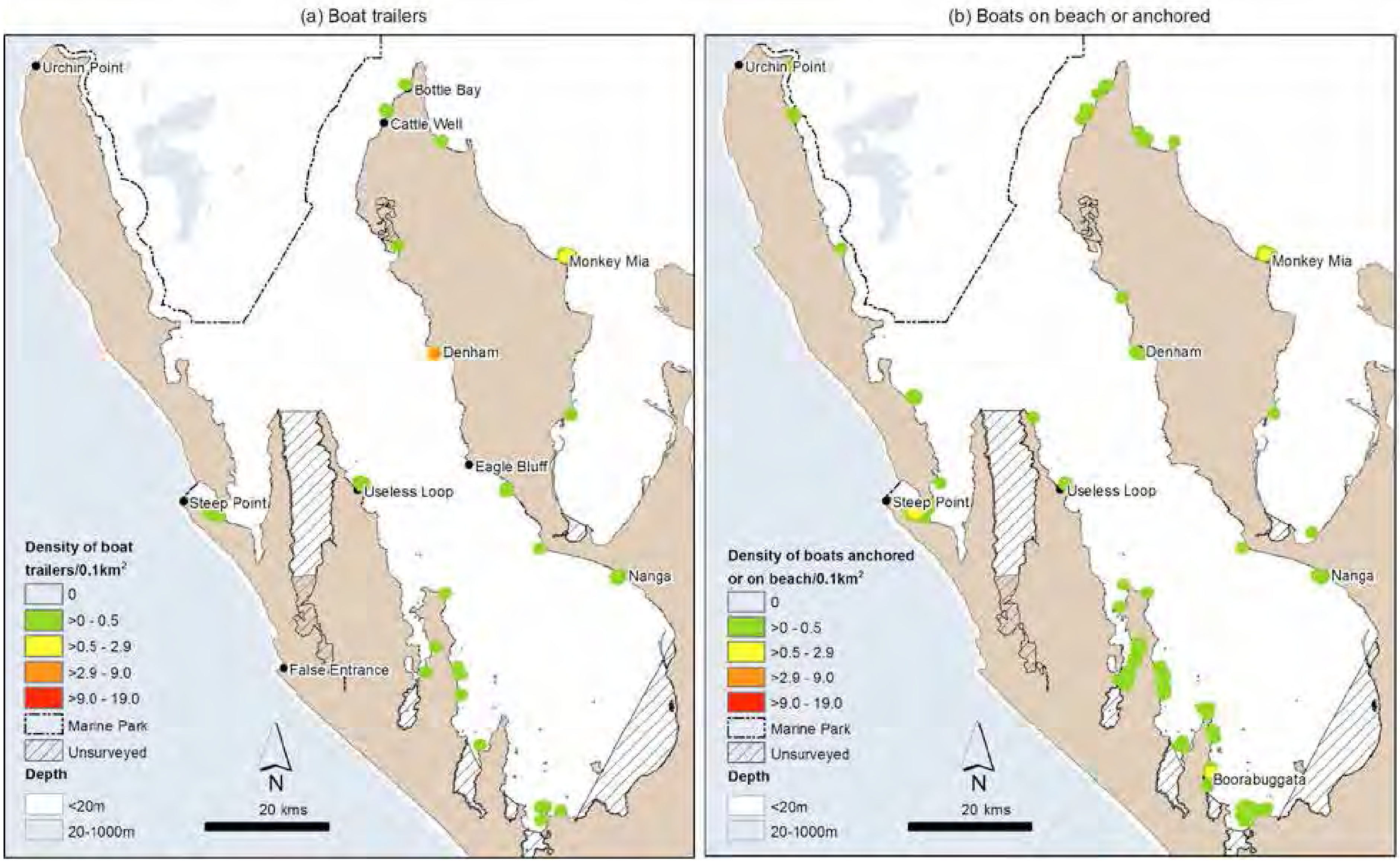

Figure 15. Density of (a) boat trailers and (b) boats on beach or anchored during Shark Bay aerial surveys.

7.3 Shore-based fishing effort

Total recreational shore-based fishing effort for Shark Bay and Carnarvon for June to August 2012 was estimated to be 29,532 fisher hours (SE±7,806; RSE=13%) and 62,356 fisher hours (SE±4,667; RSE=16%), respectively. The greatest fishing effort was recorded during the midday flights in Carnarvon (Figure 16). The afternoon flights in Shark Bay had greater fishing effort than the mornings.

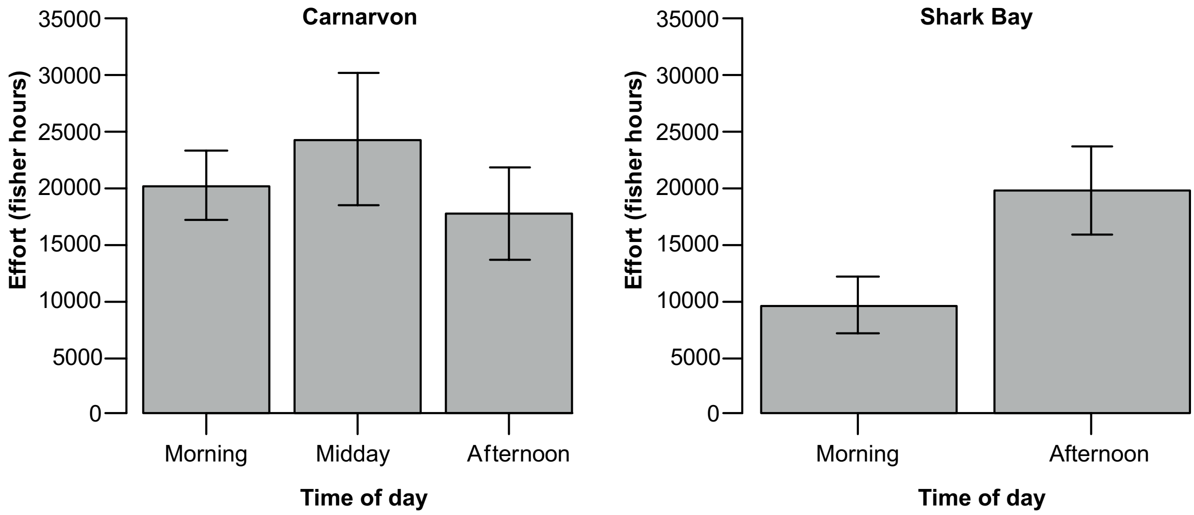

Figure 16. Fishing effort (±SE) by time of day for the Carnarvon and Shark Bay flights.

7.4 Validation of aerial counts

7.4.1 Paired-observer counts

Paired-observer counts were used to investigate potential detection bias between observers when counting the number of fishers, non-fishers, camps, boat trailers, vehicles and boats that were anchored or on the beach. In this analysis, a linear regression model was fitted for each of these variables to compare the counts obtained by each observer across an entire flight, and revealed the data to be highly correlated, with r^2 values ranging between 0.888 – 0.964 and $p<0.001$ (Figure 17; Table 11). These findings indicated that, at a flight level, detection bias was likely to be low. This is particularly important for validating counts of fishers, which were used in the calculation of fishing effort.

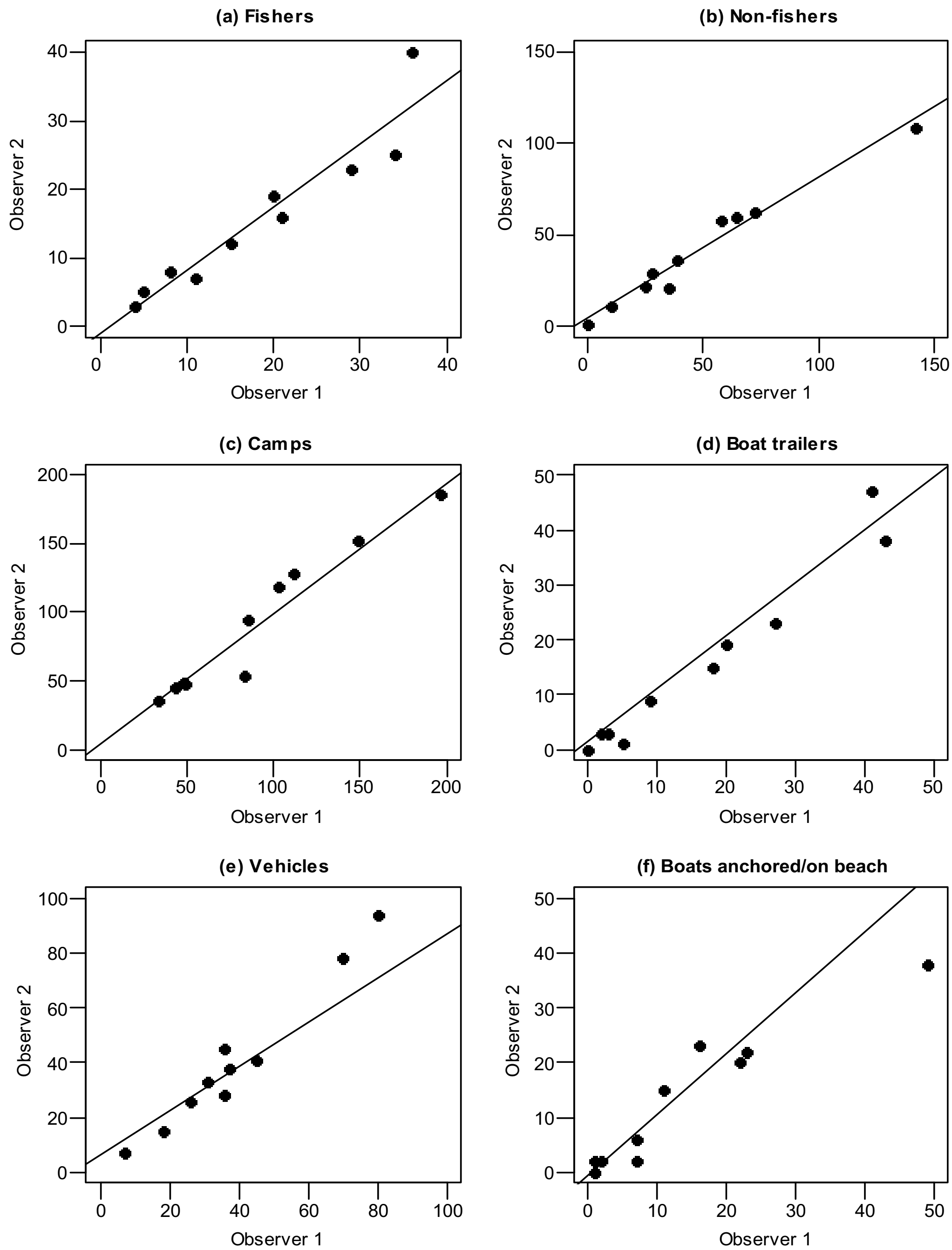

Figure 17. Paired-observer count data obtained from aerial surveys where linear regression shown by solid line.

Table 11. Components of linear regression used to compare paired-observer data obtained during aerial surveys. Bold font denotes significance at levels <0.05.

Variable	Coefficient	r^2	p
Fishers	0.922	0.889	**<0.001**
Non-fishers	0.770	0.964	**<0.001**
Camps	0.955	0.931	**<0.001**
Boat trailers	0.961	0.955	**<0.001**
Vehicles	0.807	0.959	**<0.001**
Boats anchored/on beach	1.108	0.888	**<0.001**

7.4.2 Land-based counts

On six days corresponding to paired-observer aerial surveys of Shark Bay, land-based counts were conducted at Steep Point to understand the potential bias in terms of the availability of fishers, non-fishers and camps for detection (*i.e.* was everything being seen from the air, assuming that the land-based counts were a census of activity). A linear regression model was fitted for each of these variables, and revealed that camps and fishers were significantly correlated, while non-fishers were not (Figure 18; Table 12).

Information on the number of lines in the water was also collected during the land-based counts. The aim of this was to determine if people were fishing with multiple lines, which is very difficult to detect from the air. These counts revealed that on the six days where the land-based counts occurred, the number of lines was equal to the number of fishers.

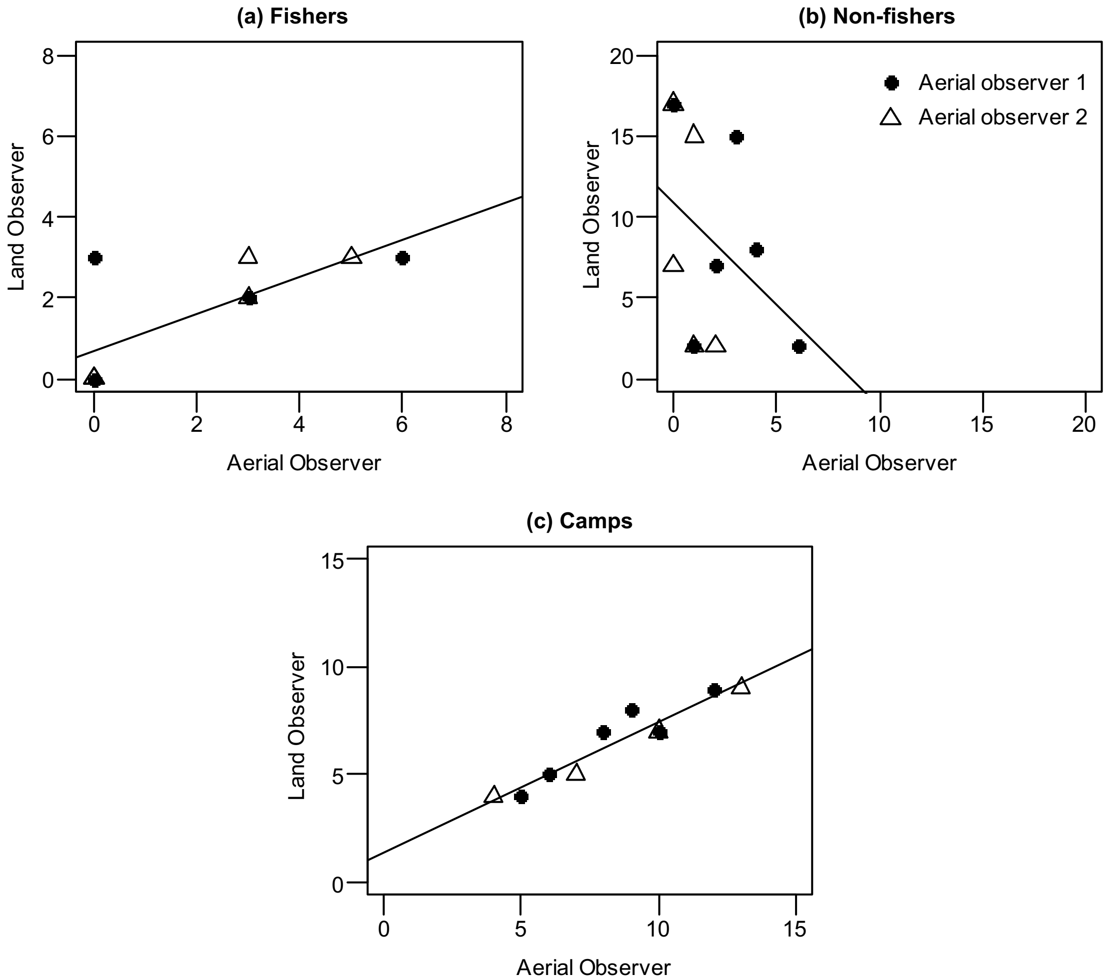

Figure 18. Comparison between aerial and ground observer counts in Shark Bay were linear regression shown by solid line.

Table 12. Components of linear regression used to compare aerial and land-based observer counts in Shark Bay. Bold font denotes significance at levels <0.05

Variable	Coefficient	r^2	p
Fishers	0.457	0.501	**0.009**
Non-fishers	-1.260	0.045	0.255
Camps	0.604	0.887	**<0.001**

8.0 Discussion

Aerial surveys of recreational shore-based fishing were undertaken in Shark Bay and Carnarvon from June to August 2012 using probability-based sampling as this was a more cost-effective technique for estimating fishing effort at sites with limited access and relatively low activity levels, when compared to the maximum count technique. This approach provided good estimates (<20% RSE) of fishing effort when sampling 6 and 9 days per month for Shark Bay and Carnarvon, respectively. The spatial and temporal distribution of fishing (and other) activities highlighted several patterns that can assist in the allocation of sampling effort in future on-site surveys for both shore and boat-based fishing. The validation of the aerial survey counts using paired-observers and land-based counts was also useful for developing an understanding of visibility bias and could be beneficial for increasing the accuracy of future surveys.

Line fishing was the dominant type of shore-based fishing activity recorded when compared to other extractive activities such as ballooning and netting. The dominance of line fishing was similar to the pattern identified in the nearby Ningaloo Marine Park (Smallwood and Beckley, 2012). Although spearfishing was not observed being undertaken from the shore during the study, this was more likely to be due to the visibility issues with sighting this activity from the air.

Temporal factors, such as month, day type and time of day, were investigated with respect to the activities counted at each site. The only significant result for month was for mean number of camps in Carnarvon, with July and, to a lesser extent, August, having greater numbers than June. July includes the school holidays and, combined with the mild winter weather conditions, attracts more visitors to the region (Shaw, 2000; BOM, 2012). Day type was significant for boat trailers in Carnarvon, with weekends/public holidays having greater numbers than weekdays. This pattern possibly reflects the activities of residents in the town, who have greater time availability to undertake boating activity on this day type. However, the number of boat trailers in Shark Bay varied significantly only by time of day, with higher numbers during the afternoon period.

This survey was timed to coincide with the peak visitation period to the Gascoyne region which occurs in the winter months. A previous survey in 1998/99 found shore-based fishing effort was highest throughout the region during winter, except for Steep Point, which experienced the greatest effort in summer months, due to fishers targeting Spanish mackerel (Sumner *et al.*, 2002). Repeating this survey during summer may therefore provide some additional understanding of the seasonal variation in recreational shore-based fishing effort and distribution.

The effect of the towns of Carnarvon and Denham, and associated permanent populations, was also explored. The mean number of fishers was greater on weekends/public holidays than weekdays in Carnarvon, which most likely indicates the effects of the adjacent permanent population. However, this was not a significant difference. Fishing activity in Denham showed no clear temporal pattern with respect to day type. Therefore, analysis of data collected from beaches adjacent to these towns does not need to be considered separately to the remainder of the survey site. There was no significant difference in fishing activity among different times of day, which counters findings from aerial surveys conducted in Perth where more fishers were present in morning and afternoons than the middle of the day (Smallwood *et al.*, 2011b). Future surveys of shore-based recreational fishing activity at sites with a large tourist population, could consider equal allocation of sampling effort across time of day, and may be able to remove day type as a stratum if the permanent population is small.

A heterogeneous spatial distribution of recreational shore-based fishers was evident throughout Carnarvon and Shark Bay, which varied for different types of fishing activity and can be largely explained by coastal habitat and access points. Line fishing was the most widely distributed and occurred along beaches, cliffs and near mangroves in Carnarvon and Shark Bay, as well as along 1 Mile Jetty. Ballooning is a common method for targeting pelagic species such as Spanish mackerel (Cusack and Roennfeldt, 2003; Commonwealth of Australia, 2009) and was concentrated around cliffs areas adjacent to deeper waters along the Quobba coastline and at Steep Point. Netting was observed at only a few locations in Carnarvon and Shark Bay, predominantly along beaches and in close proximity to mangroves (*i.e.* to the south of Monkey Mia). Heterogeneous distributions of recreational fishing have been associated with habitat type in previous studies of boat-based fishing. For example, squid jigging and seagrass (Lynch, 2006), rock lobster fishing and reef (Parnell *et al.*, 2007). Shore-based fishing has been associated with a range of habitat and coastal geomorphology types in nearby Ningaloo Marine Park (Smallwood *et al.*, 2012a). However, this current survey highlights some finer-scale variations in the habitats utilised by people participating in different methods of recreational fishing.

Some parts of the coastline have limited coastal access and were difficult to access by vehicle, which was reflected by limited fishing and other activities recorded at these locations throughout the survey (*i.e.,* to the north of Gladstone on the Carnarvon coastline). Boat trailers were recorded in highest numbers at constructed boat ramps at Carnarvon, Denham and Monkey Mia although they were also found at numerous beach launches at campsites and day use areas. This information provides a valuable insight on locations that should be targeted during on-site surveys for collecting detailed information on catch and fishing activity from both shore and boat-based fishers which cannot be obtained using aerial surveys. It also highlights that aerial surveys provide a useful tool for collecting data on 'low use' areas where recreational fishing is occurring that are costly to access by vehicle.

Recreational shore-based fishing effort for June to August 2012 was estimated to be 29,532 fisher hours (SE±7,806; RSE=13%) for Shark Bay and 62,356 fisher hours (SE±4,667; RSE=16%) for Carnarvon. Aerial surveys can only be conducted during daylight hours, and without additional information on fishing occurring outside these hours, this estimate is only for fishing occurring between 8 am – 5 pm. Following previous surveys in Western Australia, it is likely that these hours capture the majority of shore-based fishing effort. However, a complementary survey using remotely operated cameras adjacent to the Perth Metropolitan area was able to determine that night fishing accounted for 17% of fishers (Smallwood *et al.*, 2012b).

A roving creel survey conducted in 1998/99 found the total effort for shore-based fishing in Shark Bay (including Steep Point) over 12-months to be 22,296 fisher days (Sumner *et al.*, 2002). This can be converted to 74,342 fisher hours, of which 17,342 fisher hours occurred in winter (from June to August) (DoF, unpublished data). This may provide some indication that shore-based fishing effort in winter has increased in Shark Bay (to 29,532 fisher hours) since this original study. However, it should also be considered that the aerial survey may have also provided additional coverage of shore-based recreational fishing sites not able to be accessed during the roving surveys. Shore-based fishing effort for Carnarvon for the 12-month period in 1998/99 was 35,374 fisher hours, of which 15,449 fisher hours occurred in winter (DoF, unpublished data). 1 Mile Jetty in Carnarvon is a popular shore-based fishing location and was not surveyed as it was under repair in 1998/99 (Sumner *et al.*, 2002), and this may account for the low fishing effort when compared to the current study (62,356 fisher hours).

The combination of systematic random and stratified random sampling design employed in this survey, whereby surveys were grouped into 'trips' of several consecutive days and were completed twice per month, was successful in providing good (<20%RSE) estimates of fishing effort. This cost effective design is therefore likely to be suitable for other survey sites that are remote from Perth. However, difficulties in re-scheduling may occur if multiple days are lost in a single trip, or if an entire trip needs to be rescheduled, especially when sampling during winter in the South Coast bioregion and summer in the North Coast bioregion. In this situation, it would be advantageous to base the survey staff in the region, and rescheduling can occur on randomly selected days. Both local and Perth-based staff were utilised in this study.

Paired-observer counts and concurrent aerial-land counts on some flights provided an understanding of the biases associated with aerial surveys. Good correlations between the paired-observers on the total counts of fishers (and other variables) obtained on each flight indicated that detection bias was likely to be small. However, further investigation of these data within each flight is required to develop a complete understanding of how the sightings from each observer correlate at a finer-scale (*i.e.,* 'group' level), similar to the techniques applied in wildlife studies (Marsh and Sinclair, 1989; Pollock *et al.*, 2006; Koneff *et al.*, 2008). The aerial-land counts showed less correlation between methods, especially for non-fishers, which was most likely due to people being able to move to and from the beach during the 30 minutes it took to cover the designated area by land (versus the 3 minutes for the plane to cover this same area). Camps, however, were less likely to have moved in this short space of time. Conducting counts from a fixed vantage point (either by an observer or remotely operated camera) may be a more effective option for obtaining information at the exact time of the aerial survey, and may also be able to provide information on the level of night fishing activity. However, limited access, and the potential for shore-based fishers to be widely dispersed along the Carnarvon and Shark Bay coastlines, made it difficult to implement roving surveys or remotely operated camera technology to provide this information.

This study provides useful information when considering the management of nearshore and pelagic fish stocks and the marine environment in Carnarvon and Shark Bay, which are widely recognised for their ecological significance, as well as their importance to the local community for a range of recreational uses, including fishing (Shaw, 2000; DEC, 2008). Recreational fishing from boats and the shore can be expected to increase in the region in line with population growth, and also as a greater range of opportunities for undertaking these activities are developed in the region as a means of attracting tourists and generating revenue (Wise *et al.*, 2007; GDC, 2010; Wise *et al.*, 2012).

The Quobba and Miaboolya FHPAs were created with the objectives of protecting fish and the marine environment, whilst also encouraging sustainable use by people participating in recreational pursuits (DoF, 2003, 2004). Possible threats to the environment identified in the management plans for these FHPAs included recreational fishing, boating, off-road driving and camping. Several measures were introduced to help minimise these threats and achieve the objectives of the management plan, including full (or partial) restrictions on jetskiing, anchoring of vessels, netting, spearfishing and recreational line fishing at specific sites within these FHPAs (DoF, 2003, 2004). Recreational line fishers, non-fishers, camps, boat trailers and boats anchored or on the beach were identified within both FHPAs during the aerial surveys and can provide a greater understanding of usage levels and risks to environmental values. A similar understanding can be generated for other areas of interest within the study area, *i.e.,* the Shark Bay Marine Park and Shark Bay World Heritage Area.

The largely shallow water environment of Shark Bay enables the nearshore species to be targeted from boats and the shore. Conversely, the close proximity of deeper waters (up to 20m) to the cliffs around Steep Point and Quobba, enable shore and boat-based fishers to target larger pelagic species such as Spanish mackerel. Understanding the level of shore-based and boat-based fishing activity occurring in Carnarvon and Shark Bay is therefore important when considering the management of fish stocks in the Gascoyne Coast bioregion.

9.0 Conclusion

Aerial surveys of shore-based recreational fishing (and other activities) were successfully implemented in Carnarvon and Shark Bay from June to August 2012 using a probability-based design which provided good (<20% RSE) estimates of fishing effort along with an understanding of the spatial and temporal distribution of these activities. This method was particularly suited to surveying large and remote areas that have limited vehicle access and lower activity levels which restrict the implementation of concurrent land-based surveys and remotely operated cameras necessary to implement a maximum count design. The use of paired-observer counts showed good correlations and provide confidence in the aerial survey counts. This project demonstrates the feasibility of conducting aerial surveys at other regional sites and provided useful background information for future studies which may be undertaken in northern Western Australia. The coastline between Exmouth and Port Hedland is currently the only area in in the Gascoyne and Kimberley (to Camden Sound) for which detailed spatial information on recreational shore-based fishing has not been obtained. The information collected during these surveys will contribute to the management of fish stocks, while also be used to design more cost effective land-based surveys from which detailed catch information can be obtained for estimation of catch rate and total catch.

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11.0 References

ABS, 2010. Regional population growth, Australia 2009-10, cat. 3235.0, viewed 18 January 2012. Australian Bureau of Statistics, Canberra, Australia.

Bayliss, P. and Yeomans, K. M., 1989. Correcting Bias in Aerial Survey Population Estimates of Feral Livestock in Northern Australia Using the Double-Count Technique. Journal of Applied Ecology 26, 925-933.

BOM, 2012. Climate statistics: Carnarvon. http://www.bom.gov.au/climate/averages Date accessed: 30 November 2012

CALM, 1996. Shark Bay Marine Reserves Management Plan 1996-2006. Department of Conservation and Land Management, Perth, Western Australia, p. 108.

Carlsen, J. and Wood, D., 2004. Assessment of the economic value of recreation and tourism in Western Australia's National Parks, Marine Parks and Forests. Sustainable Toursim CRC, Queensland, Australia, p. 29.

Collins, J. H., 2008. Marine tourism in the Kimberley Region of Western Australia. Geographical Research 46, 111-123.

Commonwealth of Australia, 2009. Assessment of the Western Australia Mackerel Fishery. Department of the Environment, Water, Heritage and the Arts, Canberra, Australia, p. 26.

Cook, R. D. and Jacobson, J. O., 1979. A design for estimating visibility bias in aerial surveys. Biometrics 35, 735-742.

Cusack, R. and Roennfeldt, M., 2003. Fishing the Wild West. West Australian Newspapers, Perth, Western Australia.

Dalton, T. M., Thompson, R. and Jin, D., 2010. Mapping human dimensions in marine spatial planning and management: an example from Narragansett Bay, Rhode Island. Marine Policy 34, 309-319.

DEC, 2008. Shark Bay World Heritage Property Strategic Plan 2008 - 2020. Department of Environment and Conservation, Perth, Western Australia, p. 101.

DoF, 2003. Plan of management for the Miaboolya Beach Fish Habitat Protection Area. Department of Fisheries, Western Australia, Perth, Western Australia, p. 48.

DoF, 2004. Plan of management for the Point Quobba Fish Habitat Protection Area. Department of Fisheries, Western Australia, Perth, Western Australia, p. 48.

DoF, 2011. Resource assessment framework (RAF) for finfish resources in Western Australia. Western Australian Department of Fisheries, Perth, Western Australia, p. 24.

DoF, 2012. Western Australian recreational boat fishing survey. http://www.fish.wa.gov.au/Fishing-and-Aquaculture/Recreational-Fishing/Supporting-Recreational-Fishing/Pages/Western-Australian-Recreational-Boat-Fishing-Survey.aspx Date accessed: 12 December 2012

GDC, 2010. Gascoyne Development Commission: Strategic plan 2010 - 2020. Gascoyne Development Commission, Carnarvon, Western Australia, p. 20.

Graham, A. and Bell, R., 1989. Investigating observer bias in aerial survey by simultaneous double-counts. The Journal of Wildlife Management 53, 1009-1016.

Henry, G. W. and Lyle, J. M., 2003. The national recreational and indigenous fishing survey. Department of Agriculture, Fisheries and Forestry, Canberra, Australia.

Human, B. A. and McDonald, J. I., 2009. Knowledge review and gap analysis: resource condition monitoring in the Pilbara and Kimberley regions of Western Australia. Coastal and marine research condition monitoring - Scoping project. Western Australian Department of Fisheries, Perth, Western Australia, p. 192.

Jackson, G. and Moran, M., 2012. Recovery of inner Shark Bay snapper *(Pagrus auratus)* stocks: relevant research and adaptive recreational fisheries management in a World Heritage Property. Marine and Freshwater Research 63, 1180-1190.

Koneff, M. D., Royle, J. A., Otto, M. C., Wortham, J. S. and Bidwell, J. K., 2008. A double-observer method to estimate detection rate during aerial waterfowl surveys. The Journal of Wildlife Management 72, 1641-1649.

Lynch, T. P., 2006. Incorporation of recreational fishing effort into design of marine protected areas. Biological Conservation 20, 1466-1476.

Marriott, R. J., Jackson, G., Lenanton, R., Stephenson, P., Lai, E., Telfer, C., Bruce, C., Wise, B. S., Adams, D. J., Norriss, J. and Molony, B., 2012. Biology and stock status of key demersel species in the Gascoyne Coast bioregion. Western Australian Department of Fisheries, Perth, Western Australia, p. 221.

Marsh, H. and Sinclair, D. F., 1989. Correcting for Visibility Bias in Strip Transect Aerial Surveys of Aquatic Fauna. The Journal of Wildlife Management 53, 1017-1024.

Parnell, P. E., Dayton, P. K. and Margiotta, F., 2007. Spatial and temporal patterns of lobster trap fishing: a survey of fishing effort and habitat structure. Bulletin of Southern California Academy of Science 106, 27-37.

Pollock, K. H., Jones, C. M. and Brown, T. L., 1994. Angler survey methods and their applications in fisheries management. American Fisheries Society, Bethesda, Maryland.

Pollock, K. H. and Kendall, W. L., 1987. Visibility bias in aerial surveys: a review of estimation procedures. The Journal of Wildlife Management 51, 502-510.

Pollock, K. H., Marsh, H. D., Lawler, I. R. and Alldredge, M. W., 2006. Estimating Animal Abundance in Heterogeneous Environments: An Application to Aerial Surveys for Dugongs. The Journal of Wildlife Management 70, 255-262.

Shaw, J., 2000. Fisheries Environmental Management Review, Gascoyne region. Western Australian Department of Fisheries, Perth, Western Australia, p. 187.

Smallwood, C. B. and Beckley, L. E., 2012. Spatial distribution and zoning compliance of recreational fishing in Ningaloo Marine Park, north-western Australia. Fisheries Research 125-126, 40-50.

Smallwood, C. B., Beckley, L. E. and Moore, S. A., 2012a. Influence of zoning and habitats on the spatial distribution of recreational activities in a multiple-use marine park. Coastal Management 40, 381-400.

Smallwood, C. B., Beckley, L. E., Moore, S. A. and Kobryn, H. T., 2011a. Assessing patterns of recreational use in large marine parks: a case study from Ningaloo Marine Park, Australia. Ocean and Coastal Management 54, 330-340.

Smallwood, C. B., Fisher, E. A., Wise, B. S. and Gaughan, D. J., 2011b. Spatial distribution of shore-based fishers in the greater Perth Metropolitan area over summer 2010/2011. Western Australian Department of Fisheries, Perth, Western Australia, p. 28.

Smallwood, C. B., Pollock, K. H., Wise, B. S., Hall, N. G. and Gaughan, D. J., 2011c. Quantifying recreational fishing catch and effort: a pilot study of shore-based fishers in the Perth Metropolitan area. Western Australian Department of Fisheries, Perth, Western Australia, p. 60.

Smallwood, C. B., Pollock, K. H., Wise, B. S., Hall, N. G. and Gaughan, D. J., 2012b. Expanding roving-aerial surveys to include counts of recreational shore fishers from remotely-operated cameras: benefits, limitations and cost-effectiveness. North Americal Journal of Fisheries Management 32, 1265-1276.

Sumner, N. R. and Malseed, B. E., 2002. Quantification of changes in recreational catch and effort on inner Shark Bay snapper species following implementation of responsive management changes. FRDC, Perth, Western Australia, p. 48.

Sumner, N. R. and Steckis, R. A., 1999. Statistical analysis of Gascoyne region recreational fishing study, July 1996. Department of Fisheries, Western Australia, Perth, Western Australia, p. 30.

Sumner, N. R., Williamson, P. C. and Malseed, B. E., 2002. A 12-month survey of recreational fishing in the Gascoyne bioregion of Western Australia during 1998-99. Western Australian Department of Fisheries, Perth, p. 54.

Thompson, R. and Dalton, T. M., 2010. Measuring public access to the shoreline: the boat-based offset survey method. Coastal Management 38, 378-398.

Veiga, P., Ribeiro, J., Goncalves, J. M. S. and Erzini, K., 2010. Quantifying recreational shore angling catch and harvest in southern Portugal (north-east Atlantic Ocean): implications for conservation and integrated fisheries management. Journal of Fish Biology 76, 2216-2237.

Volstad, J. H., Pollock, K. H. and Richkus, W. A., 2006. Comparing and combining effort and catch estimates from aerial-access designs as applied to a large-scale angler survey in the Delaware River. North American Journal of Fisheries Management 26, 727-741.

Williamson, P. C., Sumner, N. R. and Malseed, B. E., 2006. A 12-month survey of recreational fishing in the Pilbara region of Western Australia during 1999 – 2000. Department of Fisheries, Western Australia, Perth, Western Australia, p. 61.

Wise, B. S., St John, J. and Lenanton, R. C., 2007. Spatial scales of exploitation among populations of demersal scalefish: implications for management. Western Australian Department of Fisheries, Perth, Western Australia, p. 130.

Wise, B. S., Telfer, C. F., Lai, E. K. M., Hall, N. G. and Jackson, G., 2012. Long-term monitoring of boat-based recreational fishing in Shark Bay, Western Australia: providing scientific advice for sustainable management in a World Heritage Area. Marine and Freshwater Research 63, 1129-1141.