Title: Spatial distribution and zoning compliance of recreational fishing in Ningaloo Marine Park, north-western Australia

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Abstract

Recreational fishing is often permitted in multiple-use marine parks and, to ensure a balance with biodiversity conservation, sanctuary (no-take) zones are frequently demarcated. However, compliance with such measures is rarely quantified. Aerial and land-based coastal observation surveys were conducted within Ningaloo Marine Park, north-western Australia, with the aim of identifying the spatio-temporal distribution of recreational fishing as well as quantifying participation and zoning compliance. During aerial and coastal surveys, a recreational activity type was identified for 73% and 65% of the vessels observed, respectively. About 16-17% of vessels were identified as being engaged in recreational fishing and, of these, 8-12% were observed while fishing in sanctuary zones. For people undertaking shore-based recreation, identification of activity type increased to 97% for aerial surveys and 100% for land-based surveys. Participation in recreational fishing was 9% for both survey methods and 2-4% of these fishers were observed in sanctuary zones. Peak visitor months (April – October) had a wider spatial distribution and higher density of shore and vessel-based fishers. Interviews with recreational fishers enabled collection of data about knowledge of zoning, and compliance with bag and size limits. For repeat visitors, 87% could correctly identify the location of the nearest sanctuary zone; for first time visitors this dropped to 52%. About 75% of both visitor types stated that these zones had not affected their fishing activity. No fishers had reached their bag limit and only two undersized fish were recorded in the examined catches. The multi-faceted survey approach revealed that aerial and coastal surveys produced similar data on non-compliance. Such data can be used to develop site-specific enforcement and education activities as well as providing support for planning and management of marine parks.

Keywords: aerial survey, land-based coastal survey, marine protected area

1 Introduction

Recreational fishing is a popular activity undertaken by many people around the world, and has many social and economic benefits (Cooke and Schramm, 2007; Idhe et al., 2011). As a leisure activity, it is not undertaken for commercial gain (Pitcher and Hollingworth, 2002) and, for the purposes of this paper, refers to any recreational activity which involves the extraction of aquatic organisms including line fishing, spearfishing, netting and collecting. In contrast to its social and economic benefits, the extraction of large numbers of organisms can have negative biological impacts at both the species and ecosystem levels, including the truncation of age structures, trophic cascades and habitat degradation (McPhee et al., 2002; Cooke and Cowx, 2006; Lewin et al., 2006). Management measures used to reduce such impacts are input and output controls (i.e. gear restrictions, bag and size limits) as well as temporal and spatial closures, including no-take marine protected areas (Arlinghaus et al., 2007; Cerda et al., 2010; Kenchington, 2010). Catch-and-release recreational fishing may also be encouraged to assist with the sustainable use of resources (Cooke and Schramm, 2007). Although these measures can be successful in achieving conservation targets by increasing the abundance, size and diversity of target species (Halpern, 2003; Gaines et al., 2010), non-compliance by recreational fishers is likely to erode their benefits (Maliao et al., 2004; Little et al., 2005; Guidetti et al., 2008).

Quantification of non-compliance by recreational fishers is rarely undertaken, especially with respect to spatial closures, and this paucity of data has led to the assumption of 100% compliance in some studies (Sethi and Hilborn, 2008; Wilberg, 2009). Non-compliance with bag and size limits can be measured using on-site roving creel or access point surveys which collect catch data (including length measurements) when interviewing recreational fishers (Smallwood et al., 2006; Steffe et al., 2008; Veiga et

al., 2010). Bag and size limits are one of the most commonly used management controls in recreational fishing (Radomski et al., 2001) and obtaining this data is beneficial for evaluating the effectiveness of such measures on restricting the catch of recreational fishers. Non-compliance with spatial closures is more difficult to measure using on-site interview techniques, especially if conducted at boat ramps at the completion of a fishing trip. In this situation, interviewers are reliant on self-reported information from fishers, which may be misleading, as they are unlikely to admit breaching such management measures. Off-site (i.e. phone/logbook) surveys also experience similar difficulties.

On-site observational techniques are often used for collecting data on spatio-temporal patterns of recreational use, and include aerial (Coombes et al., 2009; Smallwood et al., 2011), land-based (Parnell et al., 2010) or vessel-based (Lynch et al., 2004; Dalton et al., 2010) surveys. Although quantifying non-compliance has rarely been the aim of these studies, they offer an opportunity to collect fishery independent data to fill this knowledge gap. Some exceptions to this include the use of land-based surveys to gauge non-compliance within a small Hawaiian marine protected area (Meyer, 2007), and vessel-based patrols to identify non-compliance in two sanctuary (no-take) zones within the Great Barrier Reef Marine Park (Davis et al., 2004).

A greater understanding of the spatio-temporal patterns of recreational fishing is another benefit of conducting observation surveys. Recreational fishing is known to have a heterogeneous spatial and temporal distribution, which can be attributed to a number of factors including marine habitats (Gratwicke and Speight, 2005), proximity to access points (Meyer, 2007), boat ramps (Sidman et al., 2004), service centres (Davis et al., 2004) and seasonal effects (Morales-Nin et al., 2005). Although rarely captured, this

knowledge of recreational fishing patterns has several benefits. Identification of popular fishing spots allows management to focus enforcement activities to achieve maximum effect while also providing information on areas from which fishers may be displaced during the zoning (or re-zoning) of a marine park (Arlinghaus, 2005). Conversely, areas with no fishing activity (even if permitted) provide natural spatial refugia for target species. However, such areas are becoming more uncommon with improved technology allowing for the systematic depletion of stocks (Dayton et al., 2000).

Non-compliance by recreational fishers in marine protected areas (generally referred to as marine parks in Australia) is particularly important, as fishing is often prohibited to help achieve conservation objectives, such as the maintenance of fish diversity and abundance (CALM and MPRA, 2005). Such objectives need to be balanced against equitable access to resources and, as a result, marine parks are often zoned for multiple uses (Klein et al., 2010), whereby recreational fishing may be excluded from some sanctuary (no-take) areas. This can complicate collection of compliance data, as it may be difficult to accurately identify the zone type where people are fishing. Factors which contribute to this difficulty include the size and location of the sanctuary zones, especially if they are located in remote areas that cannot easily be viewed or accessed.

A broad study investigating the spatio-temporal patterns of all recreational activity types was conducted in Ningaloo Marine Park, north-western Australia, throughout 2007 (Smallwood et al., 2011; Smallwood et al., 2012). A component within this broader study was focussed on recreational fishing and aimed to; (1) determine its spatio-temporal distribution, (2) quantify compliance with sanctuary zones as well as bag and size limits, (3) compare the findings from the concurrent aerial and land-based

observation techniques, and (4) develop an understanding of the level of knowledge by fishers on zoning and its effects on recreational fishing.

2 Methods

2.1 Study site and nomenclature

Ningaloo Marine Park extends for 300 km along the coast, and 5.6 km seaward to the edge of state waters, to encompass one of the largest fringing coral reefs in the world (Fig. 1). A second Marine Park is located further offshore in Commonwealth waters, but was excluded from the current study due to the high costs involved in surveying so far from the coast. Although larger vessels are able to travel into exposed offshore waters for recreational activities, the sheltered lagoon located behind the fringing reef crest is suited to smaller vessels (Smallwood et al., 2012). The coastline consists of sandy beaches, intertidal platforms and cliffs which also provide a wide range of opportunities for shore-based recreation. The diversity of natural features, combined with more than 900 fish species, has led to Ningaloo being considered a premier fishing location (CALM and MPRA, 2005). Recreational line fishing is the predominant type of extractive activity undertaken in the Marine Park (Westera et al., 2003), although this has not previously been quantified in comparison with other activity types.

The Marine Park attracts 200,000 visitors annually (CALM and MPRA, 2005), who stay in the service centres of Exmouth and Coral Bay (Fig. 1), or in numerous coastal campsites dispersed along the coast. April to October are the peak visitor months (Smallwood et al., 2011), thereby avoiding the high temperatures and cyclones which occur during the remaining months (BOM, 2011). At the time of this study only three

constructed boat ramps were located within the vicinity of the Marine Park, although small vessels can launch directly off sandy beaches adjacent to campsites.

Ningaloo Marine Park is a multiple-use marine park and, as such, it aims to balance biodiversity conservation with equitable access to resources by allowing extractive and non-extractive uses (CALM and MPRA, 2005). Zoning is the primary management tool through which this outcome is achieved. Nomenclature applied to zone categories varies significantly worldwide, and those in Ningaloo Marine Park are standardised across all marine parks in Western Australia (Table 1). Spearfishing and netting are only permitted in specific areas within general use and recreation zones between Tantabiddi and Winderabandi (Fig. 1).

2.2 Observation surveys

Aerial and land-based coastal surveys were undertaken from January - December 2007 to collect geo-referenced data on all shore and vessel-based activity in Ningaloo Marine Park. For each data point, a team of two observers recorded information about platform (shore or vessel), group size and activity type. Techniques for surveying recreational fishing developed by Pollock et al. (1994) were used as a framework for the survey design.

2.2.1 Aerial surveys

Aerial surveys were ideal for this study as a single transect following the coastline could cover the entire Marine Park (Smallwood et al., 2011). A total of 34 flights were undertaken during the 12-month study. Flights were stratified by month, with two in off-peak months from November to March; increasing to a maximum of four in peak

153 months with school holidays (April, July and October). Survey days were randomly
154 selected within each month using equal probability of sampling across all day types (i.e.
155 weekends/public holidays, weekdays) while flight times were standardised between 8
156 am - 12 noon, in accordance with the maximum count aerial survey method (Volstad et
157 al., 2006). This time of day is characterised by lighter, predominantly offshore winds
158 when high levels of recreational activity were expected to occur, while also providing
159 good viewing opportunities for observers (i.e. reduced wind action and glare).
160
161 The 4-seat Cessna 172 aircraft flew at an altitude of 150 m and it took about 4 hours to
162 travel from Exmouth to Red Bluff and return (Fig. 1). Randomisation of starting
163 location was not undertaken due to the length of the coast and the only airport in the
164 region being located at the northern end of the study area. The outward (southbound)
165 and return (northbound) flights were considered as two separate activity counts, and
166 were conducted between 8 am – 10 am and 10 am – 12 noon. The turn time at Red Bluff
167 was the start of the return flight. With an average air speed of 100 knots, there was little
168 chance of duplicating observations within each flight direction although it is
169 acknowledged that duplication was likely between flight directions, especially close to
170 the turning point. To address this issue, a southbound or northbound survey was
171 randomly selected for analysis from each of the 34 flights.
172
173 A GPS and data logger were used to store positional information along with time,
174 altitude and heading. Recording an offset measurement (i.e. distance of an object from
175 an observation point) allowed the actual location of vessels and people on the shore to
176 be calculated (Vincenty, 1975). The spatial accuracy of the estimates obtained using this
177 technique are discussed in Smallwood et al. (2011), along with the mechanisms used to

178 decrease the known visibility and recording biases associated with aerial surveys (i.e.
179 glare, objects passing beneath the plane, timing errors).
180

181 2.2.2 Coastal surveys

182 Land-based coastal surveys were derived from the roving creel method which is often
183 used to study shore-based recreational fishing (Pollock et al., 1994; Meyer, 2007), but
184 have rarely been undertaken over such an expansive area as Ningaloo Marine Park.
185 More than 150 vantage points were selected along the coastline from which all
186 observations were recorded. Points were selected for their clear fields of view and
187 height above sea level which enabled good coverage of the entire shoreline and marine
188 environment. The coastline was split into three routes, each of which covered about 100
189 km of coastline and could be completed in a single day (Fig. 1). Thus, it was possible to
190 survey the entire length of the Marine Park in three days. Surveys were stratified by
191 month, with routes between Exmouth, Yardie Creek and Coral Bay completed six times
192 per month and Coral Bay to Red Bluff completed four times per month due to logistical
193 challenges and time constraints in accessing this isolated section of coast. Survey days
194 were randomly selected using equal probability of selection across all days within each
195 month. Randomisation of starting location was not incorporated due to the linear route
196 along the elongated coast. To ensure that sites were visited throughout the day, and
197 reduce the bias associated with removing such randomisation, starting times were
198 randomised between 7.30 am – 11 am, and finish times between 1.30 pm – 6 pm. Trip
199 direction route was reversed for each route (i.e. the northern area could be surveyed
200 from Exmouth to Yardie Creek or Yardie Creek to Exmouth).
201

202 Recreational activity observed during coastal surveys was recorded in a similar fashion
203 to that of the aerial surveys. However, as observations were made from a stationary

vantage point it was possible to use a Newcon LRB4000 CI binocular, range and bearing finder to calculate an actual location (Lynch et al., 2004; Dalton et al., 2010). Distances >2,000 m were consistently achieved, thereby allowing coverage of most of the lagoon environment. Beyond this range, a handheld compass was used to determine bearing, and distance was estimated using the reef crest as an additional reference point. Errors arising from multiple sightings of the same object were reduced by excluding them from subsequent counts within the same survey. However, if an identifiable vessel was first observed motoring (or transiting), but was later sighted undertaking a recreational activity during the same survey, then details of the second observation were recorded and the first sighting deleted.

2.2.3 Spatial and statistical analysis

The level of participation in recreational fishing and other activity categories was determined for the entire survey period using resampling (Efron and Tibshirani, 1993). To this end, the data were resampled with replacement to generate 1,000 resampled datasets from which the mean proportion of vessels or people participating in each activity type was calculated along with their confidence intervals (using the percentile method).

Spatio-temporal patterns of recreational fishing obtained from both observation surveys were described, and compared, using off peak and peak months. Each vessel identified as fishing was aggregated to a network of 3 x 3 km grid cells which was overlaid over the entire Ningaloo Marine Park, while people observed fishing from the shore were ascribed to 3 km long coastal segments (Smallwood et al., 2011). Mean numbers of vessels or people observed fishing within each of these spatial units could then be determined, along with associated confidence intervals.

Non-compliance with sanctuary zones was determined by importing data points into ArcGIS and overlaying them with a map of the Marine Park so that each vessel or person observed during the study could be associated with a specific zone. Absolute rates of non-compliance were calculated using the mean number of vessels (or shore fishers) counted in each sanctuary zone per survey. Only those vessels or people identified as fishing were included in this analysis. Shore-based fishers observed in special purpose (SBA) zones, and in which recreational fishing is permitted along the shoreline of many sanctuary zones (Fig. 1), were excluded from this analysis. However, these data were analysed separately to help understand to what extent special purpose (SBA) zones were being utilised by shore-based fishers. Confidence intervals were calculated for each sanctuary and special purpose (SBA) zone.

2.3 Face-to-face interviews

Similar to roving and access point surveys, people were intercepted for a face-to-face interview either during, or at the completion of, their recreational activity (Pollock et al., 1994; Smallwood et al., 2012). Interviews were conducted throughout each coastal survey (07.30 am – 6 pm), and the randomisation of days, start times and reversal of survey routes ensured that representative data were obtained throughout the Marine Park. However, due to time constraints arising from the large distances involved, the number of interviews was restricted to 5 - 10 per day. A combination of quota and purposive sampling was used to select locations and groups for interviews throughout the entire study area. Respondents within each group were selected based on who had the next birthday. Similar selection and survey designs have been well documented in tourism and recreation research (Nyaupane et al., 2004; Neuman, 2006; Coombes et al., 2009).

As part of the broader project, respondents were interviewed whilst conducting a range of recreational activity types and were asked a number of questions on visit and visitor characteristics (i.e. age, length of stay, previous visitation) (Smallwood et al., 2012). Respondents were identified by their current recreational activity, and were also asked to identify the main activity for which they came to the beach on their day of interview. Frequency of participation in all recreational activities undertaken during a respondent's entire visit to the Marine Park (up until time of interview) was also obtained. These questions provided a better understanding of the diversity of activities undertaken by respondents within each day, and across their entire visit. Further to this, respondents engaged in recreational fishing from the shore or returning from a vessel-based fishing trip were asked specific questions relating to catch, their knowledge of sanctuary zones and the effect of these zones on their fishing activity.

3 Results

3.1 Observation surveys

3.1.1 Level of participation

Analysis of vessel activity from the aerial surveys was based on number of vessels as it was sometimes difficult for observers to identify the exact number of people on board, especially those vessels with cabins that could obscure individuals from view. Vessels were either assigned to an identified (73%) or an unidentified activity (27%), whereby this second category comprised vessels for which an activity type could not be ascertained (Table 2). Identified vessels were classified into five categories; recreational fishing, diving, snorkelling, motoring and other non-extractive (i.e. sailing, kitesurfing). 'Motoring' was the most frequently observed activity (52%) and included vessels that

281 were moving fast and therefore unlikely to be trolling. Overall, 16% of vessels were
282 identified as being engaged in recreational fishing (Fig. 2a). Line fishing was the most
283 frequently observed (99%), with spearfishing comprising the remainder.
284
285 Land-based coastal surveys were also analysed using vessels as the unit of
286 measurement. Level of participation was similar to the aerial surveys, with identified
287 and unidentified activities comprising 65% and 35%, respectively (Table 2). Identified
288 vessels were assigned to the same activity categories as the aerial surveys. Motoring
289 comprised the largest category (44%) and recreational fishing comprised 16% (Fig. 2b).
290 These vessels were predominantly line fishing (98%), while the remainder were
291 spearfishing or using pots and snares to target rock lobster.
292
293 Analyses of shore activities were based on number of people and also revealed
294 similarities between the findings of the two observation surveys. During aerial surveys,
295 the percentage of people on the shore assigned to an unidentified activity type was only
296 3% (Table 2). Excluding these, the remaining 97% were classified into five categories
297 that comprised recreational fishing, relaxing (i.e. sunbaking), snorkelling, walking and
298 other non-extractive (Fig. 3a). Participation in recreational fishing was relatively low
299 (9%) when compared to other categories such as relaxing. Line fishing was dominant
300 within the recreational fishing category (99%), and the remaining people were
301 spearfishing or netting.
302
303 All 22,465 people observed on the shore during coastal surveys were identified by
304 activity type (Table 2). As with the aerial surveys, relaxing was the most frequently
305 recorded activity while recreational fishing was one of the lowest, with 9% of people

306 (Fig. 3b). Line fishing was still dominant within this category (96%), with the
307 remainder of people were collecting or netting (3%) and spearfishing (1%).
308

309 3.1.2 Spatio-temporal patterns

310 Vessels observed while engaged in recreational fishing during aerial and coastal surveys
311 exhibited similar densities and spatial distribution (Fig. 4). Vessels were located in a
312 greater number of grid cells in peak months, indicating a wider spatial distribution when
313 compared to off peak months. However, this was not evenly distributed throughout the
314 Marine Park. The highest densities were found at localised areas around Tantabiddi,
315 Yardie Creek, Lefroy Bay, Coral Bay and 14 Mile. Conversely, few vessels were
316 sighted while fishing south of Lefroy Bay or around Cape Farquhar. Variability in the
317 number of vessels was high, with confidence intervals often equal to the mean,
318 particularly in cells with low densities.
319

320 Shore-based fishers observed during aerial surveys displayed higher mean densities, and
321 expanded over twice the distance, in peak months when compared to off peak months
322 (Fig. 5a). Highest densities of fishers were found around North-West Cape, Osprey Bay
323 and Coral Bay. Few fishers were observed to the south of Lefroy Bay or around Cape
324 Farquhar. Although the coastal surveys had similar spatio-temporal patterns as the aerial
325 surveys, higher densities of shore-based fishers were distributed throughout more of the
326 segments (i.e. north of Osprey Bay, around Coral Bay, 14 Mile and Red Bluff) (Fig.
327 5b). Confidence intervals for segments with high densities were clustered around the
328 mean, while those segments with low densities had high variability.
329

330 3.1.3 Compliance with sanctuary zones

331 Across the study, 8% of vessels (95%CI ± 4) identified as fishing during aerial surveys
332 were located in sanctuary zones, as were 12% (95%CI ± 4) of vessels identified as
333 fishing during coastal surveys. The rate of identification for non-compliant vessels for
334 the entire Marine Park was identical for both observation techniques, with a mean of 0.4
335 vessels per survey (95%CI ± 1.1). Vessels engaged in fishing were observed in more
336 than half of the 18 sanctuary zones in the Marine Park (Fig. 6). During the aerial
337 surveys, the highest levels of non-compliance were recorded in Bundegi, Mangrove and
338 Pelican sanctuary zones, while during coastal surveys, Winderabandi and Maud
339 sanctuary zones had highest non-compliance.
340
341 Non-compliance with sanctuary zones by people observed while shore-based fishing
342 was 4% (95%CI ± 1) and 2% (95%CI ± 1) during aerial and coastal surveys,
343 respectively. The rate of identification for people fishing from the shore into sanctuary
344 zones, for the whole Marine Park, was a mean of 1 person per survey (95%CI ± 2) for
345 both survey techniques. Maud and Pelican sanctuary zones had the highest level of non-
346 compliance during the aerial surveys. Bundegi, Mandu, Maud, Gnarraloo and 3 Mile all
347 recorded similar rates of non-compliance during the coastal surveys (Fig. 7).
348
349 More than 27% of shore fishers observed during both the aerial (n = 201) and coastal
350 surveys (n = 554) were located in special purpose (SBA) zones, which were specifically
351 introduced to allow recreational fishing to occur along the shoreline of sanctuary zones.
352 People were observed to be fishing from the shore in all eight special purpose (SBA)
353 zones, with the most popular located adjacent to Lighthouse and Osprey sanctuary
354 zones (Fig. 8).
355

3.2 *Face-to-face interviews*

3.2.1 Level of participation

During the study, 1,208 respondents were interviewed while participating in recreational activities on the shore, or when returning from a vessel-based trip. Of these, 27% (n = 328) cited recreational fishing as the main reason for visiting the Marine Park that day, or were undertaking this activity at the time of interview. Moreover, as respondents were asked to list all the recreational activities they had participated in on their visit to the Marine Park, it could be ascertained that an additional 19% (n = 224) had fished previously on this same visit. Line fishing was the dominant type of recreational fishing for respondents on the shore (97%, n = 293) with the remaining 3% involved in netting, collecting (for shells, bait and octopus), spearfishing or using snares or pots to target crabs and rock lobster. Line fishing was also the dominant activity for respondents interviewed when returning from a vessel-based trip (93%, n = 25), while the remaining 7% had been spearfishing.

3.2.2 Knowledge of sanctuary zones

The location of the nearest sanctuary zone was correctly identified by 87% of the 204 repeat visitors who were fishing at the time of interview, while 7% did not know and the remaining 6% incorrectly identified its location. First time visitors comprised an additional 79 respondents and, of these, only 52% correctly identified the location of the nearest sanctuary zone, 39% did not know and 9% incorrectly identified its location. Interestingly, similar results were obtained from both first time and repeat visitors when asked if sanctuary zones had affected their fishing, with 74% and 75% responding that such zones had not affected their fishing, respectively. The main reasons cited were that they could still fish from the shore, fish elsewhere or that there were still plenty of

fishing options available outside sanctuary zones. The remaining fishers indicated that sanctuary zones had affected their fishing and cited the main reasons as not being able to fish at their preferred site or having to travel further to fish.

3.2.3 Compliance with bag and size limits

Fish had been caught by 48% of the respondents fishing at the time of interview. The catch comprised 39 fish species plus 20 other taxa identified to family level (verification to species level was not possible for released fish). The most frequently recorded species were spangled emperor (*Lethrinus nebulosus*) (61 fish) and chinaman cod (*Epinephelus rivulatus*) (51 fish). Catch information obtained from vessel-based fishers was based on a complete trip, as they were interviewed when they returned to the shore. Of the 27 interviews with vessel-based fishers, none of these had attained their bag limit. Although only incomplete trip information on catch was obtained for shore-based fishers (as they were interviewed while still fishing), at the time of interview, none had achieved their bag limit. Only two narrow-barred Spanish mackerel (*Scomberomorus commerson*) under the legal size limit were retained by recreational fishers interviewed during the study.

4 Discussion

Aerial and land-based surveys provided similar results on recreational fishing participation, with this activity being assigned to 16-17% of vessels and 9% of people observed in Ningaloo Marine Park. Recreational fishing is popular in coastal zones around the world (Cooke and Cowx, 2004), and marine parks are an attractive location for people conducting this activity due to their high biodiversity (Cooke et al., 2006). However, this same attribute also appeals to significant numbers of visitors participating

406 in non-extractive activities such as snorkelling or diving (Hawkins et al., 2005;
407 Davenport and Davenport, 2006), which are also conducted in the Marine Park. This is
408 especially true for shore-based fishing, which had lower participation than relaxing,
409 snorkelling and walking.
410
411 Participation in vessel-based recreational fishing may be confounded by the more than
412 30% of vessels assigned to an unidentified activity in the observation surveys. By
413 excluding these from analysis, fishing in the Marine Park could be underestimated, as
414 some of these vessels may have been participating in this activity. Even though vessels
415 can be clearly seen, there are often impediments to ascertaining activity type, especially
416 fishing, which can be hard to identify at greater distances (i.e. outside the fringing reef
417 crest). Techniques for addressing this should be considered for future research. One
418 solution may be a vessel-based survey which allows researchers to slowly traverse an
419 area and position themselves closer to their target so that an activity type can be
420 determined, similar to studies in Australia (Lynch, 2006) and North America (Dalton et
421 al., 2010). However, this may not be practical if surveying a large marine park such as
422 Ningaloo, especially when the fringing reef crest makes it difficult to move between the
423 sheltered lagoon and oceanic waters. Possible analysis-based solutions include
424 assigning all unidentified vessels to recreational fishing, to provide an indication of
425 maximum participation. In the context of the current dataset this would increase
426 participation in recreational fishing to about 42% of vessels. Alternatively, an activity
427 type could be determined based on the proportion assigned to all identified vessels.
428 These approaches also need to consider vessels assigned to diving or snorkelling as,
429 although easily identifiable by the alpha flag, they may be participating in extractive
430 activities that are not visible to observers (i.e. spearfishing, targeting crayfish using
431 snares).

Less than 3% of people on the shore were classified as having an unidentified activity type during aerial surveys, and all were identified during the coastal surveys. This was largely due to the absence of man-made structures or natural features that obscured the view of researchers when surveying from the air, an issue which has been identified in previous studies (Volstad et al., 2006). Other visibility biases such as glare and objects passing underneath the flight path were addressed, where possible, in the aerial surveys (Smallwood et al., 2011). The design of the coastal surveys allowed researchers to approach as close as necessary to people on the beach to ascertain an activity type.

Face-to-face interviews revealed that 27% of respondents cited recreational fishing as their main reason for visiting Ningaloo Marine Park on their day of interview, which is a rate about three times higher than found in the observation surveys. This may be due to the roving nature of the coastal surveys, during which time interviews were completed, resulting in a higher likelihood of intercepting respondents conducting sedentary activities, such as shore fishing. This phenomenon is referred to as length of stay bias (Pollock et al., 1994) and it also decreased the likelihood of intercepting respondents participating in activities from vessels (resulting in a small sample size). Another effect which should be considered is that the interview results are based on what the respondent perceives to be their main activity (i.e. they are not independent observations) and this may have resulted in an overestimate of participation in recreational fishing using this method.

Recreational fishing in Ningaloo Marine Park was found to occur year-round, although a clear temporal pattern was found, with greater densities during peak visitor months (April – October). Increased visitor numbers occur at this time as people try to avoid

458 unfavourable weather conditions associated with the remaining months (BOM, 2011).
459 Such temporal factors are well-documented, including effects on vessel movement
460 patterns (Sidman and Fik, 2005), and provide information which can be used for
461 planning management activities. People are also likely to participate in multiple
462 activities across a day, and may wait for favourable weather or tide conditions.
463 Sampling across a random selection of days throughout the year ensured that biases
464 associated with weather and tide were removed.
465
466 Recreational fishing had a heterogeneous spatial distribution, with some localised areas
467 of the Marine Park having high densities of recreational fishers, while other areas had
468 little or no activity. The highest densities of vessel-based fishers were found in close
469 proximity to service centres (i.e. Coral Bay), constructed boat ramps (i.e. Tantabiddi,
470 Coral Bay) and coastal camping areas where vessels can launch directly off the beach
471 (i.e. Lefroy Bay, 14 Mile and Yardie Creek). The majority of vessels were also observed
472 within the sheltered waters located inside the fringing reef crest. Shore-based fishers
473 were also found in high densities at similar locations near service centres and coastal
474 camping areas. Numerous coastal tracks around North-West Cape also enable easy
475 access to the shoreline for fishers in this northern section of the Marine Park. Such
476 associations are reflective of broader patterns of recreational activity identified from
477 vessels and the shore at Ningaloo (Smallwood et al., 2012) and elsewhere (Davis et al.,
478 2004; Sidman et al., 2004; Bruce and Eliot, 2006; Meyer, 2007). Parts of the Marine
479 Park with little fishing activity are characterised by their increased distance from service
480 centres and lack of boat launching facilities or coastal access tracks (i.e. around Cape
481 Farquhar).
482

Of the vessels and people on the shore identified as fishing in Ningaloo Marine Park, less than 12% and 4% were observed in sanctuary (no-take) zones, respectively. If using the proposed maximum participation scenario, or proportioning of known activity types, to assign values to unidentified vessels, then non-compliance by vessels would increase to about 18% for both observation methods. Previous assumptions regarding non-compliance in the Marine Park have varied from high (Westera et al., 2003) to low (Babcock et al., 2008), and this study provides the first quantified data by which it can be measured. By using an absolute measure of non-compliance (i.e. mean number of people/vessels per survey day) it was also possible to make comparisons between marine parks; indicating similar low levels of non-compliance at Ningaloo, Hawaii (Meyer, 2007) and the Great Barrier Reef Marine Park (Davis et al., 2004).

Reasons for such low levels of non-compliance at Ningaloo Marine Park could be due to a number of factors. Educational tools such as signs at many boat ramps and coastal tracks provide information on the location of sanctuary zones to people prior to accessing the Marine Park. Brochures are also available from information centres and tourist accommodation while in-water and land-based markers provide visual reference points on sanctuary zone locations. Land and vessel-based enforcement and education patrols are also conducted in the Marine Park, offering a visible deterrent to people fishing in sanctuary zones. A willingness of respondents to fish at alternative sites outside of sanctuary zones was also demonstrated during the interviews conducted in this study.

Benefits of understanding zoning compliance for future management and research include measuring the effectiveness of enforcement and biodiversity conservation efforts (Halpern et al., 2008; Gaines et al., 2010). Increased levels of enforcement result

509 in lower non-compliance with sanctuary zones (Davis et al., 2004) and also greater
510 densities of targeted fish species (Guidetti et al., 2008). However, these effects can also
511 vary throughout a marine park, with benefits less noticeable in remote, offshore areas
512 (Davis et al., 2004). Sanctuary zones located in remote areas of Ningaloo Marine Park,
513 such as at Cloates and Cape Farquhar (Fig. 1; 4-5) had low rates of non-compliance.
514 Conversely, the isolation which may shield these areas from recreational fishing activity
515 also makes it difficult to conduct enforcement operations. Linkages can also be made
516 between the social and biological elements of marine parks, which is especially salient
517 for comparing estimates obtained from fished versus unfished (sanctuary) zones, as
518 non-compliance may affect the reliability of findings (Guidetti et al., 2008).
519
520 Compliance with bag and size limits at Ningaloo Marine Park was high, with no fishers
521 exceeding their bag limit at time of interview, and only two fish retained below the legal
522 size limit. Similar high levels of compliance with such limits have been observed in
523 Australia (Steffe et al., 2008) and Europe (Veiga et al., 2010). However, such high
524 levels of compliance may also indicate that bag limits are set too high, and may not be
525 restricting catch levels. The effectiveness of such measures hinges on limits being
526 established at levels which restrict catch and protect immature (and/or large fecund)
527 individuals, or the bag and size limits are functionally meaningless (Attwood and
528 Bennett, 1995; Lewin et al., 2006).
529
530 The methods applied in this study have not previously been used to provide much
531 needed data on zoning compliance in marine parks. Factors such as size and location of
532 a marine park as well as staffing and financial constraints affect selection of the most
533 suitable survey method. Aerial surveys are suited to large areas, and, although the
534 coastal surveys took three days to cover the Marine Park, they revealed similar levels of

participation and spatio-temporal patterns of recreational fishing, especially for high use areas. Similar overall rates of non-compliance were recorded between techniques and, although the rates for specific sanctuary zones did vary, there was congruency (in terms of absence/presence of non-compliant 'events') for more than 50% of zones. Possible explanations for this variation include vessels with an unknown activity type, which were not included in this analysis, or the rarity of non-compliance 'events' which make it highly variable and difficult to observe, as indicated by the large confidence intervals.

Additional benefits of observation surveys are that they reduce the biases associated with the incorrect reporting of fishing activity, including the location at which it was undertaken. However, catch data (including length measurements) can only be obtained via interviews, as demonstrated in this study. Other survey options include the use of vessel-based surveys, which are well suited to sheltered environments (Lynch, 2006; Prior and Beckley, 2007) while mail or phone/diary techniques rely on a sampling frame from which a random number of respondents can be selected (Pollock et al., 1994). A recently implemented Recreational Fishing from Boat Licence in Western Australia now provides such a sampling frame which could be used for future surveys.

Knowledge of sanctuary zoning in Ningaloo Marine Park by respondents who were actively fishing was 87% for repeat visitors, and dropped to 52% for first time visitors. This finding indicates that educational strategies could be of benefit to visitors, especially those on their first trip to a marine park who are likely to be less aware of zoning regulations and penalties, when compared to residents (Karamanlidis et al., 2004) or regular visitors. Areas of high density (and non-compliance) of recreational fishing included Bundegi and Maud sanctuary zones, which were located near to service centres. Recreational fishers at these sites can be targeted for education and enforcement

561 due to these sites being easily accessible. Other sanctuary zones which had high non-
562 compliance (i.e. Winderabandi, Pelican and Gnarraloo) are far from services centres,
563 but are situated close to popular coastal camping sites. However, due to their
564 remoteness, they require more investment in time and resources to be accessed
565 enforcement and education patrols. Increased signage and brochure distribution (via
566 campground hosts) may still help facilitate voluntary compliance at these locations.
567
568 In conclusion, this study demonstrated that aerial and land-based observation surveys
569 provide similar data on spatio-temporal patterns of recreational fishing throughout a
570 large, multiple-use marine park. Expansion of recreational fishing in peak visitor
571 months was evident from both methods, while similar rates of non-compliance were
572 identified among sanctuary zones for shore and vessel-based fishing. Such data are
573 especially valuable in light of increasing visitor numbers to marine parks, especially
574 those located adjacent to the coast, which are easily accessible by the public. The strong
575 knowledge of zoning indicated some success of education and compliance activities,
576 although there is scope to improve the knowledge of first-time visitors. Given the
577 limited resources available to many agencies, data which can assist with developing
578 more targeted and efficient enforcement and education programs will improve the
579 likelihood of success of marine parks in conserving biodiversity.
580

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757
758
759

Table 1 Zone types in Ningaloo Marine Park [adapted from CALM and MPRA (2005)].

Table 2 Summary of vessels and people observed during aerial and coastal surveys at Ningaloo Marine Park during 2007.

Fig. 1 Ningaloo Marine Park, north-western Australia showing zoning and location of reef crest, boat ramps and settlements.

Fig. 2 Proportion of vessels (±95%CI) observed participating in recreational activities during (a) aerial and (b) coastal surveys. Note: vessels motoring or undertaking unidentified activities were excluded.

Fig. 3 Proportion of people (±95%CI) observed participating in recreational activities during (a) aerial and (b) coastal surveys. Note: people whose activity could not be identified were excluded.

Fig. 4 Mean density of vessels observed fishing during (a) aerial and (b) coastal surveys within each 9 km^2 grid cell in off peak and peak months.

Fig. 5 Mean density of people observed fishing from the shore during (a) aerial and (b) coastal surveys within each 3 km coastal segment in off peak and peak months.

Fig. 6 Mean number (±95%CI) of vessels observed fishing within each sanctuary zone during (a) aerial and (b) coastal surveys.

Fig. 7 Mean number (±95%CI) of people observed fishing from the shore within each sanctuary zone during (a) aerial and (b) coastal surveys. Note: * indicates special purpose (SBA) zone only present along part of the sanctuary zone shoreline.

Fig. 8 Mean number of people (±95%CI) observed fishing from the shore within each special purpose (SBA) zone during (a) aerial surveys and (b) coastal surveys. Note: * indicates special purpose (SBA) zone only present along part of the sanctuary zone shoreline..

Table 1

Zone type	Description
Sanctuary	Conserve marine biodiversity by excluding activities that are likely to have adverse environmental impacts (i.e. commercial and recreational fishing, oil production).
Recreation	Managed for conservation and recreation, and permit recreational fishing and commercial tourism, while excluding commercial fishing.
General use	Permit recreational fishing as well as aquaculture and some forms of commercial fishing (i.e. trawling, specimen shell collecting and wet lining), provided they do not compromise ecological values, such as water quality.
Special purpose (shore-based activities)	Areas in which recreational line fishing is permitted from the shoreline within eight of the 17 sanctuary zones. Four of these special purpose zones include the entire shoreline of the sanctuary zone.
Special purpose (benthic protection)	Managed for the conservation of benthic habitat, whereby only recreational fishing for pelagic species is permitted.

Table 2

Activity	Aerial surveys (N = 34)	Coastal surveys (N = 192)
Vessel-based (%, number of vessels)		
Identified	73%, n = 1,155	65%, n = 1,533
Unidentified	27%, n = 426	35%, n = 816
Shore-based (%, number of people)		
Identified	97%, n = 10,384	100%, n = 22,465
Unidentified	3%, n = 277	0%, n = 0

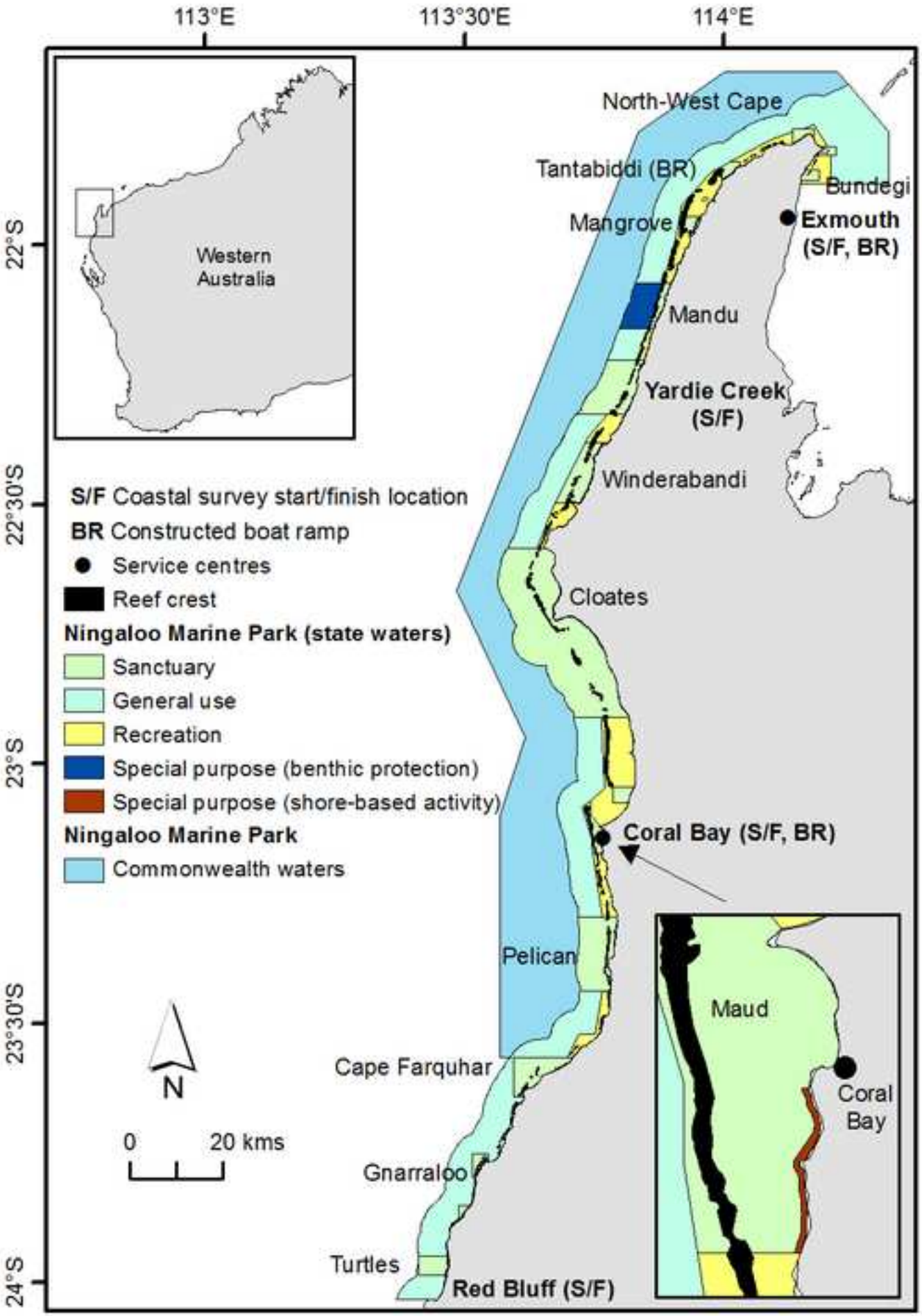


Figure 2

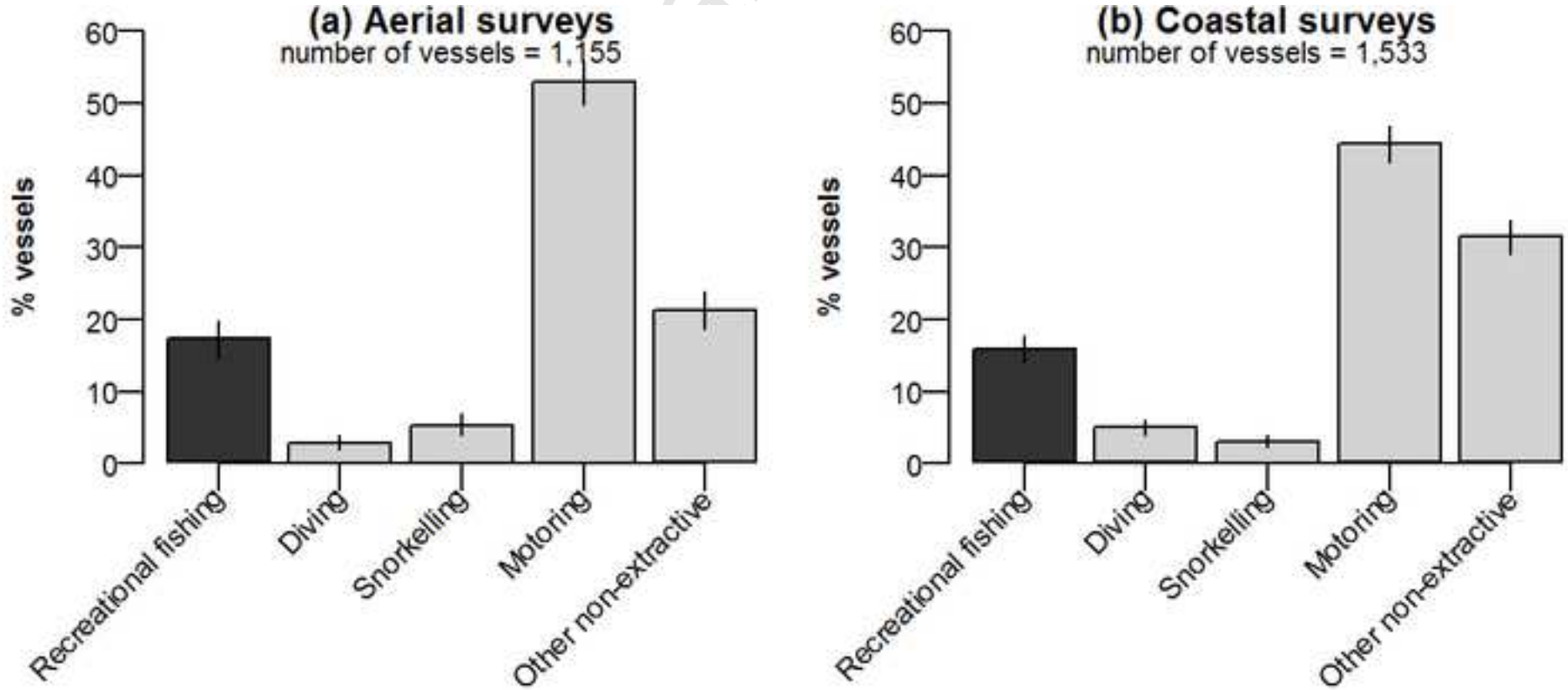

(a) Aerial surveys
number of vessels = 1,155
% vessels
60
50
40
30
20
10
0
Recreational fishing
Diving
Snorkelling
Motoring
Other non-extractive
(b) Coastal surveys
number of vessels = 1,533
% vessels
60
50
40
30
20
10
0
Recreational fishing
Diving
Snorkelling
Motoring
Other non-extractive

Figure 3

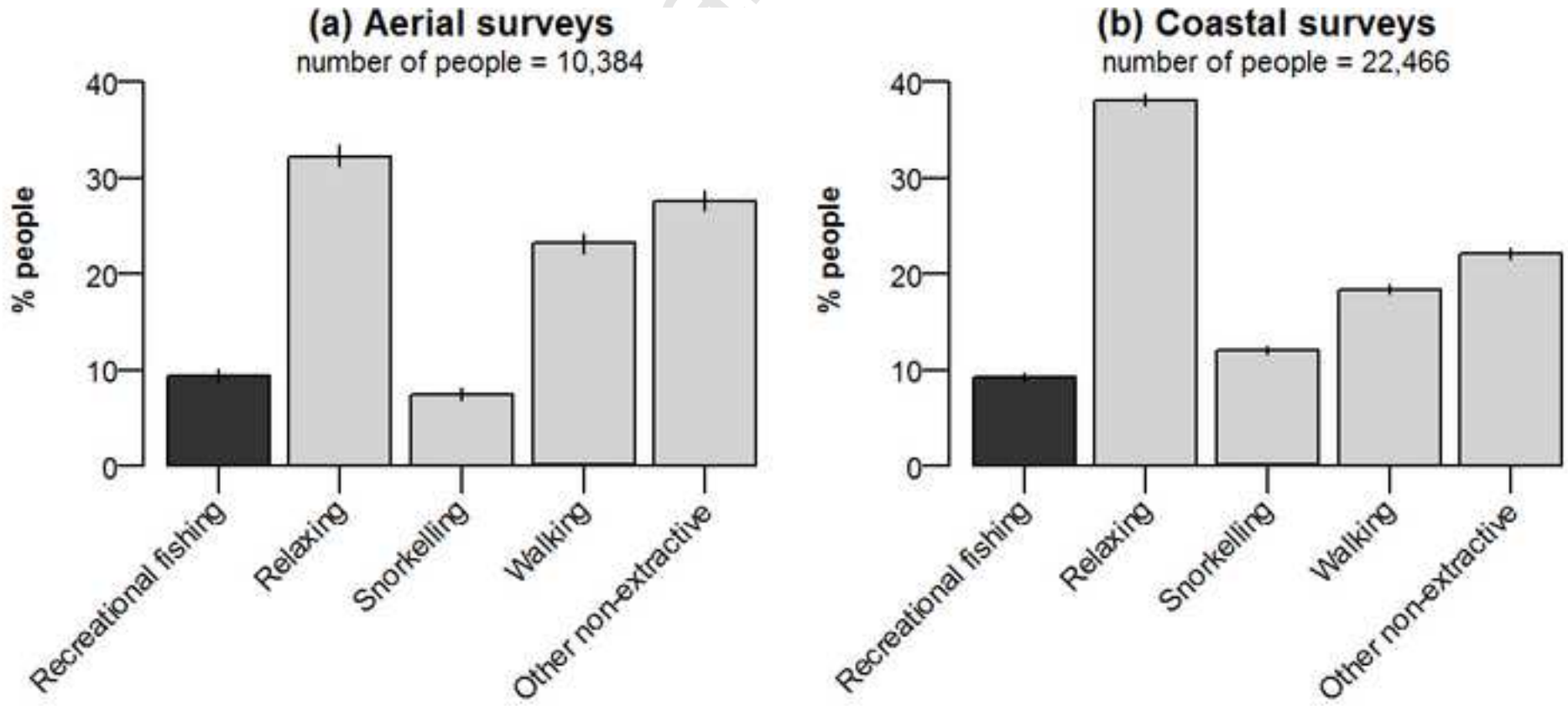

(a) Aerial surveys
number of people = 10,384
% people
40
30
20
10
0
Recreational fishing
Relaxing
Snorkelling
Walking
Other non-extractive
(b) Coastal surveys
number of people = 22,466
% people
40
30
20
10
0
Recreational fishing
Relaxing
Snorkelling
Walking
Other non-extractive

Figure 4

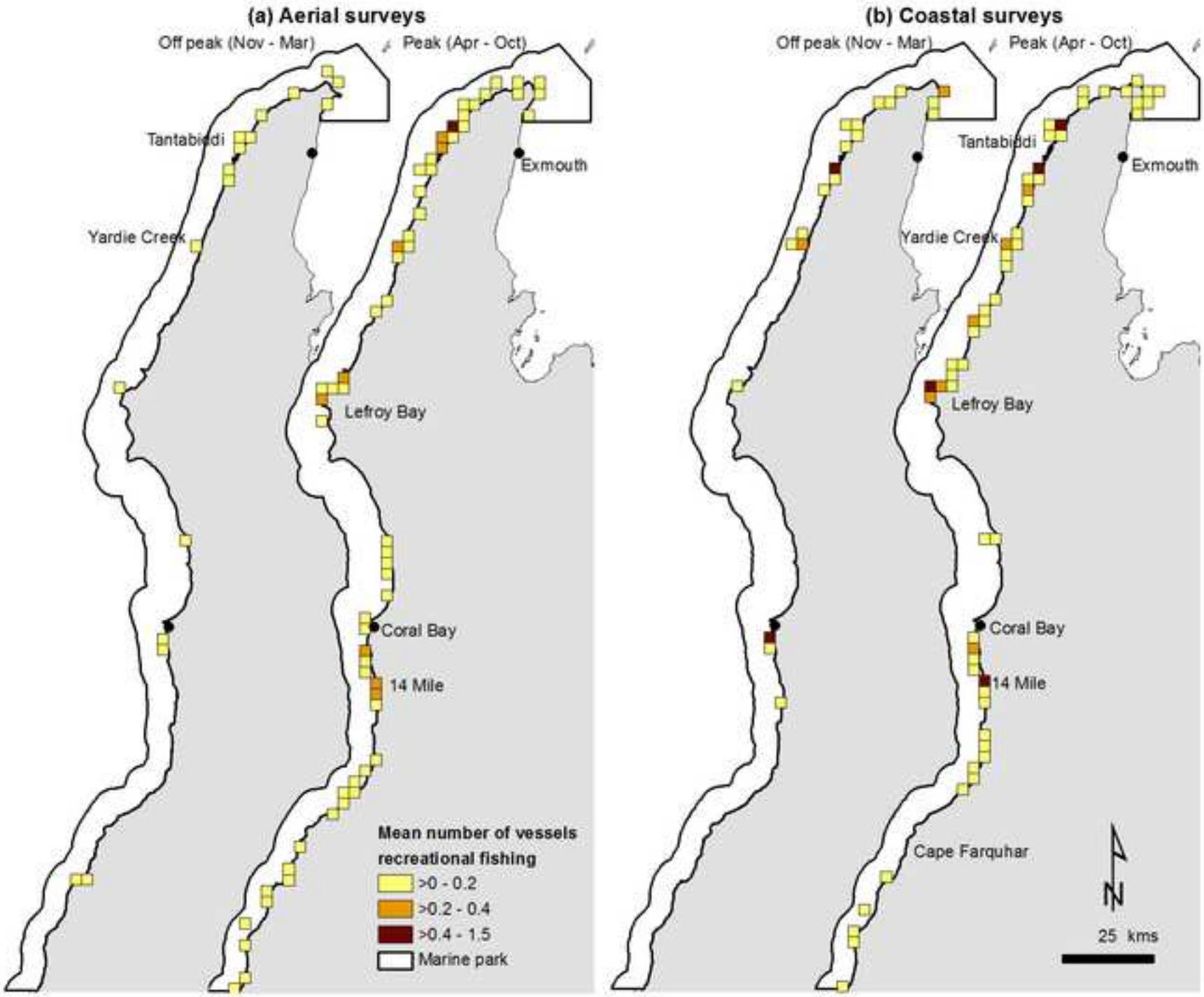
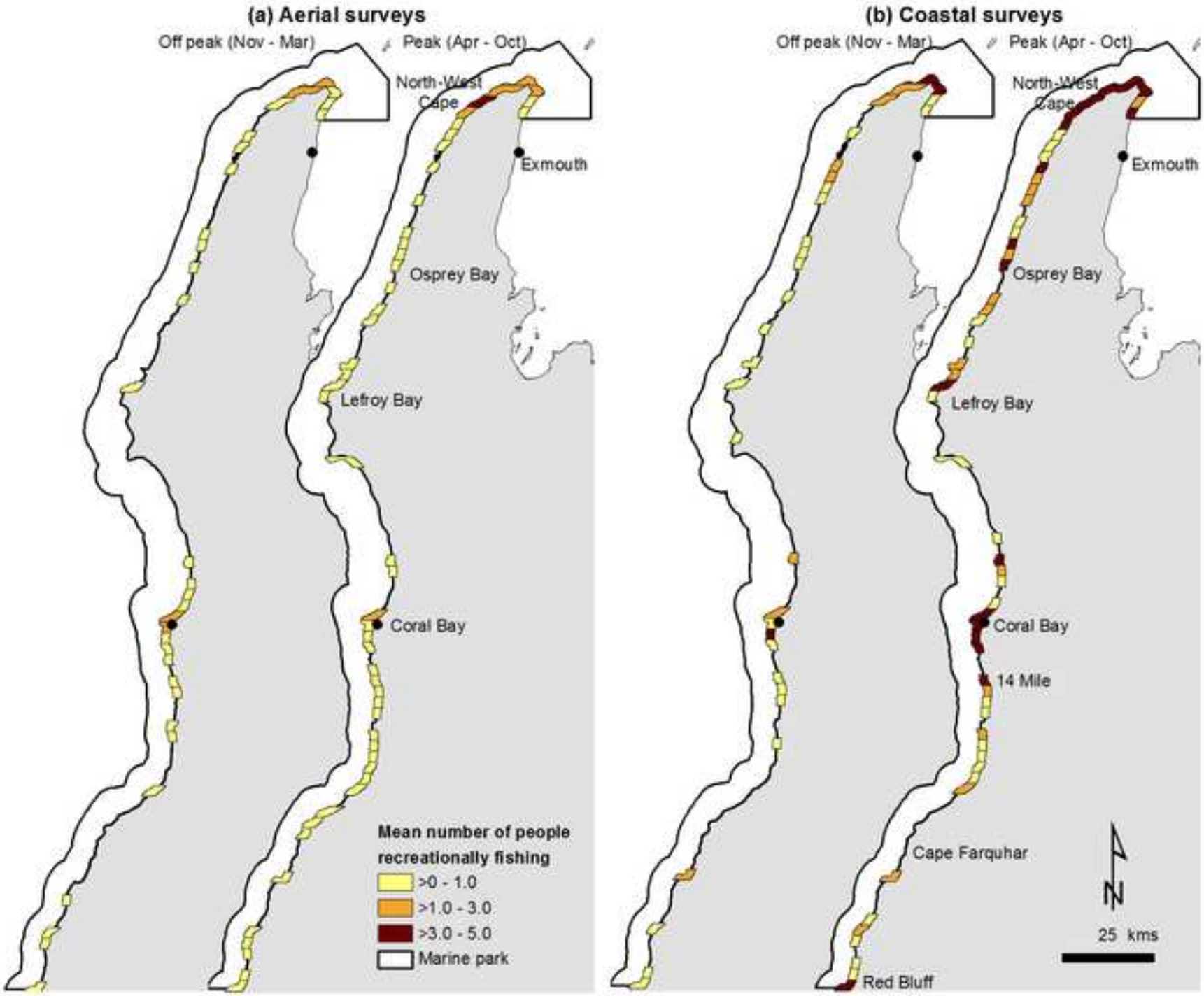
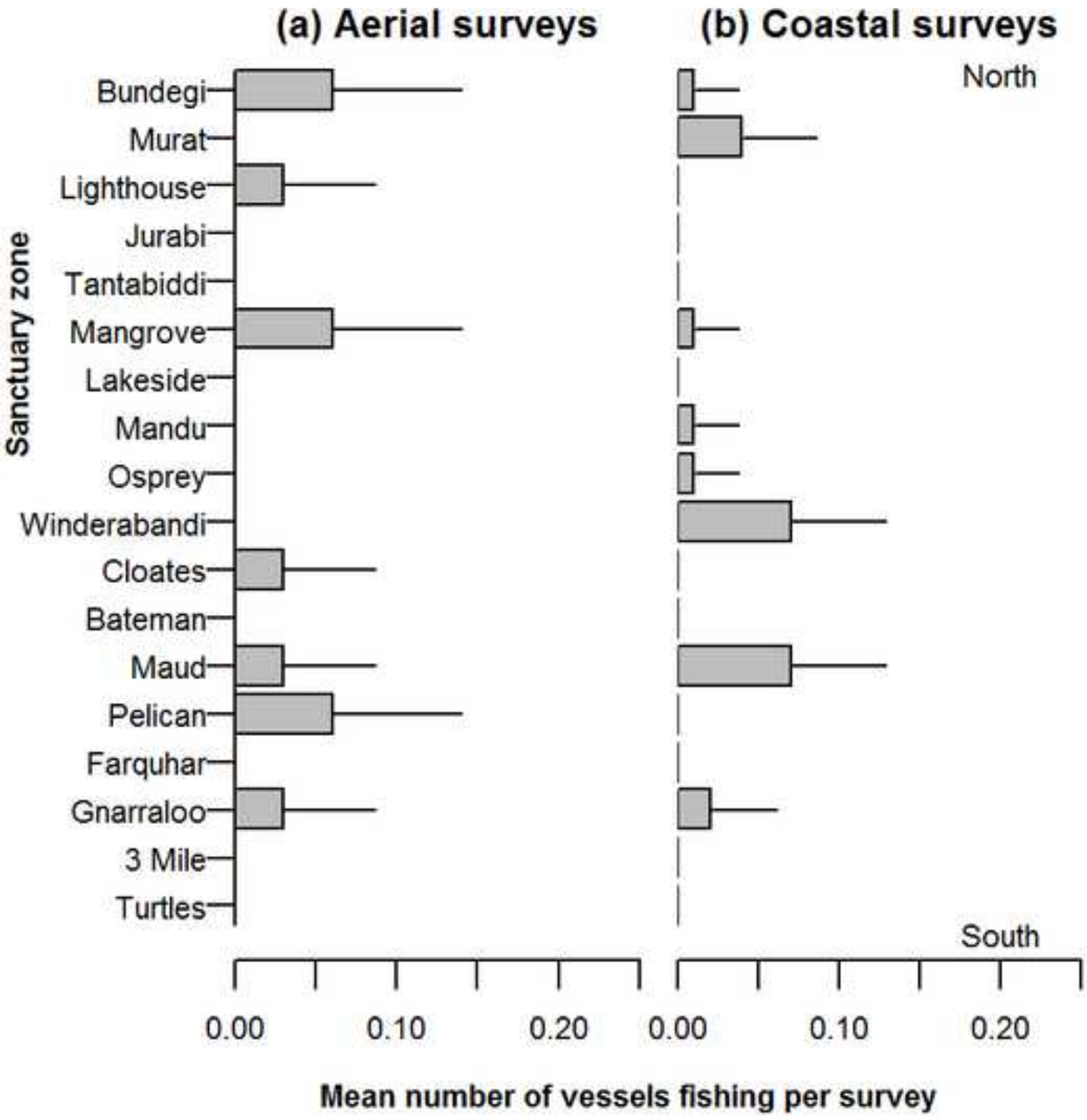

(a) Aerial surveys
Off peak (Nov - Mar)
Peak (Apr - Oct)
Tantabiddi
Exmouth
Yardie Creek
Lefroy Bay
Coral Bay
14 Mile
Mean number of vessels recreational fishing
>0 - 0.2
>0.2 - 0.4
>0.4 - 1.5
Marine park
(b) Coastal surveys
Off peak (Nov - Mar)
Peak (Apr - Oct)
Tantabiddi
Exmouth
Yardie Creek
Lefroy Bay
Coral Bay
14 Mile
Cape Farquhar
N
25 kms

Figure 5


(a) Aerial surveys
Off peak (Nov - Mar)
Peak (Apr - Oct)
North-West Cape
Exmouth
Osprey Bay
Lefroy Bay
Coral Bay
Mean number of people recreationally fishing
>0 - 1.0
>1.0 - 3.0
>3.0 - 5.0
Marine park
(b) Coastal surveys
Off peak (Nov - Mar)
Peak (Apr - Oct)
North-West Cape
Exmouth
Osprey Bay
Lefroy Bay
Coral Bay
14 Mile
Cape Farquhar
Red Bluff
N
25 kms



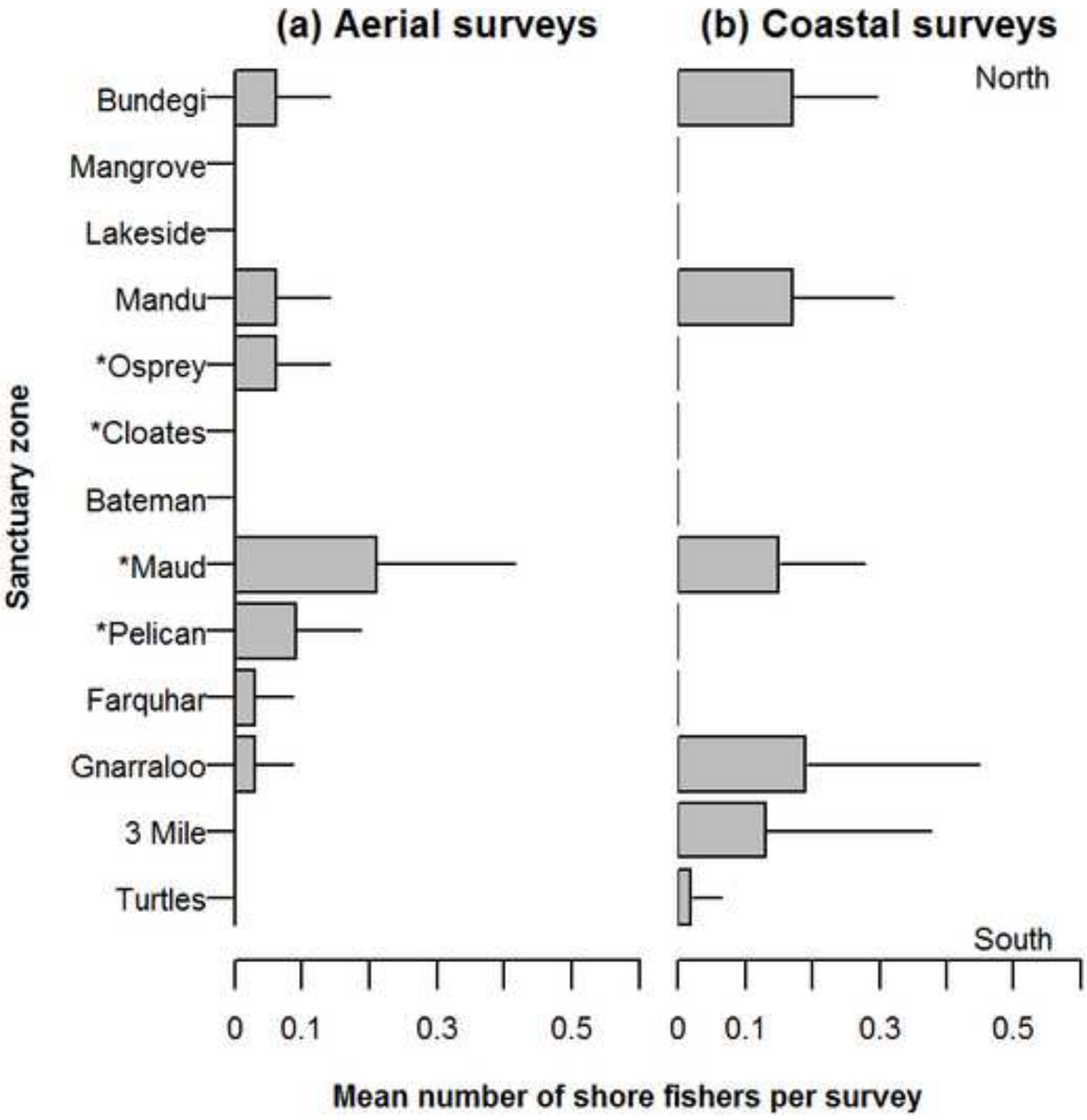
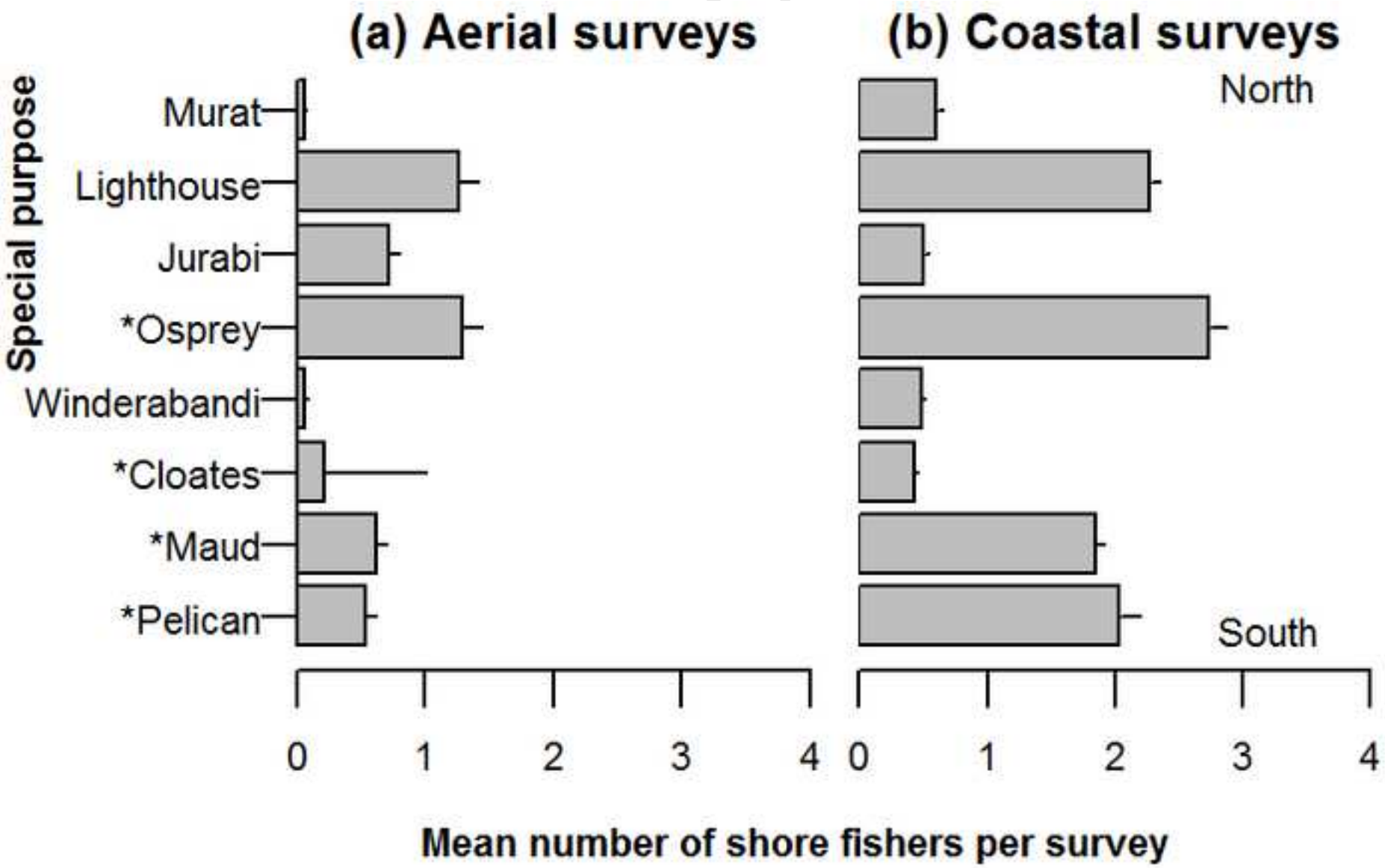


Figure 8


(a) Aerial surveys
(b) Coastal surveys
Special purpose
Murat
Lighthouse
Jurabi
*Osprey
Winderabandi
*Cloates
*Maud
*Pelican
North
South
0
1
2
3
4
0
1
2
3
4
Mean number of shore fishers per survey