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A survey of boat-based recreational fishing in inner Shark Bay 2016/17

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Executive Summary

Monitoring the temporal and spatial variability in recreational fishing provides necessary information for assessing resource sustainability, monitoring resource allocation and informing fisheries management. This is particularly important in inner Shark Bay because recreational fishing occurs in a World Heritage Area and Marine Park. The majority of boat-based recreational fishers in inner Shark Bay target Pink Snapper (*Chrysophrys auratus*) and three genetically distinct stocks of this species occur in the Denham Sound, Eastern Gulf and Freycinet Estuary Management Zones. These stocks are particularly vulnerable to exploitation because Pink Snapper spawn in winter when recreational fishing effort is typically greatest and aggregate in predictable locations each year.

The present study was initiated in response to changes to the management of recreational fishing for Pink Snapper in inner Shark Bay that were introduced in January 2016. These changes included the cessation of a harvest tag system in the Freycinet Estuary Management Zone (introduced in 2003) and the removal of a maximum size limit for Pink Snapper for all three Management Zones (introduced in 1997). The main objective of the study was to generate annual estimates of the recreational catch (both kept and released) by boat-based fishers at the three boats ramps in inner Shark Bay (Denham, Monkey Mia and Nanga) between March 2016 and February 2017 to determine the initial impact of recent management changes on recreational catch levels.

The boat-based fishery was assessed using the bus-route method which provided estimates of annual effort and recreational catch for the three boat ramps. A supplemented access point method was used which involved the installation of remotely-operated cameras at the three ramps. Supplementary data on powerboat retrievals collected from the remote cameras were combined with the catch and effort information collected as part of the bus route method enabling ramp-based levels of fishing effort and catch to be determined. Estimates of recreational fishing effort and the Pink Snapper catch were calculated for three different spatial scales: all ramps combined (incl. trips that occurred in inner Shark Bay and the Oceanic Management Zone), all ramps combined for inner Shark Bay only, and individual ramps (inner Shark Bay only).

In total, 649 boat parties were interviewed, of which 589 (91%) had been recreational fishing. The estimated annual total effort from boat-based recreational fishing in inner Shark Bay and the Oceanic Management Zone was 41,447 party-hours (standard error [se]=6,129). Estimated annual total effort from boat-based recreational fishing for inner Shark Bay only was 33,299 party-hours (se=3,961). The majority of annual fishing effort (75%) occurred between March and August and nearly a third of annual fishing effort (30%) occurred in

May. The estimated annual total effort from boat-based recreational fishing was higher at Denham (16,654 party-hours, se=1,912; excludes July to September) and Monkey Mia (15,421 party-hours, se=755) in comparison to Nanga (3,083 party-hours, se=225).

In total, 67 species/taxa were caught, including scalefish (n=51), elasmobranchs (n=13), crustaceans (n= 2) and molluscs (n=1). An estimated 110,000 individual fish (or invertebrates) were caught (kept or released, by number) from boat-based fishers using the ramps at Denham, Monkey Mia and Nanga, with 69% of catches being released. The three most commonly-caught species (by number) were Pink Snapper (58,245, se=10,249), Blue Swimmer Crab (*Portunus armatus*; 12,803, se=3,054) and Grass Emperor (*Lethrinus laticaudis*; 12,336, se=2,814) and the majority of interviewed boat parties (63%) were targeting Pink Snapper.

Approximately 13% of Pink Snapper caught from boat-based recreational fishing were kept (7,506, se=1,427) and 87% released (50,738, se=9,069). These estimates related to fish caught within the three inner Bay Management Zones and the Oceanic Management Zone. The majority (87%) of this Pink Snapper catch was from inner Shark Bay (50,330, se=7,831) of which 12% was kept (6,283, se=1,194) and 88% released (44,047, se=6,891). The estimated kept catch of Pink Snapper was converted from numbers to weight using estimates of average weight from the present study (n=130 fish measured) and published length-weight information. The estimated kept catch of Pink Snapper from boat-based recreational fishing was 25.7t (95% CI 16.0–35.4), including catches within inner Shark Bay and the Oceanic Management Zone. The estimated kept catch of Pink Snapper from boat based recreational fishing for inner Shark Bay only was 21.5t (95% CI 13.4–29.6).

The estimated mean kept catch of Pink Snapper (by weight) at Denham (5.3 t, 95% CI 1.6–9.0) was below the Total Allowable Recreational Catch (TARC) for recreational fishing in Denham Sound (11.5 t). However, this estimate was restricted to a 9-month period because major renovations along the Denham foreshore required the temporary dismantlement of the remote camera. As a result, the mean kept catch of Pink Snapper at Denham is an underestimate of the total catch at this ramp for the 12-month period. The estimated mean kept catch of Pink Snapper (by weight) at Monkey Mia (3.0 t, 95% CI 1.1–4.8) was well below the TARC for recreational fishing in the Eastern Gulf (11.25 t) and the upper 95% confidence interval was also below the TARC. This is likely to be influenced by the 3-month spawning closure (May to July) which prohibits the take of Pink Snapper in the Eastern Gulf at a time when fishing effort levels at Denham, and to a lesser extent Nanga, are relatively higher.

The estimated mean kept catch of Pink Snapper (by weight) at Nanga (2.7 t, 95% CI 1.5–3.9) was below the TARC for recreational fishing in Freycinet Estuary (3.75 t) with the 95% confidence interval exceeding the TARC. However, observations from DPIRD staff based in Denham confirm the capture of Pink Snapper at the Tamala and Carrarang stations in Freycinet Estuary during the 12-month survey. Furthermore, high visitation rates at Tamala were verified in April and July based on records kept by the station owner. Therefore, the estimated catch of Pink Snapper at Nanga is an underestimate of the total catch in Freycinet Estuary.

A large percentage of interviewed fishers (89%) were tourists (i.e. not Shark Bay residents) and the majority of fishers were well-informed and expressed strong levels of support for contemporary Pink Snapper management arrangements. Overall, nearly half of all interviewed fishers at Denham, Nanga and Monkey Mia (44%) were unsure whether or not they supported the recent removal of the harvest tag system. However, the majority of interviewed fishers at Nanga (79%), the only ramp within the Freycinet Estuary Management Zone, expressed support for the recent removal of the harvest tag system.

Catch estimates outlined in this report could be underestimates because they are not inclusive of catches from shore-based recreational fishing or on-board Tour Operator boats, over-night and multiple day fishing trips and from boats held on moorings or from boats launched on the beach. Ongoing monitoring of recreational fishing in inner Shark Bay is considered essential to determine whether Pink Snapper catches are within the management settings (TARCs) for each of the Management Zones.

A 2018/19 survey of boat-based recreational fishing in Shark Bay recently commenced, incorporating an aerial survey of the Freycinet Estuary Management Zone. This survey will assist in understanding the extent of recreational fishing at Tamala and Carrarang. It is recognised that ongoing monitoring of recreational catches will be challenging because catches occur at various remote locations. Furthermore, the TARC for Pink Snapper comprises only approximately 1,000 fish kept per year in Freycinet (~ 3.75t) and fewer than 3,500 fish kept per year in the Denham Sound (~ 11.25 t) and Eastern Gulf (~ 11.25 t) Management Zones. The 2018/19 survey will lead to recommendations for the ongoing monitoring of recreational fishing in inner Shark Bay.

1. Introduction

1.1 Recreational fishing in inner Shark Bay

Shark Bay has a long history as one of Western Australia's most popular recreational fishing destinations (Jackson and Moran, 2012). The sheltered waters of its inner gulfs attract large numbers of boat-based recreational fishers, in particular during winter when weather is milder and sea conditions more conducive to fishing from small boats (Jackson and Moran, 2012; Wise *et al*., 2012). Recreational catches in these waters are dominated by Pink Snapper (*Chrysophrys auratus*), Blue Swimmer Crab (*Portunus armatus*) and Grass Emperor (also referred to as Black Snapper, *Lethrinus laticaudis*; Wise *et al.,* 2012). Pink Snapper stocks in the Eastern Gulf, Denham Sound and Freycinet Estuary Management Zones (Figure 1) are particularly vulnerable to exploitation because they spawn in winter when recreational fishing effort is typically greatest and aggregate in predictable locations each year (Jackson and Moran, 2012; Wise *et al*., 2012). Concern that Pink Snapper in each of these Management Zones were being overfished led to a range of scientific monitoring and assessments from 1996 onwards. This included boat ramp surveys involving interviews with recreational fishers at Denham, Monkey Mia and Nanga to provide fishery managers with estimates of annual effort and catch at these ramps (Wise *et al*., 2012).

1.2 Contemporary and historical management arrangements for Pink Snapper in inner Shark Bay

A variety of management arrangements have been applied to recreational fishers harvesting Pink Snapper in inner Shark Bay since the 1950s (Appendix 1). Historically, recreational fishing for Pink Snapper was managed using minimum and maximum lengths and daily bag limits (Jackson and Moran 2012). Based on assessments that showed Pink Snapper in Eastern Gulf, Denham Sound and Freycinet Estuary had been overexploited, stricter management was progressively introduced from 1997 onwards. These measures included a 5-year moratorium in the Eastern Gulf (June 1998–March 2003), a 6-week spawning closure in the Freycinet Estuary (from 2000 onwards) and finally, in 2003, introduction of a Total Allowable Recreational Catch (TARC) for each of the three Management Zones (Jackson and Moran, 2012). Since 2003 a range of different measures have been used in each Management Zone, including a harvest tag system in Freycinet Estuary (Jackson *et al*., 2016). Following stock assessments that indicated the recovery of Pink Snapper stocks in Eastern Gulf, Denham Sound and Freycinet Estuary, a review of the management arrangements was undertaken in late 2015. This resulted in management changes introduced in January 2016 that included:

- Removal of the 700mm maximum size limit for Pink Snapper in inner Shark Bay;
- Removal of the requirement to land Pink Snapper in whole form in inner Shark Bay;

- Replacement of the lottery quota tag system with the Freycinet Estuary Management Zone in which a new possession limit of 5kg of finfish fillets (including Pink Snapper) or one day's bag limit of whole fish or trunks applies (Freycinet only).

1.3 Need for monitoring the recreational catch of Pink Snapper in inner Shark Bay

More than seven years have passed since the last boat ramp survey was undertaken in Shark Bay (January–December 2010; Wise *et al*., 2012). The cessation of the harvest tag system in 2016 means that the method used previously for regulating the recreational harvest of Pink Snapper in Freycinet Estuary no longer applies. Since 2011/12 three state-wide surveys of boat-based recreational fishing have been conducted within Western Australia and a fourth is currently underway (Ryan *et al.*, 2013, 2015, 2018). These surveys were designed to provide state-wide and bioregion-wide estimates for commonly-caught species. An additional recreational survey was required to meet the specific management objectives for the Eastern Gulf, Denham Sound and Freycinet Estuary Management Zone, recognising that obtaining accurate catch estimates for Pink Snapper at these finer-scale spatial scales is beyond the scope of ongoing state-wide surveys.

1.4 Survey objectives

The primary objective was to generate annual estimates of the total recreational catch (both kept and released) by boat-based fishers at Denham, Monkey Mia and Nanga between March 2016 and February 2017. These ramp-based estimates correspond with the three Management Zones in inner Shark Bay that are subject to separate resource assessments and management regulations. Secondary objectives included:

- Obtaining annual estimates of the total kept recreational catch (by weight) by boat-based fishers for each of the three Pink Snapper Management Zones;
- Obtaining annual and seasonal estimates of fishing effort for inner Shark Bay and for each of the Pink Snapper Management Zones;
- Profiling recreational fishers' characteristics, awareness of and attitudes towards contemporary management measures for Pink Snapper in inner Shark Bay.

2. Survey methods and analysis

2.1 Survey scope

The survey focussed on boat parties using the boats ramps at Denham, Monkey Mia and Nanga (Table 1). The temporal sampling frame of the survey spanned a one-year period between March 1, 2016 and February 28, 2017. Recreational fishing was defined as the attempted capture of any aquatic (animal) species caught including both finfish (e.g. scalefish, sharks and rays) and invertebrates (e.g. crabs and lobsters). Species taxonomy followed the Codes for Australian Aquatic Biota (Rees *et al*., 2012). All boat-based recreational fishing activity was assessed including line fishing, diving, potting and spearfishing as undertaken from powerboats retrieving at the three ramps. Recreational activities that occurred on board Tour Operator vessels were not included because these catches are reported in Tour Operator Returns (Charter logbooks). Any potential recreational activities that occurred on jetskis were also not included in addition to commercial or indigenous fishing activity.

Table 1. Survey coverage for the bus-route survey design.

Specification	Item	Bus-route survey
Person in scope	Residency status	All
	Age	All*
Activities	Platform	Boat
	Boat type	Powerboat
	Methods	All recreational fishing methods
Species	Species	All aquatic (animal) species
Geographical scope	Area covered	All areas accessed from boat ramps at Denham, Monkey Mia and Nanga
Time frame	Survey dates	1 Mar, 2016–28 Feb, 2017

*Only fishers ≥ 15 yrs old who had not been interviewed on a previous day for the attitudinal data.

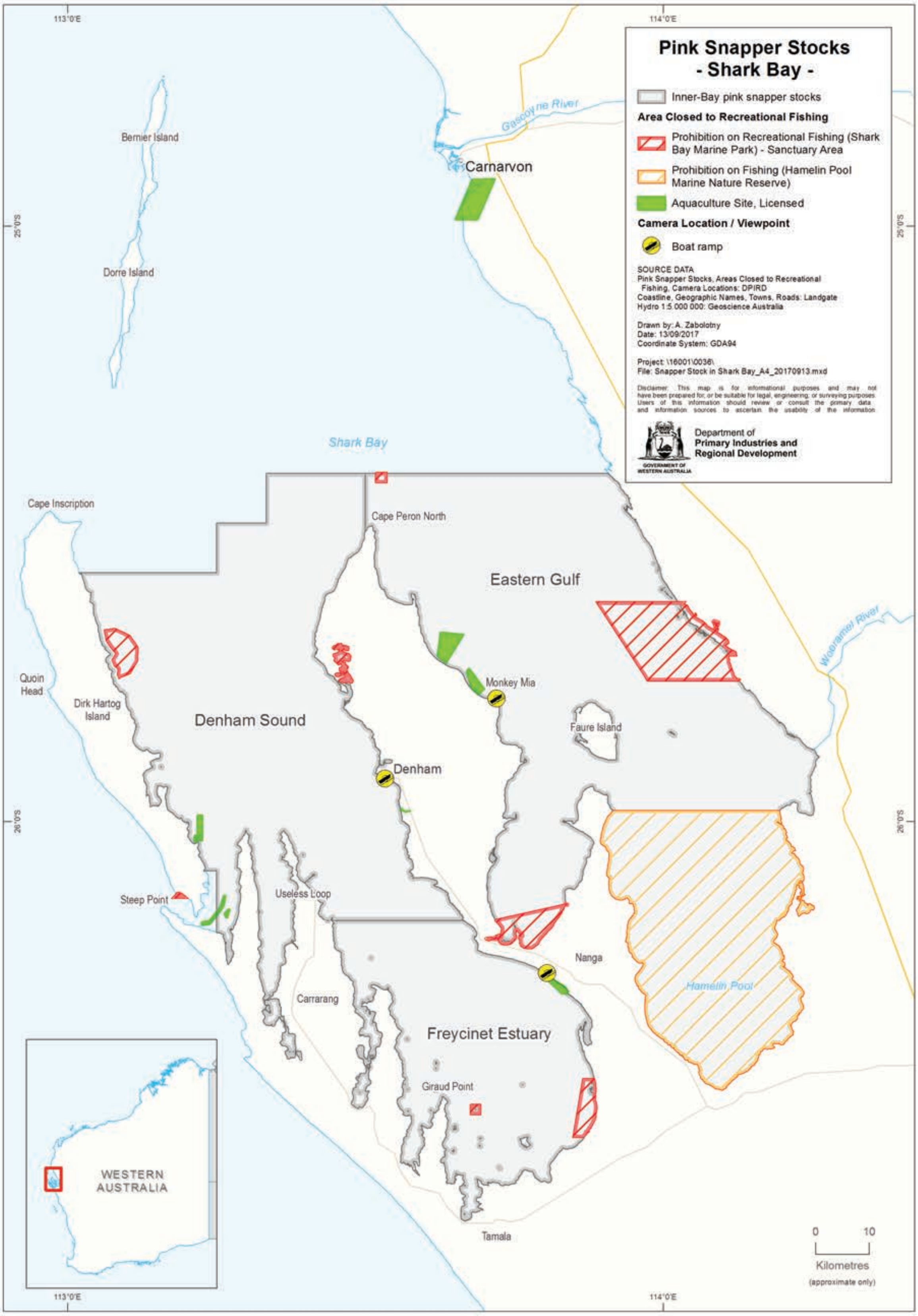

Figure 1. Map of Shark Bay indicating the Management Zone boundaries for the three inner Shark Bay Pink Snapper stocks. Yellow circles indicate the location of the three boat ramps.

2.2 Survey methods

2.2.1 Bus-route survey design (route-based estimates)

The boat-based fishery was assessed using the bus-route method (Robson and Jones, 1989; Pollock *et al.*, 1994). This method treats numerous access sites as a group and estimates of recreational fishing effort and catch derived from a bus-route survey represent expanded totals for the entire bus route. On each sampling day, survey staff visited each of the three boat ramps at Denham, Monkey Mia and Nanga. Stratified random sampling techniques were used with days being the primary sampling unit (PSU) for all strata. The design of the bus-route specified the random order in which each of the ramps were to be visited. Each bus route was 8-hours in duration, commencing at 10:00 and finishing at 18:00.

The survey year was stratified into months and day types (weekdays and weekend days) within months. Public holidays were classed as weekend days. The decision to use a daily survey period between 10:00 and 18:00 was consistent with previous boat ramp surveys in Shark Bay (Wise *et al.*, 2012) and cognisant of the perceived low levels of night time fishing activity based on anecdotal reports from DPIRD staff based in Denham. Disproportional sampling was applied for each day type with an allocation of six weekdays and six weekend days a month (144 days in total). Due to logistical issues this allocation was not reached for four of the 24 strata (Table 2).

2.2.1.1 Data collected using the bus-route survey

A range of information was collected including (but not limited to) the number of powerboats departing from and returning to each ramp during the allocated wait time and the number of interviews attempted and completed (and if not, the reason). For every boat party interviewed, it was determined whether the occupants had been fishing, what fishing methods were used, regions fished, time spent fishing, species targeted, and species caught (kept and released, Appendix 2 and 3). To assist fishers in recalling the broad location of their fishing trips they were referred to a map of inner Shark Bay and adjacent oceanic waters divided into 5 x 5 nautical mile grids (Appendix 4). To assist in the accurate identification of commonly misidentified species (e.g. emperors, mackerels), fishers were referred to a species identification guide which highlighted the key diagnostic features for these species. In some instances, catches were reported to broader taxonomic groups (e.g. hammerhead sharks, Sphyrna sp.), particularly for the released component of the catch that could not be verified by survey staff. The total length of fish and the carapace width or length of crustaceans kept by recreational fishers was also measured to the nearest mm. However, it was not feasible for all fish and crustaceans kept by recreational fishers to be measured, particularly during busy periods.

Table 2. Number of days sampled for each month and day type. WD = weekday, WE/PH = weekend/public holiday.

Season/ Year	Month	Day Type	No. days in stratum	No. survey days
Aut 16	Mar	WD	20	4
		WE/PH	11	6
	Apr	WD	20	6
		WE/PH	10	6
	May	WD	22	3
		WE/PH	9	6
Win 16	Jun	WD	21	6
		WE/PH	9	6
	Jul	WD	21	6
		WE/PH	10	6
	Aug	WD	23	6
		WE/PH	8	6
Spr 16	Sep	WD	21	6
		WE/PH	9	6
	Oct	WD	21	5
		WE/PH	10	5
	Nov	WD	22	6
		WE/PH	8	6
Sum 16/17	Dec	WD	21	6
		WE/PH	10	6
	Jan	WD	22	6
		WE/PH	9	6
	Feb	WD	20	6
		WE/PH	8	6
Total		WD	254	66
		WE/PH	111	71
		Total	365	137

The final part of the interview involved a series of demographic, awareness and attitudinal questions (Appendix 5) that were asked to one randomly-selected fisher from each boat party. On those occasions where the fisher had answered the same questions on a previous fishing trip, another fisher was chosen at random for interview. It was not always feasible to conduct this part of the survey because of time restrictions and that the collection of data on the number of boats launching and retrieving and interviewing fishers about their catch was deemed to be higher priority. All survey information was entered and stored within relational tables in a Microsoft Access database.

2.2.2 Supplementary data collected using remotely-operated cameras

An alternative technique was required to determine ramp-based levels of recreational fishing effort and catch. This was because the bus route method was designed to produce expanded estimates for the entire area accessed by fishers using all access points along the route (e.g. Denham, Monkey Mia and Nanga, combined) rather than subdividing estimates into smaller areas (Pollock *et al.*, 1994; Steffe, 2009). A supplemented access point method was used which involved the installation of remotely-operated cameras at the three ramps (Table 3; Figure 3). The supplementary camera data were used to enable the separate estimation of effort and catch for each boat ramp.

The supplemented access point survey design used a double sampling approach (Steffe *et al.*, 2008) to adjust counts of powerboat retrievals for non-fishing trips by using party-based interview information collected during the randomly scheduled survey days at those ramps. This supplemented analysis also improves the accuracy and precision of catch estimates because the camera data provide better coverage of the temporal sampling frame (i.e. scheduled and non-scheduled survey days are included; Steffe *et al*., 2008).

Upon examination of the footage obtained from the remote cameras, boat launches and retrievals were recorded across the 1-year survey period, 24-hours a day. Each boat was recorded as a powerboat, jetski, yacht, kayak, commercial vessel or other. All boat data obtained from the remote cameras were entered and stored in a Filemaker Pro database. Subsequent analysis was based on the powerboat data only. More detailed information on the camera network system and the process of reading the camera data are provided in Blight and Smallwood (2015) and Steffe *et al* (2017).

Table 3. Specifications for the remotely-operated cameras

Location	Latitude (DD)	Longitude (DD)	Installation date	Camera viewpoint	Camera type	Lens type
Denham	-25.928	113.533	29/11/2016*	Boat ramp	Mobotix M22M	L32 (6 mm)
Monkey Mia	-25.793	113.720	1/4/2016*	Boat ramp	Mobotix M15D SEC	L43-N43
Nanga	-26.255	113.805	13/12/2015	Beach launch^	Mobotix M25M	L43 (8 mm)

* Existing camera replaced on this date. Older camera was operational at the start of the survey. Specifications are for the new camera

^ Although boat parties at Nanga access the small ramp directly from the beach (i.e. beach launch), throughout the report Nanga is referred to as a boat ramp.

The remote camera data were used to expand the 8-hour time period covered in the bus-route to the period between nautical dawn and nautical dusk. The duration of this period ranged from approximately 12 hours in June 2016 to 16 hours in December 2017 (Figure 2). Daily values for the time at which nautical dawn and nautical dusk occurred (to the nearest minute) were obtained from Geoscience Australia (http://www.ga.gov.au/). The estimation of total catch for each survey day was based on filtering the powerboat data for the same day to only include those powerboat retrievals that occurred between nautical dawn and dusk. Adjustments to the camera data were required to account for short-term outages in the camera data, as outlined in Appendix 7.

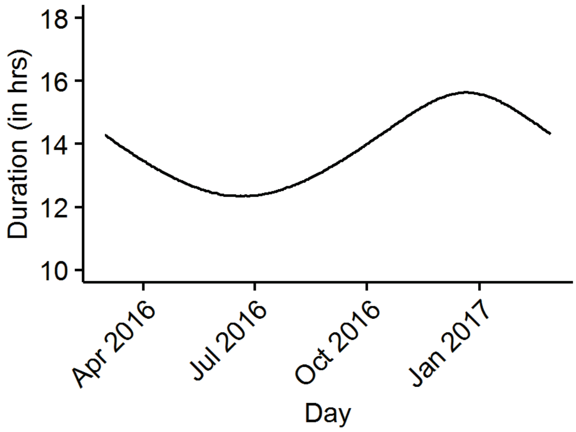

Figure 2. Daily values for the duration of time between nautical dawn and nautical dusk in Shark Bay between 1 March 2016 and 29 February 2017.

A

B

C

Figure 3. Field of view for the remote camera installed at A) Denham, B) Monkey Mia and C) Nanga.

2.3 Estimation methods

The step-by-step process of estimating recreational fishing effort and the catch using the bus-route method is outlined in Appendix 6. This includes the estimation of daily and stratum totals and the conversion of the recreational catch in numbers to the catch by weight for Pink Snapper. The analytical procedure applied to the supplementary access point method is outlined in Appendix 7. The randomisation protocol and the analysis and expansion of all data were performed in the statistical package R, ver. 3.3.1 (R Development CoreTeam, 2016), mainly using the packages 'dplyr' (Wickham and Francois, 2016) and 'lubridate' (Grolemund and Wickham, 2011).

2.4 Additional analysis steps

Although the bus-route and the supplementary access point method were based on probability-based survey protocols (Pollock *et al.*, 1994; Jones and Pollock, 2012) the following assumptions were necessary in the analysis of the data:

Unable to interview all boat parties during busy periods: It was not always possible to interview all fishing parties at a boat ramp during busy days, and in particular when parts of the Denham foreshore were being renovated. On these occasions creel staff interviewed as many boat parties as possible. The catch and effort data from those interviewed boat parties were then scaled up to the total number of boats that retrieved while field staff were at the ramps on that day prior to using the Direct Expansion method (Appendix 6). This adjustment was made at the PSU level (i.e. from all three ramps combined rather than separately for each ramp). Similar adjustments for boats not interviewed have been applied in other recent onsite recreational fishing surveys (Hartill *et al*., 2015). For the supplemented access point analysis, it was necessary to assume that the catch rate information from interviewed boat parties was representative of the catch rate of all boat parties that retrieved at the ramps between nautical dawn and dusk.

Multi-day fishing trips: When the launch date for a boat party was on an earlier date than the retrieval date, the catch and effort data were not included in the expanded estimate. This was because the fishing activity in the bus-route analysis must all occur within the defined survey time on each randomly selected survey day. Any fishing that occurs outside of this period is out-of-scope and inclusion of these out-of-scope fishing activities would lead to overestimation of fishing effort and catch from the bus-route method. The reliability of catch and effort data pertaining to previous days would also be questionable due to known issues with recall bias (e.g. Jones and Pollock, 2012). For example, if a boat party launched from

Denham and then spent 7 days camped on Dirk Hartog Island, it would not be possible to accurately record all the catch information for the entire multi-day trip. From the 589 boat parties interviewed that had been recreational fishing (i.e. 649 total interviews minus non-fishing boat parties, Table 5), 32 had fished for more than one day. As a result, 29 events were filtered out at Denham, 3 at Monkey Mia and none at Nanga.

Aggregation of catches for inner Shark Bay: For management purposes it was necessary to report on only use those catches that occurred within inner Shark Bay (i.e. Denham Sound, Eastern Gulf and Freycinet Estuary; Figure 1). This had no impact on the data collected from Nanga, very little impact on data from Monkey Mia (1 fishing event filtered out) and was largely restricted to the data collected from Denham (84 fishing events filtered out, 25 of which were multi-day trips).

Analysis at the PSU level: All estimates of recreational fishing effort and catch were based on pooling data at the Primary Sampling Unit (PSU; i.e. survey day; Pollock *et al.*, 1994; Steffe, 2009). However, all other summaries (e.g. targeting behaviour (Table 13)) were analysed at the individual trip level rather than the PSU level because of the relatively small number of interviews achieved for each day of sampling. It was also necessary to analyse the demographic, awareness and attitudinal data at the individual fisher level.

Camera outages: The process of imputing periods of data loss from the cameras was reliant on the assumption that the mechanism responsible for the camera outage was independent of the number of powerboat retrievals. Elsewhere, more complex analytical procedures have been developed to impute for missing data (Hartill *et al.*, 2016; van Poorten *et al.*, 2015; Watson and Hartill, 2005) and within Western Australia, research is underway to develop a suitable imputation technique that accounts for suitable auxiliary data (such as environmental conditions) to “fill in” missing observations in remote camera data. As part of this process, the efficacy of the approach used in the present study will be examined.

2.5. Uncertainty

Survey estimates are subject to uncertainty because data are derived from a sample of the total population. Throughout this report the standard error (se) for each estimate is used to express the level of uncertainty, in addition to the 95% confidence intervals (95% CI) that are reported for the estimated kept catch of Pink Snapper by weight. These measures indicate the extent to which each estimate may differ from the actual population value due to chance and sampling of the population. In general terms, and in the absence of survey bias, the se indicates how reliable the estimate is of the true value; the smaller the se, the more precise the estimate is and the more confidence in that estimate. The relative standard error (rse) is the se divided by the survey estimate and is a measure of precision that allows comparisons of uncertainty associated with estimates that have different magnitudes. Throughout the report the same criteria used in the state-wide survey of boat-based fishing has been applied (e.g. Ryan *et al.*, 2015), whereby an estimate with an rse greater than 40% is highlighted in bold to indicate the estimate is not precise and may be inaccurate. Similarly, caution is advised in interpreting estimates with rse greater than 40%.

2.6. Consistency with previous Shark Bay surveys

Between 1998 and 2010, 11 boat ramp surveys were conducted in Shark Bay (Sumner and Steckis, 1999; Sumner and Williamson, 1999; Sumner *et al.*, 2002; Marriot *et al.*, 2012; Wise *et al.*, 2012). These previous surveys sampled the same ramps as those in the current study and were broadly consistent in terms of within-day scheduling of shifts and sampling effort (Table 4). While the expanded estimates from these earlier surveys are somewhat comparable to the present study, there are differences in the aggregation of the data, the method of expansion (Direct Expansion vs. Time Interval Count Method) and variance estimation. In addition, an adjustment factor was used in the earlier surveys to extrapolate the estimate from the survey period and to obtain an estimate of effort that included fishing activity before the start of the day (Sumner *et al.*, 2002). This factor was not applied to the present study based on the recommendations of Steffe (2009). Differences between the respective surveys mean that comparisons of estimated effort and catch are best viewed as relative rather than absolute.

Table 4. Time period, within-day scheduling of shifts and the number of shifts for all Shark Bay boat ramp surveys.

Year	Time Period	Within-day scheduling of shifts	Number of shifts
1998/99	1 Apr 98–31 Mar 99	11:00 – 18:00	86
2000/01	1 May 00–30 Apr 01	11:00 – 18:00	101
2001/02	1 May 01–30 Apr 02	11:00 – 18:00	107
2002	1 Jan 02–31 Dec 02	11:00 – 18:00	101
2003	1 Jan 03–31 Dec 03	11:00 – 18:00	143
2004	1 Jan 04–31 Dec 04	11:00 – 18:00	151
2005	1 Jan 05–31 Dec 05	11:00 – 18:00	159
2006	1 Jan 06–31 Dec 06	11:00 – 18:00	163
2007	1 Jan 07–31 Dec 07	11:00 – 18:00	99
2007/08	1 Apr 07–31 Mar 08	11:00 – 18:00	96
2010	1 Jan 10–31 Dec10	10:00 – 18:00	126
2016/17	1 Mar 16–28 Feb 17	10:00 – 18:00	137

3. Response profiles and camera coverage

3.1 Catch and effort data

In total, 781 powerboats were retrieved at boat ramps during the allocated wait times over the 137 survey days (Table 5). During peak times it was not possible to interview all boat parties and 132 boats (17%) were classified as ‘Interview not attempted’. On these days, the catch and effort data from interviewed boat parties were scaled up to the total number of boats. Of the 649 boat parties that were interviewed, 642 (99%) participated fully in this survey interview and 589 (91%) had been recreational fishing.

3.2 Demographic, awareness and attitudinal data

From the 781 powerboat retrievals, it was not possible to obtain information from 370 (47%) boat parties either because of time restrictions, the boat was not used for recreational fishing or because the boat occupants had answered the same questions on a previous fishing trip (Table 6). Of the 411 fishers that were available for this part of the survey, 406 (99%) participated fully.

3.3 Camera coverage

Overall, across the 12-month period, camera outages were minor in nature at Monkey Mia and Nanga, where 95% and 83% of days had no or minor outages, respectively (Table 7; Appendix 9–Appendix 10). At Denham 66% of days had no or minor outages (Table 7; Appendix 8); however, renovations to the Denham foreshore meant that no camera footage was available from this camera between July and September 2016. As a result, subsequent estimates of effort and catches of Pink Snapper specific to the Denham ramp from this survey were restricted to nine months (i.e. excluding July to September; Table 7).

Table 5. Response profiles for the catch and effort data collected at Denham, Monkey Mia and Nanga between March 2016 and February 2017. Aut=Autumn, Win=Winter, Spr=Spring, Sum=Summer. WD=Weekdays, WE/PH = Weekend days and public holidays.

Season/ Year	Month	Day Type	No. powerboats returning	Interview not attempted	No. interviews	Non-response	Full response	Response rate (%)
Aut 16	Mar	WD	13	5	8	0	8	100
		WE/PH	43	2	41	2	39	95
	Apr	WD	43	2	41	0	41	100
		WE/PH	65	6	59	1	58	98
	May	WD	63	23	40	0	40	100
		WE/PH	52	0	52	0	52	100
Win 16	Jun	WD	42	11	31	0	31	100
		WE/PH	57	6	51	0	51	100
	Jul	WD	77	3	74	0	74	100
		WE/PH	27	20	7	0	7	100
	Aug	WD	27	9	18	2	16	88
		WE/PH	47	7	40	1	39	97
Spr 16	Sep	WD	35	12	23	0	23	100
		WE/PH	40	11	29	1	28	96
	Oct	WD	31	6	25	0	25	100
		WE/PH	13	2	11	0	11	100
	Nov	WD	11	1	10	0	10	100
		WE/PH	19	0	19	0	19	100
Sum 16/17	Dec	WD	5	0	5	0	5	100
		WE/PH	11	0	11	0	11	100
	Jan	WD	18	3	15	0	15	100
		WE/PH	22	1	21	0	21	100
	Feb	WD	4	0	4	0	4	100
		WE/PH	16	2	14	0	14	100
Total		WD	369	75	294	5	289	98
		WE/PH	412	57	355	2	354	99
		Total	781	132	649	7	642	99

Table 6. Response profiles for the demographic, awareness and attitudinal data collected at Denham, Monkey Mia and Nanga between March 2016 and February 2017. Aut=Autumn, Win=Winter, Spr=Spring, Sum=Summer. WD=Weekdays, WE/PH = Weekend days and public holidays.

Season/ Year	Month	Day Type	No. powerboats returning	Interview not attempted	No. interviews	Non-response	Full response	Response rate (%)
Aut 16	Mar	WD	13	10	3	1	2	67
		WE/PH	43	21	22	0	22	100
	Apr	WD	43	15	28	1	27	96
		WE/PH	65	20	45	0	45	100
	May	WD	63	52	11	0	11	100
		WE/PH	52	21	31	0	31	100
Win 16	Jun	WD	42	20	22	0	22	100
		WE/PH	57	15	42	0	42	100
	Jul	WD	77	29	48	0	48	100
		WE/PH	27	21	6	0	6	100
	Aug	WD	27	15	12	2	10	83
		WE/PH	47	14	33	0	33	100
Spr 16	Sep	WD	35	22	13	0	13	100
		WE/PH	40	25	15	1	14	93
	Oct	WD	31	20	11	0	11	100
		WE/PH	13	9	4	0	4	100
	Nov	WD	11	2	9	0	9	100
		WE/PH	19	7	12	0	12	100
Sum 16/17	Dec	WD	5	0	5	0	5	100
		WE/PH	11	5	6	0	6	100
	Jan	WD	18	5	13	0	13	100
		WE/PH	22	6	16	0	16	100
	Feb	WD	4	3	1	0	1	100
		WE/PH	16	13	3	0	3	100
Total		WD	369	199	170	4	166	98
		WE/PH	412	171	241	1	240	100
		Total	781	370	411	5	406	99

Table 7. Camera outages at Denham, Monkey Mia and Nanga between March 2016 and February 2017. Aut=Autumn, Win=Winter, Spr=Spring, Sum=Summer. WD=Weekdays, WE/PH = Weekend days and public holidays.

Season/ Year	Month	Day Type	Days in stratum	Denham		Monkey Mia		Nanga	
				Prop. missing < 0.5 in each 2-hr period	Prop. missing ≥ 0.5 in any 2-hr period	Prop. missing < 0.5 in each 2-hr period	Prop. missing ≥ 0.5 in any 2-hr period	Prop. missing < 0.5 in each 2-hr period	Prop. missing ≥ 0.5 in any 2-hr period
Aut 16	Mar	WD	20	20	0	20	0	19	1
		WE/PH	11	11	0	11	0	10	1
	Apr	WD	20	17	3	20	0	18	2
		WE/PH	10	10	0	10	0	9	1
	May	WD	22	21	1	20	1	21	1
		WE/PH	9	9	0	9	0	9	0
Win 16	Jun	WD	21	8	13	21	0	21	0
		WE/PH	9	5	4	9	0	8	1
	Jul	WD	21	0	21	21	0	20	1
		WE/PH	10	0	10	10	0	9	1
	Aug	WD	23	0	23	23	0	21	2
		WE/PH	8	0	8	8	0	6	2
Spr 16	Sep	WD	21	0	21	21	0	19	2
		WE/PH	9	0	9	9	0	8	1
	Oct	WD	21	14	7	21	0	13	8
		WE/PH	10	6	4	10	0	5	5
	Nov	WD	22	22	0	22	0	22	0
		WE/PH	8	8	0	8	0	7	1
Sum 16/17	Dec	WD	21	20	1	21	0	7	14
		WE/PH	10	10	0	10	0	4	6
	Jan	WD	22	22	0	20	2	17	5
		WE/PH	9	9	0	7	2	8	1
	Feb	WD	20	20	0	12	8	20	0
		WE/PH	8	8	0	4	4	8	0
Total		WD	254	164	90	241	13	213	41
		WE/PH	111	76	35	105	6	91	20
		Total	365	240	125	346	19	304	61

4. Fishing effort

4.1 Route-based estimates

4.1.1 Fishing effort (party-hours)

Total annual effort for boat-based recreational fishing was 41,447 party-hours (se=6,129; Figure 4; Table 8). This estimate was inclusive of fishing effort occurring between 10:00 and 18:00 as per the scheduling of the survey shifts. Total recreational fishing effort for inner Shark Bay only was estimated to be 33,299 (se=3,961) party-hours. A monthly peak in recreational fishing effort occurred in May. Recreational fishing effort was highest in autumn and lowest in summer (Figure 4; Table 8). Recreational fishing effort for weekdays was consistently higher than for weekends in the same month (Appendix 11).

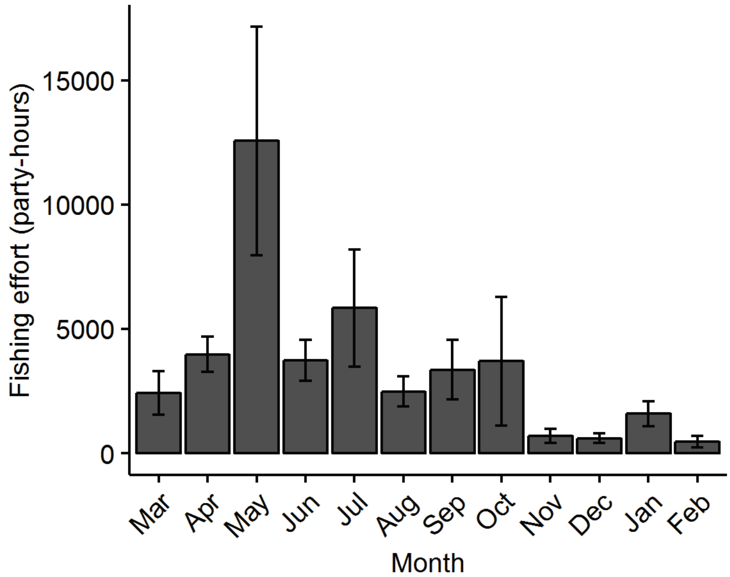

Figure 4. Recreational fishing effort (party-hours) at Denham, Monkey Mia and Nanga by month between March 2016 and February 2017. Estimates are inclusive of boat parties retrieving between 10:00 and 18:00, including effort in inner Shark Bay and the Oceanic Management Zone. Error bars represent standard errors of the means.

Table 8. Estimated recreational fishing effort (party-hours) at Denham, Monkey Mia and Nanga by season between March 2016 and February 2017. Estimates are inclusive of boat parties retrieving at the ramps between 10:00 and 18:00 including effort in inner Shark Bay and the Oceanic Management Zone; se is the standard error of the mean estimate.

Season/Year	Effort (party-hours)	se
Aut 16	18,964	4,734
Win 16	12,071	2,561
Spr 16	7,757	2,871
Sum 16/17	2,655	596
Yearly estimated total	41,447	6,129

4.2 Ramp-based estimates

4.2.1 Powerboat retrievals

The number of powerboat retrievals at Monkey Mia and Nanga between March 2016 and February 2017 was estimated to be 4,075 (se=25) and 781 (se=15), respectively (Table 9). The number of powerboat retrievals at Denham (nine months only) was estimated to be 4,166 (se=132; Table 9). Retrievals were largely confined to daylight hours, defined as the period between nautical dawn and nautical dusk (Figure 2), with retrievals at night comprising between 1 and 2% of ramp-based activity (Table 9).

Table 9. Estimated number of powerboat retrievals derived from the camera data at Denham, Monkey Mia and Nanga between March 2016 and February 2017 for the entire day (i.e. 24-hrs) and between nautical dawn and nautical dusk; se is the standard error of the mean estimate.

Location	Estimated total number of powerboat retrievals (se)		
	Full days (24-hours)	Nautical dawn to dusk	Percent during daylight hours#
Denham	4,166 (132)*	4,144 (188)*	99
Monkey Mia	4,075 (25)	4,034 (21)	99
Nanga	781 (15)	765 (16)	98

* Total does not include powerboat retrievals in Jul, Aug and Sep 2016 data due to major camera outage (Table 7).

Defined as the daily period between nautical dawn and dusk

4.2.2 Fishing effort (boat days)

Fishing effort (boat days) was similar to the number of powerboat retrievals, reflecting the high proportion of boat parties that were recreational fishing (Figure 5). Total recreational fishing effort at Monkey Mia for the 12-month period was estimated to be 3,554 boat days (se=93; Table 10) and activity was more evenly spread between months in comparison to the other two sites (Figure 5). Much lower levels of fishing effort were estimated at Nanga where an estimated 674 boat days (se=31) were reported for the 12-month period (Table 10). At Nanga, most fishing activity occurred between May and July (Figure 5C). Of those 9-months where fishing effort could be estimated at Denham, 72% of effort occurred between April and June and comparably lower levels of fishing effort occurred in March and between October and February (Figure 5A). Total recreational fishing effort at Denham for the 9-month period was 2,954 boat days (se=242). This excluded those multi-day trips and recreational fishing that occurred outside of inner Shark Bay.

4.2.3 Fishing effort (party-hours)

Total recreational fishing effort (party-hours) at Monkey Mia for the 12-month period was estimated to be 15,421 party-hours (se=755). At Nanga recreational fishing estimate was estimated to be 3,083 party-hours (se=225) for the 12-month period and at Denham, effort was estimated to be 16,654 party-hours (se=1,91) for the 9-month period. Monthly patterns of fishing effort were broadly consistent for the two units of measurement (boat days and party-hours), although the pattern differed slightly at Denham between May and June and at Nanga between May and July (Figure 5 A, D).

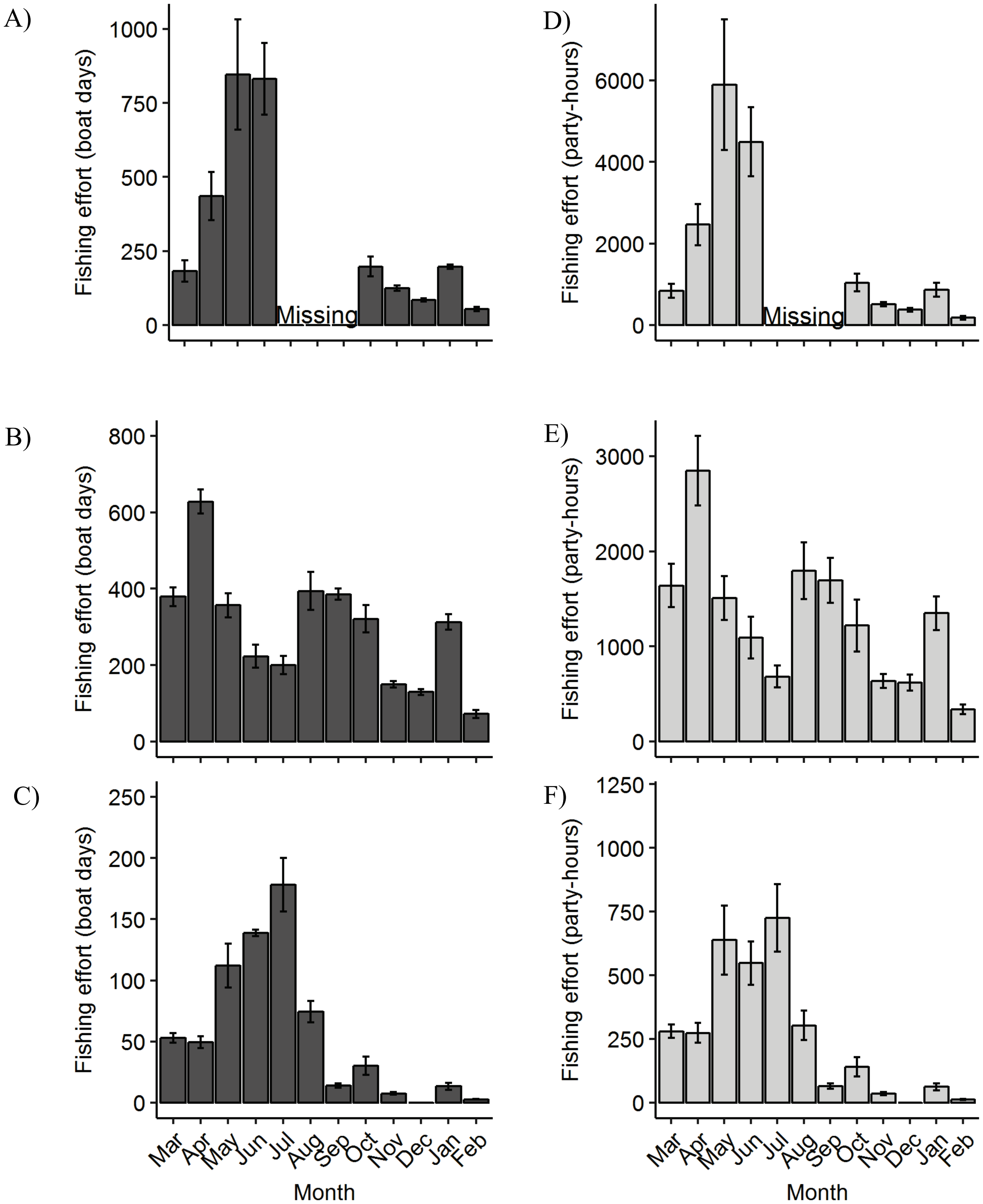

Figure 5. Estimated recreational fishing effort at Denham (A, D), Monkey Mia (B, E) and Nanga (C, F) by month between March 2016 and February 2017. Dark grey bars display fishing effort in boat days, light grey bars display fishing effort in party-hours. Fishing effort is inclusive of the period between nautical dawn and dusk; error bars represent the standard error of the mean estimates.

Table 10. Estimated recreational fishing effort at Denham, Monkey Mia and Nanga by season between March 2016 and February 2017. Fishing effort is reported in boat days and party-hours; se is the standard error of the mean estimate.

Season/Year	Denham				Monkey Mia				Nanga			
	Effort (boat days)	se	Effort (party-hours)	se	Effort (boat days)	se	Effort (party-hours)	se	Effort (boat days)	se	Effort (party-hours)	se
Aut 16	1,466	206	9,192	1,688	1,364	51	5,995	490	215	19	1,192	144
Win 16	831*	121	4,491*	848	818	63	3,570	389	392	24	1,576	168
Spr 16	322*	35	1,549*	223	857	39	3,552	369	52	8	240	40
Sum 16/17	335	12	1,421	186	515	25	2,305	204	16	3	75	15
Yearly estimated total	2,954*	242	16,654*	1,912	3,554	93	15,421	755	674	31	3,083	225

* Total does not include powerboat retrievals in Jul, Aug and Sep 2016 data due to major camera outage (Table 7)

5. Recreational catch

5.1 Route-based estimates

5.1.1 Catch in numbers

In total, boat-based fishers caught almost 110,000 individuals, of which nearly 34,000 were kept (31%) and 74,000 were released (69%). A diverse range of species/taxa were caught including scalefish (n=51), elasmobranchs (n=13), crustaceans (n=2) and molluscs (n=1). The majority of the catch comprised scalefish (Table 11). The three most commonly caught species by number were Pink Snapper, Blue Swimmer Crab and Grass Emperor and these species comprised a major component of the total catch (76%). The release rates varied dramatically between species/taxa, ranging from 0% (e.g. western rock lobster, *Panurilus cygnus*) through to 100% (e.g. silver toadfish, *Lagocephalus sceleratus*). The percentage released for Pink Snapper, Blue Swimmer Crab and Grass Emperor were 87%, 58% and 49%, respectively (Table 11; Figure 6).

5.1.2 Catch in numbers for inner Shark Bay

In total, boat-based fishers caught almost 87,000 individuals, of which approximately 24,000 were kept (27%) and 63,000 were released (73%; Table 12). The total catch comprised scalefish (n=42 species/taxa), elasmobranchs (n=13), crustaceans (n=1) and molluscs (n=1). The three most commonly caught species by number in inner Shark Bay were also Pink Snapper, Blue Swimmer Crab and Grass Emperor which comprised 82% of the total catch (Table 12; Figure 7). The percentage released for Pink Snapper, Blue Swimmer Crab and Grass Emperor were 88%, 58% and 55%, respectively (Table 12; Figure 7).

Table 11. Estimated annual catch (kept and released numbers) and percentage released by boat-based fishers between March 2016 and February 2017. Catches are inclusive of boats retrieving from the ramps at Denham, Monkey Mia and Nanga between 10:00 and 18:00. Values in bold indicate a relative standard error >40% (i.e. se >40% of the estimate).

Reporting Group	Common Name	Scientific Name	Kept	se	Rel	se	Total	se	% Rel
Bream	Pink Snapper	*Chrysophrys auratus*	7,506	1,427	50,738	9,069	58,245	10,249	87
Bream	Tarwhine	*Rhabdosargus sarba*	0	0	**69**	**69**	**69**	**69**	100
Bream	Western Yellowfin Bream	*Acanthopagrus morrisoni*	**220**	**119**	**786**	**522**	**1,007**	**613**	78
Cephalopod	Squid	Order Teuthoidea	**1,163**	**562**	**56**	**56**	**1,219**	**613**	5
Cobia	Cobia	*Rachycentron canadus*	**85**	**63**	**5**	**5**	**90**	**64**	6
Cod	Blackspotted Rockcod	*Epinephelus malabaricus*	**5**	**5**	0	0	**5**	**5**	0
Cod	Chinaman Rockcod	*Epinephelus rivulatus*	**13**	**13**	**13**	**13**	**25**	**25**	50
Cod	Goldspotted Rockcod	*Epinephelus coioides*	1,237	334	**534**	**302**	1,771	490	30
Cod	Rankin Cod	*Epinephelus multinotatus*	**891**	**600**	**589**	**374**	**1,480**	**970**	40
Coral Trout	Barcheek Coral Trout	*Plectropomus maculatus*	**545**	**286**	**387**	**287**	**932**	**465**	42
Coral Trout	Common Coral Trout	*Plectropomus leopardus*	**21**	**15**	**5**	**5**	**26**	**19**	18
Crab	Blue Swimmer Crab	*Portunus armatus*	5,359	1,364	7,444	2,047	12,803	3,054	58
Emperor	Bluespotted Emperor	*Lethrinus punctulatus*	**31**	**31**	0	0	**31**	**31**	0
Emperor	Grass Emperor	*Lethrinus laticaudis*	6,344	1,772	5,992	1,306	12,336	2,814	49
Emperor	Redthroat Emperor	*Lethrinus miniatus*	**1,854**	**1,710**	**1,638**	**1,352**	**3,493**	**3,060**	47
Emperor	Spangled Emperor	*Lethrinus nebulosus*	**330**	**176**	**486**	**206**	**815**	**345**	60
Flathead	Longspine Flathead	*Platycephalus longispinis*	0	0	**77**	**42**	**77**	**42**	100
Flathead	Yellowtail Flathead	*Platycephalus westraliae*	**378**	**186**	**164**	**122**	**543**	**222**	30
Flounders	Flounder, undifferentiated	Bothidae & Pleuronectidae spp	**45**	**33**	**5**	**5**	**51**	**33**	11
Grunter	Yellowtail Grunter	*Amniataba caudavittata*	0	0	**113**	**103**	**113**	**103**	100
Lizardfish	Largescale Saury	*Saurida undosquamis*	0	0	**6**	**6**	**6**	**6**	100
Lobster	Western Rock Lobster	*Panurilus cygnus*	**1,110**	**984**	0	0	**1,110**	**984**	0
Mackerel	Grey Mackerel	*Scomberomorus semifasciatus*	**62**	**48**	0	0	**62**	**48**	0

Reporting Group	Common Name	Scientific Name	Kept	se	Rel	se	Total	se	% Rel
Mackerel	School Mackerel	*Scomberomorus queenslandicus*	**272**	**125**	**91**	**47**	363	137	25
Mackerel	Shark Mackerel	*Grammatorcynus bicarinatus*	**366**	**171**	**63**	**40**	**428**	**174**	15
Mackerel	Spanish Mackerel	*Scomberomorus commerson*	**227**	**184**	**31**	**31**	**258**	**171**	12
Mullet	Sea Mullet	*Mugil cephalus*	**899**	**605**	0	0	**899**	**605**	0
Mulloway	Mulloway	*Argyrosomus hololepidotus*	**450**	**216**	**819**	**330**	1,269	440	65
Pearl Perch	Northern Pearl Perch	*Glaucosoma buergeri*	**11**	**11**	0	0	**11**	**11**	0
Pearl Perch	West Australian Dhufish	*Glaucosoma hebraicum*	**6**	**6**	0	0	**6**	**6**	0
Pike	Snook	*Sphyraena novaehollandiae*	0	0	**45**	**45**	**45**	**45**	100
Pike	Yellowtail Barracuda	*Sphyraena obtusata*	**20**	**20**	0	0	**20**	**20**	0
Rays	Guitarfishes, undifferentiated	*Rhinobatidae - undifferentiated*	0	0	**49**	**28**	**49**	**28**	100
Rays	Whitespotted Guitarfish	*Rhynchobatus australiae*	**9**	**9**	0	0	**9**	**9**	0
Rays	Stingrays	*Dasyatidae - undifferentiated*	0	0	35	26	**35**	**26**	100
Sergeant Baker	Sergeant Baker	*Aulopus purpurissatus*	0	0	**62**	**62**	**62**	**62**	100
Sharks	Blacktip Reef Shark	*Carcharhinus melanopterus*	0	0	**193**	**180**	**193**	**180**	100
Sharks	Bronze Whaler	*Carcharhinus brachyurus*	**18**	**14**	**37**	**20**	**55**	**24**	67
Sharks	Hammerhead Sharks	*Sphyrna* sp.	**7**	**7**	**13**	**13**	**20**	**15**	66
Sharks	Lemon Shark	*Negaprion acutidens*	0	0	**13**	**13**	**13**	**13**	100
Sharks	Whaler & Weasel Sharks	*Carcharhinidae, Hemigaleidae*	0	0	**104**	**76**	**104**	**76**	100
Sharks	Sandbar Shark	*Carcharhinus plumbeus*	0	0	**5**	**5**	**5**	**5**	100
Sharks	School Shark	*Galeorhinus galeus*	0	0	**9**	**9**	**9**	**9**	100
Sharks	Tiger Shark	*Galeocerdo cuvieri*	0	0	**33**	**19**	**33**	**19**	100
Sharks	Whitetip Reef Shark	*Triaenodon obesus*	0	0	**7**	**7**	**7**	**7**	100
Sharks	Wobbegong, undifferentiated	Family Orectolobidae	**7**	**7**	0	0	**7**	**7**	0
Snapper Tropical	Brownstripe Snapper	*Lutjanus vitta*	0	0	**34**	**34**	**34**	**34**	100
Snapper Tropical	Crimson Snapper	*Lutjanus erythropterus*	**19**	**19**	0	0	**19**	**19**	0
Snapper Tropical	Golden Snapper	*Lutjanus johnii*	0	0	**17**	**13**	**17**	**13**	100
Snapper Tropical	Mangrove Jack	*Lutjanus argentimaculatus*	**19**	**19**	0	0	**19**	**19**	0
Snapper Tropical	Red Emperor	*Lutjanus sebae*	**311**	**305**	**183**	**183**	**494**	**487**	37

Reporting Group	**Common Name**	**Scientific Name**	**Kept**	**se**	**Rel**	**se**	**Total**	**se**	**% Rel**
Snapper Tropical	Stripey Snapper	*Lutjanus carponotatus*	**518**	**339**	**71**	**52**	**589**	**344**	12
Snappers King	Goldband Snapper	*Pristipomoides multidens*	**61**	**47**	0	0	**61**	**47**	0
Tailor	Tailor	*Pomatomus saltatrix*	**116**	**52**	**243**	**143**	**359**	**151**	68
Threadfin Bream	Western Butterfish	*Pentapodus vitta*	0	0	**958**	**557**	**958**	**557**	100
Toadfish	Silver Toadfish	*Lagocephalus sceleratus*	0	0	**483**	**449**	**483**	**449**	100
Toadfish	Weeping Toadfish	*Torquigener pleurogramma*	0	0	**391**	**391**	**391**	**391**	100
Trevally	Bluespotted Trevally	*Caranx bucculentus*	**61**	**61**	0	0	**61**	**61**	0
Trevally	Giant Trevally	*Caranx ignobilis*	0	0	**7**	**7**	**7**	**7**	100
Trevally	Golden Trevally	*Gnathanodon speciosus*	**24**	**16**	**45**	**45**	**69**	**47**	65
Tuna	Longtailed Tuna	*Thunnus tonggol*	**79**	**64**	0	0	**79**	**64**	0
Tuskfish Wrasse	Baldchin Groper	*Choerodon rubescens*	**443**	**268**	**202**	**130**	**645**	**392**	31
Tuskfish Wrasse	Blackspot Tuskfish	*Choerodon schoenleinii*	1,031	211	951	240	1,982	317	48
Tuskfish Wrasse	Bluebarred Parrotfish	*Scarus ghobban* spp complex	**12**	**12**	0	0	**12**	**12**	0
Whiting	Western Trumpeter Whiting	*Sillago burros*	0	0	**23**	**23**	**23**	**23**	100
Whiting	Whiting, undifferentiated	*Sillaginidae - undifferentiated*	0	0	**19**	**19**	**19**	**19**	100
Whiting	Yellowfin Whiting	*Sillago schomburgkii*	**1,745**	**769**	**45**	**36**	**1,790**	**782**	3

Table 12. Estimated inner Shark Bay annual catch (kept and released numbers) and percentage released by boat-based fishers between March 2016 and February 2017. Catches are inclusive of boats retrieving from the ramps at Denham, Monkey Mia and Nanga between 10:00 and 18:00. Values in bold indicate a relative standard error >40% (i.e. se >40% of the estimate).

Reporting Group	Common Name	Scientific Name	Kept	se	Rel	se	Total	se	% Rel
Bream	Pink Snapper	*Chrysophrys auratus*	6,283	1,194	44,047	6,891	50,330	7,831	88
Bream	Tarwhine	*Rhabdosargus sarba*	0	0	**69**	**69**	**69**	**69**	100
Bream	Western Yellowfin Bream	*Acanthopagrus morrisoni*	**220**	**119**	**786**	**522**	**1,007**	**613**	78
Cephalopod	Squid	Order Teuthoidea	**1,163**	**562**	**56**	**56**	**1,219**	**613**	5
Cobia	Cobia	*Rachycentron canadus*	**49**	**34**	**5**	**5**	**54**	**34**	10
Cod	Goldspotted Rockcod	*Epinephelus coioides*	825	241	**521**	**302**	1,346	441	39
Cod	Rankin Cod	*Epinephelus multinotatus*	**109**	**46**	169	67	278	100	61
Coral Trout	Barcheek Coral Trout	*Plectropomus maculatus*	**195**	**148**	0	0	**195**	**148**	0
Crab	Blue Swimmer Crab	*Portunus armatus*	5,295	1,346	7,380	2,042	12,675	3,032	58
Emperor	Bluespotted Emperor	*Lethrinus punctulatus*	**31**	**31**	0	0	**31**	**31**	0
Emperor	Grass Emperor	*Lethrinus laticaudis*	3,702	934	4,574	848	8,276	1,643	55
Emperor	Redthroat Emperor	*Lethrinus miniatus*	**426**	**426**	**244**	**244**	**670**	**670**	36
Emperor	Spangled Emperor	*Lethrinus nebulosus*	**73**	**39**	**198**	**109**	**272**	**120**	73
Flathead	Longspine Flathead	*Platycephalus longispinis*	0	0	**77**	**42**	**77**	**42**	100
Flathead	Yellowtail Flathead	*Platycephalus westraliae*	**327**	**175**	**164**	**122**	**491**	**213**	33
Flounders	Flounder, undifferentiated	*Bothidae & Pleuronectidae spp*	**45**	**33**	**5**	**5**	**51**	**33**	11
Grunter	Yellowtail Grunter	*Amniataba caudavittata*	0	0	**113**	**103**	**113**	**103**	100
Lizardfish	Largescale Saury	*Saurida undosquamis*	0	0	**6**	**6**	**6**	**6**	100
Mackerel	Grey Mackerel	*Scomberomorus semifasciatus*	**62**	**48**	0	0	**62**	**48**	0
Mackerel	School Mackerel	*Scomberomorus queenslandicus*	**272**	**125**	**91**	**47**	363	137	25
Mackerel	Shark Mackerel	*Grammatorcynus bicarinatus*	**360**	**170**	**63**	**40**	**423**	**173**	15
Mackerel	Spanish Mackerel	*Scomberomorus commerson*	**26**	**15**	0	0	**26**	**15**	0
Mullet	Sea Mullet	*Mugil cephalus*	**456**	**411**	0	0	**456**	**411**	0
Mulloway	Mulloway	*Argyrosomus hololepidotus*	326	127	**743**	**324**	1,069	369	69
Pike	Snook	*Sphyraena novaehollandiae*	0	0	**45**	**45**	**45**	**45**	100

Reporting Group	Common Name	Scientific Name	Kept	se	Rel	se	Total	se	% Rel
Pike	Yellowtail Barracuda	*Sphyraena obtusata*	**20**	**20**	0	0	**20**	**20**	0
Rays	Guitarfishes, undifferentiated	*Rhinobatidae - undifferentiated*	0	0	**30**	**22**	**30**	**22**	100
Rays	Whitespotted Guitarfish	*Rhynchobatus australiae*	**9**	**9**	0	0	**9**	**9**	0
Rays	Stingrays	*Dasyatidae - undifferentiated*	0	0	**35**	**26**	**35**	**26**	100
Sergeant Baker	Sergeant Baker	*Aulopus purpurissatus*	0	0	**62**	**62**	**62**	**62**	100
Sharks	Blacktip Reef Shark	*Carcharhinus melanopterus*	0	0	**193**	**180**	**193**	**180**	100
Sharks	Bronze Whaler	*Carcharhinus brachyurus*	**18**	**14**	**37**	**20**	**55**	**24**	67
Sharks	Hammerhead Sharks	*Sphyrna* sp.	**7**	**7**	**13**	**13**	**20**	**15**	66
Sharks	Lemon Shark	*Negaprion acutidens*	0	0	**13**	**13**	**13**	**13**	100
Sharks	Whaler & Weasel Sharks	*Carcharhinidae, Hemigaleidae*	0	0	**104**	**76**	**104**	**76**	100
Sharks	Sandbar Shark	*Carcharhinus plumbeus*	0	0	**5**	**5**	**5**	**5**	100
Sharks	School Shark	*Galeorhinus galeus*	0	0	**9**	**9**	**9**	**9**	100
Sharks	Tiger Shark	*Galeocerdo cuvieri*	0	0	**19**	**14**	**19**	**14**	100
Sharks	Whitetip Reef Shark	*Triaenodon obesus*	0	0	**7**	**7**	**7**	**7**	100
Sharks	Wobbegong, undifferentiated	Family Orectolobidae	**7**	**7**	0	0	**7**	**7**	0
Snapper Tropical	Brownstripe Snapper	*Lutjanus vitta*	0	0	**34**	**34**	**34**	**34**	100
Snapper Tropical	Golden Snapper	*Lutjanus johnii*	0	0	**17**	**13**	**17**	**13**	100
Snapper Tropical	Stripey Snapper	*Lutjanus carponotatus*	**467**	**337**	**62**	**51**	**528**	**341**	12
Snappers King	Goldband Snapper	*Pristipomoides multidens*	**45**	**45**	0	0	**45**	**45**	0
Tailor	Tailor	*Pomatomus saltatrix*	**116**	**52**	**243**	**143**	**359**	**151**	68
Threadfin Bream	Western Butterfish	*Pentapodus vitta*	0	0	**958**	**557**	**958**	**557**	100
Toadfish	Silver Toadfish	*Lagocephalus sceleratus*	0	0	**483**	**449**	**483**	**449**	100
Toadfish	Weeping Toadfish	*Torquigener pleurogramma*	0	0	**391**	**391**	**391**	**391**	100
Trevally	Giant Trevally	*Caranx ignobilis*	0	0	**7**	**7**	**7**	**7**	100
Trevally	Golden Trevally	*Gnathanodon speciosus*	**24**	**16**	**45**	**45**	**69**	**47**	65
Tuna	Longtailed Tuna	*Thunnus tonggol*	**61**	**61**	0	0	**61**	**61**	0
Tuskfish Wrasse	Baldchin Groper	*Choerodon rubescens*	0	0	**31**	**20**	**31**	**20**	100
Tuskfish Wrasse	Blackspot Tuskfish	*Choerodon schoenleinii*	783	213	786	160	1,568	276	50

Reporting Group	Common Name	Scientific Name	Kept	se	Rel	se	Total	se	% Rel
Tuskfish Wrasse	Bluebarred Parrotfish	*Scarus ghobban spp complex*	**12**	**12**	0	0	**12**	**12**	0
Whiting	Western Trumpeter Whiting	*Sillago burros*	0	0	**23**	**23**	**23**	**23**	100
Whiting	Whiting, undifferentiated	*Sillaginidae - undifferentiated*	0	0	**19**	**19**	**19**	**19**	100
Whiting	Yellowfin Whiting	*Sillago schomburgkii*	**1,745**	**769**	**45**	**36**	**1,790**	**782**	3

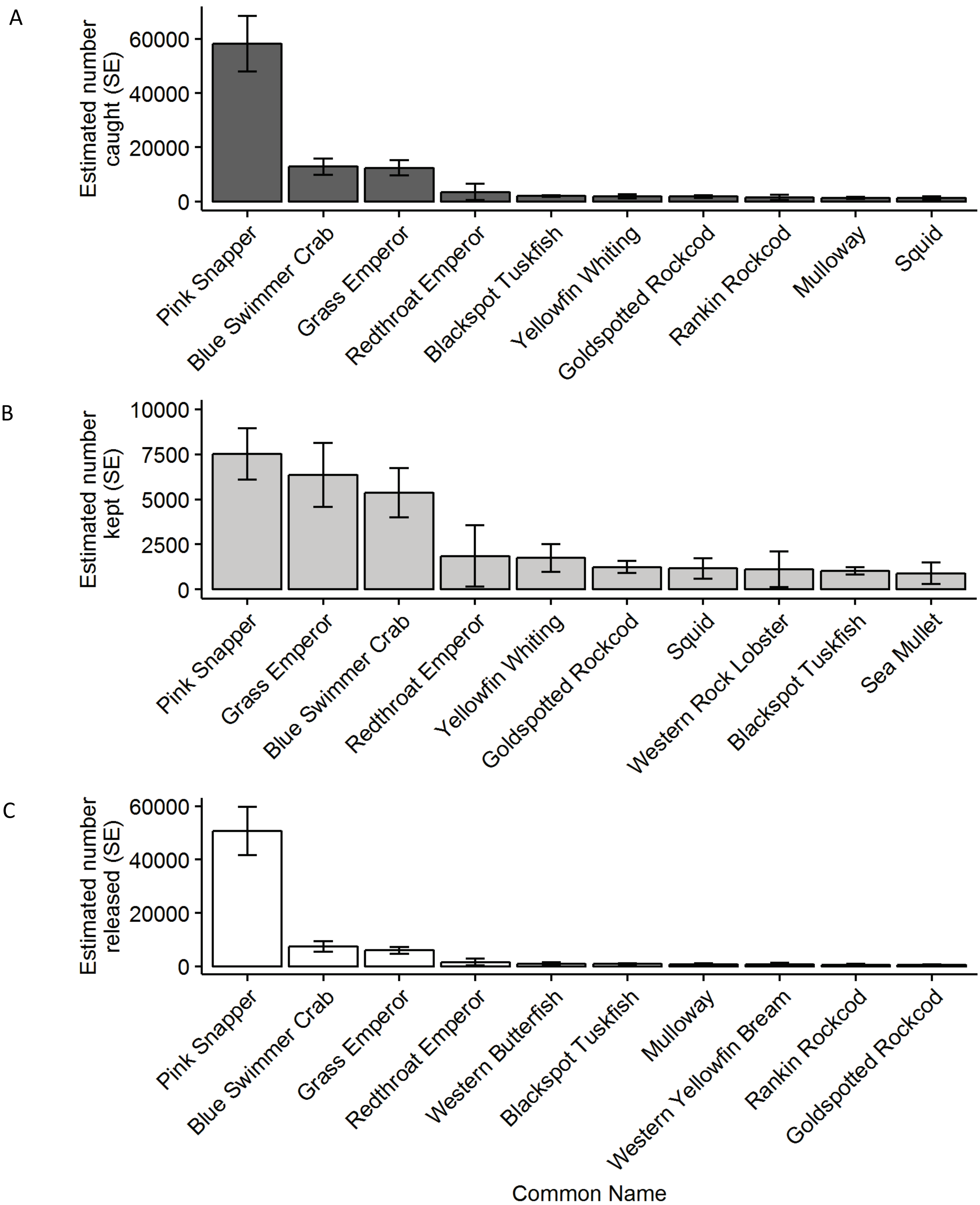

Figure 6. Estimated number of species that were A) caught, B) kept and C) released by boat-based fishers between March 2016 and February 2017. Catches are inclusive of boats retrieving from the ramps at Denham, Monkey Mia and Nanga between 10:00 and 18:00 and are ranked to display the top 10 species or taxa (by number); se = standard error of the mean estimate.

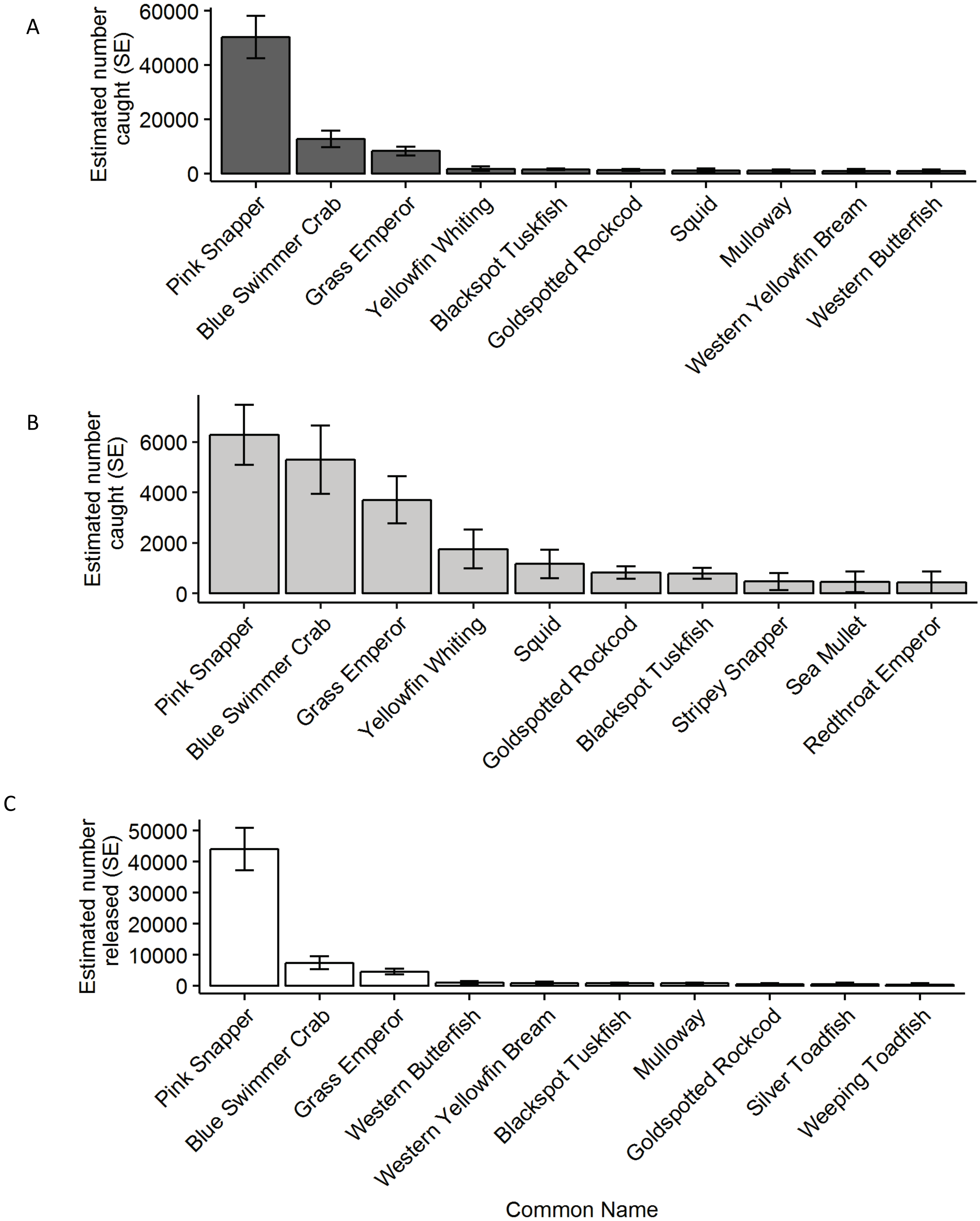

Figure 7. Estimated number of species that were A) caught, B) kept and C) released by boat-based recreational fishers in inner Shark Bay between March 2016 and February 2017. Catches are inclusive of boats retrieving from the ramps at Denham, Monkey Mia and Nanga between 10:00 and 18:00 and are ranked to display the top 10 species or taxa (by number); se = standard error of the mean estimate.

5.1.3 Targeted catch

Fishers were asked whether or not their boat party was targeting a particular species. On those occasions where two different targeted species were reported, the first was assumed to be the main target species. Secondary target species are not included in this report and 40 out of the 589 boat parties interviewed that had been recreational fishing did not provide any information about their targeted catch (Table 13). The majority of boat parties were targeting Pink Snapper (63%) and this was the main target species in all seasons, although less so in spring (Table 13). Blue Swimmer Crab, Whiting (all species), Grass Emperor and Cod (all species) were the next most commonly targeted species/groupings (Table 13).

Table 13. Targeted species as reported by boat-based fishers in Shark Bay between March 2016 and February 2017. Boat parties were interviewed at Denham, Monkey Mia and Denham.

	All		Aut 16		Win 16		Spr 16		Sum 16/17	
Targeted category	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
Pink Snapper	347	63.2	151	71.9	126	65.3	37	38.5	33	66.0
Blue Swimmer Crab	35	6.4	2	1.0	11	5.7	15	15.6	7	14.0
Whiting (all species)	24	4.4	2	1.0	12	6.2	8	8.3	2	4.0
Grass Emperor	23	4.2	16	7.6	4	2.1	3	3.1	-	-
Cod (all species)	23	4.2	10	4.8	10	5.2	3	3.1	-	-
Squid	20	3.6	2	1.0	9	4.7	4	4.2	5	10.0
Bottom species	11	2.0	1	0.5	2	1.0	8	8.3	-	-
Baldchin Groper	6	1.1	2	1.0	2	1.0	2	2.1	2	2
Barcheek Coral Trout	6	1.1	6	2.9	-	-	-	-	-	-
Blackspot Tuskfish	6	1.1	3	1.4	-	-	3	3.1	-	-
Mackerel	6	1.1	1	0.5	5	2.6	-	-	-	-
Mackerels/Tunas	6	1.1	1	0.5	5	2.6	-	-	-	-
Tuskfish	6	1.1	1	0.5	2	1.0	2	2.1	1	2.0
Crab	4	0.7	-	-	-	-	4	4.2	-	-
Mulloway	4	0.7	1	0.5	2	1.0	1	1.0	-	-
Emperors (all species)	3	0.6	2	1.0	1	0.5	-	-	-	-
Mullets (all species)	3	0.6	-	-	-	-	3	3.1	-	-
Red Emperor	3	0.6	3	1.4	-	-	-	-	-	-
Flathead (all species)	2	0.4	1	0.5	-	-	1	1.0	-	-
Snappers/Bream	2	0.4	1	0.5	-	-	1	1.0	-	-
Spanish Mackerel	2	0.4	2	1.0	-	-	-	-	-	-
Trout	2	0.4	-	-	-	-	1	1.0	-	-
Common Coral Trout	1	0.2	-	-	-	-	1	2.0	1	2.0
Sea Mullet	1	0.2	-	-	1	0.5	-	-	-	-
Tailor	1	0.2	1	0.5	-	-	-	-	-	-
Western Rock Lobster	1	0.2	1	0.5	-	-	-	-	-	-
Yellowfin Whiting	1	0.2	-	-	1	0.5	-	-	-	-
	549		210		193		96		50	

5.1.4 Zero catches

The percentage of boat parties that went recreational fishing and did not catch anything is reported below to assist in evaluating the relative success of recreational fishers in Shark Bay (Table 14). The majority of fishing boat parties caught one or more animals (i.e. scalefish, elasmobranchs, crustaceans and molluscs) during their fishing trip (81%). The percentage of trips where a catch occurred was highest in autumn and lowest in summer (Table 14).

Table 14. Number of interviews where no catches were reported by fishing boat parties expressed as a percentage of all interviews within each season between March 2016 and February 2017. Boat parties were interviewed at Denham, Monkey Mia and Denham.

Season	No. interviews with no catch	No. interviews	% with no catch
Aut 16	32	215	14.8
Win 16	38	203	18.7
Spr 16	24	110	21.8
Sum 16/17	17	61	27.9
Total	111	589	18.8

5.1.5 Fishing methods

Most boat-based fishing events involved line fishing (88% of reported methods), followed by drop nets (7%), spearguns (3%), gill nets (0.7%), cast nets (0.5%) and snares (0.5%). Fishing with lines was the dominant method in all seasons (Table 15).

Table 15. Fishing methods reported by boat-based fishers in Shark Bay between March 2016 and February 2017. Boat parties were interviewed at Denham, Monkey Mia and Denham. The number of fishing methods reported was greater than the number of interviewed fishing boat parties.

	All		Aut 16		Win 16		Spr 16		Sum 16/17	
Method	No.	%	No.	%	No.	%	No.	%	No.	%
Lines	540	88.2	207	93.2	189	91.3	94	79.7	50	76.9
Drop nets	43	7.0	2	0.9	13	6.3	20	17.0	8	12.3
Speargun	19	3.1	9	4.1	3	1.5	1	0.9	6	9.2
Gill net	4	0.7	2	0.9	2	1.0	0	0	0	0
Cast net	3	0.5	0	0	0	0	3	2.5	0	0
Snare	3	0.5	2	0.9	0	0	0	0	1	1.5
	612		222		207		118		65	

5.1.6 Pink Snapper catch distribution

Interviewed boat parties kept between one and 12 Pink Snapper (Figure 8A). Of those boat parties that kept Pink Snapper, nearly half (48%) kept ≤ 2 fish and 84% kept ≤ 5 fish (Figure 8A). Interviewed boat parties released between one and 60 Pink Snapper (Figure 8B) and caught (kept and released) between one and 84 Pink Snapper (Figure 8C). Of those boat parties that caught Pink Snapper, half (50%) caught ≤ 10 fish and 73% caught ≤ 20 fish (Figure 8C).

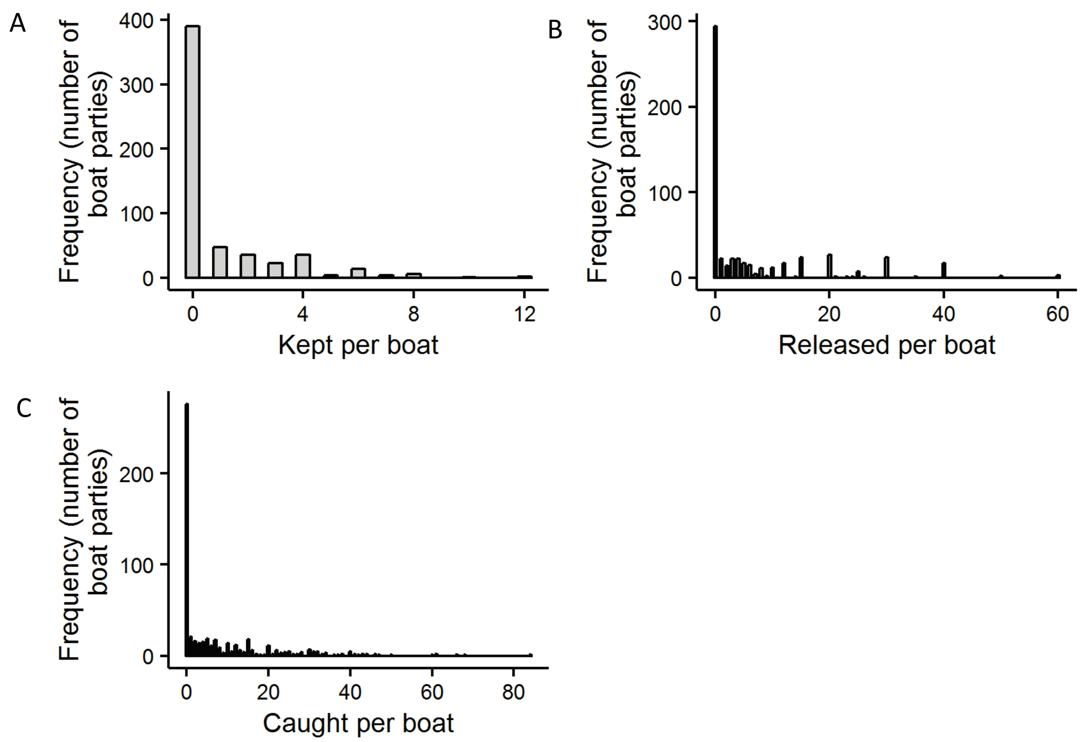

Figure 8. Pink Snapper catch distribution for number of fish A) kept per boat, B) released per boat and C) caught (kept and release) per boat between March 2016 and February 2017. Boat parties were interviewed at Denham, Monkey Mia and Denham.

5.1.7 Measured fish

The majority of measured fish were Pink Snapper, which ranged in size from 520mm TL to 870mm TL (Table 16). The overall mean length for Pink Snapper was 645mm TL (Table 16). The mean length at Nanga (669 mm TL) was slightly higher than that reported at Denham (634 mm TL) and Monkey Mia (617mm TL) noting that the sample size at Denham was very small (Figure 9B). Overall, 28% of measured Pink Snapper were greater than 700mm TL which was the maximum legal size in Shark Bay prior to January 2016. The percentage of Pink Snapper greater than 700mm TL was 20% at Denham, 19% at Monkey Mia and 33% at Nanga.

Table 16.The number of measured fish, mean total length, median total length, minimum total length and maximum total length kept by boat-based recreational fishers between March 2016 and February 2017. Boat parties were interviewed at Denham, Monkey Mia and Denham.

Common Name	No. measured	Mean TL (mm)	Median TL (mm)	Min TL (mm)	Max TL (mm)
Pink Snapper	130	645	630	520	870
Grass Emperor	48	427	405	320	630
Blackspot Tuskfish	37	524	515	400	775
Goldspotted Rockcod	20	650	653	450	920
Shark Mackerel	7	699	700	515	885
School Mackerel	6	623	625	580	700
Yellowfin Whiting	6	350	370	240	380
Northern Sand Flathead	3	422	420	390	455
Baldchin Groper	2	493	493	475	510
Barcheek Coral Trout	2	530	530	490	570
Bluespotted Emperor	2	330	330	320	340
Mulloway	2	733	733	565	900
Rankin Rockcod	2	478	478	350	605
Sea Mullet	2	325	325	325	325
Stripey Snapper	2	370	370	340	400
Tailor	2	540	540	450	630
Grey Mackerel	1	670	670	-	-
Spangled Emperor	1	525	525	-	-
Spanish Mackerel	1	975	975	-	-
Striped Barracuda	1	415	415	-	-

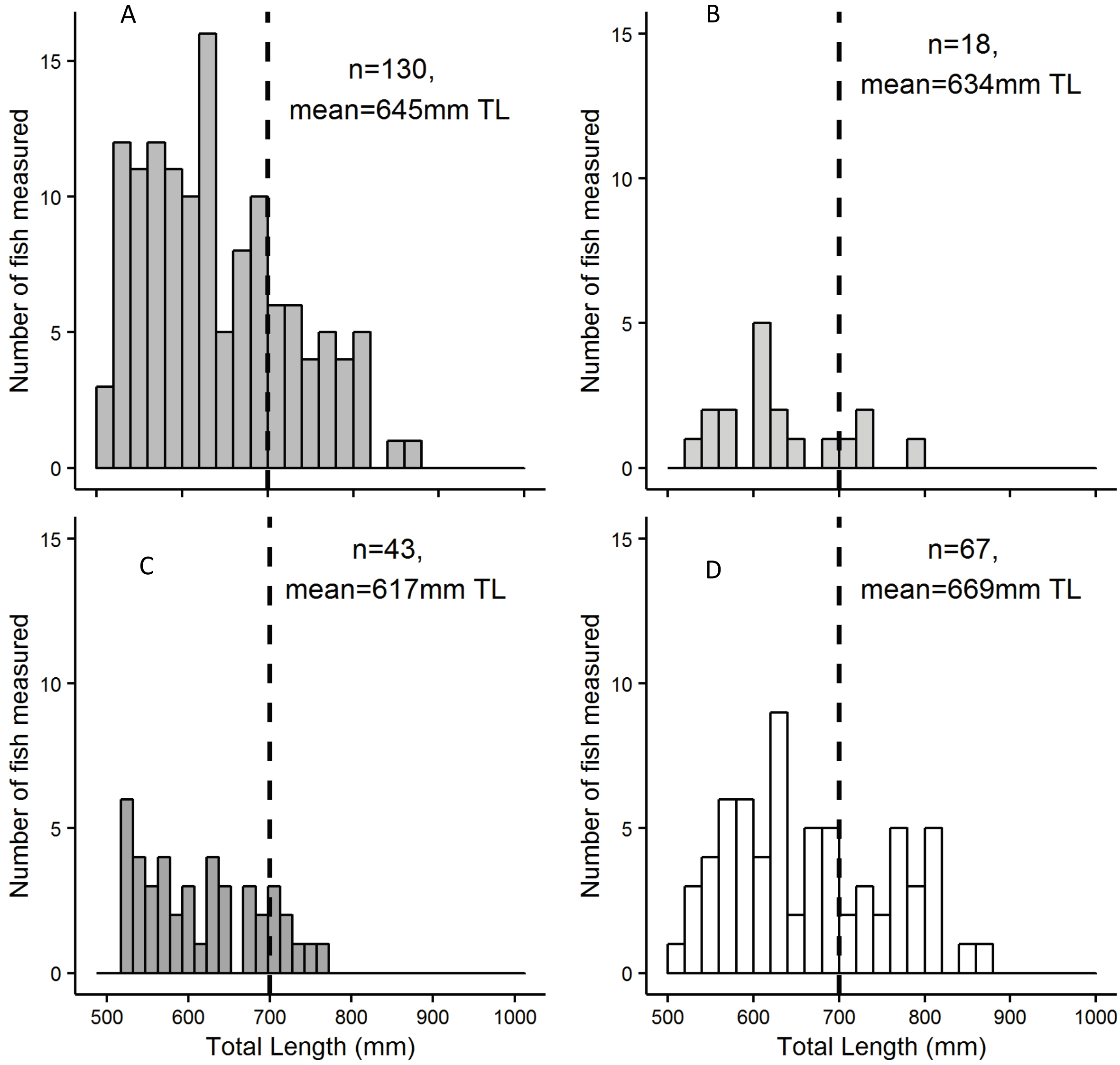

Figure 9. Length-frequency data for Pink Snapper for A) all locations, B) Denham, C) Monkey Mia and D) Nanga between March 2016 and February 2017. Dotted line represents the maximum legal size of 700 mm total length that was in place between 1997 and 2016.

5.2 Ramp-based estimates for Pink Snapper

5.2.1 Harvest rates

At each ramp, harvest rates were highly variable within each month and day type (Figure 10A, B and C). The mean harvest rate at Denham was less than 1.1 Pink Snapper per boat per day for all months and day types (Figure 10A). The mean harvest rate at Monkey Mia peaked at 1.5 Pink Snapper per boat (August, weekday) and, aside from August, was very low (<0.5 Pink Snapper per boat) in all other months (Figure 10B). The mean harvest rate at Nanga peaked at 3.5 Pink Snapper per boat (May, weekday) and catches were restricted to a 5-month period (April to August; Figure 10C).

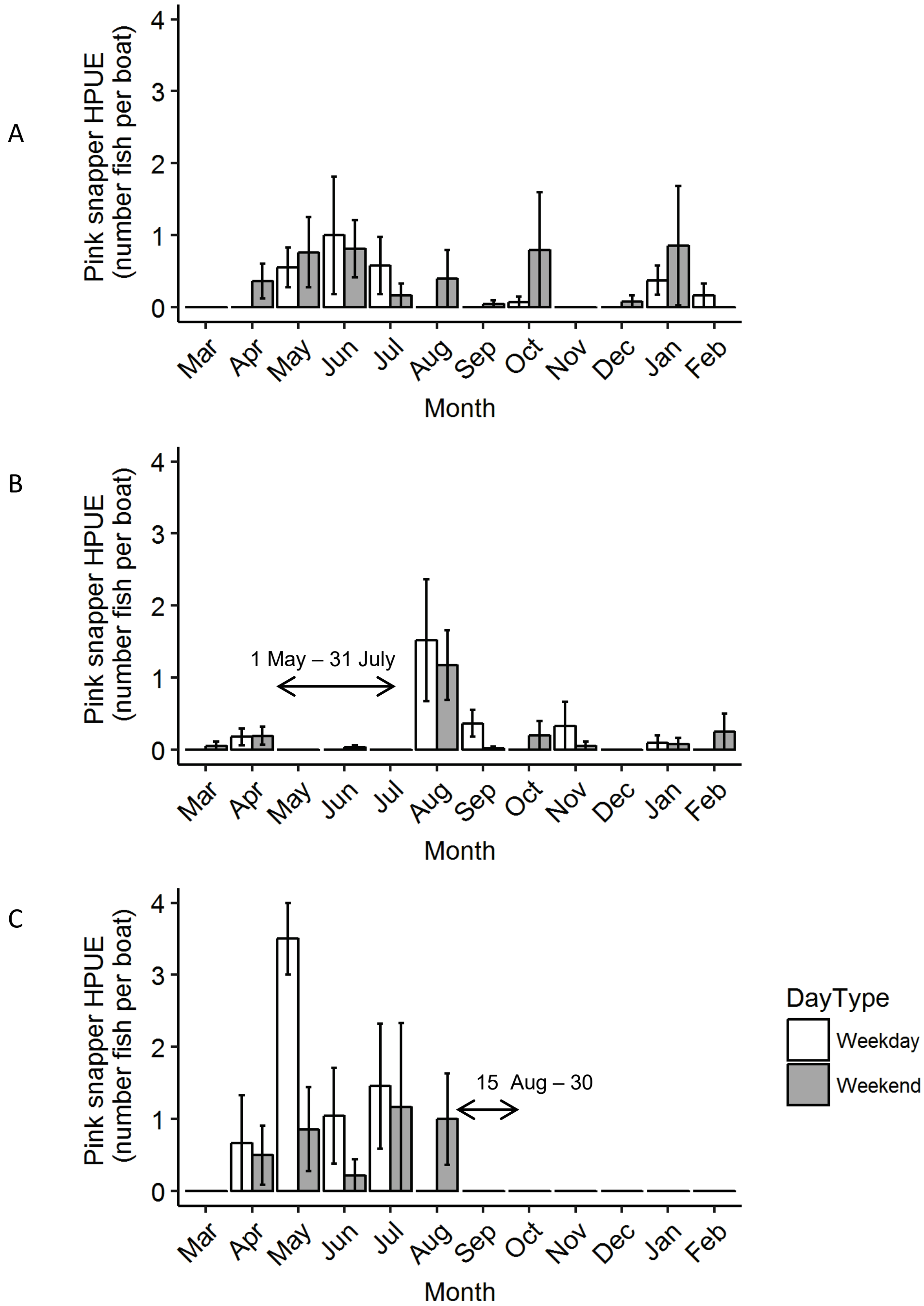

Figure 10. Harvest rate (HPUE) for pink snapper for A) Denham, B) Monkey Mia and C) Nanga by month and day type between March 2016 and February 2017. HPUE represents the mean number of Pink Snapper kept per boat. Arrows and text outline the timing of the closures within the Eastern Gulf (B) and Freycinet Estuary (C) Management Zones. Error bars represent the standard error of the mean.

5.2.2 Catch by numbers

The catch of Pink Snapper (kept, released, total in numbers) and the percentage released by boat-based fishers at Denham, Nanga and Monkey Mia between March 2016 and February 2017 were estimated (Table 17). These catch estimates are inclusive of boats retrieving from the ramps at Denham, Monkey Mia and Nanga between nautical dawn and dusk. The Denham catch estimate is only for a 9-month period because fishing effort could not be calculated for July, August and September 2016 due to a major camera outage. The results indicate that the catch was highest at Denham, comparably smaller numbers of Pink Snapper were harvested at Monkey Mia and Nanga and that the percentage of Pink Snapper released was high at all three locations (> 74%, Table 17).

Table 17. Estimated annual catch of Pink Snapper (kept and released, in numbers) and percentage released by boat-based fishers at Denham, Monkey Mia and Nanga between March 2016 and February 2017. Catches are inclusive of boats retrieving from the ramps between nautical dawn and dusk.

Ramp	Kept	se	Rel	se	Total	se	% rel
Denham	1,549*	556*	16,869*	3,534*	18,418*	3,841*	92
Monkey Mia	873	273	6,328	1,347	7,201	1,461	88
Nanga	709	162	2,012	493	2,721	638	74

* Denham total does not include catch in Jul, Aug and Sep 2016 data due to major camera outage (Table 7)

6. Pink Snapper kept catch by weight

To determine the Pink Snapper kept catch by weight (in tons, t), the estimated kept catch in numbers was multiplied by the average Pink Snapper weight (Table 18), after taking into consideration the variance of both estimates (Appendix 7 and 8).The estimated kept catch of Pink Snapper from all three ramps was 25.7 t (95% CI 16.0–35.4), 21.5 t (95% CI 13.4–29.6) of which occurred within inner Shark Bay (Table 18). An estimated 5.3 t (95% CI 1.6–9.0) of Pink Snapper were caught at Denham, noting this estimate was only for a nine-month period. An estimated 3.0 t (95% CI 1.1–4.8) and 2.7 t (95% CI 1.5–3.9) of Pink Snapper were caught at Monkey Mia and Nanga, respectively. The route-based average Pink Snapper weight (3.4kg) was applied to the Denham and Monkey Mia data because the number of measured fish in relation to the estimated kept catch was small at these ramps (Table 18). The ramp-based average Pink Snapper weight was applied at Nanga (3.8kg) because the sample size of measured fish comprised a larger percentage of the total kept catch at this ramp (Table 18). Notwithstanding the fact the Denham kept catch was restricted to nine-months, the estimated kept catch for the route (full 12-months) and each ramp do not match exactly. This is due to the two different methods used to estimate the route and ramp-based catches and the different average weights applied to each method.

Table 18. Estimated pink snapper annual catch (numbers kept and weight) at Denham, Monkey Mia and Nanga between March 2016 and February 2017.

	Kept	No. fish measured	Av total length (mm)	Av wt (kg)	Total kept (t)	se	95% CI
Route ^	7,506	130	645	3.4	25.7	4.9	16.0−35.4
Route (inner Shark Bay only)^	6,283	130	645	3.4	21.5	4.1	13.4−29.6
Denham#	1,549*	130	634	3.4	5.3*	1.9	1.6−9.0
Monkey Mia#	873	130	634	3.4	3.0	0.9	1.1−4.8
Nanga#	709	67	669	3.8	2.7	0.6	1.5−3.9

* Denham total does not include catch in Jul, Aug and Sep 2016 data due to major camera outage (Table 7)

^ Estimated derived from the bus route method, # Estimate derived from the supplementary access point method

7. Fishers' characteristics

7.1 Gender and age

The majority of fishers were males (72%) and in the 45–59 year age group (38% of females, 37% of males; Figure 11). The percentage of fishers within each of the age groups was broadly consistent between genders, with more males than females fishing (Figure 11).

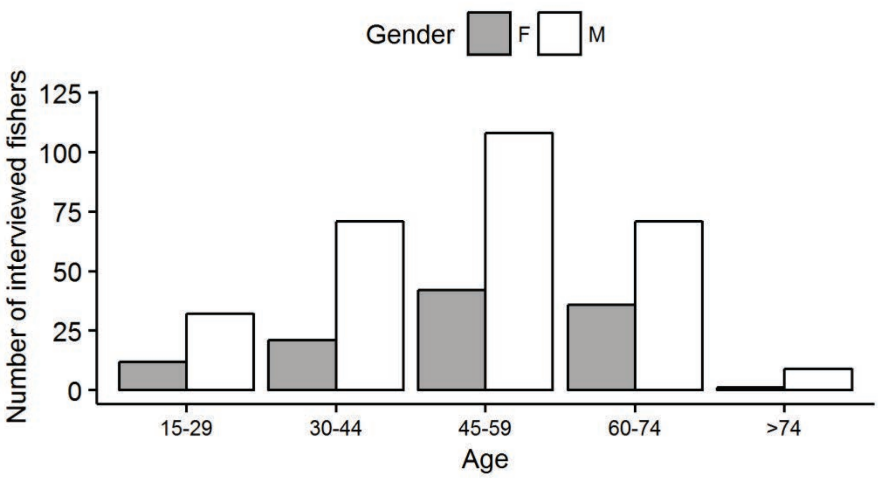

Figure 11. Number of fishers interviewed at boat ramps in Shark Bay between March 2016 and February 2017 by age group and gender. Fishers were interviewed at Denham, Monkey Mia and Denham.

7.2 Area of residence

Fishers who did not reside in the Shark Bay region (i.e. not postcode 6537) dominated the number of fishers interviewed (Figure 12). Collectively tourists comprised 89% of interviewed fishers overall, and were the dominant group in all seasons.

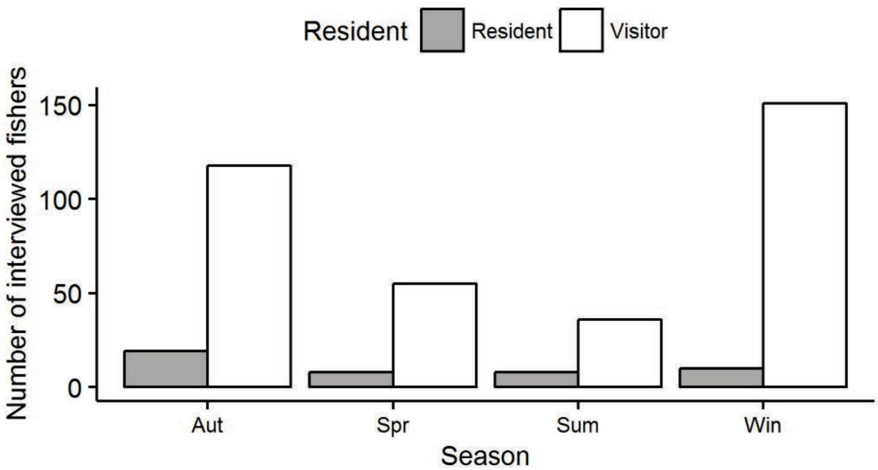

Figure 12. Number of resident and visiting fishers interviewed at boat ramps in Shark Bay between March 2016 and February 2017. Fishers were interviewed at Denham, Monkey Mia and Denham. Resident fishers had a postcode of 6537.

7.3 Avidity

The number of days fished in Western Australia (by recall) in the 12 months prior to interview is a measure of fishing avidity. The largest percentage of interviewed fishers had fished between 10 and 19 days in the previous 12 months and the smallest percentage of fishers had fished less than 10 days in the previous 12 months (Figure 13).

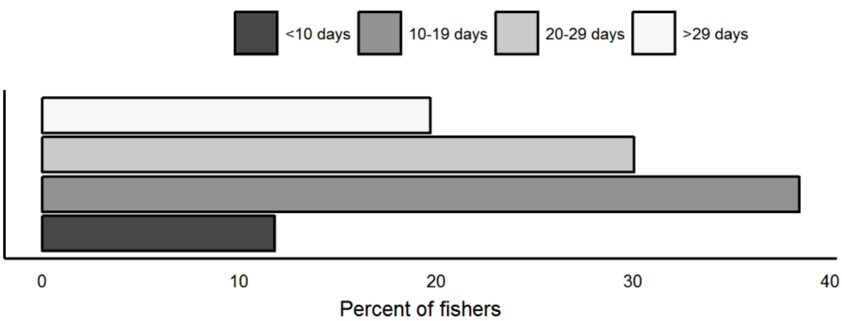

Figure 13. Percentage of days fished by avidity class obtained from fishers interviewed at boat ramps in Shark Bay between March 2016 and February 2017. Fishers were interviewed at Denham, Monkey Mia and Denham (n=406 interviews).

7.4 Awareness of fishing regulations

The majority of interviewed fishers (82%) were able to accurately recall the minimum legal size limit for Pink Snapper in Shark Bay (500 mm TL; Figure 14). A small percentage of fishers (12%) were aware that a minimum legal size applied to Pink Snapper but were unable to recall the correct size (aware (aided); Figure 14). The remainder of fishers were unaware of this regulation (6%). A similar trend was apparent for fishers' recollection of the daily bag limit for Pink Snapper in Shark Bay. The majority of fishers (86%) were able to accurately recall the daily bag limit for Pink Snapper (2 per fishers per day; Figure 14). A small percentage (10%) were aware that a daily bag limit applied to Pink Snapper but were unable to recall the correct limit (aware (aided); Figure 14) while the remainder (4%) were unaware of this regulation.

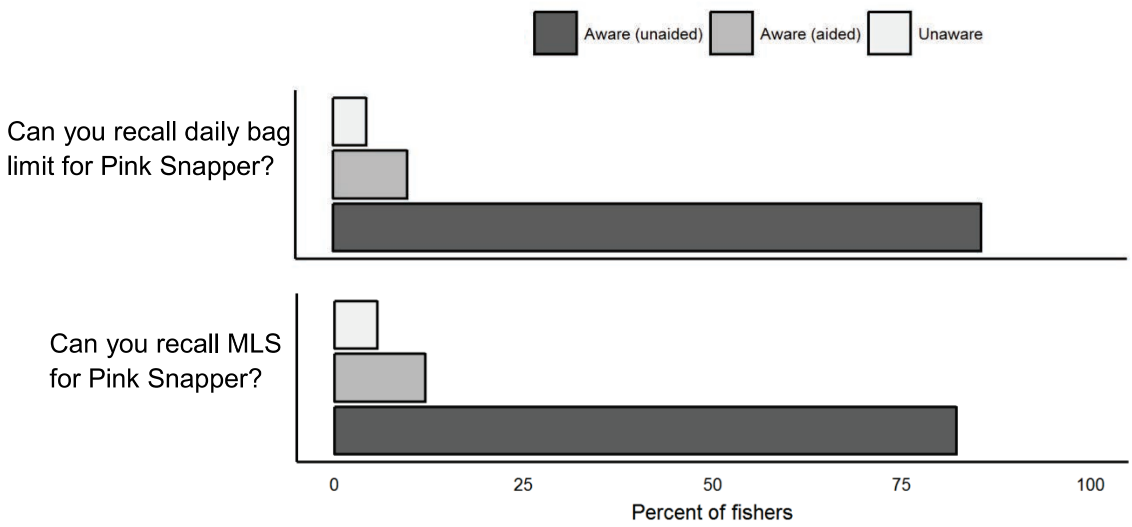

Figure 14. Interviewed fishers' awareness of the minimum legal size (MLS) and the daily bag limit for Pink Snapper. Fishers were interviewed between March 2016 and February 2017 at Denham, Monkey Mia and Denham (n=406 interviews).

7.5 Attitudes towards fishing regulations

The majority of interviewed fishers (82%) agreed with the daily bag limit for Pink Snapper and the minimum legal size (83%; Figure 15). A similar percentage of fishers were unsure about their attitude towards the two regulations. While less than 1% of fishers thought that the minimum legal size should be higher, 11% thought that the bag limit should be higher (Figure 15).

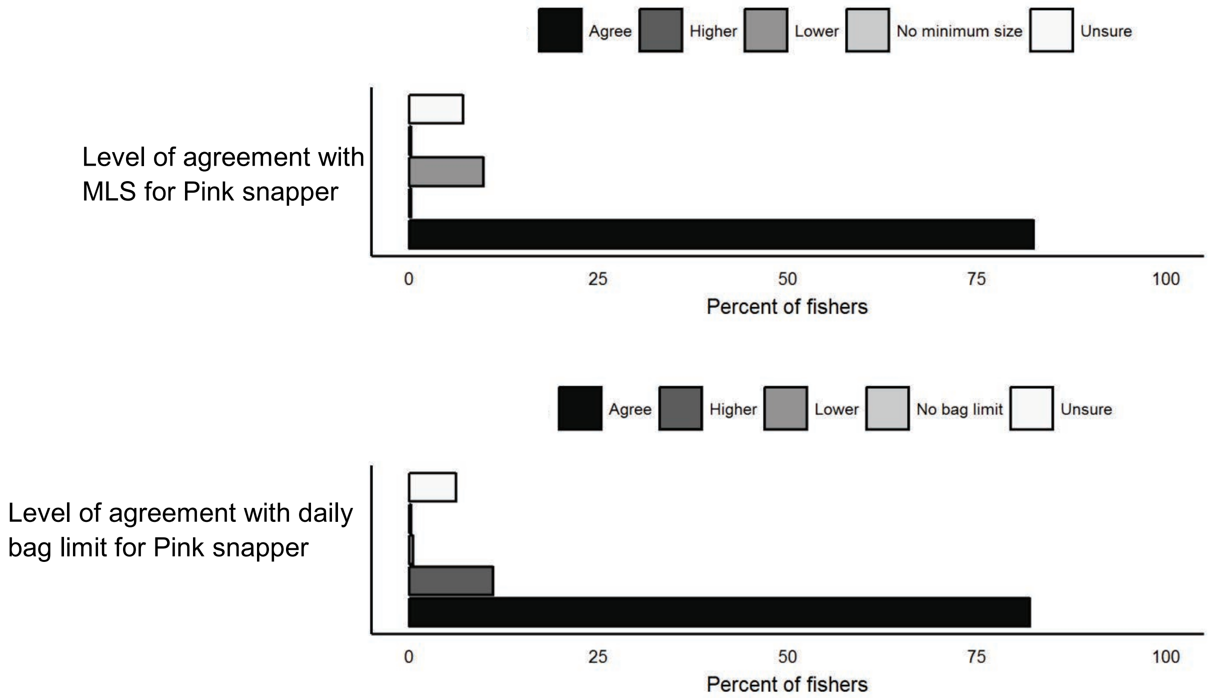

Figure 15. Interviewed fishers' levels of agreement with the minimum legal size (MLS) and the daily bag limit for Pink Snapper. Fishers were interviewed between March 2016 and February 2017 at Denham, Monkey Mia and Denham (n=406 interviews).

Overall, 45% of fishers were unsure whether they agreed with the recent removal of the harvest tag system for Pink Snapper while 44% agreed, 8% neither agreed nor disagreed, 3% strongly agreed and 1% disagreed (Figure 16). Stronger levels of support for the removal of the harvest tag system were reported by fishers at Nanga which was the only surveyed location within Freycinet Estuary (Figure 1; Figure 16). At this ramp, 73% of fishers agreed and 6% strongly agreed with the removal of the harvest tag system (Figure 16).

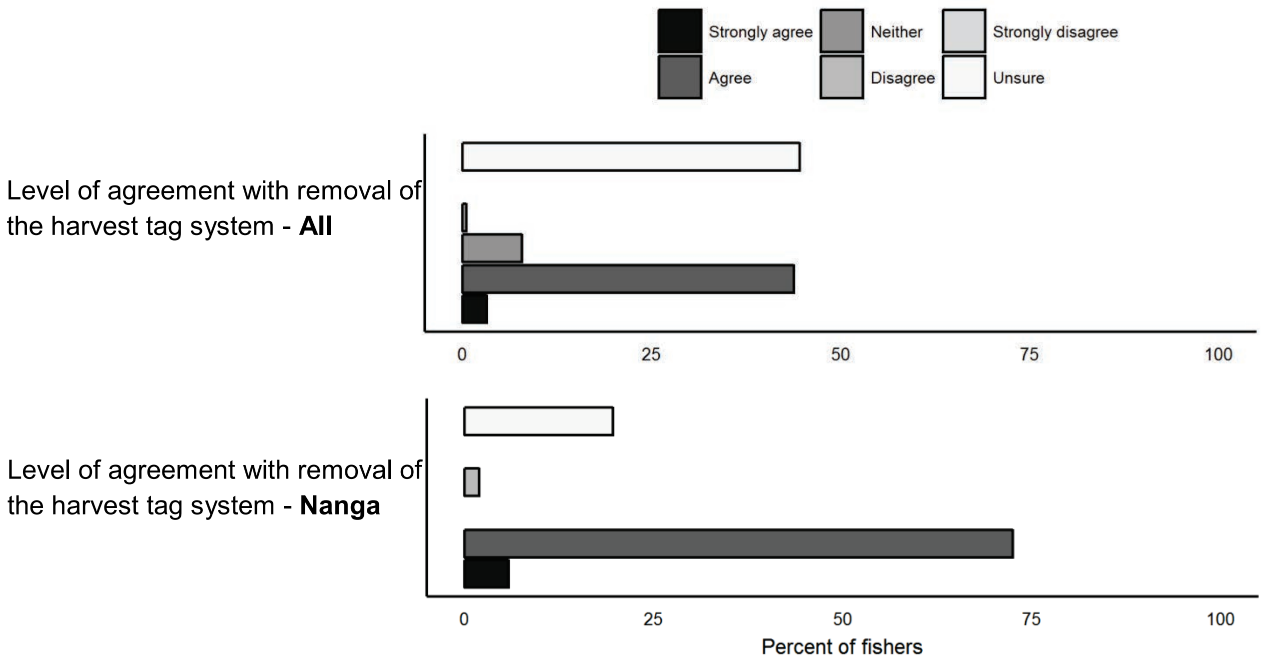

Figure 16. Interviewed fishers' levels of agreement with the removal of the harvest tag system for Pink Snapper in Freycinet Estuary displayed for all fishers (n=406 interviews) and only those interviewed at Nanga (n=51). Fishers were interviewed between March 2016 and February 2017.

8. Summary and recommendations for future surveys

8.1 Overview

The present study investigated boat-based recreational fishing originating from the boat ramps at Denham, Monkey Mia and Nanga in Shark Bay between March 2016 and February 2017. The study was initiated in response to major changes to the management of the Shark Bay recreational Pink Snapper fishery that were introduced in January 2016. These changes followed recent stock assessments that indicated that the spawning biomass of all three Pink Snapper stocks in Shark Bay were estimated to have recovered to be above the target (40% of the unfished level) in 2015 (Jackson *et al.*, 2017). The harvest tag system for Pink Snapper in Freycinet Estuary (introduced in 2003; Jackson *et al.*, 2016) was replaced with the Freycinet Estuary Management Zone wherein a new possession limit of 5 kg of finfish fillets or one day's bag limit of whole fish or fish trunks applies. In addition, the maximum size limit for Pink Snapper (700 mm total length, first introduced in 1997) was also removed. Further information on these changes is available here: http://www.fish.wa.gov.au/Fishing-and-Aquaculture/Recreational-Fishing/Recreational-Fishing-Rules/Shark-Bay-pink-snapper/Pages/index.aspx

Since 2011/12 three state-wide surveys of boat-based recreational fishing have been conducted within Western Australia and a fourth is currently underway (Ryan *et al.*, 2013, 2015, 2017). These surveys were designed to provide state-wide and bioregion estimates for commonly-caught species but cannot provide accurate and precise catch estimates at the smaller spatial scales required in inner Shark Bay. Thus a different survey method was needed to monitor Pink Snapper catches within the three Management Zones in inner Shark Bay. For some species catch estimates outlined in this report will be underestimates because they are not inclusive of catches from shore-based fishers or on-board Tour Operator vessels, boat-based trips at night and over multiple days, from boats held on moorings or from boats launched from the beach.

8.2 Contemporary recreational fishing in Shark Bay

Recreational fishing effort peaked in May, and higher levels of activity were observed in autumn (March–May) and winter (June–August), in comparison to spring (September–November) and summer (December –February). The particularly high level of recreational fishing effort estimated for May (30% of annual route-based effort; Figure 4) was corroborated by counts of the number of powerboat retrievals obtained from the remote cameras.

In total, 67 species or taxa were caught, including scalefish (n=51), elasmobranchs (n=13), crustaceans (n=2) and molluscs (n=1). The three most commonly-caught species (by number) were Pink Snapper, Blue Swimmer Crab and Grass Emperor and the majority of interviewed boat parties (63%) were targeting Pink Snapper. Catch estimates for the majority of species caught were imprecise (i.e. se>40% estimate; Table 11, Table 12) which reflects the fact they are captured in fairly small quantities. Boat-based catches of Pink Snapper were highly variable, ranging from one to 84 fish caught per boat (kept and released); however, nearly half of all boat parties that retained a pink snapper kept only 1 or 2 fish (Figure 8). Although fishers motives for releasing their catch was not profiled in the present study, the high percentage of released pink snapper (87%) is likely to be mainly a result of the minimum size (500 mm total length) because the 2015/16 state-wide survey of boat-based fishers in Western Australia revealed that 76% of pink snapper were released because they were "undersize" as opposed to 6% for "over limit" (Ryan *et al.*, 2017).

8.3 Comparison with historical surveys in Shark Bay

Over the last 18 years, 12 bus route surveys have been conducted in Shark Bay. Differences in the analysis and expansion of the catch and effort data obtained from the present and previous surveys preclude a direct and statistical comparison; however, the results enable relative changes in fishing effort and the magnitude of catches to be determined (Wise *et al.*, 2012). The estimated level of recreational fishing effort in 2016/17 for inner Shark Bay (33,299 party-hours; se=3,961) was approximately half that estimated for the historical peak in 1998 (69,581 party-hours, se=5,541), and lower than that estimated for each of the 10 surveys conducted between 2000 and 2010 (Figure 17).

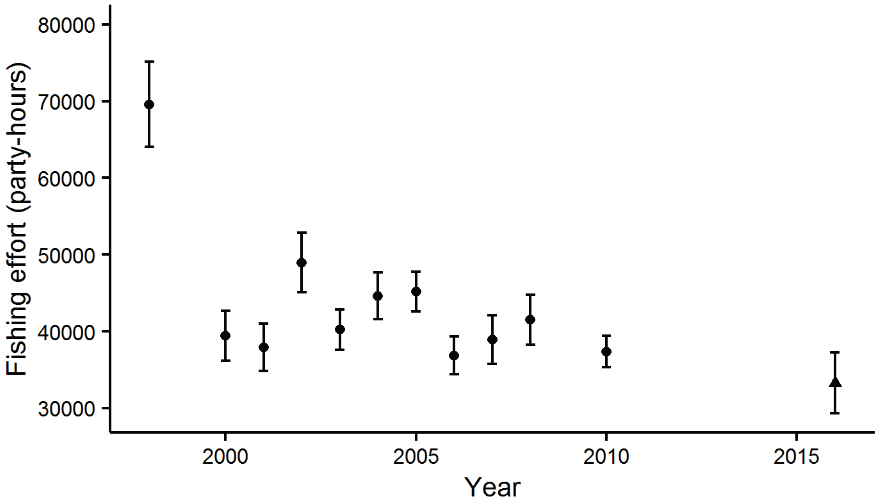

Figure 17. Comparison of recreational fishing effort (party-hours) obtained from 12 bus-route surveys conducted in Shark Bay between 1998 and 2016. Black circles denote the earlier surveys, black triangle denotes the present survey. Error bars are the standard error of the mean. All surveys were 12-months in duration; 2002–2007 and 2010 are calendar years, other surveys commenced at various times (refer to Table 4).

Overall, a high proportion of interviewed boat parties at Denham, Monkey Mia and Nanga were engaged in recreational fishing although this proportion did vary between months and day types. This suggests that the number of powerboat retrievals obtained from the remote cameras could be a good proxy for boat-based recreational fishing effort at each of the ramps (Table 8). The number of powerboat retrievals at Denham reported for 2011/12 (Ryan *et al.*, 2013), 2013/14 (Ryan *et al.*, 2015) and from the present study suggest that recreational fishing activity has remained stable during more recent years at this ramp, assuming the proportion of boats used for recreational fishing has not varied through time. The number of powerboat retrievals at Monkey Mia was more variable between these three years but does not indicate an increase in fishing effort post-management changes in January 2016 (Table 19). The results clearly confirm low levels of fishing effort at Nanga in comparison to Denham and Monkey Mia (Table 8) but because data from this location have only been analysed for 2016/17 it is unknown whether historical levels of fishing effort were different.

Table 19. Comparison of the number of powerboat retrievals (full 24-hrs) recorded from the remote cameras at Denham, Monkey Mia and Nanga. 2011/12 and 2013/14 estimates are reported in Ryan *et al.*(2013) and Ryan *et al.* (2015). 2016/17 estimates are from the present study. Numbers in brackets for Denham are the number of powerboat retrievals excluding July, August and September.

	Year					
Location	2011/12	se	2013/14	se	2016/17	se
Denham	4,564 (3,213)	17	5,191(3,560)	124	4,166*	132
Monkey Mia	3,207	21	6,365	401	4,075	25
Nanga	-	-	-	-	781	15

*Denham total does not include catch in Jul, Aug and Sep 2016 data due to major camera outage (Table 7)

Recreational fishing in inner Shark Bay steadily increased from the 1960s through to the 1990s resulting in all three Pink Snapper stocks becoming over-exploited (Jackson and Moran, 2012). The peak in recreational catches in 1998 (139,847 fish kept and released; Wise *et al.*, 2012) led to the implementation of additional management measures that were progressively introduced, including a TARC for each Pink Snapper stock implemented in 2003. The estimated kept catch (by number and weight) of Pink Snapper in inner Shark Bay between March 2016 and February 2017 was higher than that obtained from the proceeding 2010 survey (15–20 t); however, the estimated released catch in the 2010 survey was higher. The high percentage of released Pink Snapper in the present study (88% inner Shark Bay) was consistent with the historical surveys (88–95%; Wise *et al.*, 2012).

The estimated mean kept catch of Pink Snapper (by weight) at Denham (5.3 t, 95% CI 1.6–9.0; Table 18) was below the Total Allowable Recreational Catch (TARC) for recreational fishing in Denham Sound (11.5 t) with the upper 95% confidence interval below the TARC. However, this estimate was restricted to a 9-month period because major renovations along the Denham foreshore required the temporary dismantlement of the remote camera. As a result, the mean kept catch of Pink Snapper at Denham is an underestimate of the total catch at this ramp for the 12-month period. During 2011/12 and 2013/14, approximately 30% of annual powerboat retrievals at Denham occurred during these three months (Table 19). Under the assumption that the catch is proportional to the number of powerboat retrievals, upscaling the Denham estimate of 5.3 t to account for these missing months would equate to approximately 6.9 t, below the recreational TARC for Denham Sound (11.5 t). However, this simplistic approach ignores potential inter-annual variations in Pink Snapper harvest rates. In addition, the ‘out of scope’ activities (e.g. multi-day fishing trips, boats held on moorings) were not included in the nine-month estimate. It cannot be confirmed if the recreational TARC for Denham Sound was exceeded although the available evidence suggests the total catch is unlikely to have been substantially greater than the TARC.

The estimated mean kept catch of Pink Snapper (by weight) at Monkey Mia (3.0 t, 95% CI 1.1–4.8) was well below the TARC for recreational fishing in the Eastern Gulf (11.25 t) and the upper 95% confidence interval was also below the TARC. Even after consideration of the potential 'out of scope activities' (e.g. boats held on moorings at Monkey Mia, beach launches), it is unlikely the TARC for Eastern Gulf was exceeded. This is likely to be influenced by the 3-month spawning closure (May to July) which prohibits the take of Pink Snapper in the Eastern Gulf at a time when fishing effort levels at Denham, and to a lesser extent Nanga, are relatively higher.

The estimated mean kept catch of Pink Snapper (by weight) at Nanga (2.7 t, 95% CI 1.5–3.9; Table 18) was below the TARC for recreational fishing in Freycinet Estuary (3.75 t) with the 95% confidence interval exceeding the TARC. Within Freycinet Estuary recreational fishers operating out of Tamala and Carrarang stations have always taken quantities of Pink Snapper (e.g. Jackson *et al.*, 2016). However, there has been an observed increase in the popularity of these fishing locations over the last 10–15 years with a corresponding increase in the percentage of the total Pink Snapper catch taken from these locations compared with Nanga. An aerial survey conducted between June and August 2012 revealed the presence of camps, vehicles, boats anchored on the water, and trailers on the beach at multiple locations within Freycinet Estuary (Smallwood and Gaughan, 2013). Direct observations from Fisheries and Marine Officers confirm the capture of Pink Snapper at Tamala and Carrarang during the 12-month survey (Byron Francis, *pers. comm.*). Furthermore, high visitation rates at Tamala were verified over April and July during the survey based on records kept by the station owner. Therefore, the estimated catch of Pink Snapper at Nanga is an underestimate of the total catch in Freycinet Estuary.

8.4 Human dimensions of recreational fishing in Shark Bay

The adoption of ecologically sustainable development and ecosystem-based fisheries management policies recognise the need to consider the effects of fishing on target species and the broader ecosystem, in addition to the economic health of the fishery (Fletcher *et al.*, 2002; Fletcher, 2005). The availability of Pink Snapper stocks and satisfaction of the recreational fishing community is likely to be linked to both the economic health of the fishery and the local economy because a large proportion of interviewed fishers in the present study were non-residents. Overall, fishers were well-informed and expressed strong levels of support for contemporary Pink Snapper management arrangements. While the majority of recreational fishers interviewed at Nanga (in the Freycinet Estuary Management Zone) expressed support for the recent removal of the harvest tags, nearly half of all interviewed fishers were unsure whether or not they supported this recent change. Repeating the same question at a later stage, in addition to the ongoing monitoring of catch levels, would provide the opportunity to gauge the effectiveness of this management change. A broader understanding of the human dimensions of recreational fishing in Shark Bay could also be of benefit to future management and policy implementation (e.g. Brooks *et al.*, 2015; Griffiths *et al.*, 2017) .

8.5 Recommendations for future surveys

To ensure that fishing activities in Shark Bay continue to be managed at sustainable levels, ongoing monitoring of recreational catches are required. This is particularly important because for many species the recreational catch in Shark Bay surpasses the commercial catch. For example, in 2015 commercial catches of Pink Snapper in inner Shark Bay were 1–2 t and charter boat catches were 2.5 t (Jackson *et al.*, 2017) in comparison to the estimated recreational kept catch of 21.5 t (95% CI 13.4–29.6) obtained from the present study. Therefore trends in commercial and charter boat catches derived from statutory fishing returns do not accurately reflect trends in total fishing mortality. Furthermore, the fishing levels reported for 2016/17 may differ from those in subsequent years because of a time-lag between the implementation of new management measures and potential changes in fishers' behaviours.

In March 2018, subsequent boat ramp and aerial surveys commenced in Shark Bay. These surveys will provide an additional estimate of the recreational catch at Denham, Monkey Mia and Nanga in addition to estimates of recreational fishing effort for the entire Freycinet Estuary Management Zone. This will provide more accurate information on the recreational harvest to assist in assessing whether or not contemporary harvest levels in the Freycinet Estuary Management Zone are exceeding the TARC.

The 2018 surveys have been informed by the results of the present study. The design is based on a traditional access point design rather than a bus route design (Georgeson *et al.*, 2015; Pollock *et al.*, 1994). This approach has three main advantages that will likely improve the accuracy of the catch estimates for Pink Snapper. Firstly, because the scheduling of shifts is now done separately for each ramp, the sampling intensity is proportionally allocated to known levels of fishing activity and cognisant of the seasonal closures that occur in the Eastern Gulf and Freycinet Estuary. Deploying several survey staff at busy times should also allow a larger proportion of boat parties to be interviewed and allow more Pink Snapper to be measured which would assist in providing a more precise catch (by weight). Secondly, the traditional access point design provides fuller coverage of the PSU, negating the need to assume that the 'snapshot' of activity measured during the wait time is representative of the entire fishing day. Examination of the daily camera data in the current study revealed that on some days fishing activity was recorded outside the wait time at each ramp but no activity was observed during the wait time (i.e. zero catch recorded because of partial coverage of the

PSU). Finally, unlike the bus-route design, should a major camera outage occur, ramp based estimates for the full 12-months could still be obtained using the traditional access point design.

Where possible it is recommended that future onsite surveys in Shark Bay are aligned to coincide with the state-wide surveys of boat-based fishing to assist in the corroboration of survey results. The commencement of the 2018 boat ramp and aerial surveys was designed to ensure a six-month overlap with the 2017/18 state-wide survey of boat based fishing. This will assist in demonstrating the utility of the results and for determining total catch estimates for each of the inner Shark Bay Pink Snapper stocks (Georgeson et al., 2015; Hartill et al., 2015). It is also recommended that the remote cameras continue to be an integral part of the supplementary access point design because they improve the accuracy and precision of effort estimation (Steffe *et al.*, 2017). Because the number of powerboat retrievals appears to be closely related to recreational fishing effort in Shark Bay, examining camera footage between onsite surveys would also provide a means to detect potential changes in fishing activity. This low-level monitoring would assist in assessing whether dedicated onsite surveys would be required to determine the actual catch levels for Pink Snapper and other species should an increase in boating activity be observed.

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Appendix 1 Chronology of the management of Pink Snapper in Shark Bay.

(adapted from Wise *et al*., 2012)

Year/Time period	Management action
1950s–1970s	Minimum size limit of 380mm; no daily bag limits.
1977	Daily bag limit of 10 ‘reef fish’ (includes Pink Snapper) per person state-wide.
1986	Minimum size limit increased to 410mm.
1990	Hamelin Pool Marine Nature Reserve gazetted. Shark Bay Marine Park gazetted.
1991	Daily bag limit reduced to eight ‘reef fish’ per person state-wide. Shark Bay inscribed on the World Heritage List.
1992	Shark Bay beach-seine and mesh-net fishery legislated.
1996	Commercial fishing for Pink Snapper in Shark Bay prohibited, except beach-seine and mesh-net fishery. Eastern Gulf: daily bag limit of four Pink Snapper per person introduced; minimum size limit increased to 450mm.
1997	Western Gulf: minimum size limit increased to 450mm; daily bag limit reduced to four Pink Snapper, with only two individuals >700mm. Eastern Gulf: Pink Snapper fishery (rec. and comm.) closed in May, then reopened July; daily bag limit reduced to two Pink Snapper individuals per person; slot size limit 500–700mm.
1998	Eastern Gulf: moratorium, Pink Snapper fishery closed in June.
2000	Denham Sound: daily bag limit reduced to two fish per person; size limit increased to 500mm, with only one Pink Snapper >700mm. Freycinet Estuary: same as Denham Sound plus 6-week spawning-season closure (15 August–30 September). Eastern Gulf: Pink Snapper fishery remains closed.
2002	Ministerial Working Group reviewed Pink Snapper research and management and considered management options for 2003–2005.
2003	All areas: daily bag limit one Pink Snapper per person with slot limit size 500–700mm. Denham Sound: TAC 10t (8t rec., 2t comm.). Freycinet Estuary: TAC 5t (3.8t via 900 rec. lottery quota tags; 1.2 comm. via 300 quota tags); spawning season closure (15 August–30 September). Eastern Gulf: moratorium lifted in March; TAC 15t (12t rec.; 3t comm.); spawning-season closure (1 April–31 July).
2005	Research and management reviewed and regulations updated for 2006–2008.
2006	Denham Sound: TAC increased to 15t (12t rec; 3t comm.). Freycinet Estuary: rec. lottery quota tags increased to 1050 and comm. quota tags increased to 350. Eastern Gulf: spawning-season closure reduced (1 May–31 July).
2008	Research and management reviewed and regulations unchanged for 2009–2011.
2015	A review of management arrangements was undertaken following stock assessments that indicated the recovery of Pink Snapper stocks in Eastern Gulf, Denham Sound and Freycinet.
2016	700mm maximum size limit for inner gulf Pink Snapper and the requirement to land Pink Snapper in whole form no longer applies. Freycinet Estuary: lottery quota tag system replaced with the Freycinet Estuary management zone in which a new possession limit of 5kg of finfish fillets or one day’s bag limit of whole fish or fish trunks applied.

Appendix 2 Boat Ramp Header form

Interviewer name		Date (dd/mm/yyyy)		Ramp	

Start Time (24-hr)		Finish Time (24-hr)	
Wind speed (knots)	☐ Calm (0) ☐ Light (1-12) ☐ Mod (13 – 20) ☐ Strong (21 – 30) ☐ Gale (>30)	Wind direction	

Water	☐ Calm ☐ Slight ☐ Mod ☐ Rough ☐ Very Rough	Cloud Cover (%)		Rainfall	☐ Nil ☐ Light ☐ Mod ☐ Heavy

Boat launches			
Time	Type	Time	Type

Boat retrievals			
Time	Type	Time	Type

Total number of trailers	
Start	Finish

Boat types
P: Powerboats
Y: Yachts
J: Jetskis
C: Commercial
O: Other

Comments

Appendix 3 Interview form

Date		Ramp		Boat Rego		Interview Time	

Retrieval Time (24-hr)		Launch Time (include date if different to today) (24-hr)		Boat type	☐ Power ☐ Yacht ☐ Jetski ☐ Other	Recreational Fishing?	☐ Yes ☐ No

FISHERS ONLY

Number People on the Boat	
Number of People Fishing	
Number of Licences	
Block Number Primarily Fished (in terms of time)	

Gear types, number used and time spent fishing (decimal hours)			
Lines, **G**ill/ c**A**st / **S**coop /RL **P**ot / S**n**are / **D**rop net / Sp**E**argun / **H**and / **T**raps / Gidg***l***e / **J**ig / Shepherds Hoo**K** / **O**ther			

Species Targeted 1	
Species Targeted 2	

Species (Sex for crabs and lobsters)	Block number (if diff to above)	Number Kept	Number Released	CFL (mm)	TL (mm)	Weight (grams)	CFL (mm)	TL (mm)	Weight (grams)

REFUSALS

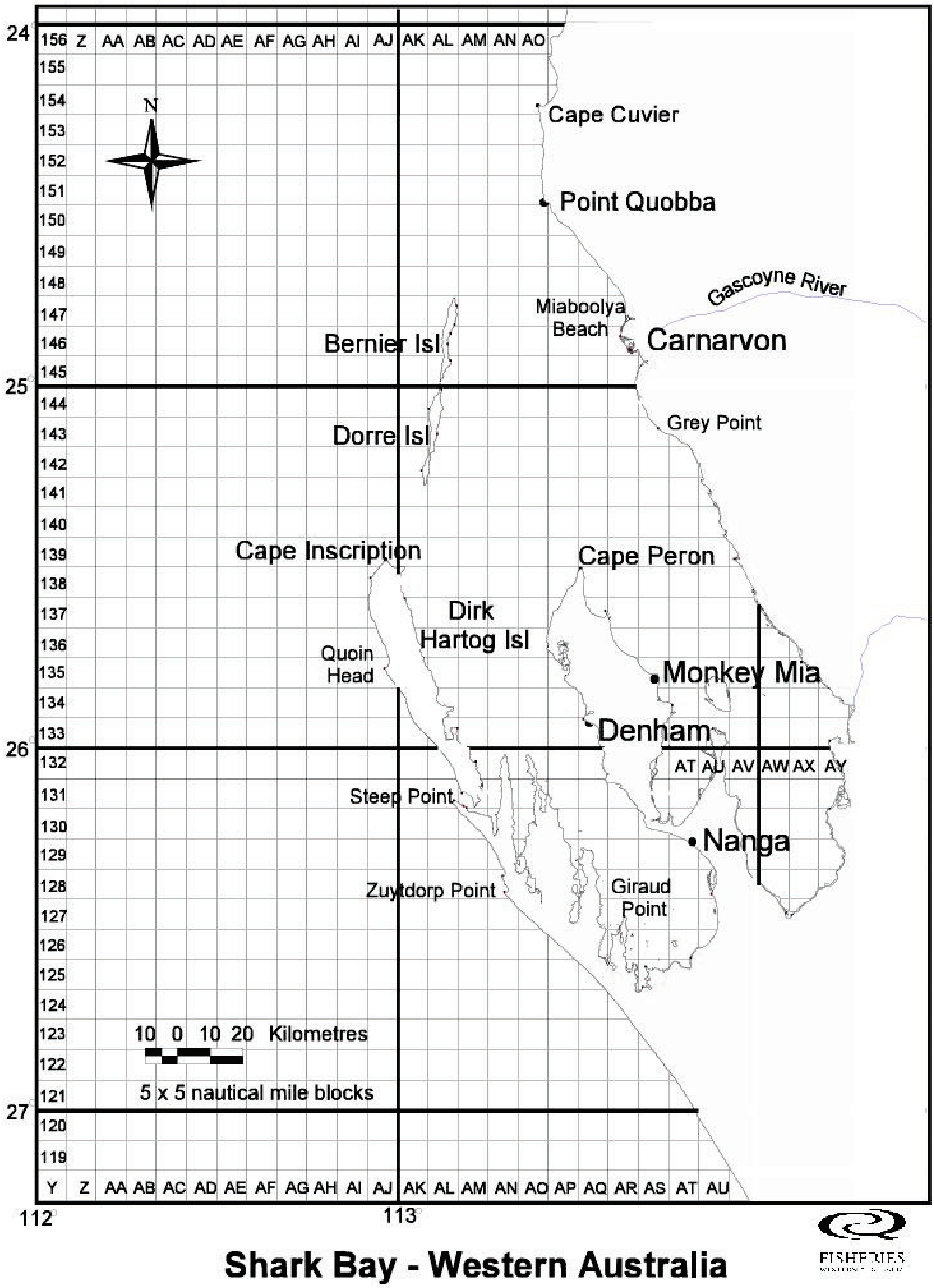
Refused interview *(tick)*	☐ Yes ☐ No

Why? *(tick)*	☐ No time (fisher)	☐ Not interested	☐ Not fishing	☐ Information will be used against recreational fishers
	☐ Interviewer	☐ Other *(reason)*		

Species (Sex for crabs and lobsters)	Block number (if diff to above)	Number kept	Number released	CFL (mm)	TL (mm)	Weight (grams)	CFL (mm)	TL (mm)	Weight (grams)

Appendix 4 Map of Shark Bay aggregated in 5x5 nautical mile blocks.

Each recreational boat party was asked in which block the majority of their recreational fishing activity occurred



Appendix 5 Awareness/Attitudinal form

Date (dd/mm/yyyy)		Ramp		Boat Rego		Interview Time	

Interviewed before? If Y, select other fisher	☐ Yes ☐ No	Gender	☐ M ☐ F	Age	☐ 15-29 ☐ 30-44 ☐ 45-59 ☐ 60-74 ☐ > 74	Avidity	☐ <10 ☐ 10-19 ☐ 20-29 ☐ 30+	Postcode	

(a) The next few questions are about fishing regulations relating to *pink snapper* which may or may not apply to the kinds of fishing you do. **Can you recall the *minimum size limit* for *pink snapper* in Shark Bay?** (IF KNOWN EXACTLY CODE AWARE (UNAIDED), OTHERWISE ASK), **Actually it's 500 mm. can you recall hearing anything about this … or not..**	☐ Aware (unaided) ☐ Aware (aided) ☐ Unaware
(b) **(And) do you agree with this *minimum size limit*.. or do you think it should be higher, or lower.. or should there be no size limit at all for pink snapper?**	☐ Agree ☐ Higher ☐ Lower ☐ No minim. size ☐ Unsure

(c) **Can you recall the daily bag limit for pink snapper in Shark Bay? (**IF KNOWN EXACTLY CODE AWARE (UNAIDED), OTHERWISE ASK**), Actually it's 2 snapper (5 mixed). Can you recall hearing anything about this … or not?**	☐ Aware (unaided) ☐ Aware (aided) ☐ Unaware
(d) **(And) do you agree with this daily bag limit.. or do you think it should be higher, or lower..or should there be no daily bag limit at all for pink snapper?**	☐ Agree ☐ Higher ☐ Lower ☐ No bag limit ☐ Unsure

(e) In addition, on Jan 1st 2016 the harvest tag system for pink snapper in Freycinet Estuary was *removed*. **Do you strongly agree, agree, neither agree or disagree, mildly disagree or strongly disagree with this change?**	☐ Strongly agree ☐ Agree ☐ Neither agree or disagree ☐ Disagree ☐ Strongly disagree ☐ Unsure

(f) **Are you aware of any *other current regulations* for *pink snapper* in Shark Bay?**	☐ Area/spawning closures ☐ In possession limits ☐ Marine Park ☐ Previous regulation ☐ Incorrect ☐ Unaware

REFUSALS

Refused interview *(tick)*	

Why? *(tick)*	☐ No time (fisher)	☐ Not interested	☐ Not fishing	☐ Information will be used against recreational fishers
	☐ Interviewer	☐ Other *(reason)*		

Appendix 6 Expansion of the bus-route data

6.1 Basic notation

j Denotes the stratum being considered ($j = 1, \dots, J$)

J Denotes the total number of strata

i Denotes the primary sampling unit (PSU, day) within the stratum ($i = 1, \dots, N_j$)

N_j Denotes the total population size (all possible sampling days) in stratum j

n_j Denotes the sample size in stratum j

z_{ij} Denotes the value of the ith unit of stratum j

$\overline{z}_j$ Denotes the sample mean for stratum j

$$s_j^2 = \left[\frac{\sum_{i=1}^{n_j}(z_{ij} - \bar{z}_j)^2}{(n_j - 1)}\right]$$

is the sample variance for stratum j

6.2 Single survey day

The Direct Expansion method was used as opposed to the Time Interval Count method because the former is recommended when parked cars and trailers may not belong exclusively to anglers (refer to Pollock *et al*., 1994), a situation encountered in Shark Bay and in many other parts of the State. Furthermore, major renovations to the Denham foreshore occurred during the survey period that resulted in boat trailers being parked in areas aside from the designated trailer parking bays at this ramp. The use of the Time Interval method would have underestimated fishing effort at these times.

6.2.1 Fishing Effort

$\hat{E}_k$ Denotes estimated party-hours of effort for the kth survey day

T Denotes the total time to complete the route, including travelling and waiting

w_i Denotes the waiting time at the ith site ($i = 1, \dots, n$ sites)

e_{ji} Denotes the trip duration for the jth boat party at the ith site

$$\hat{E}_k = T \sum_{i=1}^{n} \frac{1}{w_i} \sum_{j=1}^{m} e_{ji}$$ Equation 1

Because deviations to the timing of the bus-route were occasionally encountered due to traffic the actual wait time (w_i) at each ramp was used in Equations 1 and 2 rather than the scheduled wait time.

6.2.2 Catch

Notation is the same as for fishing effort except for:

$\hat{C}_k$ Denotes estimated number of fish caught for the kth survey day

c_{ji} Denotes the catch as reported from the jth boat party at the ith site

$$\hat{C}_k = T \sum_{i=1}^{n} \frac{1}{w_i} \sum_{j=1}^{m} c_{ji}$$ Equation 2

6.3 Expansion to stratum totals

6.3.1 Effort

The daily effort values were expanded for each day type stratum (2 levels; weekdays (WD), weekend days and public holidays (WE)) in each month (12 levels; March, April,…February). This was done by multiplying the number of possible sample days in each stratum by the mean of the daily estimate of fishing effort.

$$\bar{E}_j = \frac{\sum \hat{E}_{kj}}{n_j}$$ Equation 3

where $\bar{E}_j$ is the estimate of mean daily fishing effort for the jth day type stratum, in units of party- hrs.

$$\hat{E}_j = N_j \bar{E}_j$$ Equation 4

where:

$\hat{E}_j$ is the estimate of total fishing effort for the jth day type stratum, in units of party-hrs.

6.3.2 Catch

The daily catch values were expanded for each day type stratum (2 levels; weekdays (WD), weekend days and public holidays (WE)) in each month (12 levels; March, April,…February). This was done by multiplying the number of possible sample days in each stratum by the mean of the daily estimate of the catch.

$$\bar{C}_{j} = \frac{\sum \hat{C}_{kj}}{n_j}$$ Equation 5

where $\bar{C}_{j}$ is the estimate of mean daily catch for the *j* th day type stratum, in numbers of fish.

$$\widehat{C}_{j} = N_j \bar{C}_{j}$$ Equation 6

where:

$\widehat{C}_{j}$ is the estimate of total catch for the *j* th day type stratum, in numbers of fish.

6.4 Calculate annual totals from stratum totals

6.4.1 Effort

This was done by adding the estimates of fishing effort for the day type strata together to obtain monthly totals, then by adding monthly totals to obtain annual totals

$$\hat{E}_{Tot} = \sum_{j=1}^{J} \widehat{E}_{j}$$ Equation 7

where $\hat{E}_{Tot}$ is total fishing effort calculated by combining the estimates of each stratum. The term $\hat{E}_{Tot}$ refers to monthly effort totals when adding day type strata, and to the annual effort total when monthly totals are combined.

6.4.2 Catch

This was done by adding the catch estimates of the day type strata together to obtain monthly totals, then by adding monthly totals to obtain annual totals.

$$\hat{C}_{Tot} = \sum_{j=1}^{J} \widehat{C}_{\text{j}}$$ Equation 8

where $\hat{C}_{Tot}$ is the total catch calculated by combining the estimates of each stratum. The term $\hat{C}_{Tot}$ refers to monthly effort totals when adding day type strata, and to the annual catch total when monthly totals are combined.

6.4.3 Catch by weight for Pink Snapper

This was done using the expanded estimate of the annual kept catch in numbers and the average weight ($\overline{w}$) based on the length data collected during onsite surveys and the length-weight conversion provided for Pink Snapper in Western Australia by Smallwood *et al.* (2017). Because of the small sample size for the average weight in most months and day types, the conversion was applied to the annual catch total.

$$\widehat{W}_{Tot} = \hat{C}_{Tot}\overline{w}$$ Equation 9

6.5 Calculate the precision of the estimates

6.5.1 Effort

$$Var(\bar{E}_j) = \frac{s_j^2}{n_j}$$ Equation 10

$Var\left(\bar{E}_j\right)$ is the estimated variance of mean daily fishing effort for the jth day type stratum within a month.

$$SE\ (\bar{E}_j) = \sqrt{var\left(\bar{E}_j\right)}$$ Equation 11

where:

$SE\ (\bar{E}_j)$ is the estimated standard error of the mean fishing effort

$$Var(\hat{E}_j) = N_j^2 \, Var\,(\bar{E}_j)$$ Equation 12

where:

$Var(\hat{E}_j)$ is the estimated variance of total effort for a stratum, calculated separately for each day type within each month.

$$SE\left(\hat{E}_\mathrm{j}\right) \; = \sqrt{var\,(\hat{E}_j)}$$ Equation 13

where:

$SE\left(\hat{E}_j\right)$ is the estimated standard error of total effort for a stratum.

$$Var(\hat{E}_{Tot}) \; = \sum_{j=1}^{J} Var\,(\hat{E}_j\,)$$ Equation 14

where:

$Var(\hat{E}_{Tot})$ is the estimated total variance calculated by combining the estimated effort variances for each stratum. The term $Var(\hat{E}_{Tot})$ refers to monthly variance totals when adding variances from day type strata, and to the annual variance when seasonal variances are combined.

$$SE\left(\hat{E}_{Tot}\right) \; = \sqrt{var\,(\hat{E}_{Tot})}$$ Equation 15

6.5.2 Catch

$$Var(\bar{C}_j) = \frac{s_j^2}{n_j}$$ Equation 16

$Var\,\left(\bar{C}_j\right)$ is the estimated variance of mean daily catch for the j th day type stratum within a month.

$$SE\,(\bar{C}_j) = \sqrt{var\left(\bar{C}_j\right)}$$ Equation 17

where:

$SE\ (\bar{C}_j)$ is the estimated standard error of the mean catch

$$Var(\hat{C}_j) = N_j^2\ Var\ (\bar{C}_j)$$ Equation 18

where:

$Var(\hat{C}_j)$ is the estimated variance of the total catch for a stratum, calculated separately for each day type within each month.

Equation 19

$$SE(\widehat{C}_j) = \sqrt{var\ (\hat{C}_j)}$$

where:

$SE(\widehat{C}_j)$ is the estimated standard error of the total catch for a stratum.

$$Var(\hat{C}_{Tot}) = \sum_{j=1}^{J} Var\ (\widehat{C}_j)$$ Equation 20

where:

$Var(\hat{C}_{Tot})$ is the estimated total variance calculated by combining the estimated catch variances for each stratum. The term $Var(\hat{C}_{Tot})$ refers to monthly variance totals when adding variances from day type strata, and to the annual variance when seasonal variances are combined.

Equation 21

$$SE(\hat{C}_{Tot}) = \sqrt{var\ (\hat{C}_{Tot})}$$

6.5.3 Catch by weight for Pink Snapper

This was done using the variance of a product (Goodman, 1960) based on the total kept catch (in numbers) for each month and day type and the average pink snapper weight (treating each measured fish as a replicate value).

$$Var(\widehat{W}) = \left[\hat{C}^2\, Var\,(\overline{w})\right] + \left[\overline{w}^2\, Var\,(\hat{C})\right] - \left[Var(\overline{w})\, Var\,(\hat{C})\right] \qquad \text{Equation 22}$$

Appendix 7 Expansion of the supplemented access point data

7.1 Basic notation

j Denotes the stratum being considered ($j = 1, \dots, J$)

J Denotes the total number of strata

i Denotes the primary sampling unit (PSU, day) within the stratum ($i = 1, \dots, N_j$)

N_j Denotes the total population size (all possible sampling days) in stratum j

n_j Denotes the sample size in stratum j

z_{ij} Denotes the value of the i th unit of stratum j

$\overline{z}_j$ Denotes the sample mean for stratum j

$$s_j^2 = \left[\frac{\sum_{i=1}^{n_j}(z_{ij} - \bar{z}_j)^2}{(n_j - 1)}\right]$$

is the sample variance for stratum j

7.2 Single survey day

7.2.1 Number of powerboat retrievals

The number of powerboat retrievals ($\hat{P}_{k\mathrm{j}}$) for the kth survey day in the jth day type in a month at each ramp was estimated for the period between nautical sunrise and nautical sunset as:

$$\hat{P}_{k\mathrm{j}} = \sum_{i=1}^{n} x_i \qquad \text{Equation 1}$$

where:

x_i is the number of powerboats that retrieved at the ramp between nautical sunrise and nautical sunset in the ith minute ($\mathrm{i} = 2, 3, \dots \mathrm{n}$ minutes). If any 2-hr period (04:00–05:59, 06:00–07:59,…) in the kth survey day had a proportion of missing footage <0.5, the missing period was scaled up to the total number of minutes in the period. If the proportion of missing footage was ≥ 0.5, the day was treated as missing at random.

7.2.2 Proportion of powerboats used for recreational fishing

The proportion of boats wherein the occupants went recreational fishing ($\overline{Prop}_{kj}$) and fished within inner Shark Bay (i.e. not the Oceanic Management Zone) was estimated for the kth survey day in the jth day type in a month at each ramp.

$$\overline{Prop}_{kj} = \frac{\sum_{i=1}^{n} P_k}{\sum_{i=1}^{n} T_k} \qquad \text{Equation 2}$$

where:

P_k Denotes the number of powerboats used for recreational fishing within inner Shark Bay for the kth survey day

T_k Denotes the total number of powerboats for the kth survey day

Only those boat parties interviewed between nautical sunrise and nautical sunset were included.

7.2.3 Mean trip duration

To provide estimates of fishing effort in the same unit of measurement as used in the bus route analysis (refer to Appendix 6), fishing effort was also converted from the number of boats to party-hours. The average length of each fishing trip within inner Shark Bay ($\overline{Trip}_{kj}$) was estimated for the kth survey day in the jth day type in a month at each ramp.

$$\overline{Trip}_{kj} = \frac{\sum_{i=1}^{n} L_i}{n} \qquad \text{Equation 3}$$

where:

L_i Denotes the trip length for the ith boat party

7.2.4 Catch rate

As the catch rate was derived from complete trips the "ratio of means" estimator was used to estimate the daily catch rate ($\bar{R}_{kj}$;Hoenig *et al.*, 1997; Pollock *et al.*, 1994).

$$\bar{R}_{kj} = \frac{\sum_{i=1}^{n} C_i}{\sum_{i=1}^{n} L_i} \qquad \text{Equation 4}$$

where:

C_i Denotes the catch for the ith boat party

L_i Denotes the trip length for the ith boat party

7.3 Expansion to stratum totals

7.3.1 Powerboat retrievals

The number of powerboat retrievals $(\hat{P}_j)$was calculated for each day type stratum (2 levels; weekdays (WD), weekend days and public holidays (WE)) in each month (12 levels; March, April,…February).

$$\hat{P}_j = \frac{\sum \hat{P}_{kj}}{n_j} N_j \qquad \text{Equation 5}$$

7.3.2 Fishing effort (boat days)

The mean proportion of powerboats used for recreational fishing within inner Shark Bay $(\overline{Prop}_j)$ was calculated for each day type stratum (2 levels; weekdays (WD), weekend days and public holidays (WE)) in each month (12 levels; March, April,…February).

$$\overline{Prop}_j = \frac{\sum \overline{Prop}_{kj}}{n_j} \qquad \text{Equation 6}$$

Fishing effort in boat days $(\hat{E}_j)$ was then calculated.

$$\hat{E}_j = \hat{P}_j \overline{Prop}_j \qquad \text{Equation 7}$$

7.3.3 Trip duration

$$\overline{Trip}_j = \frac{\sum \overline{Trip}_{kj}}{n_j} \qquad \text{Equation 8}$$

where:

$\overline{Trip}_j$ = Denotes mean trip duration (in hours).

7.3.4 Fishing effort (party-hours)

$$\hat{E}_{jnew} = \hat{E}_j \, \overline{Prop}_j$$ Equation 9

where:

$\hat{E}_{jnew}$ Denotes mean fishing effort (in party-hours).

7.3.5 Catch rate

The mean daily catch rate $(\bar{R}_j)$ was calculated for each day type stratum (2 levels; weekdays (WD), weekend days and public holidays (WE)) in each month (12 levels; March, April,…February).

$$\bar{R}_j = \frac{\sum \bar{R}_{kj}}{n_j}$$ Equation 10

7.3.6 Catch

The estimated catch was then calculated for each day type stratum (2 levels; weekdays (WD), weekend days and public holidays (WE)) in each month (12 levels; March, April,…February).

$$\hat{C}_j = \hat{E}_j \, \bar{R}_j$$ Equation 11

7.4 Calculate annual totals from stratum totals

7.4.1 Effort

This was done by adding the fishing effort estimates of the day type strata together to obtain monthly totals, then by adding monthly totals to obtain annual totals.

$$\hat{E}_{Tot} = \sum_{j=1}^{J} \hat{E}_{\mathrm{j}}$$ Equation 12

where $\hat{E}_{Tot}$ is total fishing effort (in boat trips) calculated by combining the estimates of each stratum. The term $\hat{E}_{Tot}$ refers to monthly effort totals when adding day type strata, and to the annual effort total when monthly totals are combined.

$$\hat{E}_{Totnew} = \sum_{j=1}^{J} \hat{E}_{jnew}$$ Equation 13

where $\hat{E}_{Totnew}$ is total fishing effort (in party-hours) calculated by combining the estimates of each stratum. The term $\hat{E}_{Totnew}$ refers to monthly effort totals when adding day type strata, and to the annual effort total when monthly totals are combined.

7.4.2 Catch

This was done by adding the catch estimates of the day type strata together to obtain monthly totals, then by adding monthly totals to obtain annual totals.

$$\hat{C}_{Tot} = \sum_{j=1}^{J} \hat{C}_{\mathrm{j}}$$ Equation 14

where $\hat{C}_{Tot}$ is the total catch calculated by combined the estimates of each stratum. The term $\hat{C}_{Tot}$ refers to monthly effort totals when adding day type strata, and to the annual catch total when monthly totals are combined.

7.4.3 Catch by weight for Pink Snapper

This was done using the expanded estimate of the annual kept catch in numbers and the average weight ($\overline{w}$) based on the length data collected during onsite surveys and the length-weight conversion provided by Smallwood *et al*. (2017). Because of the small sample size for the average weight in most strata, the conversion was applied to the annual catch total.

$$\widehat{W}_{Tot} = \hat{C}_{Tot}\,\overline{w}$$ Equation 15

7.5 Calculate the precision of the estimates

7.5.1 Powerboat retrievals

The finite population correction factor was applied to the variance and standard error of the estimated number of powerboat retrievals because >20% full PSU coverage was achieved for each stratum (refer to Steffe *et al.*, 2017).

$$Var(\bar{P}_j) = \frac{s_j^2}{n_j}$$ Equation 16

$Var\left(\bar{P}_j\right)$ is the estimated variance of the mean daily number of powerboat retrievals for the jth day type stratum within a month.

$$SE\ (\bar{P}_j) = \sqrt{var\left(\bar{P}_j\right)}$$ Equation 17

where:

$SE\ (\bar{P}_j)$ is the estimated standard error of the mean daily number of powerboat retrievals

$$Var(\hat{P}_j) = [N_j^2\ Var\ (\bar{P}_j)]\ (1 - f)$$ Equation 18

$$(1 - f)\ = \frac{(N - n)}{N}$$

where:

$Var(\hat{P}_j)$ is the estimated variance of the total number of powerboat retrievals for a stratum, calculated separately for each day type within each month.

Equation 19
$$SE\left(\hat{P}_{\mathrm{j}}\right)\ = \sqrt{var\ (\hat{P}_j)}$$

where:

$SE\left(\hat{P}_j\right)$ is the estimated standard error of the total number of powerboat retrievals for a stratum.

$$Var(\hat{P}_{Tot}) = \sum_{j=1}^{J} var\,(\hat{P}_j) \qquad \text{Equation 20}$$

where $Var(\hat{P}_{Tot})$ is the estimated total variance calculated by combining the estimated variances for each stratum. The term $Var(\hat{P}_{Tot})$ refers to monthly variance totals when adding variances from day type strata, and to the annual variance when seasonal variances are combined.

$$SE(\hat{P}_{Tot}) = \sqrt{var\,(\hat{P}_{Tot})} \qquad \text{Equation 21}$$

7.5.2 Mean trip duration

$$Var(\overline{Trip_j}) = \frac{s_j^2}{n_j} \qquad \text{Equation 22}$$

$Var\left(\overline{Trip_j}\right)$ is the estimated variance of the mean daily trip length for the jth day type stratum within a month.

$$SE\,(\overline{Trip_j}) = \sqrt{var\left(\overline{Trip_j}\right)} \qquad \text{Equation 23}$$

7.5.3 Effort (boat days)

The variance of recreational fishing effort, $Var(\hat{E})$, was derived from the variance of a product (Goodman, 1960) based on the expanded estimate of the number of powerboat retrievals for a stratum $(\hat{P}_j)$ and the mean proportion of boats used for recreational fishing $(\overline{Prop}_j)$.

$$Var(\hat{E}) = \left[\hat{P}_j^{\,2}\, Var\,(\overline{Prop_j})\right] + \left[\overline{Prop_j}^{\,2}\, Var\,(\hat{P}_j)\right] - \left[Var(\hat{P}_j) Var\,(\overline{Prop_j})\right] \qquad \text{Equation 24}$$

where $Var\left(\overline{Prop_j}\right)$ was estimated from:

$$Var(\overline{Prop_j}) = \overline{Prop_j}\left(\frac{1-\overline{Prop_j}}{n_j}\right) \qquad \text{Equation 25}$$

7.5.4 Effort (party-hours)

This was also done using the variance of a product (Goodman, 1960).

$$Var(\hat{E}_{new}) = \left[\hat{E}_j^{\,2}\, Var\left(\overline{Trip}_j\right)\right] + \left[\overline{Trip}_j^{\,2}\, Var\left(\hat{E}_j\right)\right] - \left[Var(\hat{E}_j) Var\left(\overline{Trip}_j\right)\right]$$ Equation 26

7.5.5 Catch (numbers)

The variance of the catch (numbers of fish; $Var(\hat{C})$) was derived from the variance of a product (Goodman, 1960) based on the expanded estimate of fishing effort and the catch rate.

$$Var(\hat{C}) = \left[\hat{E}^2\, Var\left(\bar{R}_j\right)\right] + \left[\bar{R}_j^{\,2}\, Var\left(\hat{E}^2\right)\right] - \left[Var(\hat{E}^2) Var\left(\bar{R}_j\right)\right]$$ Equation 27

7.5.6 Catch (by weight)

This was done using the variance of a product (Goodman, 1960).

$$Var(\widehat{W}) = \left[\hat{C}^2\, Var\left(\bar{w}\right)\right] + \left[\bar{w}^2\, Var\left(\hat{C}\right)\right] - \left[Var(\bar{w}) Var\left(\hat{C}\right)\right]$$ Equation 28

Appendix 8 Camera outages at Denham between March 2016 and February 2017.

White cells indicate no or minor outages (proportion missing < 0.5 in each 2-hr period), grey cells indicate major outages (proportion missing ≥ 0.5 in each 2-hr period)

	Date																														
Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
M																															
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Appendix 9 Camera outages at Monkey Mia between March 2016 and February 2017.

White cells indicate no or minor outages (proportion missing < 0.5 in each 2-hr period), grey cells indicate major outages (proportion missing ≥ 0.5 in each 2-hr period)

	Date																														
Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
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Appendix 10 Camera outages at Nanga between March 2016 and February 2017.

White cells indicate no or minor outages (proportion missing < 0.5 in each 2-hr period), grey cells indicate major outages (proportion missing ≥ 0.5 in each 2-hr period)

	Date																														
Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
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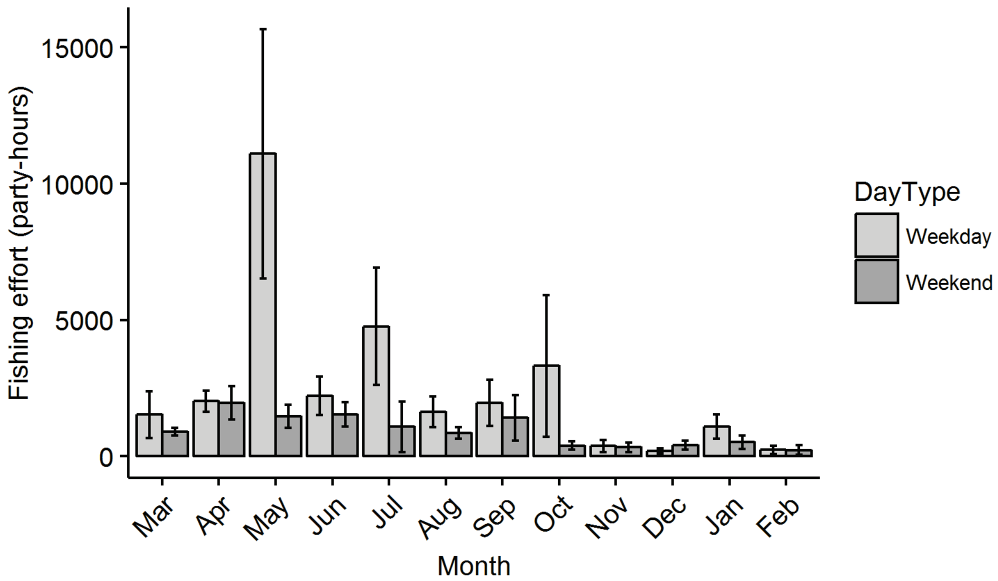
Appendix 11 Recreational fishing effort (party-hours) at Denham, Monkey Mia and Nanga by month and day type between March 2016 and February 2017.

Estimates are inclusive of boat parties retrieving between 10:00 and 18:00. Error bars represent the standard error of the mean



Appendix 12 Indicative budget for the survey (in AUD $)

Funding provided by the Recreational Fishing Initiatives Fund

	Planning	Data collection	Data entry	Analysis
Equipment	-	-	-	-
Cameras	-	-	-	-
Misc	-	-	-	-
Fieldwork	-	-	-	-
Staff	-	74,895	-	-
Additional staff costs	-	-	-	-
Lead scientist	-	-	-	-
Data entry (catch and effort)	-	-	-	-
Data entry (camera reading)	-	-	-	-
Technical support	-	-	-	-
Total ($)	**0**	**74,895**	**0**	**0**

In-kind contribution from DPIRD

	Planning	Data collection	Data entry	Analysis
Equipment	-	-	-	-
Cameras	15,000	-	-	-
Misc	500	-	-	-
Fieldwork	-	-	-	-
Staff	-	3,000	-	-
Additional staff costs	-	-	-	-
Lead scientist	6,600	-	-	15,500
Data entry (catch and effort)	-	-	500	-
Data entry (camera reading)	-	-	18,000	-
Technical support	-	3,000	-	-
Total ($)	**22,100**	**6,000**	**18,500**	**15,500**