Survey of marine boat-based recreational fishing in south-eastern Queensland (2007–08)

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Queensland Government

Acknowledgements

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A special thank you must be extended to the recreational fishers and stakeholders who patiently allowed our field staff to interview them and measure their catches during the year. Without their commitment to the good management of Queensland’s fisheries resources, this survey would not have been possible. Dave Bateman representing Sunfish on the RFISH coordinating committee deserves special mention as he encouraged support for these regional-scale surveys.

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Executive summary

This report presents the first fine-scale regional data on marine boat-based recreational fishing activities in south-eastern Queensland. The survey will provide managers, policy makers, industry and researchers with information about marine boat-based recreational fishing effort, catches, releases and harvests in south-eastern Queensland. Principally, it will be used to enhance the design of future on-site surveys throughout Queensland. It underestimates total recreational fishing activity in the region because it surveyed a subset of recreational fishers (i.e. those returning to public boat ramps between the hours of 7 am and 6 pm). It did not survey shore-based fishers, people fishing at night, or boats returning to private access points such as marinas and private jetties.

The survey was designed to provide information about recreational fishing activities over a fine spatial scale (10s of km). Boat ramps were allocated to one of 14 survey routes within south-eastern Queensland, from Currumbin Creek in the south to Noosa River in the north. Ramps within these routes were surveyed between October 2007 and November 2008. A total of 6533 ramp surveys were completed; 7657 boats crews were interviewed, of which 4559 (60%) were fishing, and 3933 fish were measured. Data were analysed using two methods:

(1) the 'established' bus route access point method

(2) a conditional two-part generalised linear model (GLM). This was done to investigate which method provides the most precise estimates.

The estimates of annual fishing effort were similar with both methods: 1,230,456 boat hours with a relative standard error (RSE) of 0.042 for the established method and 1,227,303 (0.036) for the two-part GLM. The two-part GLM, however, provided 76–81% better precision when estimating the annual harvest of individual species of fish (e.g. yellowfin bream: established method estimated harvest at 107,631 fish with RSE of 0.156, while the two-part GLM estimated harvest at 115,974 fish with RSE of 0.030).

As sample size decreased, the two-part GLM provided more precise estimates than the established method. Of the 3933 fish measured there were few kingfish, mackerel, mulloway, rockcods or sharks. The precision of annual harvest estimates for these species was unacceptably high. This method is inefficient at collecting recreational fishing data for these less commonly caught species. The most abundantly harvested inshore species was the trumpeter whiting (annual estimate 300,379 fish), while the most abundantly harvested rocky reef species was snapper (annual estimate 37,299 fish).

Few undersized fish were measured at ramps and the most popular reason for release was because the fish were undersized. Release rates varied among the species caught (e.g. 22% for trumpeter whiting and 77% for snapper).

Fishing effort and the species composition of the harvest varied both among and within routes and appeared related to the accessibility to fish habitat types. The ramps of Route 04 registered the greatest fishing effort. These ramps provide access to the calm and relatively pristine environments of southern Moreton Bay. Information on spatial variation of effort and catch will be used to design future surveys and enhance survey efficiency.

This survey relied on fishery-dependant harvest per unit effort to estimate annual harvest. To be comparable with future surveys it is essential to understand how this harvest efficiency changes over time. Boat-based recreational fishers today use different technology and gear than 10 years ago and this has likely improved harvest efficiency.

Over time the demographics and attitudes of recreational fishers can change and this is especially the case in the growing region of south-eastern Queensland. These technological and social changes may affect many things including harvest efficiency, the species targeted and the proportion of shore-based to boat-based fishers. Therefore, these temporal changes need to be quantified in order to interpret comparisons of fishery-dependent data over time accurately.

This pilot study has highlighted the complexity and diversity of marine boat-based recreational fishing in south-eastern Queensland. It has provided valuable information and will assist in the sustainable management of the Rocky Reef Fishery and the East Coast Inshore Finfish Fishery.

Introduction

Recreational fishing: monitoring and management

Recreational fishing is a popular activity in Queensland with approximately 20% of the resident population going fishing at least once a year (McInnes 2006). This recreational fishing activity has developed substantial social and economic value within the state. Many businesses, from tackle stores to camping grounds, benefit from the activities and spending habits of recreational fishers and their families.

The development of sustainable and profitable primary industries is a core goal of Queensland Primary Industries and Fisheries (QPIF), part of the Department of Employment, Economic Development and Innovation (DEEDI). A recreational fishing resource that is well managed and sustainable gives stakeholders the confidence to invest for the future, provides jobs and enhances the social benefits for Queenslanders and its visitors.

South-eastern Queensland has a rapidly growing population, predicted to grow from 2.8 million people to 4.4 million people by 2031 (Queensland Department of Infrastructure and Planning 2009). This human population growth has the potential to affect the benefits that recreational fishing brings in positive and negative ways. For example, a larger population of fishers may increase sales for businesses related to recreational fishing, or increase fishing pressure (potentially depleting fish stocks and lowering the participation rate).

These potential positive and negative pressures require proactive management of the fishery. The recreational fishery for many of Queensland's species forms a considerable proportion of overall harvest, making accurate and timely recreational catch estimates a prerequisite for pro-active management.

Past monitoring activity and the need for this access site survey

QPIF has one of the largest recreational datasets in Australia. Four statewide recreational fishing surveys (RFISH) have been completed since 1997 (McInnes 2008) and in 2000–01 QPIF participated in the National Recreational and Indigenous Fishing Survey (NRIFS).

These surveys have provided valuable data on the participation rate in recreational fishing as well as its catch and release, which have fed directly into the development of management arrangements. While these surveys provided useful statewide estimates, the spatial resolutions of catch data were broad and, in the case of RFISH, restricted to the statistical areas of the anglers' residences.

The development of the access point survey presented here was in direct response to the need for more detailed estimates of localised recreational fishing activity (10s of km) for use in management decisions, fisheries stock assessments and addressing the recommendations of the Department of the Environment, Water, Heritage and the Arts to allow continued operation of fisheries in Commonwealth waters. The survey was also designed to improve our understanding of the recreational catch in the Rocky Reef Fishery (e.g. snapper, pearl perch) and the East Coast Inshore Finfish Fishery (e.g. bream, whiting, flathead).

The results of this pilot survey will be used to design and implement future recreational surveys, thereby continually improving QPIF's estimates of recreational fishing activity. Precise and accurate estimates of recreational fishing activities, combined with appropriate management actions, will ensure that recreational fishing continues to be a socially and economically rewarding industry in Queensland.

Access point surveys

Access point surveys involve interviewing fishers or obtaining fishing data at the access points to the fishery: for example, boat ramps or entrances to beaches (Pollock et al. 1994).

A key advantage of this approach is that the burden of data collection rests with the trained interviewer and not with the interviewee. This can lead to more accurate species identification than can be derived from a self-administered survey tool such as a recreational fishing diary (Pollock et al. 1994). Interviewing fishers at the end of their fishing trip also reduces the potential of 'recall bias', whereby fishers remember incorrectly the details of their fishing trips (Pollock et al. 1994).

Access point surveys have been used in Western Australia (Sumner et al. 2008), South Australia (Kinloch et al. 1997) and New South Wales (Murray-Jones & Steffe 2000; Steffe et al. 2008) to provide estimates of recreational fishing effort and harvest. They have also been used to assess the scale of fisheries and to evaluate the effectiveness of management programs (Steffe et al. 2008).

The access point survey presented in this report incorporated a ‘bus route’ design (Robson & Jones 1989). In this design the survey route is analogous to a bus route, with stops at designated boat ramps. The researcher visits each boat ramp along a route for a set period of time. At each ramp, researchers count trailers and interview fishers; this allows them to calculate recreational fishing effort and catch. The bus route survey design is considered to be an effective way of sampling multiple access points spread over a broad geographic area (Robson & Jones 1989).

The survey was completed in the south-eastern region of Queensland from September 2007 to November 2008. It was a pilot study and cannot quantify total effort or total harvest from the recreational fishery in south-eastern Queensland because of the following reasons:

- Freshwater fishing activities were not sampled.
- The survey only sampled public boat ramps. In south-eastern Queensland, fishers can access the fishery at many places where surveys cannot be undertaken (e.g. private boat ramps and marinas). Activity commencing from private access points was not sampled or estimated.
- Not all public boat ramps in south-eastern Queensland were sampled.
- The survey did not sample shore-based fishing.
- Night time fishing activity was not sampled. Boat ramps were sampled during daylight hours (7 am to 6 pm); therefore, the activity of fishers returning to ramps outside this period is omitted.

It is likely that these omitted fishing activities are substantial (Steffe 2009). Therefore, the values for harvest and effort presented here are undoubtedly less than the total harvest and effort by south-eastern Queensland’s recreational fishing community.

Despite not being able to estimate total recreational fishery activity, this survey will provide useful information on the harvest and effort of south-eastern Queensland’s marine boat-based recreational fishery. This includes the spatial and temporal variance of species caught among ramps, routes, seasons, and type of day (weekend or weekday). This information is valuable for the development of future surveys with larger temporal and spatial scales.

Methods

Survey design

The survey was based on the access point bus route method described in Pollock (1994) and was conducted from 25 September 2007 to 2 November 2008. The adaption of the survey design to the south-eastern Queensland region and staff training were conducted by Mr Len Olyott and Ms Kara Dew.

Research staff collected data from fishery access points (boat ramps) by moving from one ramp to the next along predetermined routes (called bus routes). The bus route method was chosen because the survey covered a broad geographic area with many access points (Jones & Robson 1991). The time interval count method was used to estimate effort based on trailers observed at boat ramps because it was expected that few interviews would be obtained from many of the quieter ramps and that the majority of trailers would be related to fishing activities. A flow diagram describing the logical steps used to estimate effort and catch is shown in Figure 1.

Queensland Transport's records of publicly accessible ramps and QPIF knowledge were used to identify 98 boat ramps used by anglers in south-eastern Queensland. Most boat-based recreational fishers using public ramps in south-eastern Queensland use one or more of these ramps. Ramps were allocated to one of 15 different routes (Appendix 1); however, after three months Route 07, which sampled ramps on Russell Island, was discontinued because it contributed few data. As such, Route 07 is not included in the analysis. Each route was sampled once in a day between approximately 7 am and 6 pm (11 hours).

The survey design was adapted from Pollock et al. (1994). Each ramp along a route was allocated a specific wait time (W) during which the interviewer counted the initial number of boat trailers present and recorded the time that boats were launched or retrieved. For retrieved boats, the interviewer recorded whether or not the boat had been fishing and if so asked if the fisher would like to participate in the survey. If the fisher complied, the following information was collected: species caught, number harvested, their length (fork length for fish, carapace width for crabs), number released and reason, target species, the number of people fishing, the launch time and catch location (see Appendix 2 for example data sheets).

Catch location was generally imprecise because recreational fishers are hesitant to reveal their favourite fishing locations. Catch locations were allocated to their respective regions as used by the QPIF Long Term Monitoring Program: for example, Sunshine Coast offshore, Brisbane offshore, Gold Coast offshore, Moreton Bay (e.g. Figure 4).

At the expiry of the wait time, the interviewer continued along the bus route to the next boat ramp and repeated the procedure. Wait time ranged from 6–90 minutes, with a longer wait time at busier ramps so that more interviews could be completed. The average wait time was 33 minutes, more than double the 15 minutes recommended by Robson and Jones (1989), potentially improving the resolution of our data. During the first month of sampling, shift time was six hours; however, due to fiscal constraints shift time was standardized at four hours for the remainder of the survey.

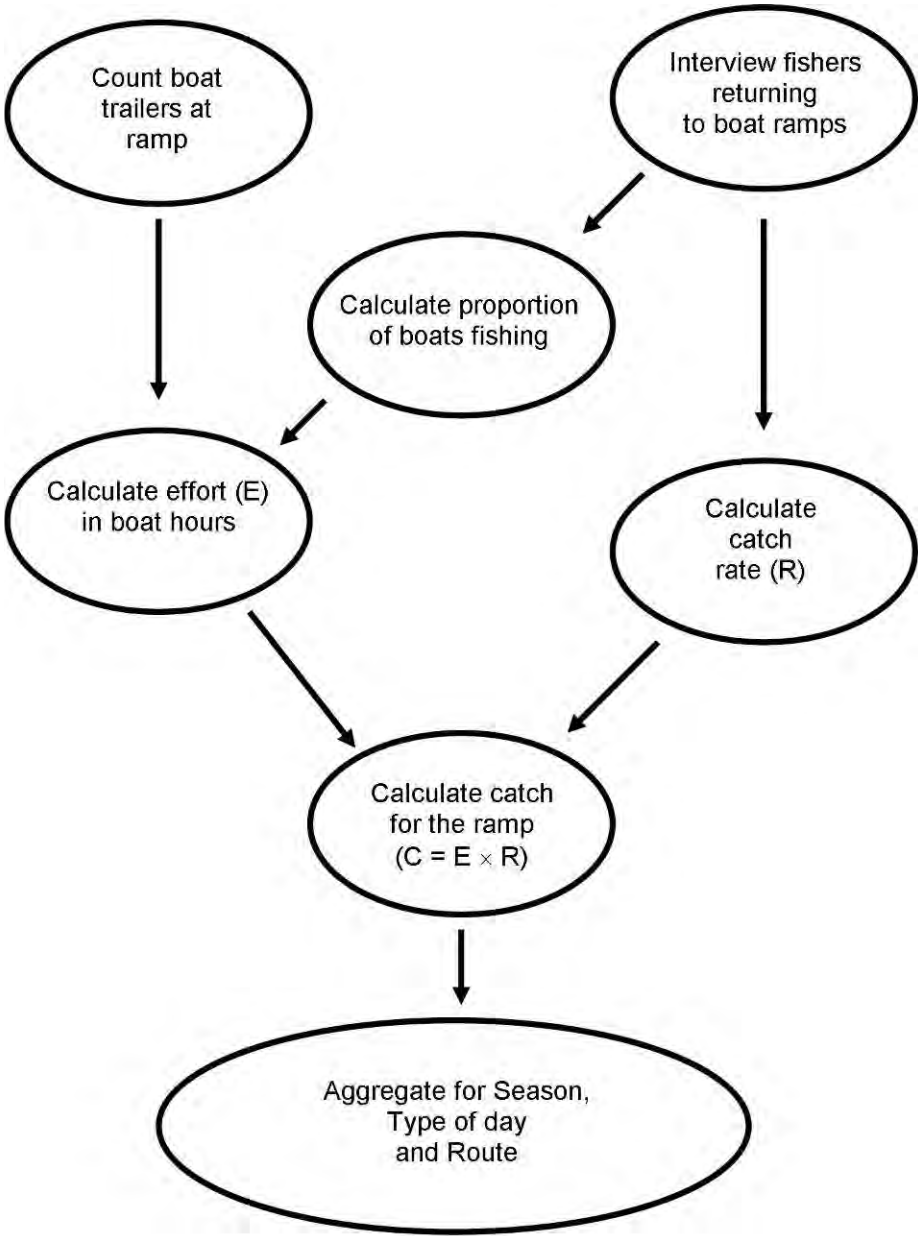


Figure 1: Flow diagram depicting the methodology used to estimate effort and catch from interviews and trailer counts at boat ramps. (Adapted from Pollock et al. 1994; Sumner et al. 2008). Catch can be replaced with harvest to calculate total harvest if needed.

To increase the probability that individual access points are sampled across a range of times during the fishing day, bus route surveys traditionally start at a randomly chosen location along the route, with all stops being completed until the researcher returns to the start location (Robson & Jones 1989).

Due to the essentially linear nature of these routes and resource constraints, this survey was unable to start anywhere other than at either end of a route. To reduce potential confounding effects of always sampling ramps in the same order, routes commenced at a variety of times and were traversed either forwards or backwards.

Staff training and data quality

Trained QPIF staff collected data at the ramps. All staff were trained and examined on data collection procedures, fish identification, and workplace health and safety. The Australian fish names standard (Seafood Services Australia Ltd 2007) was used for all common and scientific species names (see Appendix 3).

Staff wore a uniform that distinguished them from Queensland Boating and Fisheries Patrol officers and explained to fishers that they were collecting research data and were not enforcement officers.

To improve data quality, datasheets were reviewed by the project data coordinator before entry into a Microsoft Access database. The electronic records were validated against the paper datasheets by a different staff member using an exception reporting procedure.

Statistical analysis

Details of the statistical methods are presented in Appendix 4.

Results

Sample size

Routes were surveyed 1008 times with sampling effort concentrated on weekends and public holidays (64%) as this was when most fishing effort occurred (Table 1). Boat ramp visits commenced as early as 6.55 am and finished as late as 5.54 pm, with 50% of visits occurring after 9 am and before 2 pm (Figure 2).

A total of 6533 boat ramps visits were completed during the period and 7657 boats crews were interviewed. Of the boat crews interviewed, 4559 were fishing (Table 2) and 697 (15%) declined to participate.

During the survey 3933 fish were measured. Some species were more common than others and the species measured varied considerably among routes and ramps. More inshore species were measured than rocky reef species (Table 3).

Table 1: Number of surveys completed for each route by season and day type (WD = weekdays, WE = weekends and public holidays).

	Spring		Summer		Autumn		Winter		
Route	**WD**	**WE**	**WD**	**WE**	**WD**	**WE**	**WD**	**WE**	**Total**
Route 01	6	11	6	9	6	12	8	13	71
Route 02	6	12	6	12	7	11	5	15	74
Route 03	6	12	6	8	5	11	8	16	72
Route 04	6	11	6	12	6	11	6	14	72
Route 05	7	10	7	7	6	12	9	14	72
Route 06	5	10	5	9	7	10	9	16	71
Route 08	7	11	5	11	6	8	10	14	72
Route 09	5	12	6	10	5	12	10	14	74
Route 10	5	12	5	10	6	11	8	14	71
Route 11	6	12	6	12	5	11	11	15	78
Route 12	6	11	6	12	5	9	7	11	67
Route 13	7	10	5	12	5	15	7	12	73
Route 14	6	10	7	10	7	12	7	12	71
Route 15	6	12	7	11	5	12	7	10	70
Total	84	156	83	145	81	157	112	190	1008

Table 2: Number of fishing boats interviewed during the survey for each route by season and day type (WD = weekdays, WE = weekends and public holidays).

	Spring		Summer		Autumn		Winter		Total
	WD	WE	WD	WE	WD	WE	WD	WE	
Route 01	2	30	5	11	6	25	6	24	109
Route 02	10	50	9	27	14	28	10	57	205
Route 03	15	53	10	56	8	41	7	42	232
Route 04	39	137	31	116	37	92	21	98	571
Route 05	22	56	15	48	3	98	10	54	306
Route 06	25	128	24	88	13	42	11	65	396
Route 08	22	67	6	48	14	30	9	70	266
Route 09	37	103	3	67	8	100	18	58	394
Route 10	17	67	14	74	18	82	16	55	343
Route 11	51	114	9	47	8	48	9	41	327
Route 12	18	71	13	53	13	53	19	63	303
Route 13	22	78	17	63	16	134	25	51	406
Route 14	17	68	11	74	18	76	15	52	331
Route 15	17	52	11	65	13	107	28	77	370
Total	314	1074	178	837	189	956	204	807	4559

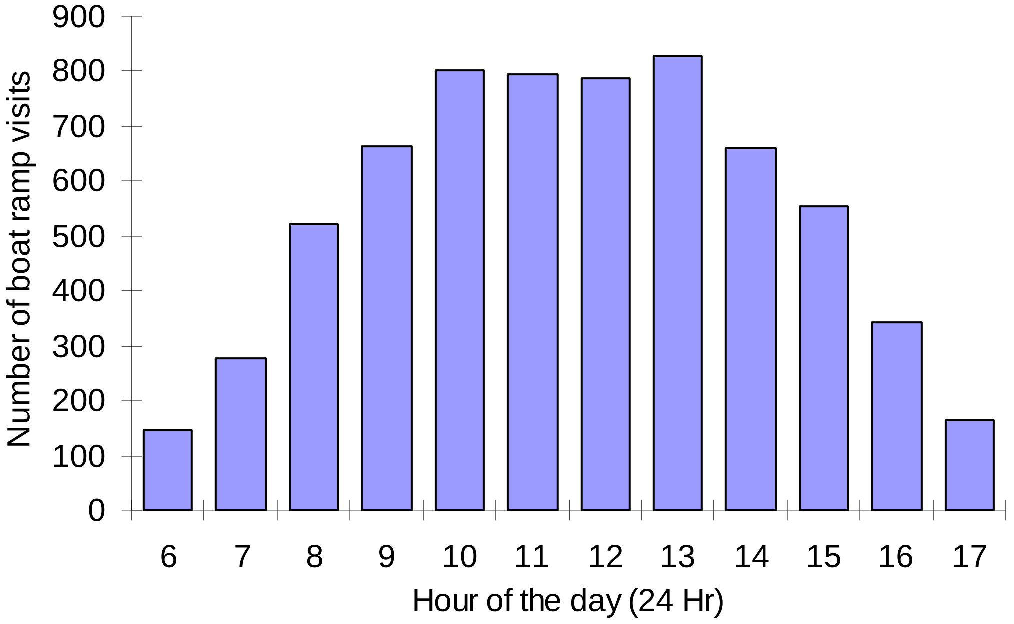


Figure 2: Frequency histogram showing the number of boat ramp visits at different hours of the day. The earliest visit was at 0655 and the latest was at 1754.

The species measured were dominated by a few common species. Yellowfin bream, sand whiting, dusky flathead, trumpeter whiting and blue swimmer crabs were the most abundant inshore species measured. Snapper, grass emperor, Venus tuskfish and pearl perch dominated the rocky reef species measured (Table 3). Few large pelagic species or rockcods were measured.

Table 3: Numbers of fish measured at ramps by season and day type (WD = weekdays; WE = weekends and public holidays).

	Spring		Summer		Autumn		Winter		Total
Species	**WD**	**WE**	**WD**	**WE**	**WD**	**WE**	**WD**	**WE**	
Inshore species									
Yellowfin bream	62	74	26	128	56	152	98	240	836
Sand whiting	48	146	39	140	48	113	34	76	644
Dusky flathead	35	86	4	28	22	54	18	64	311
Trumpeter whiting	47	20	32	7	8	22	34	86	256
Blue swimmer crab	70	70	7	55	19	19	5	5	250
Tailor	5	5	1	18	7	20	3	89	148
Mud crab	4	16	8	33	11	23	9	5	109
Northern sand flathead	0	11	3	9	3	3	1	23	53
Tarwhine	1	9	3	9	9	9	1	7	48
Silver javelin	0	9	2	11	1	4	0	2	29
Rocky Reef species									
Snapper	13	65	9	59	21	59	29	58	313
Grass emperor	7	14	3	38	5	21	12	14	114
Venus tuskfish	4	15	0	19	3	18	5	3	67
Pearl perch	0	7	0	8	8	13	6	19	61
Moses snapper	1	5	2	7	2	4	2	3	26
Goldspotted rockcod	0	3	2	3	1	2	1	3	15
Maori rockcod	0	5	0	1	1	3	1	3	14
Golden trevally	0	3	1	1	2	2	3	0	12
Spangled emperor	1	0	0	9	1	1	0	0	12
Thicklip trevally	4	1	0	5	0	2	0	0	12
Pelagic Species									
Cobia	0	5	0	3	1	6	2	1	18
Yellowtail kingfish	0	1	0	3	1	1	0	12	18
School mackerel	0	4	0	0	2	10	0	1	17
Spanish mackerel	0	1	1	2	2	2	4	0	12
Amberjack	1	1	0	0	5	0	3	2	12

Fishing effort

Fishing effort by season and day type

The established method estimated total fishing effort, with relative standard errors (RSE), for the year as 1,230,456 (0.042) boat hours and the two-part GLM estimated 1,227,303 (0.036) boat hours. More fishing effort occurred on weekends and public holidays than on weekdays in every season except spring. Fishing intensity was greater during weekends and public holidays.

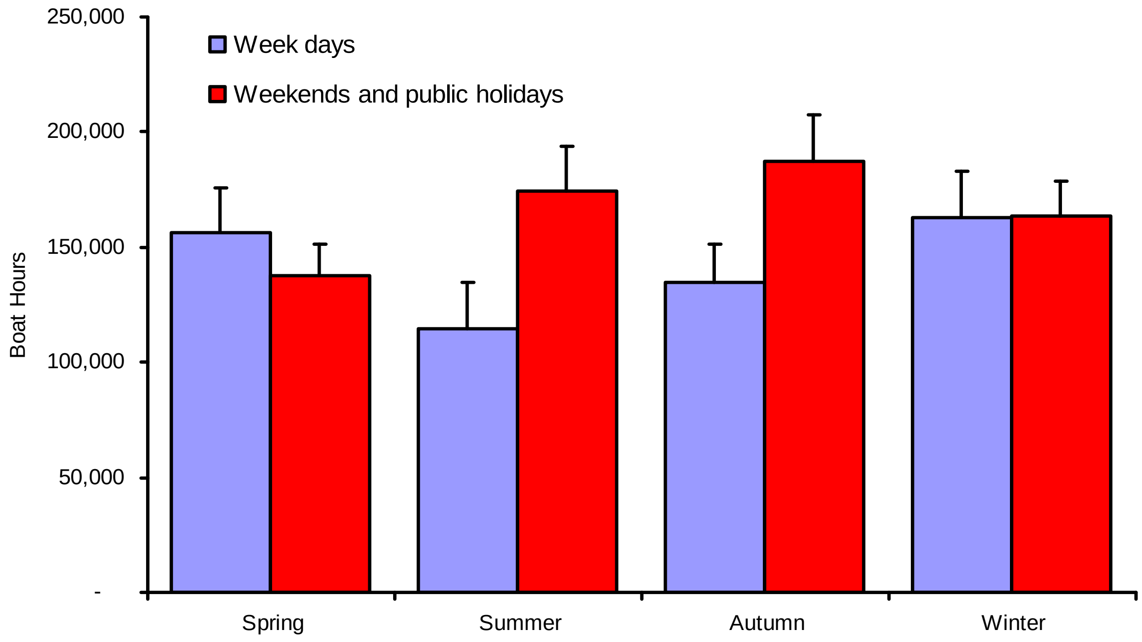


Figure 3: Estimated total fishing effort (SE) in boat hours on weekdays and weekends and public holidays stratified by seasons. Estimates were made by expanding relevant means and variances obtained from individual boat ramp survey data.

Fishers per boat by route

The average number of fishers (SD) per boat in this survey was 2.21 (0.995). This was similar to that reported by O’Neill (2000) who estimated 1.98 fishers per boat in the Burnett River, Maroochy River and Pumicestone Passage during the 14 months ending August 1998.

Effort in fisher hours

Effort varied among the routes, with most effort concentrated in routes closer to major population centres providing access to substantial bodies of calm water and fish habitat: for example, Route 04 (Figure 4). Effort also varied within the routes, with certain boat ramps being much busier than others (Figure 5).

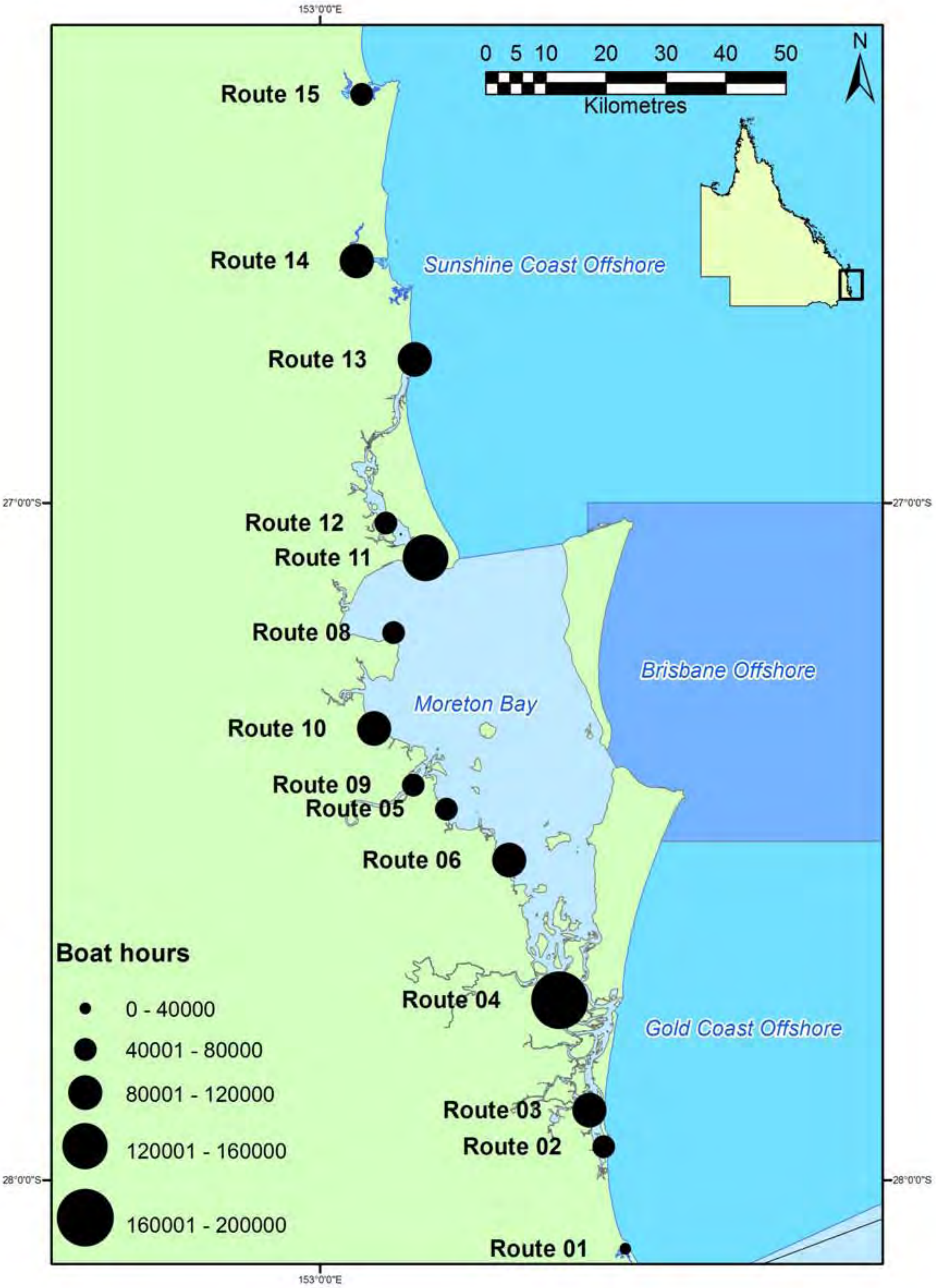


Figure 4: Fishing effort in boat hours for the year across all 14 routes. QPIF's Long Term Monitoring Program water body names are also shown. Inset map shows Queensland, Australia.

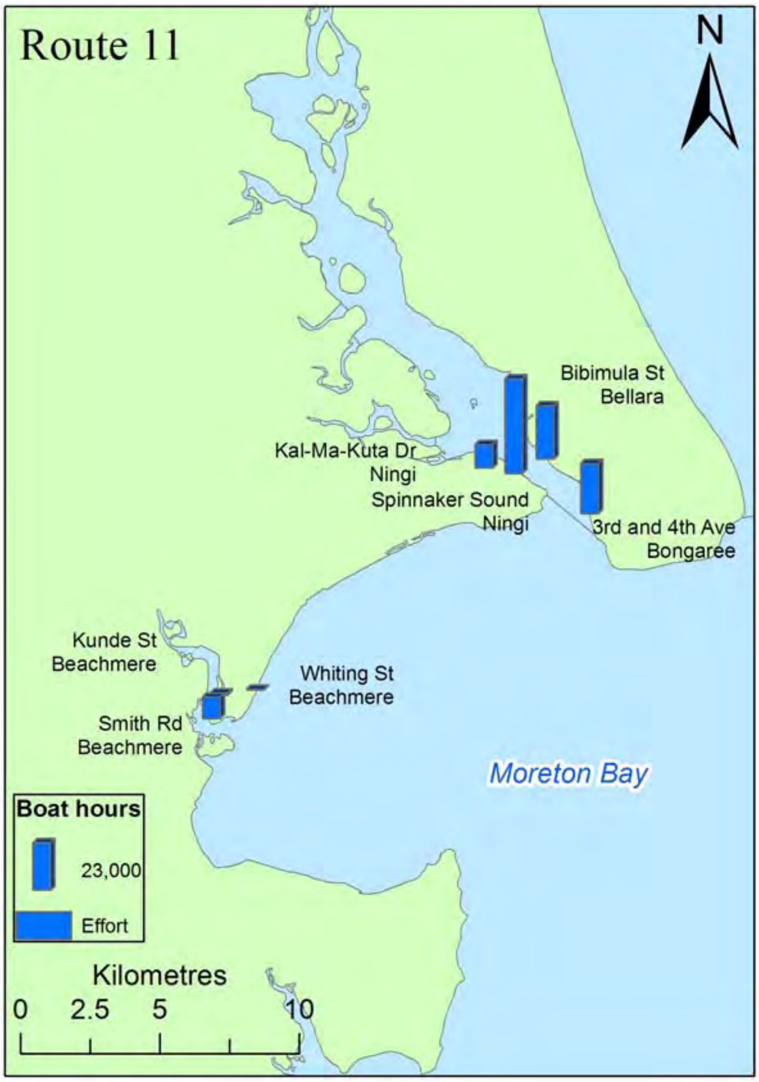


Figure 5: Fishing effort at the boat ramps within Route 11, which provide access to northern Moreton Bay and Pumicestone Passage.

Fish harvested and released

The estimates of the number of animals most commonly harvested and released from inshore and rocky reef habitats are presented in Table 4. Trumpeter whiting was the most abundantly harvested inshore species with snapper being the most abundantly harvested from rocky reefs. The RSE of the harvest estimates ranged from 0.156 for yellowfin bream to 0.774 for amberjack. Natural variability and the number of animals measured affect the RSE. Estimates with an RSE greater than 0.50 should be treated cautiously.

Table 4: Estimates and relative standard errors (RSE) of the number of animals harvested and released from boats launching at public ramps for the most abundant species caught. Estimates were made using the established access design expansion. * indicates RSE > 0.5 and estimates should be treated cautiously.

Common name	Number harvested (RSE)	Number released (RSE)	Percent of catch released
Inshore and estuarine			
Trumpeter whiting	300,379 (0.303)	84,839 (0.237)	22%
Yellowfin bream	107,631 (0.156)	288,833 (0.116)	73%
Blue swimmer crab	96,198 (0.285)	179,720 (0.313)	65%
Sand whiting	80,261 (0.172)	91,609 (0.194)	53%
Mud crab	30,181 (0.296)	111,614 (0.255)	79%
Dusky flathead	27,302 (0.169)	40,749 (0.164)	60%
Tailor	19,937 (0.411)	18,450 (0.385)	48%
Northern sand flathead	7207 (0.337)	6230 (0.319)	46%
Tarwhine	4388 (0.369)	9143 (0.362)	68%
Silver javelin	1691 (0.544)*	11,595 (0.399)	87%
Rocky reef			
Snapper	37,299 (0.249)	127,654 (0.171)	77%
Grass emperor	12,616 (0.458)	32,012 (0.244)	72%
Golden trevally	7077 (0.599)*	1501 (0.642)*	17%
Pearl perch	5284 (0.421)	11,622 (0.399)	69%
Venus tuskfish	4647 (0.334)	2779 (0.372)	37%
Moses snapper	2850 (0.359)	14,595 (0.316)	84%
Pelagic species			
Amberjack	2528 (0.774)*	819 (1.455)*	24%
Cobia	1543 (0.599)*	208 (0.634)*	12%
Yellowtail kingfish	1112 (0.755)*	2170 (0.871)*	66%

Number of fish and crustaceans harvested per boat

Most boat crews interviewed harvested no animals (55.4%) with 19.1% harvesting 1–2 animals. Groups catching more than 10 fish and crabs comprised 4.9% of groups interviewed (Figure 6).

The size range of harvested fish

Within a species, the harvest tended to be greatest in the size classes following the minimum legal size. Frequency histograms for the size classes of inshore species and rocky reef species are shown in Figure 7 and Figure 8, respectively.

In March 2009 the minimum legal size for some of these species was increased and the effect of this is shown with the yellow bars (e.g. Figure 8, ‘Yellowtail kingfish’). Several species had a number of undersized fish harvested as indicated by the red bars (e.g. Maori rockcod and yellowtail kingfish).

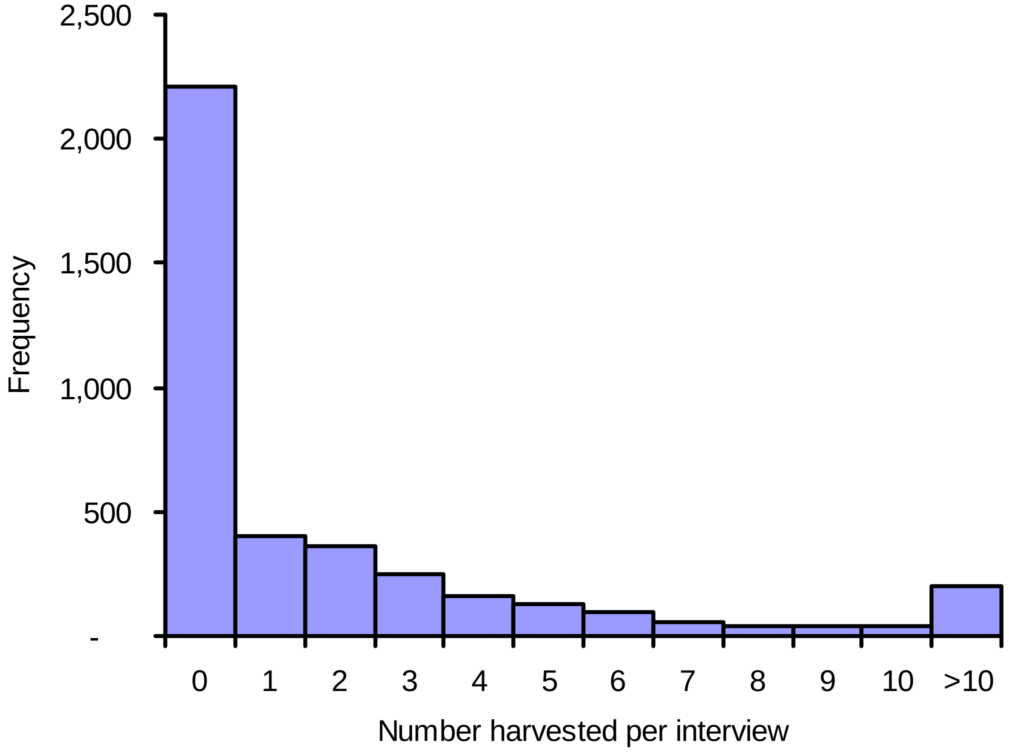
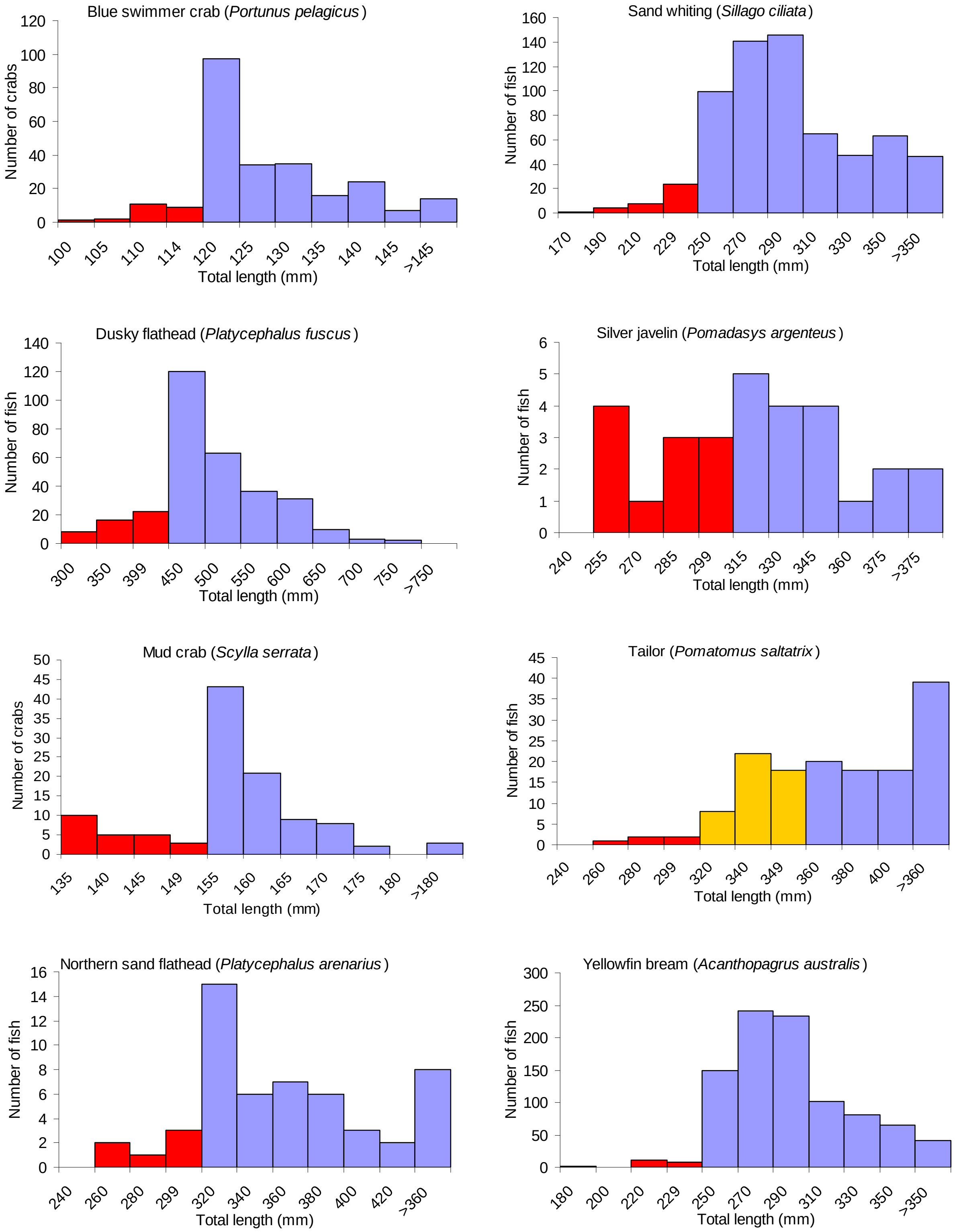


Figure 6: Frequency histogram showing the number of individual animals harvested per interview.


Blue swimmer crab (*Portunus pelagicus*)

Sand whiting (*Sillago ciliata*)

Dusky flathead (*Platycephalus fuscus*)

Silver javelin (*Pomadasys argenteus*)

Mud crab (*Scylla serrata*)

Tailor (*Pomatomus saltatrix*)

Northern sand flathead (*Platycephalus arenarius*)

Yellowfin bream (*Acanthopagrus australis*)

Figure 7: Frequency histograms for inshore species by total length for species where more than 29 fish were measured at interviews. Size classes are ‘less than or equal to’ the value shown unless otherwise indicated. Red bars = undersize based on regulations before 1 March 2009; blue bars = within legal size limits; yellow bars = within size prior to 1 March 2009 but outside size limits after 1 March 2009.

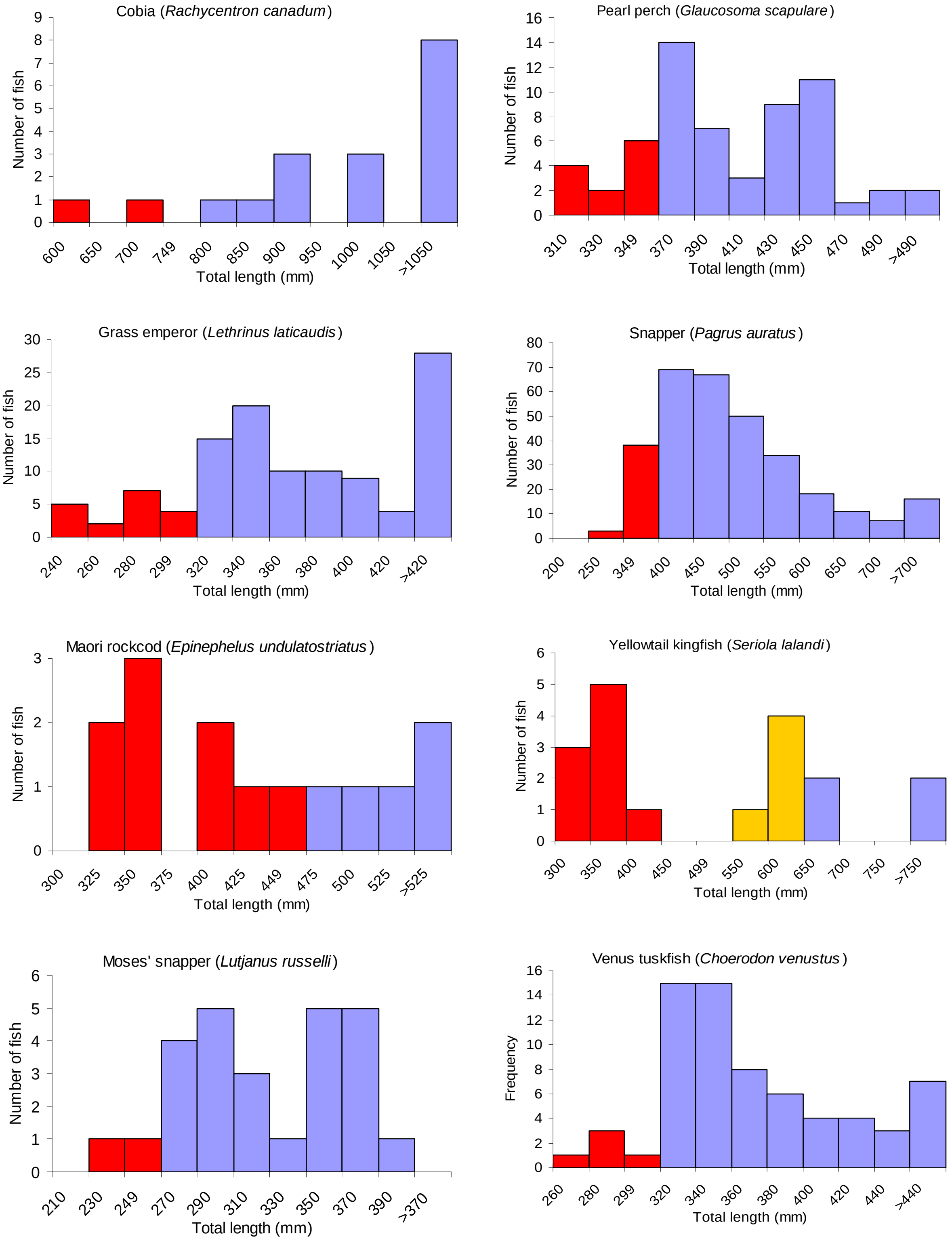


Figure 8: Frequency histograms for rocky reef species by total length for species where more than 14 fish were measured at interviews. Size classes are 'less than or equal to' the value shown unless otherwise indicated. Red bars = undersize based on regulations before 1 March 2009; blue bars = within legal size limits; yellow bars = within size prior to 1 March 2009 but outside size limits after 1 March 2009.

Variability in harvest

Within routes: fishers launching at ramps in close proximity can have different fishing characteristics

Different fish were harvested at different ramps within a route and this variability can occur over a small spatial scale. For example, when comparing the harvest of snapper and dusky flathead along Route 14, which covers the Maroochy and Mooloolah Rivers, snapper dominated at the mouth of the Mooloolah River but were not landed at ramps in the Maroochy River (Figure 9).

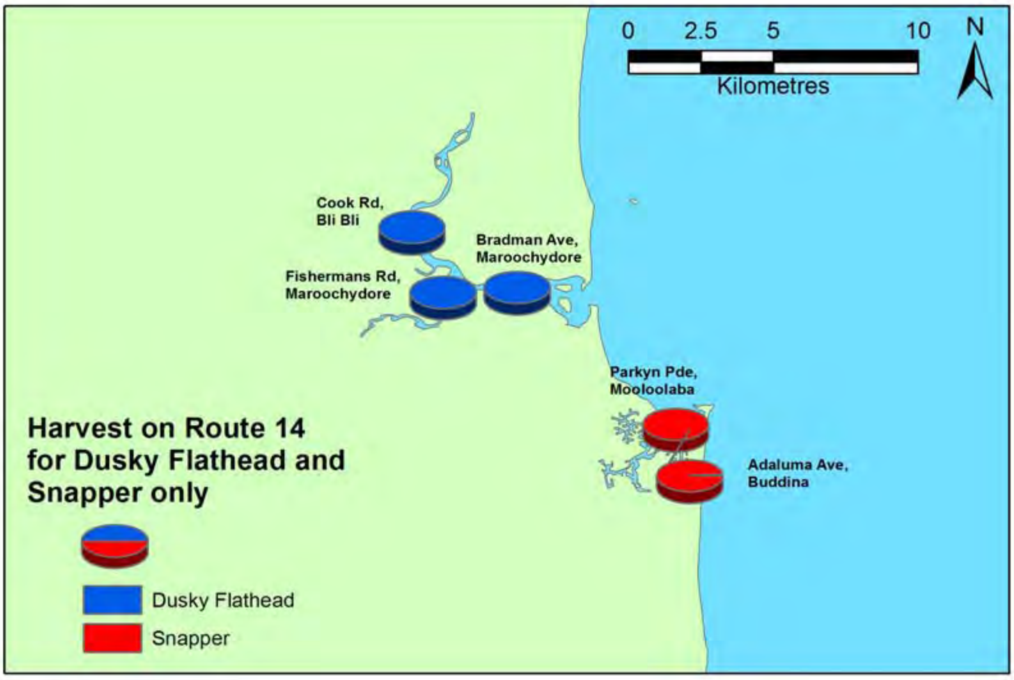


Figure 9: Dusky flathead and snapper harvests at five ramps along Route 14 in the Mooloolah and Maroochy Rivers.

Across routes: different species are harvested in different places

The composition of species harvested varied among the routes. Some species were harvested at all routes: for example, yellowfin bream and whiting species (Figure 10). Routes with better access to offshore reefs tended to catch a greater proportion of offshore species.

Fishers using Routes 06, 02 and 14 harvested the greatest number of snapper whereas dusky flathead were more numerous at Routes 04, 11 and 13 (Figure 11). The patterns were similar for these species when harvest numbers were converted to weights based on the average size for the species at the respective route (Figure 12). However, for dusky flathead more individuals were harvested at Route 02 than at Route 03 but the total weight of harvested dusky flathead was greater at Route 03 (Figure 11 and Figure 12).

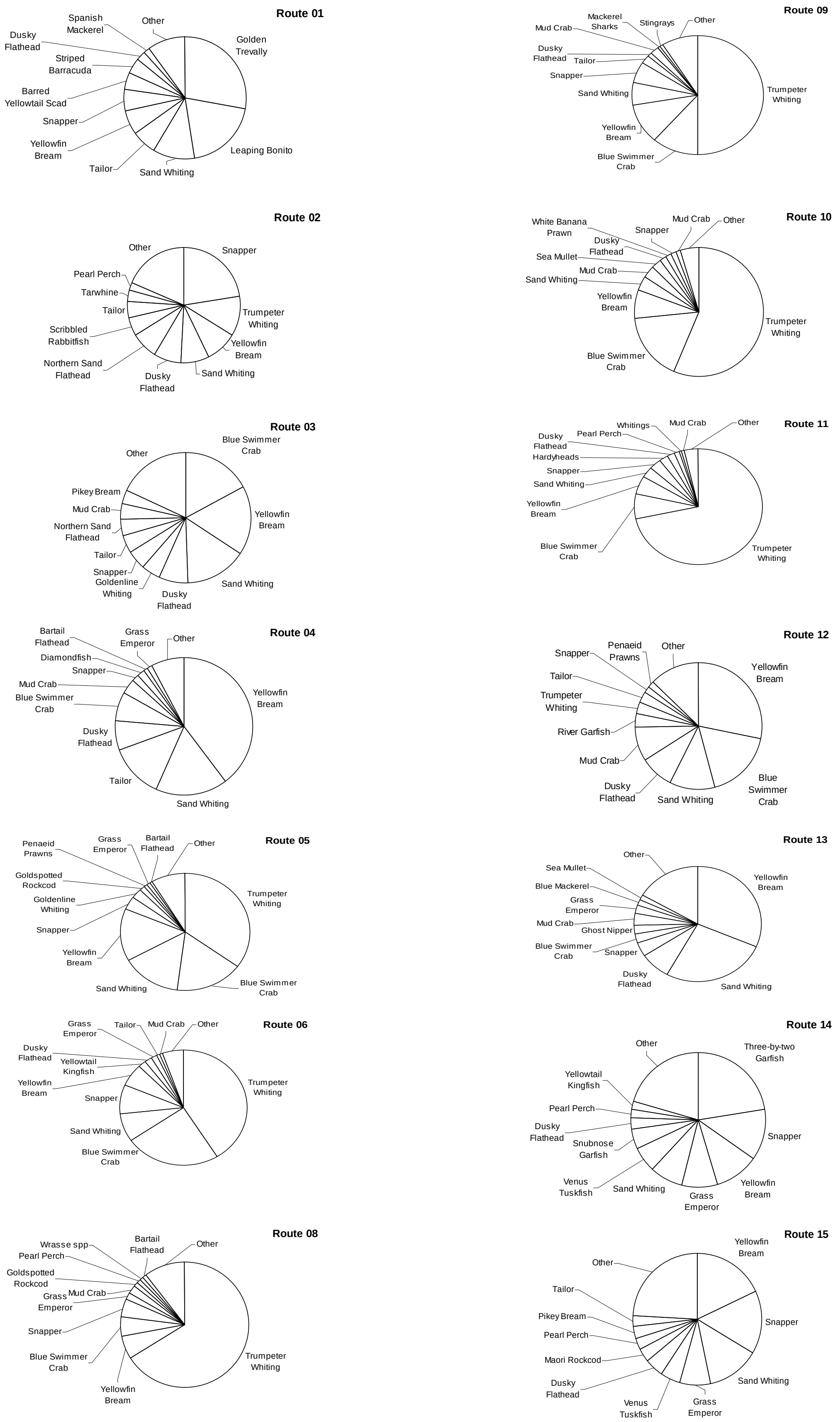


Figure 10: Ten most abundant species harvested for each route.

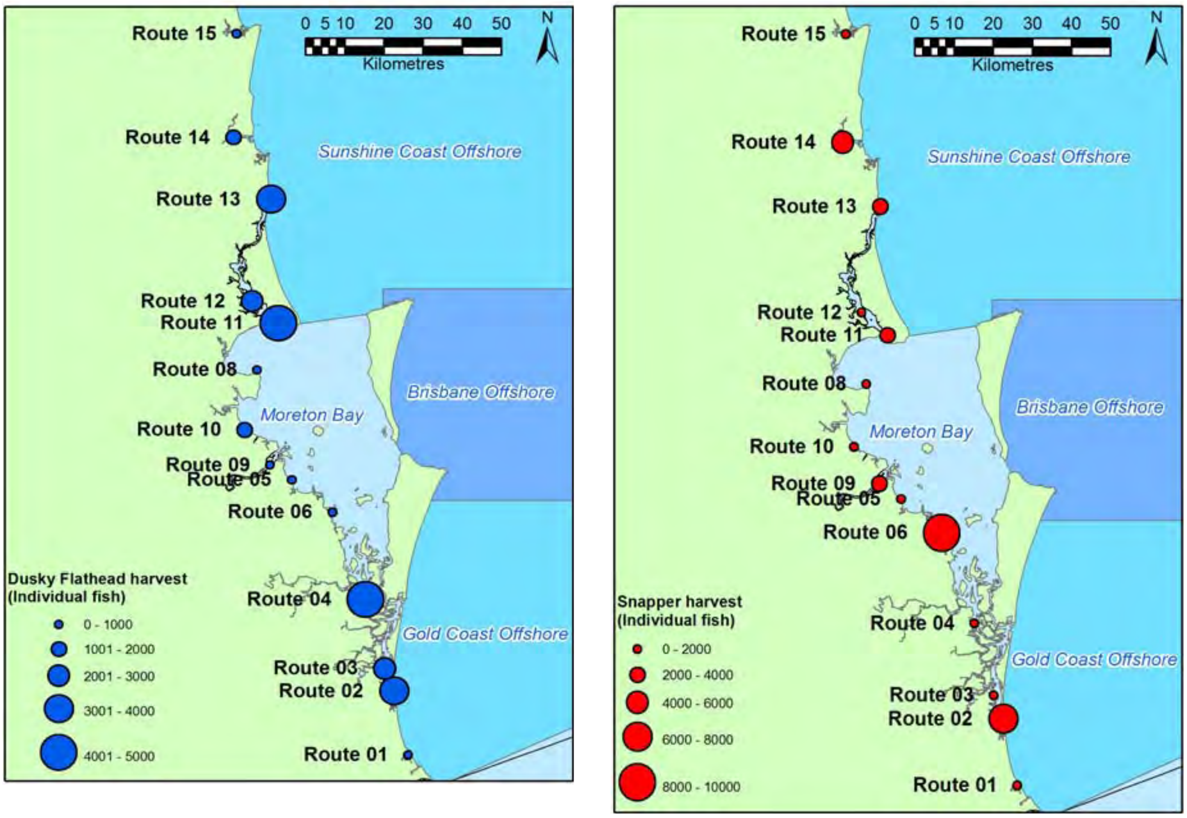


Figure 11: Estimated annual dusky flathead and snapper harvest across the 14 routes surveyed reported as number of fish.

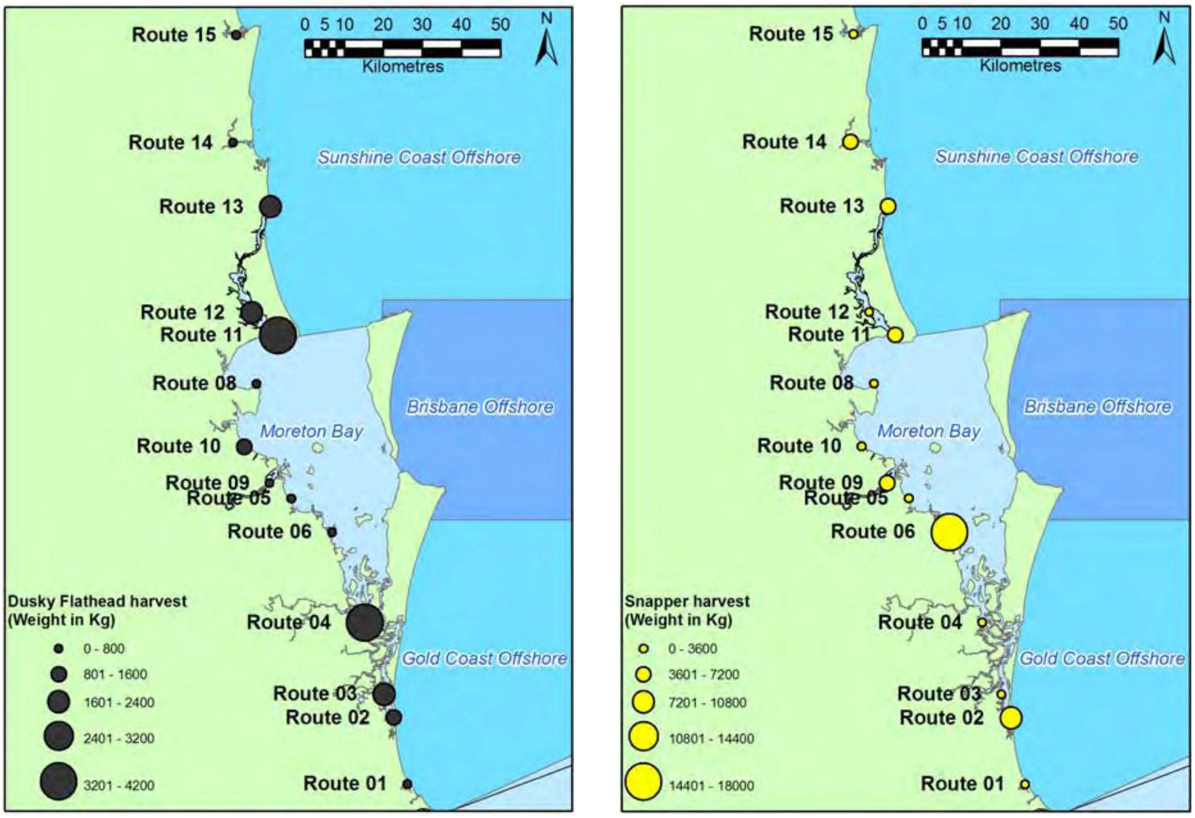


Figure 12: Estimated annual dusky flathead and snapper harvest across the 14 routes surveyed reported as weight (kg) of fish.

Variability in fish size by location and season

The size of yellowfin bream harvested did not vary greatly among routes. The size of snapper harvested was different among routes. Route 10 harvested the largest average size (SE) snapper, 557 (±65) mm (*n* = 9) and Route 03 the smallest average size (SE) 304 (±8) mm (*n* = 8). The average size of dusky flathead was also different among routes with Route 06 having the largest average size (SE) 502 (±19) mm (*n* = 18) and Route 01 having the smallest average size (SE) 404 (±12) mm (*n* = 6) (Figure 13).

In some routes few fish were measured; for example, only seven snapper were measured at Route 12 and only eight yellowfin bream in Route 01. Where few fish were measured the estimated average size for that route should be interpreted with caution.

The average size of yellowfin bream was similar across all seasons. Larger snapper were harvested in winter, whereas larger dusky flathead were harvested in summer (Figure 13).

Comparison of regional and annual estimates from the established and two-part GLM methods

The established method estimated total fishing effort (RSE) for the year as 1,230,456 (0.042) boat hours and the two-part GLM estimated 1,227,303 (0.036) boat hours. Estimates of harvest were similar; however, RSE estimated by the two-part GLM were 76–81% smaller, indicating a more precise estimate (Table 5).

Table 5: Mean harvest estimates (RSE) for three major inshore species and two rocky reef species using the established method and a two-part general linear model (binomial and gamma).

Species	Established method	Two-part GLM
Yellowfin bream	107,631 (0.156)	115,974 (0.030)
Sand whiting	80,261 (0.172)	76,366 (0.042)
Dusky flathead	27,302 (0.169)	31,938 (0.041)
Snapper	37,299 (0.249)	38,223 (0.052)
Grass emperor	12,616 (0.458)	9914 (0.095)

Reasons for release

Interviewed fishers released a total of 4911 fish during the period. The major reason for releasing fish from boat-based fishing was because they were undersized (Figure 14). A similar pattern was found for rocky reef fish (Figure 15) and inshore fish (Figure 16). For mud crabs, which are regulated by size and sex, being female was the dominant reason for release followed by undersize (Figure 16).

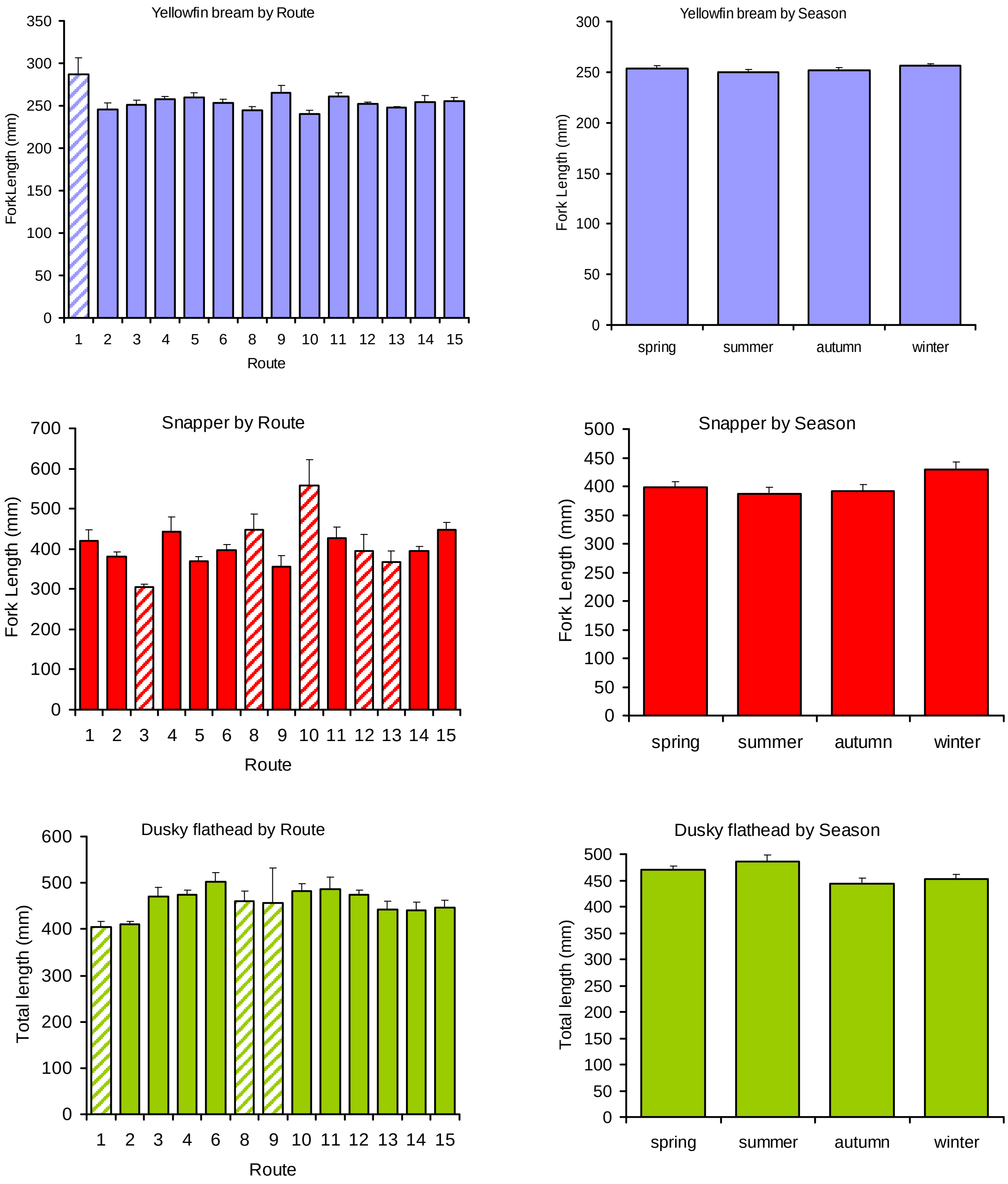


Figure 13: Mean (SE) size of fish measured at ramps by route and by season. Diagonal lines indicate that less than 10 fish were measured at the route.

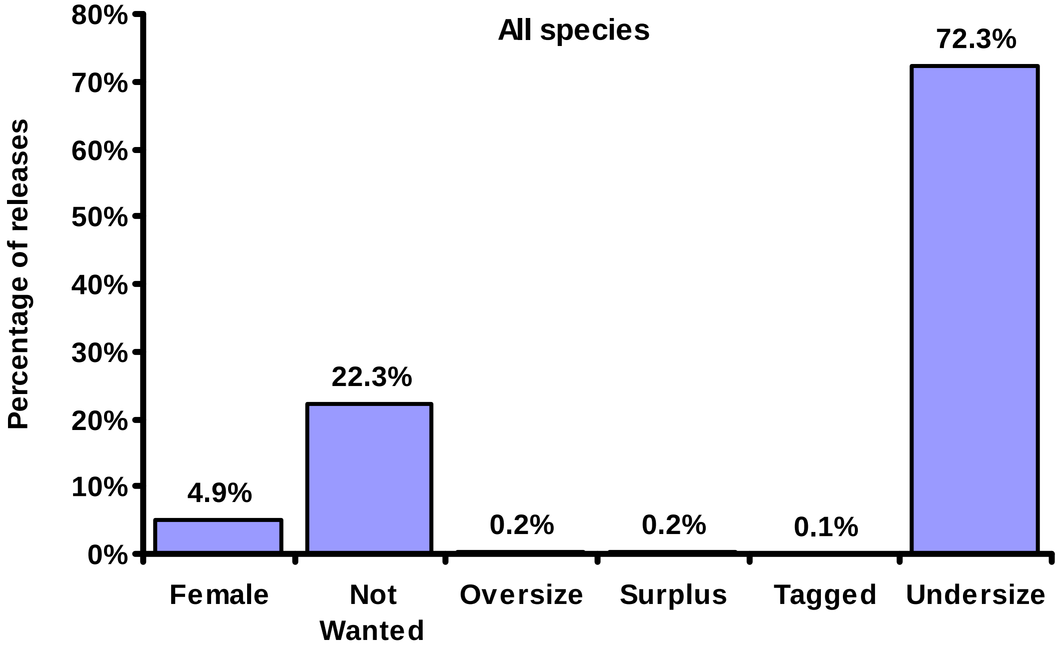


Figure 14: Reasons for release of fish and crustaceans caught by boat-based fishers in south-eastern Queensland. Interviewed fishers released 4911 fish and crustaceans.

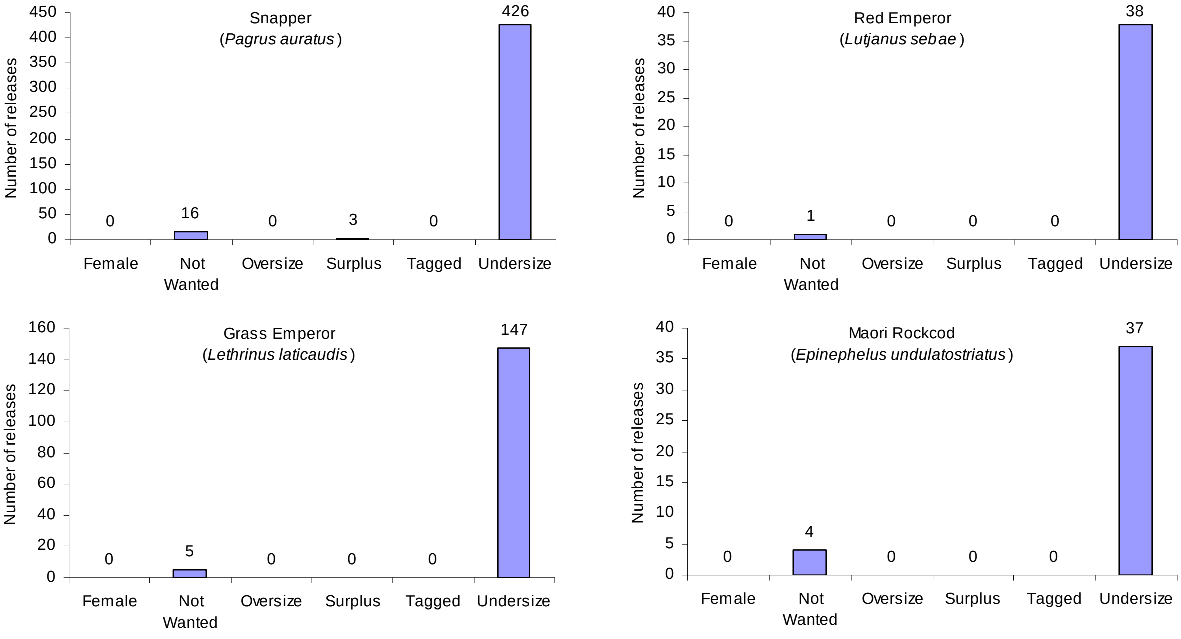


Figure 15: Reasons for release of four rocky reef species caught in south-eastern Queensland. Numbers above the bars are the number of animals released.

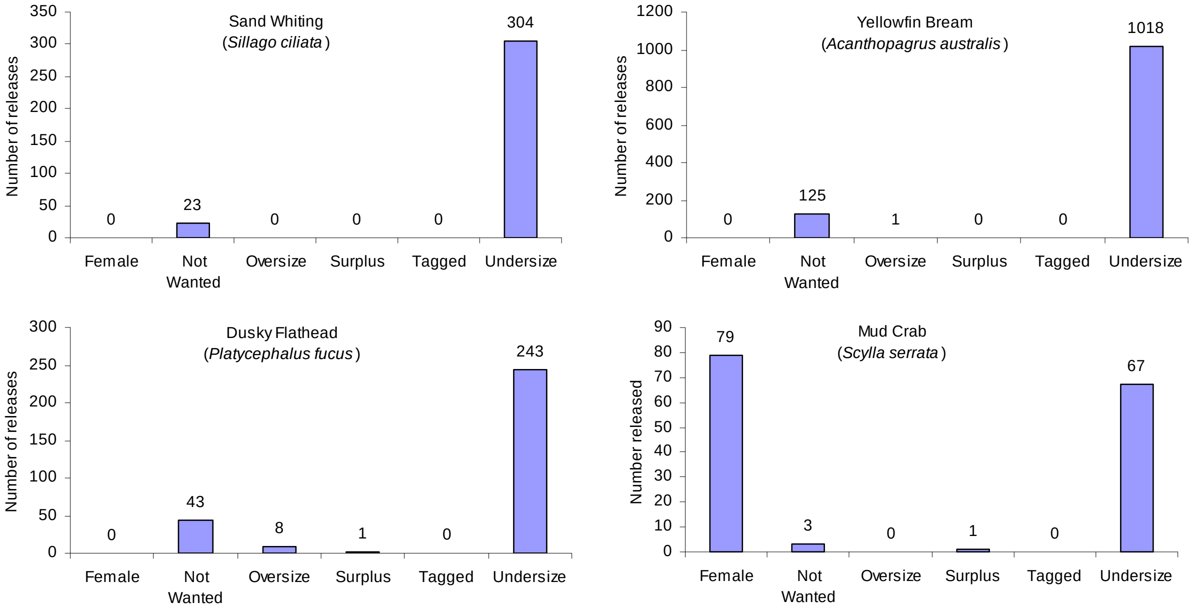


Figure 16: Reasons for release of four inshore species caught in south-eastern Queensland. Numbers above the bars are the number of animals released.

Discussion

This pilot study has provided the first fine-scale regional data on recreational fishing activities in south-eastern Queensland. It does not provide an estimate of total recreational harvest for the region because it does not measure recreational fishing in freshwater, activity from private access points, fishers returning to ramps before 7 am and after 6 pm, and shore-based fishers. However, it does provide good effort and harvest data for fishers using public marine boat ramps and good estimates of the variance in the data within the various strata.

The knowledge gained from this survey will be used to design efficient recreational fishing surveys in the future.

Effort

The estimates of recreational fishing effort provided by the established expansion method and the two-part GLM were similar and the precision of the effort estimates for the region were good (RSE less than 0.05), which may reflect the high sampling frequency per strata.

The results demonstrate that the survey design is able to provide a precise estimate of the recreational fishing effort sampled. If the survey was expanded to include activities not sampled (e.g. night time fishing activity), then it is likely that this precision would be maintained.

Effort was not evenly distributed across south-eastern Queensland. The greatest effort was observed at Route 04, which provides access to the waterways of southern Moreton Bay, and Route 12, which provides access to Pumicestone Passage and northern Moreton Bay.

Geographically, these routes include the first major boat ramps north and south of Brisbane to offer access to large expanses of safe, natural and aesthetically pleasing environments where people can enjoy recreational fishing. People go fishing for many reasons in addition to catching fish; for example, ‘to relax and unwind’ and ‘to be outdoors’ were both rated in the top five reasons for going fishing (Henry & Lyle 2003). Therefore, recreational fishing effort may be high at these two routes for reasons other than their ability to produce catches of fish. If this is the case, sustainable management of recreational fishing in these regions is broader than conserving fish stocks. It also implies maintaining the ease of access and the quality and aesthetics of these habitats as the population in south-eastern Queensland grows.

Fishing effort also varied among ramps within routes. The distances between ramps was often small (< 3 km), and adjacent ramps often, but not always, provide access to the same habitats (e.g. Route 14 discussed below). The busier ramps however, tended to have more parking spaces or larger boat ramps.

Variation among ramps within a route is most likely due to logistical factors, such as parking spaces and boat ramp facilities, as well as the access the ramps provide to fishing habitats. Bigger, better quality ramps are more likely to attract more effort. These logistical factors may also affect the types of boats and therefore fishers using them, requiring sampling to be stratified by ramp characteristics. For example, it may be the case that large ramps with abundant parking space attract larger boats, which may tend to fish differently (e.g. offshore). Smaller ramps may attract smaller boats wishing to avoid the crowds of the bigger ramps and these fishers may tend to fish inshore. Data need to be collected to establish whether or not this is the case.

The intensity of fishing effort was greater on weekends and public holidays than during the week. We expected that boat ramps would be busier on weekends. However, the estimated annual effort on weekdays in spring was greater than that on weekends and public holidays in spring. Further sampling is required to determine if this is a regular annual pattern and whether it is related to perceptions of the fishery during that season or some other factor more directly affecting fishers (e.g. the weather).

Harvest and release

Large sample sizes are needed to obtain precise estimates of variable populations. Recreational fishing harvest is variable because many factors influence it. For example, the abundance and catchability of fish varies, the skill level of fishers varies, and the weather varies (which affects fishing effort). This inherent variability has affected the precision of the harvest estimates provided by this survey.

Although 3933 fish were measured, only a few species were measured in substantial numbers. For species such as yellowfin bream, sand whiting and dusky flathead, sample sizes were relatively large (*n* >300) and distributed across the strata ‘season’ and ‘day type’. The precision (RSE) of these harvest estimates was relatively high (0.156–0.172) compared to other species. With more than 300 snapper measured, the RSE for the estimate of snapper harvest was higher (0.249) but small enough to provide confidence in the estimate.

This suggests that variation in snapper harvest is greater than, for example, variation in dusky flathead.

Estimates of the number of fish released has an additional bias attached to it compared to estimates of harvest because it relies on potentially inexperienced fishers (1) identifying fish and (2) recalling the number released. These biases may increase or decrease the variance in numbers released. Estimates of harvest are less subject to this identification and memory bias because they are counted and identified by trained staff at the ramps.

Established method vs two-part GLM

The harvest estimates made by the two-part GLM were more precise with considerably smaller RSE than those made by the established method. The harvest per unit effort (HPUE) data contained many zeroes simply because many boat crews did not harvest any animals. This resulted in a distribution that was positively and significantly skewed.

The established method used in this study and many others assumes that the underlying distributions are normal. Predictions are less reliable when this assumption is breached by data sets that are strongly skewed. In addition to this skewing, some data were not collected; for example, on some occasions during the 13 months no data were collected for ramps within a route due to logistical factors.

The two-part GLM reduced the variance of its estimates because of the way in which it dealt with large numbers of zeroes and null values within the dataset. In essence, the two-part GLM estimated values for the null cells in the data set from the surrounding cells and modelled the data against distributions that were considered a better match to the true data distribution than the normal distribution. For example, for those sessions when no fishers were interviewed at boat ramps, the model estimated the catch variables based on those from the surrounding boat ramps within that route. The two-part GLM analysed the zero and the non-zero components of the data separately, with the binomial and the gamma distributions respectively, and then integrated them to provide an overall estimate.

Both the established and the two-part GLM estimates of harvest were expected to be similar because both methods use the same data set. However, the substantially smaller variance around these estimates provided by the two-part GLM suggests that the merits of this method should be investigated further. If further research demonstrates that the two-part GLM delivers more precise estimates, then more cost-efficient sampling designs can be developed.

Reasons for release

Most boat crews interviewed at ramps declared that they harvested no fish, and in many cases the crews had caught fish but released them.

Release rates for fish varied among species. For inshore species, more yellowfin bream, blue swimmer crabs and mud crabs were released than were harvested; however, more trumpeter whiting and tailor were harvested than released. Release rates also varied among the rocky reef species. Snapper had a high release rate of 77%. This may be because undersize juvenile fish were caught and released within inshore areas, where they occur as juveniles. The number of Venus tuskfish released was low (37% of the catch).

The most common reason for releasing fish was because they were undersize. This demonstrates that most recreational fishers comply with minimum size limit regulations. For species that were also regulated by sex (e.g. mud crabs), being female was the major reason for release.

The second most popular reason for releasing fish was that they were simply not wanted. A broad range of species were released for this reason, including table fish such as snapper, yellowfin bream and whiting. Fishers engaging in catch and release fishing used this as their reason for release.

Size range of species harvested

The size frequency of harvested fish showed that recreational fishers generally released undersized fish. There were a few species, however, where the number of undersized fish harvested suggests management action is necessary. These fish tended to be species that were not as frequently caught. Therefore, fishers may be less adept at identifying these species and unfamiliar with the regulations. For rocky reef species where a large proportion of undersized fish were caught (e.g. the Maori rockcod), our sample size was small and may not be representative of the overall harvest.

There was little variation in the size of fish harvested when examined by season or route. Samples that appeared to be different to the general trend tended to have small sample sizes. For example, yellowfin bream harvested at Route 01 appeared to be larger than those from other routes; however, less than 10 fish were measured in Route 01. Estimates obtained from these small sample sizes should be treated cautiously.

Variation in harvest

The survey highlighted the fact that species and numbers of fish harvested differed among routes. Species harvested also varied among the ramps within a route. The likely reason for this is that different ramps provide access to different fish habitats.

This appeared to be the case within Route 14, which encompassed ramps in the Mooloolah and Maroochy Rivers. The Mooloolah River provides relatively limited estuarine habitats but safe access to ocean rocky reef habitats. The Maroochy River, however, has extensive estuarine habitats but a surf bar hindering access to offshore rocky reef habitats. Fishers using the Mooloolah River ramps harvested more snapper and fewer dusky flathead than those using the Maroochy River ramps.

This survey sought to sample all inshore recreational catch. However, when designing a survey that focuses on a particular suite of species, for example rocky reef species, depending on the hypothesis being tested it may be efficient to weight sampling effort towards the ramps fishers use to harvest those species.

Harvest per unit effort (HPUE): variation through time and space

This survey has used estimates of HPUE and release per unit effort (RPUE), derived from boat crew interviews, in the expansion calculations to estimate total harvest and total fish released.

Recreational HPUE may be an appropriate indicator of the catchability of fish provided the biases and errors in the estimate are understood. Unlike a fishery independent survey, where fishing time and fishing method are standardised across surveys, recreational HPUE is unlikely to be derived from standardised methods across fishers or time. This is particularly the case in a region such as south-eastern Queensland.

Recreational fishers in south-eastern Queensland often use different methods to catch different species (e.g. artificial lures, baits, traps and trolling). They are often opportunistic and will fish for a range of species using several methods during a trip (Henry & Lyle 2003). For example, fishers may set some crab pots, travel offshore to fish a rocky reef before collecting their pots on the return journey. They may then fish for some inshore species before returning to the boat ramp. Other fishers may travel directly out to a rocky reef, fish for a few hours and then return directly. Accurate assessments of time spent fishing in the different habitats by these two trips would at best be difficult to determine from interviews at boat ramps. Therefore in this survey, time on the water, which included travel time to and from fishing sites, was substituted for fishing time.

Time on the water and the opportunity to fish in different habitats is likely to depend on the accessibility of these habitats from particular ramps. Travel time is likely to be a greater proportion of time on the water when ramps are distant from fishing locations (compared to ramps that are close to fishing locations). Ramps that provide access to a greater diversity of habitats are likely to have more diverse fishing activities. Therefore, using HPUE among ramps to gauge the catchability of particular species among locations is likely to be confounded by the spatial peculiarities of the ramps.

Over time, HPUE may also be confounded by such things as changes in fishing technology or attitudes of recreational fishers. Technologies and fishing skills advance over time; for example, the widespread use of GPS, depth sounders, braided line and internet discussion forums have most probably improved the harvest efficiency of recreational fishers (Neville 2009). Larger boats and bigger engines also allow people to fish in less accessible regions. The proportion of fishers practising catch and release fishing may also change over time. The effects of these changes, unless accurately and precisely estimated, confound temporal comparisons of fishery-dependent estimates of HPUE.

A further factor potentially affecting the observed catchability of fish within south-eastern Queensland is the changing spatial demographic of recreational fishers. As the populations of suburbs and subregions within south-eastern Queensland grow, their demography undoubtedly also changes. For example, if large numbers of retirees or, alternatively, young families migrate to particular regions it is likely that the demography and fishing preferences of recreational fishers within those regions will also change. This may affect the observed harvest at those ramps and, depending on the hypothesis being tested, confound long-term comparisons of harvest and the respective rates.

The effects of complex social interactions such as these and how they should be interpreted are not well understood in the field of recreational fishery assessment and monitoring. QPIF acknowledges the biases inherent in fishery-dependent data and therefore interprets these data cautiously.

Future monitoring and assessment

This pilot study generated good information about the effort and harvest of marine boat-based recreational fishers launching from public ramps in south-eastern Queensland. It is not however, able to estimate the total effort and harvest of boat-based recreational fishers.

In south-eastern Queensland there are many private jetties and marinas, and the harvest from trips commencing from these private access points is likely to be significant. Fishing effort from private access points should be quantified to establish its magnitude and character. If this effort is small and has similar harvest characteristics to fishing activity launched from public ramps, then we may be able to estimate it from the current survey design by direct expansion. However, if fishing effort from private access points is sizeable or has different characteristics then separate estimates are required; for example, if boats moored in marinas and on private jetties are larger and predominantly fish offshore compared to boats launched from trailers at public ramps. Directly measuring effort from private access points is difficult because they are private. One method to capture this activity on rocky reef fisheries may be to combine roving and aerial surveys of boats fishing on rocky reefs.

This survey also highlights the fact that broad-scale surveys that randomly sample the population of fishers are unlikely to cost-effectively deliver precise estimates for species that are rarely caught by the general population of recreational fishers, simply because too few data are collected.

As the number of animals recorded in the harvest decreased, the estimates became less reliable. This is evident when looking at the harvest estimates for pelagic species (e.g. amberjack and yellowtail kingfish). The harvest estimate RSE for these species were 0.775 and 0.755, respectively.

A similar situation exists for other species that were rarely harvested (e.g. the rockcods, emperors and Spanish mackerel). In cases where a suite of species are caught by a small group of fishers within the general population of recreational fishers (e.g. offshore game fish), then it may be possible to improve the precision of estimates by developing a sampling methodology that targets those fishers rather than randomly sampling from the greater pool of all recreational fishers.

Involving recreational fishers in monitoring and management

Recreational fishers are interested in the management of their fisheries, as evidenced from the submissions received from recreational fishing groups to the *Your Fish. Your Future. Department of Employment, Economic Development and Innovation Queensland Fisheries Strategy 2009–14*.

Recreational fishers realise that fisheries are not resilient to ever-increasing fishing pressure and habitat degradation. With our growing population, especially in the south-eastern corner of the state, fisheries and the habitats they depend on are capable of being over-exploited. This realisation is driving bodies representing recreational fishers to become willing partners with government in managing our fisheries and their supporting habitats. There is potential for recreational fishers to assist in the assessment and monitoring of their fisheries through the collection of fishery-dependent or fishery-independent data. QPIF currently has a number of monitoring programs that involve recreational fishers (e.g. the Online Recreational Fishing Diary program, the Keen Angler program and the Fishcare Volunteer program).

This survey has highlighted the inherent variability of recreational fishing data and the need to collect representative samples of fishing activity following a structured methodology that is consistent through time. All data used for management decisions affecting the business and recreational benefits of Queenslanders must be of the highest quality so that it is rigorous in the face of challenge. Skill in following protocols, fish identification, measurement techniques and accurate record keeping are required if all stakeholders are to have confidence in the data collected and its subsequent interpretation. In this study staff were trained and tested prior to collecting data, yet for some rarely observed species further identification training was needed. These identification and data quality issues are present in all surveys where a diverse group of people collect the data; training, therefore, is paramount.

Conclusion

This pilot study has highlighted the complexity and diversity of marine boat-based recreational fishing in south-eastern Queensland. The study has also provided valuable catch information for numerous rocky reef and inshore fish species that will assist in the sustainable management of the Rocky Reef Fishery and the East Coast Inshore Finfish Fishery. Quality data and robust sampling design are paramount in delivering reliable recreational catch estimates and the findings of this survey will be used to design efficient surveys and monitoring programs in the future.

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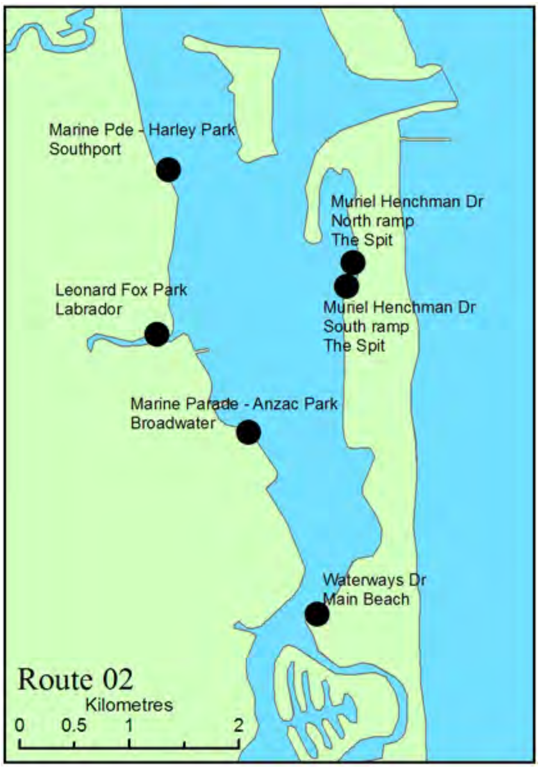
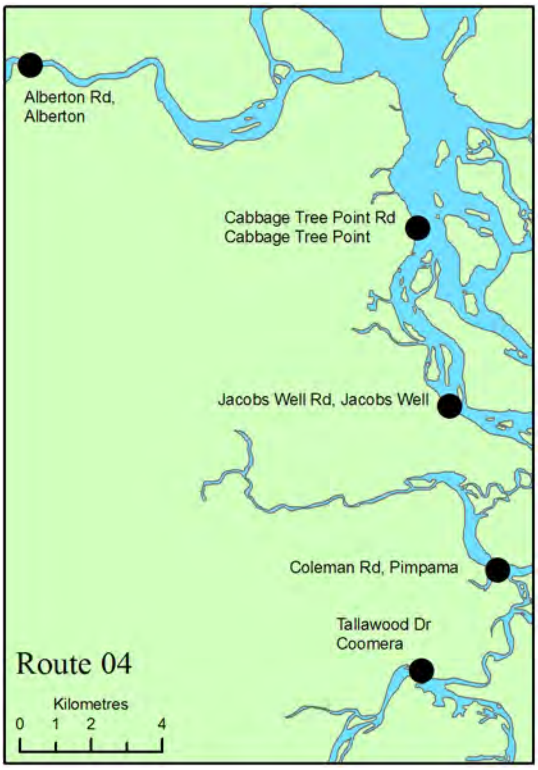
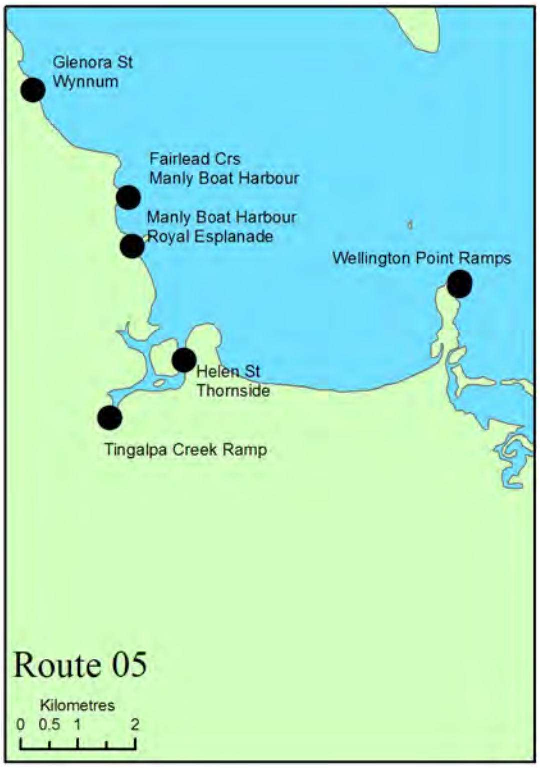
Appendix 1

Boat ramps and routes



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Thornside
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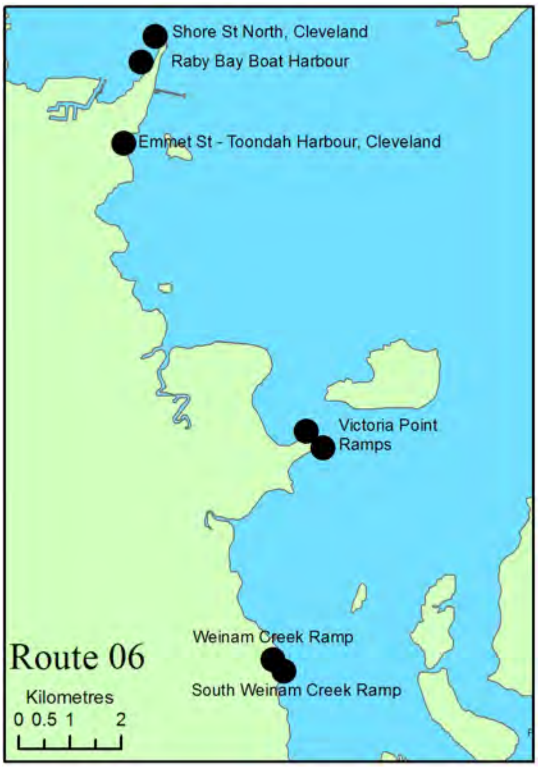
Route 05
Kilometres
0 0.5 1 2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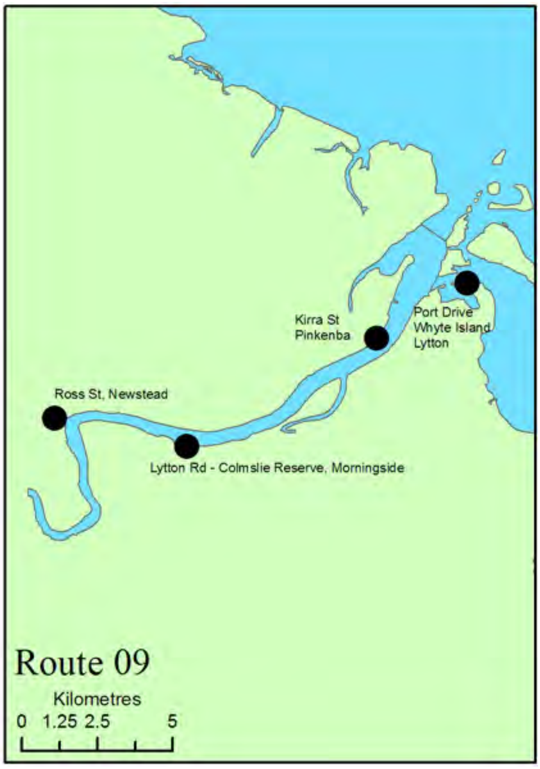
Raby Bay Boat Harbour
Emmet St - Toondah Harbour, Cleveland
Victoria Point
Ramps
Weinam Creek Ramp
South Weinam Creek Ramp
Route 06
Kilometres
0 0.5 1 2


Uhlman Rd, Burpengary
O'Leary Ave
Burpengary
Bayview Tce, Deception Bay
Thurecht Pde
Scarborough
Bird O'Passage, Scarborough
Flinders Pde, Scarborough
Eveline St
Margate
Thomas St
Clontarf
Oxley Ave
Woody Point
Route 08
Kilometres
0 1 2 4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Pinkenba
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Whyte Island
Lytton
Ross St, Newstead
Lytton Rd - Colmslie Reserve, Morningside
Route 09
Kilometres
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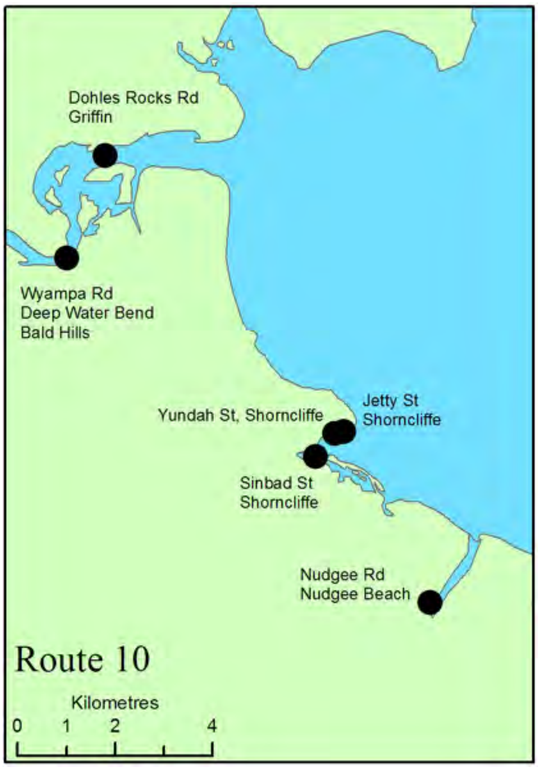
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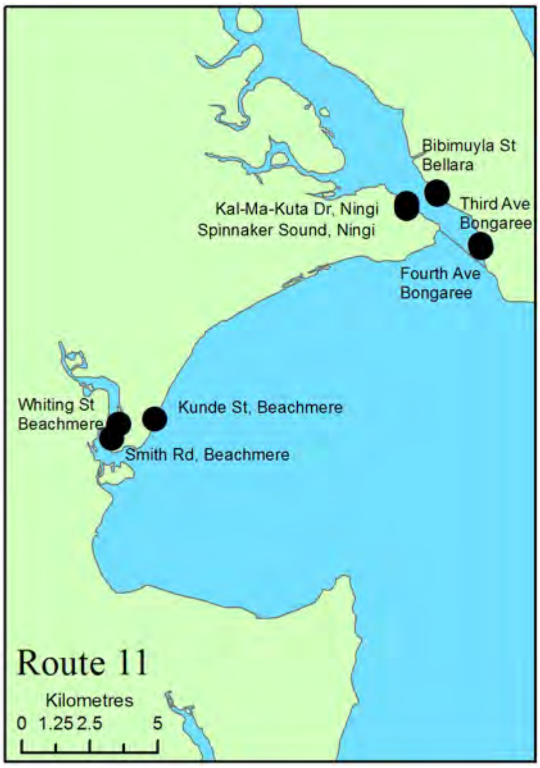
Griffin
Wyampa Rd
Deep Water Bend
Bald Hills
Yundah St, Shorncliffe
Jetty St
Shorncliffe
Sinbad St
Shorncliffe
Nudgee Rd
Nudgee Beach
Route 10
Kilometres
0 1 2 4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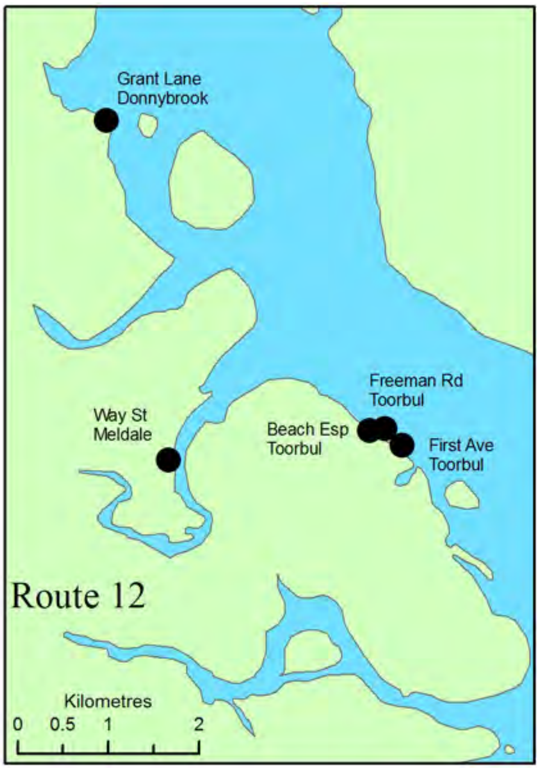
Bellara
Kal-Ma-Kuta Dr, Ningi
Spinnaker Sound, Ningi
Third Ave
Bongaree
Fourth Ave
Bongaree
Whiting St
Beachmere
Kunde St, Beachmere
Smith Rd, Beachmere
Route 11
Kilometres
0 1.25 2.5 5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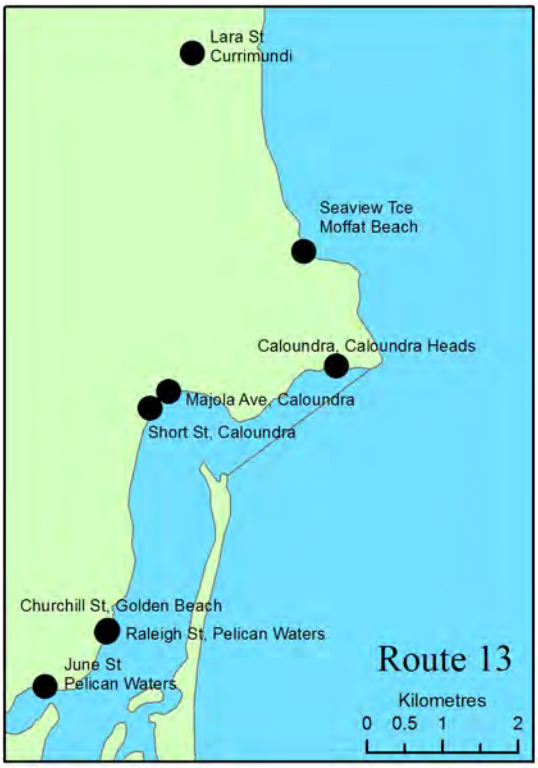
Toorbul
Way St
Meldale
Beach Esp
Toorbul
First Ave
Toorbul
Route 12
Kilometres
0 0.5 1 2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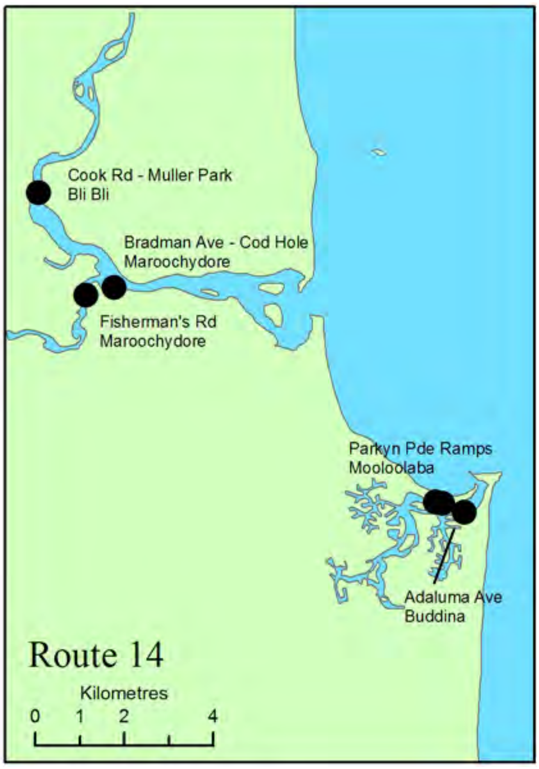
Currimundi
Seaview Tce
Moffat Beach
Caloundra, Caloundra Heads
Majola Ave, Caloundra
Short St, Caloundra
Churchill St, Golden Beach
Raleigh St, Pelican Waters
June St
Pelican Waters
Route 13
Kilometres
0 0.5 1 2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Bli Bli
Bradman Ave - Cod Hole
Maroochydore
Fisherman's Rd
Maroochydore
Parkyn Pde Ramps
Mooloolaba
Adaluma Ave
Buddina
Route 14
Kilometres
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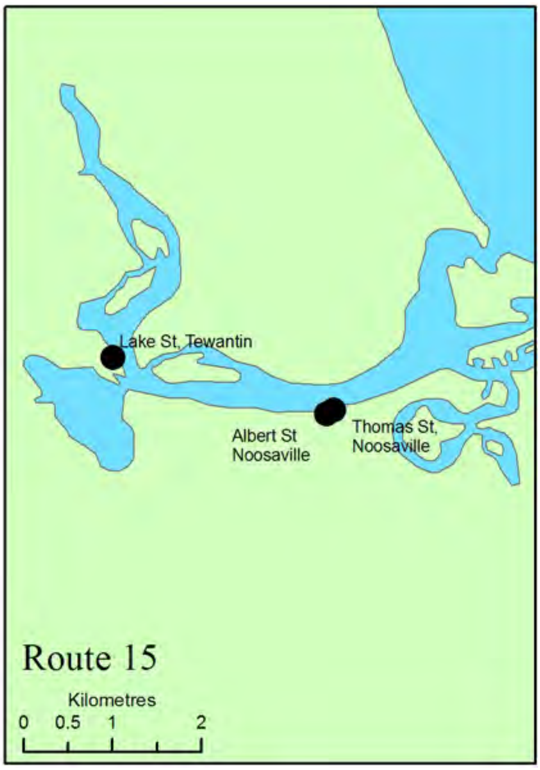
1
2
4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Albert St
Noosaville
Thomas St,
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Route 15
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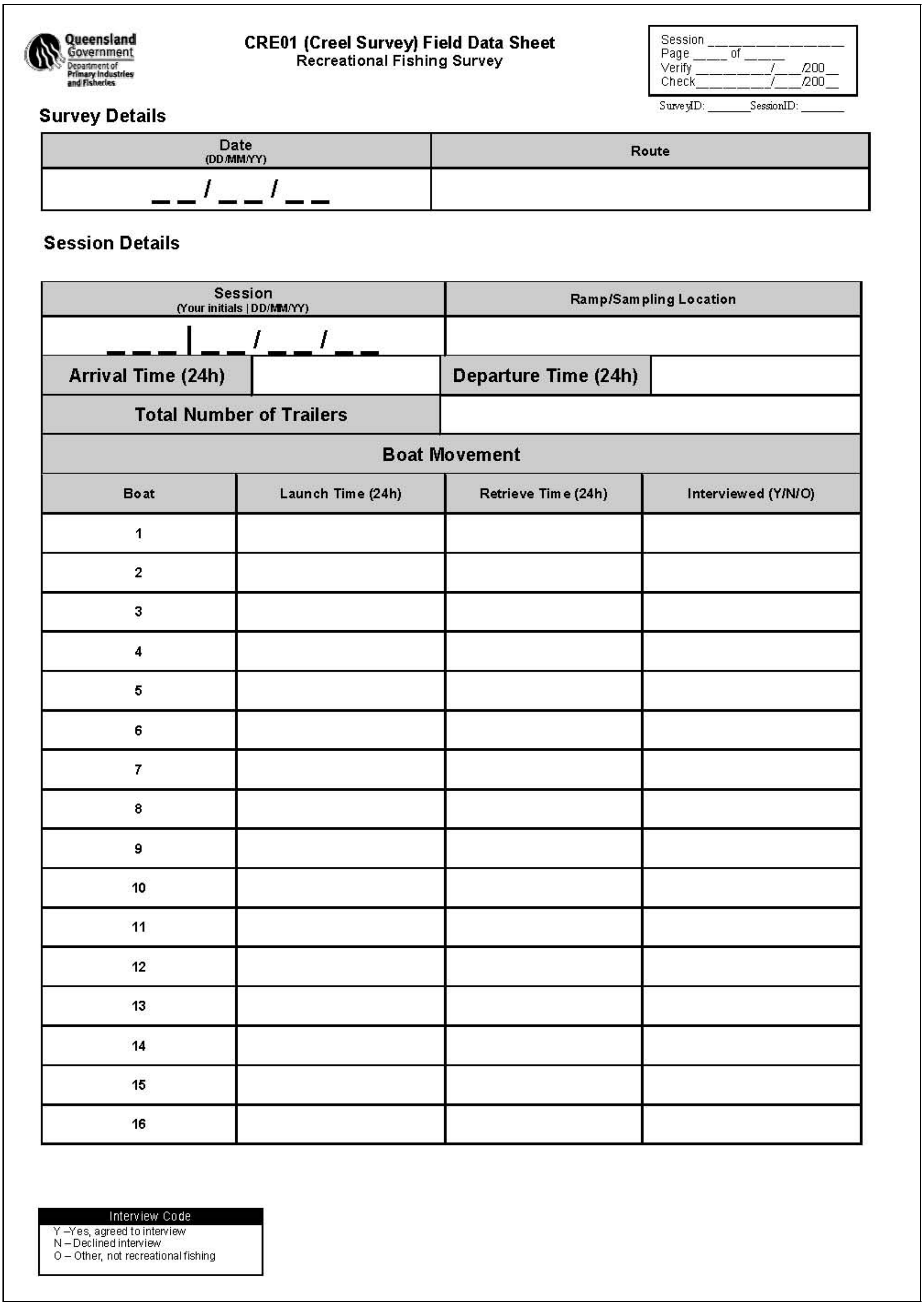
1
2

Appendix 2

Data sheets



Queensland Government
Department of Primary Industries and Fisheries

CRE01 (Creel Survey) Field Data Sheet
Recreational Fishing Survey

Session ________________
Page ____ of _____
Verify _________/___/200__
Check_________/___/200__

SurveyID: _______SessionID: _______

Survey Details

Date (DD/MM/YY)	Route
_ _ / _ _ / _ _	

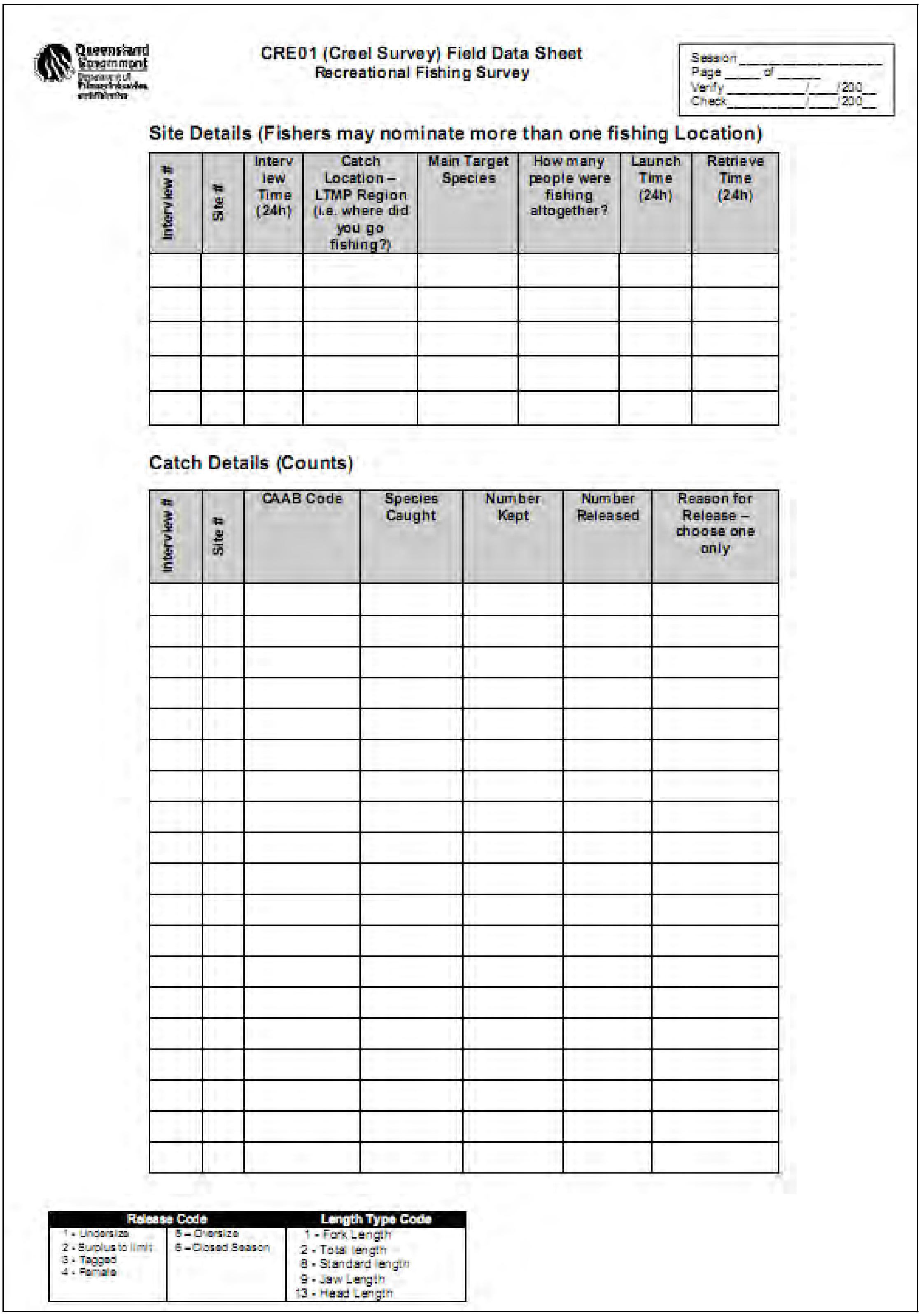
Session Details

Session (Your initials | DD/MM/YY)		Ramp/Sampling Location	
_ _ _ | _ _ / _ _ / _ _			
Arrival Time (24h)		**Departure Time (24h)**	
Total Number of Trailers			

Boat Movement

Boat	Launch Time (24h)	Retrieve Time (24h)	Interviewed (Y/N/O)
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			

Interview Code
Y –Yes, agreed to interview
N – Declined interview
O – Other, not recreational fishing



Queensland Government
Department of Primary Industries and Fisheries

CRE01 (Creel Survey) Field Data Sheet
Recreational Fishing Survey

Session ____________________
Page _____ of ______
Verify ____________/____/200__
Check____________/____/200__

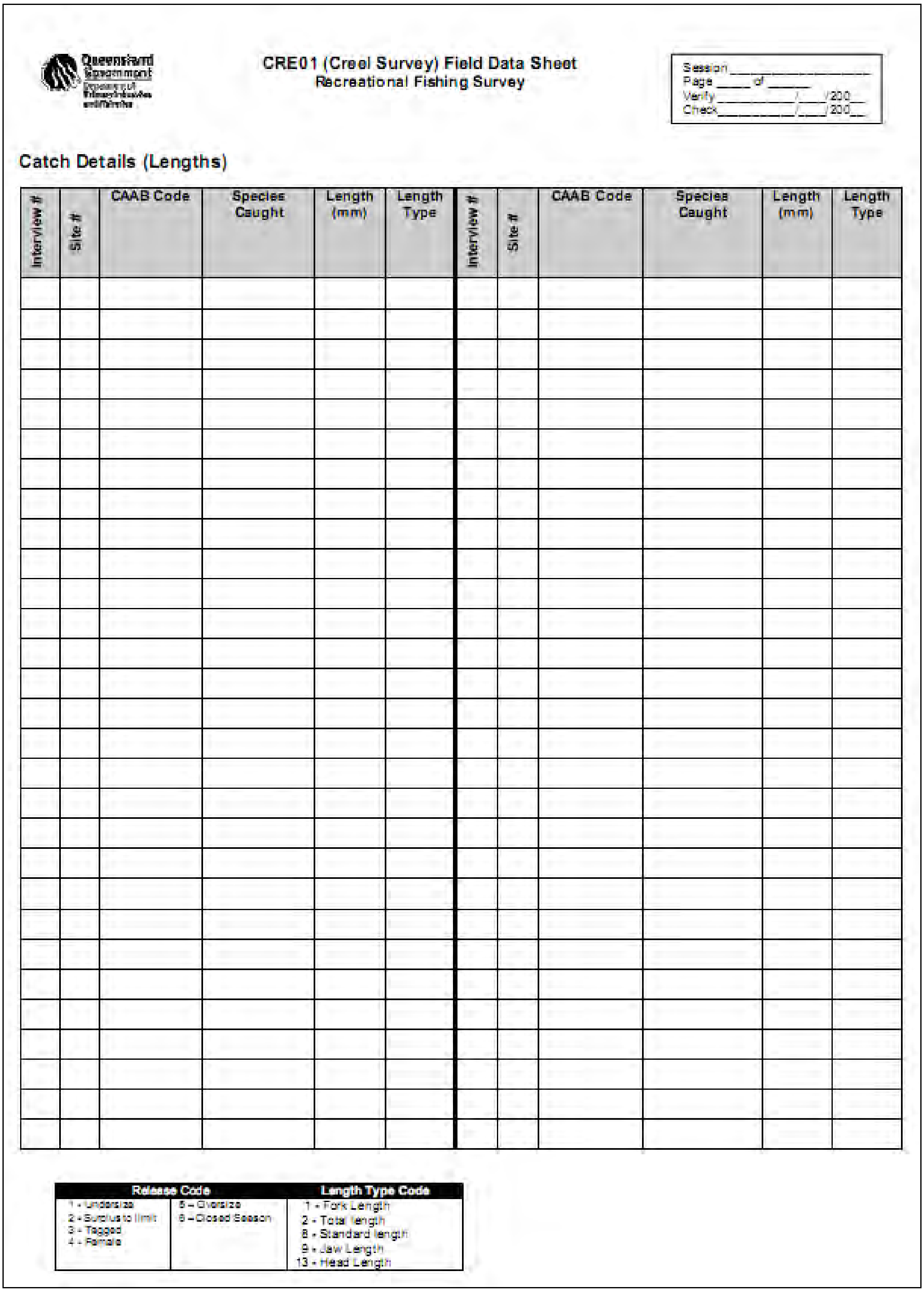
Site Details (Fishers may nominate more than one fishing Location)

Interview #	Site #	Interview Time (24h)	Catch Location – LTMP Region (i.e. where did you go fishing?)	Main Target Species	How many people were fishing altogether?	Launch Time (24h)	Retrieve Time (24h)

Catch Details (Counts)

Interview #	Site #	CAAB Code	Species Caught	Number Kept	Number Released	Reason for Release – choose one only

Release Code		Length Type Code
1 - Undersize 2 - Surplus to limit 3 - Tagged 4 - Female	5 – Oversize 6 – Closed Season	1 - Fork Length 2 - Total length 8 - Standard length 9 - Jaw Length 13 - Head Length



Queensland Government

CRE01 (Creel Survey) Field Data Sheet

Recreational Fishing Survey

Session ____________________
Page _____ of ______
Verify ___________/____/200__
Check___________/____/200__

Catch Details (Lengths)

Interview #	Site #	CAAB Code	Species Caught	Length (mm)	Length Type	Interview #	Site #	CAAB Code	Species Caught	Length (mm)	Length Type

Release Code		Length Type Code
1 = Undersize 2 = Surplus to limit 3 = Tagged 4 = Female	5 – Oversize 6 – Closed Season	1 = Fork Length 2 = Total length 8 = Standard length 9 = Jaw Length 13 = Head Length

Appendix 3

List of common and scientific names (sorted by common name) used in this report. Names follow the Australian fish names standard (Seafood Services Australia Ltd 2007).

Common name	**Scientific name**
Amberjack	*Seriola dumerili*
Blue swimmer crab	*Portunus pelagicus*
Cobia	*Rachycentron canadum*
Dusky flathead	*Platycephalus fuscus*
Golden trevally	*Gnathanodon speciosus*
Goldspotted rockcod	*Epinephelus coioides*
Grass emperor	*Lethrinus laticaudis*
Maori rockcod	*Epinephelus undulatostriatus*
Moses’ snapper	*Lutjanus russelli*
Mud crab	*Scylla serrata*
Northern sand flathead	*Platycephalus arenarius*
Pearl perch	*Glaucosoma scapulare*
Sand whiting	*Sillago ciliata*
School mackerel	*Scomberomorus queenslandicus*
Silver javelin	*Pomadasys argenteus*
Snapper	*Pagrus auratus*
Spangled emperor	*Lethrinus nebulosus*
Spanish mackerel	*Scomberomorus commerson*
Tailor	*Pomatomus saltatrix*
Tarwhine	*Rhabdosargus sarba*
Thicklip trevally	*Carangoides orthogrammus*
Trumpeter whiting	*Sillago maculata*
Venus tuskfish	*Choerodon venustus*
Yellowfin bream	*Acanthopagrus australis*
Yellowtail kingfish	*Seriola lalandi*

Appendix 4

Statistical methods and analysis

The principal sampling unit (PSU) was the survey of a ramp, with randomly selected days providing the replicates. Estimation was based on stratification by season (four levels: spring, summer, autumn and winter), day type (two levels: weekday (WD) and weekends and public holidays (WE)) and ramp (106 levels), creating a survey with 848 strata (four seasons × two day-types × 106 ramps).

The number of replicates per base stratum ranged between five and 16, averaging nine. Stratification to the ramp (rather than route) level was adopted because, for most of the variables being analysed, it was expected that there could be considerable variation between ramps (within routes). Estimation at the ramp level partitions this variation to attributable sources, whereas estimation at the route level pools this into the random error term and hence inflates the estimated standard errors and confidence intervals.

When scaling the fishing effort up from the sampled days to the total days in each stratum, the finite population correction factor for the variance was not used. This is only appropriate in census-like situations when each observed value is known and without error. In our survey, each day's effort (at each ramp) is estimated from a snapshot in time, and hence could be somewhat different to the true population value for that day. By not using the finite population correction factor, our estimated standard errors will be somewhat conservative, and the confidence intervals wider.

Estimates of fishing effort, harvested and released fish and their respective variances were made by scaling-up the stratified survey data. Two separate estimation approaches were used to derive these total estimates.

Established survey approach

This uses the standard method as outlined in Pollock et al. (1994), and these formulae are provided below. Given the defined level of stratification, the means and variances are estimated at the individual-cell level. These are then scaled-up for the total days in each stratum, and summed as appropriate.

Some potential problems with this approach include:

- Some cells have nil observations, with some of the variables to be estimated. Here, assumed values or best estimates need to be included, both for the mean values and their associated variance.
- Given the average of nine observations per stratum cell (with some having only five), the individual-cell estimated variances may be unstable; these will be up or down simply due to random chance, with little expectation that these patterns would be repeated had a different sample of days been taken. This could inflate the overall variance if some of the more important or 'high-impact' stratum cells also have high estimates for their variances.
- The normal (or t) distribution is assumed to apply. While large-sample theory indicates that the estimated means under this approach should be approximately unbiased, this is not the case for the variance estimates. These are very much affected by skewed data, which is often the case with fisheries catch rates. Also, these frequently also have an inflated zero-class, which is rarely accommodated adequately by any single statistical distribution.

Conditional generalised linear models (GLMs)

The alternative to using actual grid-cell means and variances is to statistically model each of the key variables of interest. The major advantages of this approach include:

- The choice of models, distributions and statistical assumptions is greatly expanded, including GLMs (for GLMs see McCullagh & Nelder 1989). These can also be expanded to incorporate conditional or two-part GLMs.
- On the appropriate scale or link-function, pooled variances are estimated. These are more stable and better reflect large-sample expectations. They may also be smaller as they adequately model the underlying data, rather than being inflated as occurs when the distribution is not appropriate.
- A parsimonious model gives a more stable response surface at the lowest stratum level. Statistical models can test the significance and relative magnitude of the individual interaction terms. If the highest-order interaction is significant, then the adjusted means at this level (i.e. the individual stratum-cell level) will reflect the actual observed data at this level. However, when the highest-order and perhaps also some mid-order interactions are non-significant, it indicates that these individual cell patterns are reflecting no more than expected random drift. In this situation, a simplified (or parsimonious) model is better employed. Estimation of the key variables is still at the individual cell level, but the fitted response patterns will be somewhat smoothed (again better reflecting the overall expectation for the population).

The key variables which were statistically modeled were:

Boat effort

Estimated boat effort was based on the trailer counts at each ramp, suitably scaled for waiting time; see equation (1) below. These data proved to be positively skewed, and at the individual ramp level 17% of all daily observations were zero. Hence, it was concluded that no single statistical distribution would adequately model these data. A two-part or conditional model (MacNeil et al. 2009) was adopted, using GenStat 11 statistical software (VSN International Ltd 2007).

The first part of this conditional model adopts a binomial GLM with the logit link to model the zero-class, namely the proportion of all observations that were zeros. All higher-order interactions were screened and discarded if not significant. When generating the ‘season by day type by ramp’ tables of means and standard errors, the ‘full’ option was adopted, as this provides stable estimates of any missing combinations in the sample scheme (missing cells are estimated with minimum variance from the patterns in the surrounding data).

The second part of the conditional model only considers the values greater than zero, or the zero-truncated portion of these data. A gamma GLM with the log link function (Feuerverger 1979; Ye et al. 2001) is adopted here. In a review of 78 zero-truncated fisheries and ecological data sets, Myers and Pepin (1990) showed the gamma to be generally similar, but more often slightly superior, to log-normal fits. Mayer et al. (2005) showed the gamma to be stable across a range of data sets, and a logical compliment to the binomial in a two-part conditional model.

At the stratum-level, estimates of overall boat effort are then the product of the mean proportion presence (from the binomial model) and the mean effort (from the gamma model). Standard errors for these overall values are calculated using the standard variance formulae for products (Goodman 1960).

Proportion of fishers

This was based on the interviews and estimated the proportion of boats that had been fishing. A binomial GLM with the logit link was used to analyse these data. Again, all possible interactions were initially fitted and screened for significance.

Total fishing effort is then the product of total boat effort multiplied by the proportion of fishers. The same variance formulae were used to estimate the relevant standard errors.

Harvest per unit effort (HPUE)

HPUE was calculated via the recommended mean of ratios estimator (Hoenig et al. 1997). Individual interviews within ramps and days were considered as sub-samples, and averaged to standardise back to the level of the principal sampling unit. These data contained many zeroes because on many boat trips fishers did not harvest any animals, particularly when considering each species individually.

The distribution of these data was positively and significantly skewed. We again used a conditional (two-part) GLM. The inflated number of zeros was modelled separately with the binomial distribution and log link. The actual catch numbers (> 0) were still skewed and, based on the residual plots, the gamma distribution (with log link) was found to model this second component adequately. Overall estimates were again calculated by integrating these two models.

For each of the three key variables, all analyses considered the main effects of day type, season and ramp, along with their interactions. Generally the three-way interaction and two-way interactions involving ramp (which all had relatively high degrees of freedom) were non-significant, and of a lower order of magnitude than the other effects. Hence, these interactions were omitted to arrive at a simpler and more parsimonious model. The season by day type interaction, with only three degrees of freedom, was retained as it was generally significant ($p < 0.05$).

These mean and variance data generated by the two-part GLM were scaled-up using the formulae below to estimate fishing effort and the number of yellowfin bream, sand whiting, dusky flathead, snapper and grass emperor harvested. The estimates and variances of fishing effort and harvest provided by the established method and the two-part GLM method were compared.

Established estimates of mean and variance for the principal sampling unit and expansion method

Strata:

Day type (d): two levels: weekends and public holidays, and weekdays
Season (s): four levels: spring, summer, autumn and winter
Route (r): 14 levels: 1 to 15, omitting 7
Ramps nested in routes (b): 3 to 9

The principal sampling unit (PSU) is a visit to a boat ramp (b). Routes were surveyed on randomly selected days within the strata season (s) and day type (d) during which trailer effort (t) at the ramps was sampled by counting all trailers at ramps. Trailer effort (t) represents trailers related to fishing boats and non-fishing boats (e.g. ski boats, jets skis etc.). For each route, average trailer effort was calculated for each ramp within season and day type using

$$\bar{t}_{dsb} = \frac{\sum_{i=1}^{n_{dsb}} \frac{t_i}{w_i} \times D}{n_{dsb}} \qquad \textbf{(1)}$$

Where t_i is the trailer minutes counted during w_i minutes of waiting at a ramp on each of n visits during the strata. D is the number of fishing hours in a day (11 hours). The estimated variance within these strata is calculated using the general variance equation

$$s_{dsb}^2 = \frac{1}{n_{dsb} - 1} \sum_{m=1}^{n_{dsb}} \left(t_{dsbm} - \bar{t}_{dsb}\right)^2 \qquad \textbf{(2)}$$

The proportion of trailers involved in fishing was estimated from interviews. The mean proportion fishing (f_{dsb}) is calculated for each ramp (b) stratified by season (s) and day type (d).

$$\bar{f}_{dsb} = \frac{\sum_{i=1}^{n_{dsb}} f_i}{n_{dsb}} \qquad \textbf{(3)}$$

For the established method but not the two-part GLM, in cases where trailers were present but no interviews were conducted $\bar{f}_{dsb}$ was set to 0.5. Mean trailer effort for each strata ($\bar{t}_{dsb}$)

was multiplied by the mean proportion of fishing trailers ($\bar{f}_{dsb}$) to estimate mean fishing effort ($\bar{e}_{dsb}$) at each ramp stratified by season (s) and day type (d).

$$\bar{e}_{dsb} = \bar{t}_{dsb} \times \bar{f}_{dsb} \qquad \textbf{(4)}$$

The total effort for each strata is calculated by

$$\hat{e}_{dsb} = \bar{e}_{dsb} \times N_{dsb} \qquad \textbf{(5)}$$

Where N_{dsb} is the number of days in the strata. The variance of $\bar{e}_{dsb}$ was calculated as the variance of a product (Goodman 1960; Bohrnstedt & Goldberg 1969) assuming that the covariance between these variables is approximately zero.

$$\mathrm{Var}(\bar{e}_{dsb}) = \left[\bar{f}^{2}_{dsb} \times \mathrm{Var}(\bar{t}_{dsb})\right] + \left[\bar{t}^{2}_{dsb} \times \mathrm{Var}(\bar{f}_{dsb})\right] - \left[\mathrm{Var}(\bar{t}_{dsb}) \times \mathrm{Var}(\bar{f}_{dsb})\right]$$

(6)

and following, the variance of $\hat{e}_{dsb}$ is

$$\mathrm{Var}(\hat{e}_{dsb}) = \mathrm{Var}(\bar{e}_{dsb}) \times N^{2}_{dsb} \qquad \textbf{(7)}$$

Harvest per boat hour (R_{dsb}) was stratified by season and day type and calculated at the level of the principal sampling unit using

$$\bar{R}_{dsb} = \frac{\sum_{j=1}^{n} h_j}{\sum_{j=1}^{n} L_j} \qquad \textbf{(8)}$$

Where h_j is the harvest and L_j is the time spent fishing (in boat hours) from the jth interview.

The harvest for strata dsb is estimated using

$$\hat{H}_{dsb} = \hat{e}_{dsb} \times \bar{R}_{dsb} \qquad \textbf{(9)}$$

The variance of harvest for this strata is a variance of a product and calculated with

$$\mathrm{Var}(\hat{H}_{dsb}) = \left[\bar{R}^{2}_{dsb} \times \mathrm{Var}(\hat{e}_{dsb})\right] + \left[\hat{e}^{2}_{dsb} \times \mathrm{Var}(\bar{R}_{dsb})\right] - \left[\mathrm{Var}(\hat{e}_{dsb}) \times \mathrm{Var}(\bar{R}_{dsb})\right]$$

(10)

where $\mathrm{Var}(\overline{R}_{dsb})$ is the variance of the mean harvest rate and is calculated from the general form of equation (2).

Total harvest is estimated by summing the harvest across all (*k*) strata

$$\hat{H} = \sum_{k=1}^{n} \hat{H}_k \qquad \textbf{(11)}$$

And the variance is estimated as

$$\mathrm{Var}(\hat{H}) = \sum_{k=1}^{n} \mathrm{Var}(\hat{H}_k) \qquad \textbf{(12)}$$

The standard error is calculated using

$$\mathrm{SE}(\hat{H}) = \sqrt{\mathrm{Var}(\hat{H}_k)} \qquad \textbf{(13)}$$

Appendix 5

Equations for converting fork length (FL) to total length (TL) and weight. CW = carapace width as measured across the carapace from the tips of the 9th anterolateral spines, NtN = notch to notch as measured across the carapace from the base of the 9th anterolateral spines.

Common name	Species name	FL to TL (TL =)	Length to weight (WT =)	Reference
Inshore species				
Yellowfin bream	*Acanthopagrus australis*	$0.4201 + 1.10874 \times FL$	$0.0277 \times TL^{2.8385}$	(O'Neill 2000), (Hoyle et al. 1999)
Sand whiting	*Sillago ciliata*	$0.0589 + 1.06502 \times FL$	$0.0093 \times TL^{2.976}$	(O'Neill 2000), (Hoyle et al. 1999)
Dusky flathead	*Platycephalus fuscus*		$0.0041 \times TL^{3.1262}$	(O'Neill 2000)
Trumpeter whiting	*Sillago maculata*		$1.57 \times 10^{-5} \times FL^{2.96}$	(Weng 1993)
Blue swimmer crab	*Portunus pelagicus*	$CW = (NtN + 16.04)/0.938$	$5.97 \times 10^{-5} \times CW^{3.056}$	(Potter & Sumpton 1986)
Tailor	*Pomatomus saltatrix*	$1.764 + 1.114 \times FL$	$1.176 \times 10^{-5} \times FL^{3.01}$	(Bade 1977)
Mud crab	*Scylla serrata*		$0.0078 \times CW^{3.06}$	(Ali et al. 2004)
Northern sand flathead	*Platycephalus arenarius*		$8.32 \times 10^{-5} \times L^{2.98}$	(Steffe et al. 1996)*
Tarwhine	*Rhabdosargus sarba*	$0.4201 + 1.10874 \times FL$	$2.56 \times 10^{-5} \times L^{2.9806}$	Weight (Malseed & Sumner 2001); TL uses same as Yellow fin bream
Rocky reef species				
Snapper	*Pagrus auratus*		$0.0447095 \times FL^{2.79}$	(Ferrell & Sumpton 1996)
Grass emperor	*Lethrinus laticudis*	$1.032536 \times FL$	$9.153 \times 10^{-6} \times L^{3.089}$	(Ayvazian et al. 2004) and QPIF unpublished data
Venus tuskfish	*Choerodon venustus*		$0.0229 \times FL^{2.9724}$	(Platten 2004)
Pearl perch	*Glaucosoma scapulare*		$0.040 \times FL^{2.787}$	QPIF unpublished data
Moses snapper	*Lutjanus rusellii*	$1.048 \times FL$	$0.0201 \times FL^{2.907}$	(Letourneur et al. 1998), QPIF unpublished data

Goldspotted rockcod	*Epinephelus coioides*		$0.0105 \times TL^{3.084}$	(Letourneur et al. 1998)
Spangled emperor	*Lethrinus nebulosus*	$1.07321 \times FL$	$0.02040 \times FL^{2.975}$	(Letourneur et al. 1998)
Thicklip trevally	*Carangoides orthogrammus*	$1.1129 \times FL$	$0.01750 \times FL^{2.994}$	Fishbase.org, (Letourneur et al. 1998)
Golden trevally	*Gnathanodon speciosus*	$1.16339 \times FL$	$0.194 \times FL^{3.008}$	Fishbase.org, (Letourneur et al. 1998)
Other pelagic species of interest				
Yellowtail kingfish	*Seriola lalandi*	$1.10074 \times FL$	$1.28 \times 10^{-5} \times FL^{3}$	QPIF unpublished data, (Stewart et al. 2002)
Cobia	*Rachycentron canadum*	$0.9949 + 0.8916 \times FL$	$0.00153 \times TL^{3.428}$	(Franks et al. 1998)
Spanish mackerel	*Scomberomorus commerson*	$4.274 + 1.06 \times FL$	$0.00284 \times FL^{3.22}$	(Mackie et al. 2003)
School mackerel	*Scomberomorus queenslandicus*	$35.362 + 1.055 \times FL$	$(3.775 + 0.006 \times FL)^{e}$	(Begg & Sellin 1998)
Amberjack	*Seriola dumerili*	$1.305 + 1.14 \times FL$	$0.0325 \times FL^{2.87}$	(Thompson et al. 1999)