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Long-term monitoring of boat-based recreational fishing in Shark Bay, Western Australia: providing scientific advice for sustainable management in a World Heritage Area

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Abstract. Effective management of a recreational fishery must include long-term monitoring programs that allow determination of trends in temporal and spatial variability of catch and effort data. Such monitoring becomes of inherently greater importance when managing a recreational fishery in a World Heritage Area, such as Shark Bay, Western Australia. Between 1998 and 2010, 11 12-month bus-route surveys of boat-based recreational fishing were undertaken at three key boat ramps in Shark Bay. These surveys demonstrated that, in response to the progressive implementation of new management measures, the estimated annual recreational fishing-boat effort decreased by 46%. As a consequence, the estimated annual retained and released catches of the key species, pink snapper (*Pagrus auratus*), declined and the proportions of the catches of this species that were released each year increased. Annual catches of other species also declined, however, the composition of species retained and released each year varied. The study demonstrated that monitoring of the recreational fishery within Shark Bay provided both immediate and longer-term data on the responses by recreational fishers to changes in management. This produced the information necessary to assess the effectiveness of management measures that were introduced and to modify these as required.

Additional keywords: catch and release, creel survey, onsite survey.

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Introduction

Sustainable management of the natural resources found within World Heritage areas (UNESCO 1972) requires an understanding of all impacts on the ecosystem of human uses, including all fishing activities (Lewin *et al.* 2006; Hughes *et al.* 2007). Consequently, nations that are successfully implementing approaches designed to deal with cumulative impacts on the environment also find it necessary to undertake ongoing monitoring of all fishing sectors (Babcock and Pikitch 2004; Fletcher *et al.* 2010). The impacts on fish abundance associated with harvesting pressures exerted by both commercial and recreational fishing sectors have been broadly documented (Cooke and Cowx 2006; Arlinghaus *et al.* 2007). Whereas, historically, only the commercial fishing sector has been held accountable for population depletions in the marine environment, there is now also evidence of dramatic declines in fish populations being attributed to recreational fishing pressures (McPhee *et al.* 2002; Post *et al.* 2002; Cooke and Cowx 2004, 2006; Granek *et al.* 2008; FAO 2011).

Recreational fishing is a socially and economically important use of fisheries resources in most parts of the world (Cooke and Schramm 2007; Granek *et al.* 2008). Globally, the numbers of people participating in recreational fishing have been estimated to be 10.6% of the total population in economically developed countries (FAO 2011). Recreational fishers are usually selective in their fishing practices, particularly when it comes to targeting species, selecting those species considered of greater appeal, higher value or that offer better angling challenges (Cooke and Cowx 2006; Lewin *et al.* 2006; FAO 2011). Recognition that recreational fishers are contributing or have the potential to contribute to the declines of fish populations should motivate the introduction of more effective management measures to mitigate adverse impacts of angling on fish populations and their ecosystems. Effective management will need to be accompanied, however, by long-term monitoring programs to provide greater understanding of the temporal variability and trends in catch and effort by which to assess the performance of the multiple objectives required for the management of ecosystems (Cooke and Cowx 2006; Lewin *et al.* 2006).

Recreational fishing surveys are used by fisheries agencies in many parts of the world to obtain a variety of information for management purposes (Pollock *et al.* 1994; Henry and Lyle 2003; National Research Council 2006; Hartill *et al.* 2012). It is, generally, more difficult to collect data on recreational fisheries than it is on commercial fisheries, mainly because of recreational fishers being more numerous, diverse and diffuse (Bradford and Francis 1999; Bradford 2000; National Research Council 2006). Recreational fisheries use a large number of access points and platforms for fishing and their nature ranges from avid fishers to infrequent participants (Pollock *et al.* 1994; National Research Council 2006). Consequently, surveys of recreational fishing have a variety of customised designs that reflect the specific objectives of the survey, the spatial and temporal scale to be covered, the nature of the recreational fishery, and the constraints on resources that are available to conduct the survey (Hartill *et al.* 2012).

Shark Bay in Western Australia's Gascoyne region is located at the northern end of the ecological transition zone between temperate and tropical marine faunas off the coast of Western Australia and, thus, exhibits rich species diversity (Fig. 1) (Logan and Cebulski 1970; Hutchins 2001; Wyatt *et al.* 2005). In recognition of the region's unique natural environment, the Shark Bay Marine Park and the Hamelin Pool Marine Nature Reserve were established in 1990, followed by World Heritage listing in 1991 (Table 1) (Shaw 2000; Francesconi and Clayton 1996). Pink snapper (*Pagrus auratus*) has long been an iconic species for the Shark Bay area. The stock structure of pink snapper in Shark Bay is complex, with management of the fishery recognising four discrete stocks in the region, namely, one in the oceanic waters; and the remaining three stocks located in each of the three areas (i.e. Denham Sound, Freycinet Estuary and the Eastern Gulf) that comprise Shark Bay (Fig. 1) (Moran *et al.* 1998, 2003; Nahas *et al.* 2003; Jackson 2007).

Fish stocks in the Shark Bay region are exploited by commercial, charter and recreational fishing sectors, which in the past have led to some conflict over the use of fish resources (Moran *et al.* 2003). Historical and current management arrangements (Table 1) inside Shark Bay's inner gulfs involve seasonal closures, marine protected areas, total allowable catches (TACs) and management quota tags for pink snapper in the Freycinet Estuary (Jackson and Moran 2012). Historically, commercial fishing of pink snapper was permitted within the inner gulfs of Shark Bay and monitored through the use of compulsory logbooks. However, since 1996, the commercial take of this species has been prohibited except for a minor catch taken by the beach-seine and mesh-net fishery (Department of Fisheries 2011). The charter sector has historically taken only small catches, with the introduction in 2001 of mandatory reporting of daily fishing activities through a logbook program (Department of Fisheries 2011).

The ongoing promotion of the region as a World Heritage Area encouraged greater levels of tourism (Buckley 2004; Hughes *et al.* 2007; McCluskey 2008) and, consequently, recreational fishing pressure. However, no monitoring of the recreational sector was considered until the community began raising concerns over their observations of large quantities of pink snapper landed at Monkey Mia in the mid-1990s (Jackson and Moran 2012). Fishery-independent assessments of pink snapper within the inner gulfs of Shark Bay in 1997 and 1998 confirmed that there was a need for immediate remedial action to allow stocks to rebuild as a result of recreational over fishing (Stephenson and Jackson 2005). Driven by the need to reduce and then maintain the recreational-fishing pressure within sustainable levels, several management measures were progressively enacted (Mitchell *et al.* 2008), and a research monitoring program and annual surveys of boat-based recreational fishing were implemented to monitor the effectiveness of fisheries regulations.

The first comprehensive 12-month onsite creel survey of boat-based recreational fishing commenced in 1998 and such surveys were repeated almost every subsequent year (Table 2). The objective of these surveys was to collect a time series of estimates of boat-based recreational fishing effort and catches of pink snapper and other key species to provide input to the assessments and advice for management of these species within the three inner areas of Shark Bay. The present paper describes the trends in the estimates of boat-based recreational catch and effort in Shark Bay over a decade, comparing these estimates with catches from the commercial and charter sectors. These analyses enabled the determination of the influence of the changes in management arrangements within Shark Bay over time.

Materials and methods

Location surveys

Shark Bay is located in the central coast of Western Australia (Fig. 1). It is a large, semi-enclosed marine embayment covering $\sim$14 000 km^2 (Nahas *et al.* 2003), with an average depth of 9 m. The waters of Shark Bay are generally deeper (20 m) north of Denham Sound and the Eastern Gulf and shallower in Freycinet Estuary ($<$15 m) and the Hamelin Pool nature reserve ($<$10 m) (Nahas *et al.* 2003). Three major boat ramps are used by recreational fishers to access the inner gulfs of Shark Bay, one is located at Denham within Denham Sound, one at Nanga in Freycinet Estuary and one at Monkey Mia in the Eastern Gulf (Fig. 1).

Survey design and analysis

Between 1998 and 2010, 11 boat ramp-based creel surveys were undertaken (Table 2). Each survey was designed to provide estimates of the boat-based recreational fishing effort and catches taken by line fishing over a 12-month period. On two occasions (in 2002 and 2007), surveys overlapped by a few months and, to obtain estimates for each of the overlapping 12-month period, the data in these overlapping months were employed in the separate analyses undertaken to estimate catch and effort for each of the overlapping periods (Table 2). The bus-route method, which was used for these surveys, requires that survey interviewers visit all boat ramps within the route on each sampled day (Robson and Jones 1989; Jones *et al.* 1990). The primary sampling unit (PSU) for the bus-route survey was the sampling day, which was randomly selected from all days within the stratum, i.e. the month.

The design of the survey for the bus route, consisting of the three major boat ramps in Shark Bay, specified the random order in which the boat ramps were to be visited, the random direction of travel around the bus route, and the amount of wait time to be spent at each ramp. Pollock *et al.* (1994) advised that the interviewer must adhere strictly to the schedule of visits. In practice, a small amount of implementation error occurred in the surveys and, accordingly, the wait time for each visit was determined from the start and end times at the boat ramp, each of which was recorded by the interviewer. The numbers of vehicles and associated boat trailers parked at each ramp at both the start and end of the visit were recorded, together with data

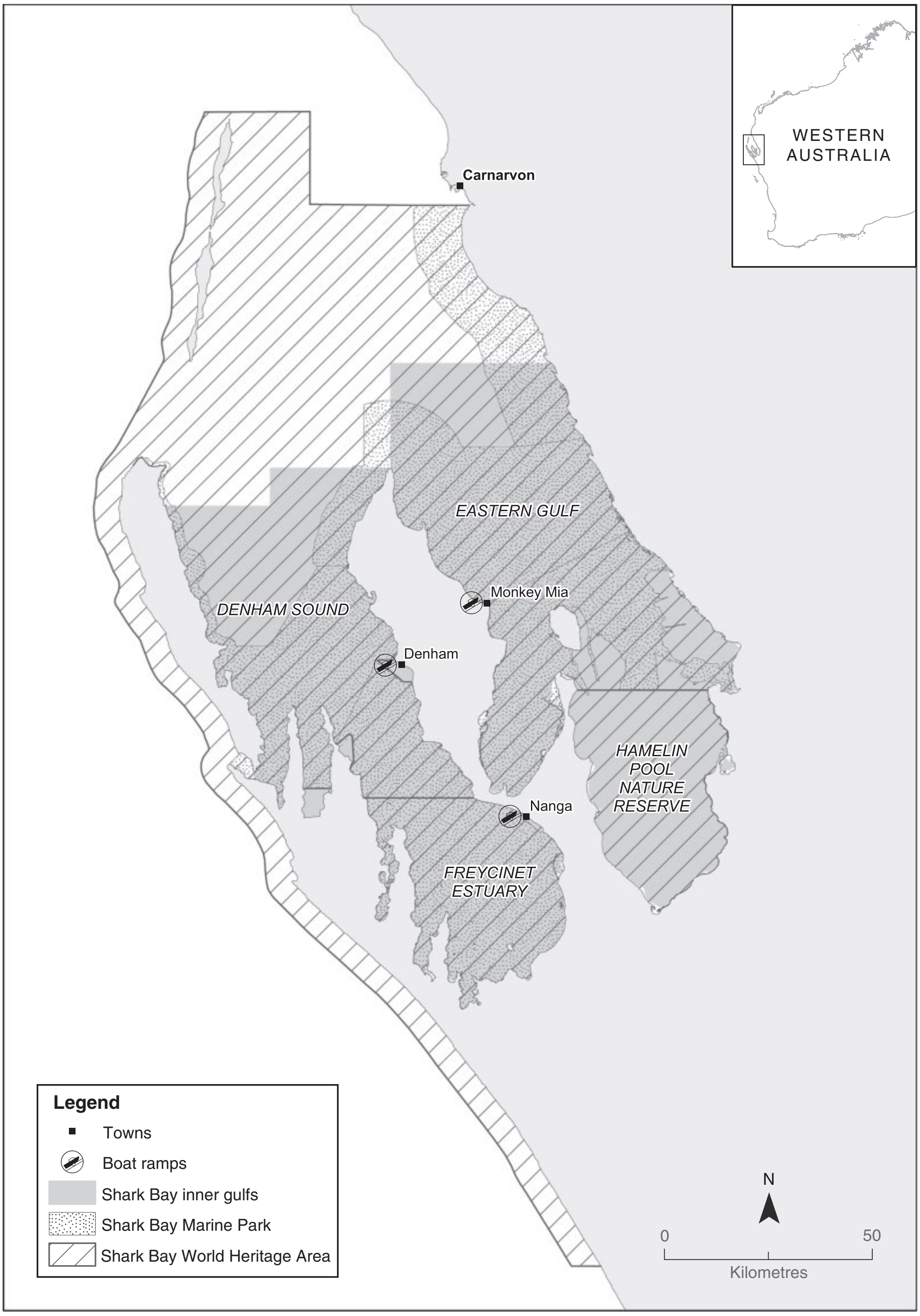

Fig. 1. Map of the Shark Bay, showing the boat-ramp locations and the Western Gulf including Denham Sound, Freycinet Estuary and the Eastern Gulf.

relating to launches and retrievals of boats during the wait time at each ramp. The surveys of recreational fishing occurring at the boat ramps were undertaken between 1100 hours and 1800 hours, except in 2010, when the start time was scheduled to commence 1 h earlier, at 1000 hours. The decision to use a daily survey period from 1100 hours to 1800 hours was based on discussions with regional fisheries and marine officers, local community members and results from a pilot survey carried out

Table 1. Chronology of the management of pink snapper in Shark Bay

t = tonnes, rec. = recreational, com. = commercial, TAC = total allowable catch; quota tags are the management tool to allocate the TAC in Freycinet Estuary. Refer to Jackson and Moran (2012) for more detailed explanation of management changes

1950s–1970s	Minimum size limit of 380 mm; 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 410 mm.
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 450 mm.
1997	Western Gulf: minimum size limit increased to 450 mm; daily bag limit reduced to four pink snapper, with only two individuals >700 mm. Eastern Gulf: pink snapper fishery (rec. and com.) closed in May, then reopened July; daily bag limit reduced to two pink snapper individuals per person; slot size limit 500–700 mm.
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 500 mm, with only one pink snapper >700 mm. 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 size limit 500–700 mm. Denham Sound: TAC 10 t (8 t rec.; 2 t com.). Freycinet Estuary: TAC 5 t (3.8 t via 900 rec. lottery quota tags; 1.2 t com. via 300 quota tags); spawning season closure (15 August – 30 September). Eastern Gulf: moratorium lifted in March; TAC 15 t (12 t rec.; 3 t com.); spawning-season closure (1 April – 31 July).
2005	Research and management reviewed and regulations updated for 2006–2008.
2006	Denham Sound: TAC increased to 15 t (12 t rec.; 3 t com.). Freycinet Estuary: rec. lottery quota tags increased to 1050 and com. 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.

Table 2. Shark Bay recreational survey dates

Survey year	Time period
1998–1999	1 April 1998 to 31 March 1999
2000–2001	1 May 2000 to 30 April 2001
2001–2002	1 May 2001 to 30 April 2002
2002	1 January 2002 to 31 December 2002
2003	1 January 2003 to 31 December 2003
2004	1 January 2004 to 31 December 2004
2005	1 January 2005 to 31 December 2005
2006	1 January 2006 to 31 December 2006
2007	1 January 2007 to 31 December 2007
2007–2008	1 April 2007 to 31 March 2008
2010	1 January 2010 to 31 December 2010

in 1996 (Sumner and Steckis 1999). This information confirmed that few vessels were retrieved at the boat ramps before 1100 hours, that most activity occurred in the later part of the day, and that most recreational boats had returned to the boat ramps by 1800 hours.

Interview staff remained essentially constant, with a total of five staff over the 12.5 years and with considerable overlap when staff left or joined the survey team. Interviewers were required to interview as many returning recreational boat parties as possible (Robson and Jones 1989). When several boats returned to the ramp at the same time, the interviewers randomly chose which of the boat parties to interview but recorded all parties returning to the access point. Although the interview questionaries used for data collection were modified slightly over time to collect supplementary data, the essential information required for analysis remained consistent (Sumner *et al.* 2002; Marriott *et al.* 2012). Data collected by interviewers included boat launch and retrieval times, number of fishing lines, location of fishing activity (5×5 nautical-mile blocks), number of persons in the party, time spent fishing and number of individuals of each fish species that were caught and either retained or released. When time permitted, the lengths of fish were recorded.

The interval count method, based on counts of vehicles and associated boat trailers (Pollock *et al.* 1994), was used for the Shark Bay surveys because fishing effort in this region was relatively small, few interviews were expected, and it was reasonable to attribute parked vehicles and their associated boat trailers to fishing parties. Because of the paucity of data for some months, data were stratified by season rather than month for these analyses. Data collected at the boat ramps visited within each sampling day were subsequently expanded to produce estimates of the total catch and fishing effort in the three Shark Bay areas (Denham Sound, Freycinet Estuary and Eastern Gulf) for each 12-month survey, using the methods described below.

The estimate of the total boating activity time (h) e_{dm} during the daily survey period T over all boat ramps r $(1 \le r \le R)$ on Day d $(1 \le d \le D_m)$ in Stratum m $(1 \le m \le M)$ (Jones and Robson 1991) was calculated as

$$e_{dm} = T \sum_{r=1}^{R} \frac{1}{w_{rdm}} \sum_{b=1}^{B_{rdm}} X_{rbdm},$$

and its variance as

$$Var(e_{dm}) = T^2 \sum_{r=1}^{R} \frac{B_{rdm}^2}{w_{rdm}^2} Var(\overline{X}_{rdm}), \text{ where}$$

$$Var(\overline{X}_{rdm}) = \frac{1}{B_{rdm}(B_{rdm}-1)} \sum_{b=1}^{B_{rdm}} (X_{rbdm} - \overline{X}_{rdm})^2,$$

and where X_{rbdm} is the time that Boat b ($1 \le b \le B_{rdm}$) was on the water (or the trailer associated with Boat b was at the site) during the wait time w_{rdm} of the interviewer's visit to the boat ramp. B_{rdm} is the total number of boats that were on the water during that period. If there were too few trailers at a ramp at the time of the interviewer's visit to calculate the above variance, i.e. $B_{rdm} < 2$, the estimated variance of the mean of the pooled values of X_{rbdm} across all boat ramps for Day d and Stratum m was employed in the calculation rather than $Var(\overline{X}_{rdm})$.

The proportion p_{dm} of boats that were fishing on Day d in Stratum m was estimated as

$$p_{dm} = \frac{n_{dm}^{Fishing}}{n_{dm}},$$

and, assuming a binomial distribution, its variance as

$$Var(p_{dm}) = \frac{p_{dm}(1-p_{dm})}{n_{dm}},$$

where n_{dm} represents the number of boating parties interviewed on Day d in Stratum m and $n_{dm}^{Fishing}$ is the number of these parties that had been fishing. If no boating parties were successfully interviewed on Day d, the estimate of the proportion fishing during Day d, and its variance, were derived from the pooled interview data over all surveyed days for the stratum.

An estimate of the total fishing time e_{dm}^f during the survey period T on Day d for Stratum m was calculated as

$$e_{dm}^f = p_{dm} e_{dm},$$

where the variance of e_{dm}^f is calculated using the formula for the variance of a product presented by Goodman (1960), i.e.

$$Var(e_{dm}^f) = (p_{dm}e_{dm})^2 \times \left[\frac{Var(p_{dm})}{p_{dm}^2} + \frac{Var(e_{dm})}{e_{dm}^2} - \frac{Var(p_{dm})Var(e_{dm})}{(p_{dm}e_{dm})^2}\right],$$

which has been employed in similar access-point studies of recreational fishing (e.g. Steffe *et al.* 2008).

The total fishing time $\hat{E}_m^*$ within the daily survey period for Stratum m, over all possible survey days, was calculated as

$$\hat{E}_m^* = \frac{D_m}{d_m} \sum_{d=1}^{d_m} e_{dm}^f = D_m \bar{e}_{dm}^f,$$

and its variance as

$$Var(\hat{E}_m^*) = \frac{D_m^2}{d_m(d_m-1)} \left[\sum_{d=1}^{d_m} \left(e_{dm}^f - \frac{1}{d_m}\sum_{d=1}^{d_m} e_{dm}^f\right)^2\right] \times \left[\frac{D_m - d_m}{D_m}\right] + \frac{D_m}{d_m}\sum_{d=1}^{d_m}[Var(e_{dm}^f)].$$

An adjustment factor f_m was required to extrapolate from the estimate for the survey period and, thereby, to obtain an estimate of effort that included fishing activity before the start of the daily survey period (Sumner and Williamson 1999). For each Trip t for which interview data were recorded within Stratum m, the durations (h) of the trip L_{tm}, i.e. the period between launch and retrieval, and the period between the interviewer's arrival at the boat ramp and retrieval of the boat at the ramp, L'_{tm}, were calculated. Next, the duration (h) of the overlapping period while the boat was at sea and the interviewer was at the ramp, L^*_{tm}, was calculated as the minimum of L_{tm} and L'_{tm}. The means $\bar{L}_m$ and $\bar{L}^*_m$, variances $Var(\bar{L}_m)$ and $Var(\bar{L}^*_m)$, and correlation $Corr(\bar{L}_m, \bar{L}^*_m)$ over all interviews for Stratum m were then calculated. Subsequently, the adjustment factor and its variance were calculated as

$$f_m = \frac{\bar{L}_m}{\bar{L}^*_m}, \text{ and}$$

$$Var(f_m) \approx \left(\frac{\bar{L}_m}{\bar{L}^*_m}\right)^2 \left[\frac{Var(\bar{L}_m)}{\bar{L}_m^2} + \frac{Var(\bar{L}^*_m)}{(\bar{L}^*_m)^2} - \frac{2Corr(\bar{L}_m, \bar{L}^*_m)\sqrt{Var(\bar{L}_m)Var(\bar{L}^*_m)}}{\bar{L}_m \bar{L}^*_m}\right], \text{ respectively.}$$

The total fishing time $\hat{E}_m$ for Stratum m, over all possible survey days, was then calculated by multiplying the total fishing time within the daily survey period by the expansion factor. Thus,

$$\hat{E}_m = f_m \hat{E}^*_m,$$

and its variance was

$$Var(\hat{E}_m) \approx (f_m\hat{E}^*_m)^2 \left[\frac{Var(f_m)}{f_m^2} + \frac{Var(\hat{E}^*_m)}{(\hat{E}^*_m)^2} - \frac{Var(f_m)Var(\hat{E}^*_m)}{(f_m\hat{E}^*_m)^2}\right].$$

The catch rate $\hat{R}_m$ for each stratum was estimated as the ratio of the means for catch and fishing effort (Crone and Malvestuto 1991), i.e.

$$\hat{R}_m = \frac{\sum_{b=1}^{n_m} c_{bm}}{\sum_{b=1}^{n_m} L_{bm}},$$

where n_m is the number of boating parties in the stratum that were interviewed, c_{bm} is the catch for the specific species and area within Shark Bay for which an estimate of total catch was required, and L_{bm} is the duration (h) of the fishing trip, i.e. the difference between launch and retrieval times, reported by the interviewed party in Boat b. The variance for $\hat{R}_m$ was estimated using the formula described in Kendall and Stuart (1969), as follows:

$$Var(\hat{R}_m) \approx \hat{R}_m^2 \left(\frac{Var(\bar{c}_m)}{\bar{c}_m^2} + \frac{Var(\bar{L}_m)}{\bar{L}_m^2} - \frac{2Corr(\bar{c}_m, \bar{L}_m)\sqrt{Var(\bar{c}_m)Var(\bar{L}_m)}}{\bar{c}_m \bar{L}_m} \right),$$

where $Corr(\bar{c}_m, \bar{L}_m)$ represents the correlation between $\bar{c}_m$ and $\bar{L}_m$. The mean, correlation and variance (of the mean) for catch and trip duration were calculated using standard statistical equations.

The total catch $\hat{C}_m$ for Stratum m was calculated as

$$\hat{C}_m = \hat{E}_m \hat{R}_m,$$

and, by using the formula presented by Goodman (1960, eqn 5), its variance as

$$Var(\hat{C}_m) \approx \hat{C}_m^2 \left(\frac{Var(\hat{E}_m)}{\hat{E}_m^2} + \frac{Var(\hat{R}_m)}{\hat{R}_m^2} - \frac{Var(\hat{E}_m)Var(\hat{R}_m)}{(\hat{E}_m \hat{R}_m)^2} \right).$$

The total catch over all M strata was calculated as

$$\hat{C} = \sum_{m=1}^{M} \hat{C}_m,$$

and its variance as

$$Var(\hat{C}) = \sum_{m=1}^{M} Var(\hat{C}_m).$$

Survey estimates of annual boat-based recreational catch (or effort), e.g. x and y, were compared by calculating the ratio

$$Z = \frac{|x - y|}{\sqrt{[\mathrm{SE}(x)]^2 + [\mathrm{SE}(y)]^2}},$$

which, for large sample sizes, is approximately normally distributed with mean of zero and standard deviation of 1 (Cochran 1977; Sokal and Rohlf 1981). The level of significance that was employed for all comparisons was $\alpha = 0.05$.

Commercial and charter catches

A commercial beach-seine and mesh-net fishery has operated in Shark Bay since 1941 (Lenanton 1970); however, the fishery came under formal management only in 1992. The fishery operates primarily out of Denham Sound and uses a combination of beach-seine and haul-net gear. The requirement that commercial operators in Western Australia complete and submit compulsory logbooks, thereby providing comprehensive records of catch (kg) and effort data, is monitored to ensure compliance.

The charter industry of Western Australia came under formal management in 2001, creating a licensing system aimed at regulating the industry. As a result, mandatory catch and effort data, which provide details of daily catches (number of fish of each species) and fishing effort, have been collected from this sector since September 2001. Compliance is monitored to ensure that reports are submitted by each charter-boat operator.

For comparative purposes, as commercial catches were reported only in terms of mass and not numbers of fish, the numbers of pink snapper retained in the charter logbooks and surveys of boat-based recreational fishing were converted to weight by using estimates of average fish weight that had been reported by the Department of Fisheries (2010), i.e. 2.6 kg in Denham Sound, 3.0 kg in the Eastern Gulf and 3.6 kg in Freycinet Estuary. The use of average weights in each area provides a useful means to highlight differences between the sectors; however, it should be noted that these may vary temporally as a result of strong or weak recruitment and may be affected by changing management arrangements, such as increases in size limits and bag limits, or by inadequate sample sizes.

Results

The surveys of boat-based recreational fishing were designed to sample 25–45% of days within the 12-month survey period, with 28% of days sampled during most years, except in 1998–1999 and 2007–2008, when the numbers of sample days were reduced as a result of surveying a broader region (Table 3). Over the survey period at each of the ramps in Shark Bay, consistently greater than 81% of the interviewed boating parties (Table 3) had been fishing. Non-response rates were not recorded in earlier surveys of boat-based recreational fishing; however, supplementary data collected during the 2010 survey demonstrated that fishers were very willing to cooperate with interviewers; indeed, of all of the fishing parties approached in 2012, only one declined to be interviewed.

The median wait times at each boat ramp varied little over the 12-month survey period, except where the design dictated, such that between 1998–1999 and 2002, reduced wait times were allocated to the Monkey Mia boat ramp and the Eastern Gulf was closed to fishing (Tables 1, 4, Fig. 1). Wait times were increased at Monkey Mia when the Eastern Gulf was reopened to fishing in 2003, at the expense of wait times at ramps in the Western Gulf. From 2006 onwards, wait times were increased at the Denham boat ramp.

The median number of vehicles and associated boat trailers at the Nanga and Monkey Mia ramps at the start and finish of each sampling day remained steady, ranging between zero and five, whereas the numbers at the Denham ramp varied between one and nine (Table 4). The averages of the estimated adjustment factor f_m were initially higher between 1998–1999 and 2002, ranging between 1.3 and 1.5, subsequently remaining at 1.3, before reducing to 1.1 in 2010 (Table 4).

The initial 1998–1999 boat-based recreational fishing survey produced the highest total estimated fishing-boat effort of

Table 3. Number of sample days, interviews and, in parentheses, interviews of parties that had engaged in fishing at each boat ramp for each survey in Shark Bay

Survey year	Denham ramp		Nanga ramp		Monkey Mia ramp	
	Sample days	Interviews	Sample days	Interviews	Sample days	Interviews
1998–1999	86	216 (210)	86	166 (162)	86	99 (90)
2000–2001	101	203 (190)	103	128 (123)	102	109 (88)
2001–2002	107	188 (180)	106	132 (130)	107	98 (84)
2002	101	170 (164)	101	123 (118)	101	73 (62)
2003	143	163 (156)	143	66 (61)	143	196 (178)
2004	151	217 (207)	151	63 (60)	151	259 (239)
2005	159	190 (183)	159	49 (43)	159	223 (205)
2006	163	172 (162)	161	36 (34)	162	209 (176)
2007	99	165 (151)	99	68 (65)	99	202 (173)
2007–2008	96	167 (152)	96	64 (62)	96	192 (161)
2010	126	290 (248)	126	53 (50)	126	281 (229)

Table 4. Median wait time at each boat ramp (expressed as a proportion of the total daily survey period), median numbers of vehicles and associated trailers at the start and finish of survey days at each boat ramp, and averages of the estimated adjustment factors, with s.e. given in parentheses, for each survey in Shark Bay

Survey year	Denham ramp		Nanga ramp		Monkey Mia ramp		Adjustment factor
	Wait time	Trailers start/finish	Wait time	Trailers start/finish	Wait time	Trailers start/finish	
1998–1999	0.3	6/2.5	0.3	5/4	0.2	5/1	1.5 (0.33)
2000–2001	0.3	7/1	0.3	1/0	0.2	1/1	1.3 (0.14)
2001–2002	0.3	5/1	0.3	1/0	0.2	1.5/0	1.4 (0.16)
2002	0.3	9/2	0.3	3/0.5	0.2	2/1	1.5 (0.31)
2003	0.2	7/1	0.2	0/0	0.3	4/1	1.3 (0.06)
2004	0.2	8/2	0.2	0/0	0.3	2/1	1.3 (0.14)
2005	0.2	8/3	0.2	0/0	0.3	3/1	1.3 (0.06)
2006	0.3	7.5/2	0.2	0/0	0.3	5/1	1.3 (0.12)
2007	0.3	5/3	0.2	0/0	0.3	4/1	1.3 (0.07)
2007–2008	0.3	5/3	0.2	0/0	0.3	4/1	1.3 (0.06)
2010	0.3	4.5/3	0.2	0/0	0.3	5/1	1.1 (0.03)

~70 000 fishing-boat hours in Shark Bay; estimated fishing-boat effort was substantially lower ($Z \geq 3.03$) thereafter, ranging between 37 000 and 49 000 boating hours (Fig. 2). Whereas the overall estimated fishing-boat effort was variable, effort in 2000–2001 exhibited a substantial decline ($Z = 4.67$) from the estimate for the 1998–1999 survey; a subsequent increase occurred between 2001–2002 and 2002 ($Z = 2.23$) and a less pronounced decline from the value for the preceding year was apparent in 2006 ($Z = 2.31$). Comparisons were subsequently carried out to determine whether these variations resulted from effort displacement among the three areas of Denham Sound, Freycinet Estuary and the Eastern Gulf.

Fishing-boat effort in Denham Sound was estimated at ~30 000 fishing-boat hours in 1998–1999, with a marked decline between 1998–1999 and 2000–2001 ($Z = 2.57$). Following an increased effort in 2002 ($Z = 2.09$), effort declined again in 2003 ($Z = 2.45$), remaining relatively consistent thereafter ($Z \leq 1.64$) (Fig. 2). Other than in 1998–1999, 2001–2002 and 2002, when values were similar to those for Denham Sound

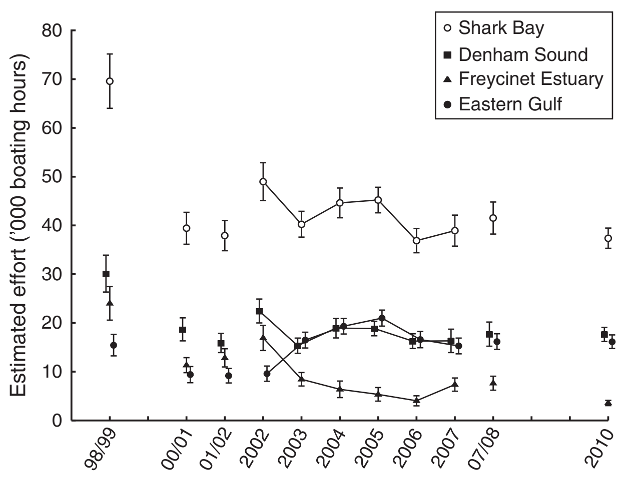

Fig. 2. Estimated fishing effort (and s.e.) in each area in Shark Bay for each survey.

($Z \leq 1.55$), estimates of fishing effort for Freycinet Estuary were consistently less ($Z \geq 2.61$) than those for Denham Sound, with ~24 000 fishing-boat hours being estimated for 1998–1999. Effort trends in Freycinet Estuary paralleled those of the latter area. The value of the estimate declined substantially in 2003 ($Z = 2.89$), with the subsequent estimates of fishing-boat effort between 2003 and 2010 being the lowest ($Z \geq 3.29$) of the three areas in Shark Bay (Fig. 2). Estimated fishing-boat effort in the Eastern Gulf in 1998–1999 was ~15 000 fishing-boat hours. This represented the lowest fishing-boat effort of the three areas in Shark Bay for this survey. As with the two areas in the Western Gulf, the estimate of fishing effort in the Eastern Gulf for 2000–2001 exhibited a marked decrease ($Z = 2.19$) from that estimated for 1998–1999, with effort remaining at this level until 2002 ($Z \leq 0.10$). However, in 2003, the estimated fishing-boat effort in this Gulf increased substantially ($Z = 3.06$), then remaining at approximately the same level in subsequent years (Fig. 2).

The estimated number of retained pink snapper in Denham Sound in 1998–1999 was ~8500 fish individuals, varying in subsequent years, before declining noticeably ($Z = 3.40$) in 2003 to a lower level (<3500 fish individuals) and remaining low thereafter ($Z \leq 1.75$) (Fig. 3). The estimated numbers of released pink snapper for this area were consistently higher ($Z \geq 4.22$) than the numbers retained (Fig. 3). From 2005 onwards, estimated numbers of released pink snapper were lower ($Z \geq 2.05$) than the numbers that had been released in the earlier years (>30 000 fish). Similar trends in estimated catches of pink snapper were also evident in Freycinet Estuary (Fig. 3), with numbers declining ($Z \geq 3.96$) from ~7000 fish individuals in 1998–1999 to greatly reduced catches (<1500 fish) from 2003 onwards. The estimated number of released pink snapper was variable and, although the estimated numbers appeared slightly higher (>11 000 fish) before 2005 than those in subsequent years (<9000 fish), there was insufficient evidence to conclude that the decrease was real. Since 2004, estimated recreational catches from Freycinet Estuary were similar to, or lower ($Z = 3.48$ for 2006 and 3.93 for 2010) than, the smaller of the catches from Denham Sound and the Eastern Gulf (Fig. 3). The estimated numbers of pink snapper retained in the Eastern Gulf were variable and lower than 1900 fish individuals and zero in 2001–2002 and 2002 when the area was closed to fishing (Fig. 3, Table 1). The numbers of released pink snapper were variable and generally lower than 26 000 fish individuals, with the number released in 2004 being higher ($Z \geq 2.42$) than the estimated numbers released for all years except 2003 and 2005 (Fig. 3).

The number of species reported for catches from Denham Sound, Freycinet Estuary and Eastern Gulf varied among surveys (Table 5). Overall, Denham Sound recorded the highest number of different species, i.e. 42–68, compared with those from the Eastern Gulf, which contained between 31 and 50 different species, and those for Freycinet Estuary, which comprised only between 14 and 38 different species. The top six species retained, identified on the basis of the top five retained species in the three areas, accounted for between 77% and 81% of the estimated retained catch and between 80% and 86% of the estimated number of released fish over all surveys (Table 6). The overall catch was dominated by pink snapper and black snapper (*Lethrinus laticaudis*), followed by whiting species (Sillaginidae), western butterfish (*Pentapodus vitta*), blackspot tuskfish (*Choerodon schoenleinii*) and tailor (*Pomatomus saltatrix*).

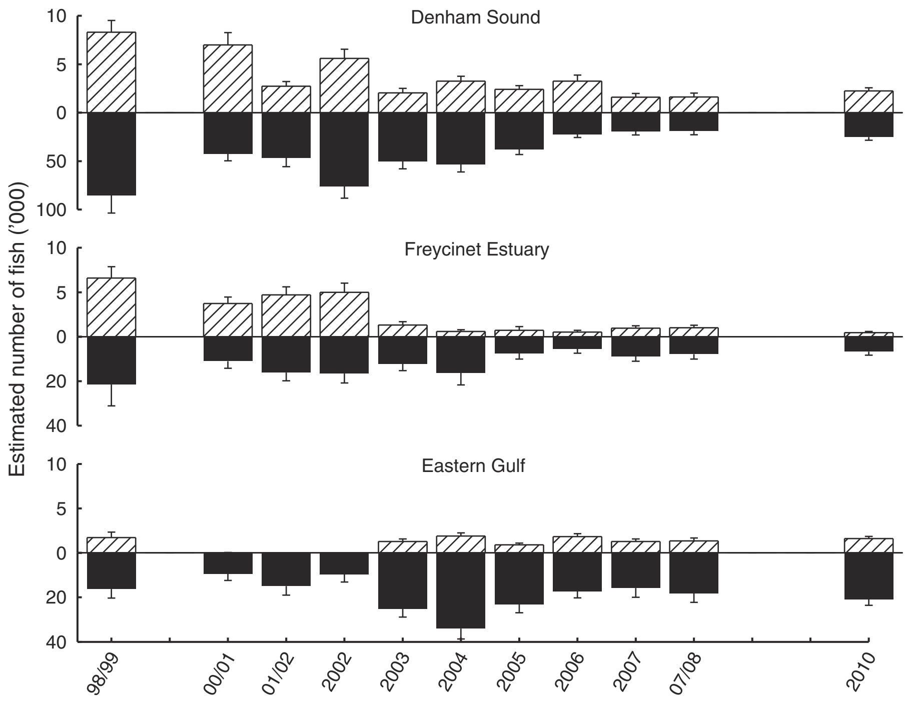

Fig. 3. Estimated number of pink snapper retained (upper) and released (lower) in each area in Shark Bay for each survey.

In Denham Sound, the estimated total number of retained and released fish was variable, but, overall, declined between 1998–1999 and 2010 (Fig. 4). Black snapper represented the highest proportion (22–45%) of retained fish over the 12.5-year period, followed by pink snapper (11–33%), with lower proportions of whiting species (2–24%), western butterfish (0–15%) and tailor (0–10%). Pink snapper accounted for the majority (42–75%) of the estimated released fish in Denham Sound, with black snapper (8–23%) and western butterfish (5–14%) being released in lower numbers over the same time period (Fig. 4). Similarly, the estimated total number of retained and released fish in Freycinet Estuary was variable, but, overall, declined between 1998–1999 and 2010 (Fig. 4). Prior to 2003, retained catches in this Estuary were dominated by pink snapper (40–66%). Subsequently, pink snapper (17–53%) and black snapper (15–35%) were retained in similar proportions in most years. The landed catches of other species, including western butterfish (0–17%), tailor (1–12%) and blackspot tuskfish (0–22%) have increased in numbers over time, to contribute higher proportions of the retained catch. The number of released pink snapper accounted for 51–83% of the released fish for Freycinet Estuary. Other species that were released included black snapper (3–19%), western butterfish (2–9%) and blackspot tuskfish (1–10%). Miscellaneous other species contributed to numbers of fish retained and released in both Denham Sound and Freycinet Estuary.

Table 5. Number of different species observed (retained and released) for each survey in the three areas of Shark Bay

Year	Denham Sound	Freycinet Estuary	Eastern Gulf
1998–1999	51	38	46
2000–2001	68	35	50
2001–2002	48	29	36
2002	42	29	31
2003	52	18	43
2004	59	24	41
2005	47	20	47
2006	49	14	39
2007	56	23	49
2007–2008	55	22	50
2010	55	17	50

The estimated total numbers of retained and released fish in the Eastern Gulf declined, initially, from high levels in 1998–1999, before increasing between 2003 and 2005, then declining and remaining relatively stable thereafter (Fig. 4). The estimated number of retained fish was dominated by black snapper (20–56%) and whiting species (1–55%), with lower numbers of pink snapper (0–12%), western butterfish (1–21%) and blackspot tuskfish (0–9%), varying among surveys (Fig. 4). The numbers of released pink snapper accounted for 30–56% of released fish in the Eastern Gulf; however, other species that comprised a high proportion of the released catch included black snapper (13–30%), western butterfish (4–11%) and blackspot tuskfish (1–8%).

A comparison of total pink snapper catches from the commercial, charter and recreational sectors, where possible, demonstrated that at least since 1998, when rigorous recreational catch data first became available, the inner gulfs of Shark Bay has been primarily an area for recreational fishing with recreational catches accounting for more than 75% of the pink snapper catches (Fig. 5).

Discussion

Surveys of boat-based recreational fishing, which were conducted in the inner gulfs of Shark Bay between 1998 and 2010, provided important information on trends in fishing activity and demonstrated that fishing-boat hours decreased by 46% over this period. Within this overall decline, it has been possible to determine the influence of the various management measures progressively introduced since the mid-1990s to reduce pink snapper catches and recreational-fishing effort. These measures included increases in minimum length, introduction of a maximum length, reductions in bag limit, a moratorium in the Eastern Gulf, a spawning closure in the Freycinet Estuary and, subsequently, Eastern Gulf, and the introduction of a TAC (Jackson and Moran 2012).

All areas within Shark Bay initially experienced major declines in boat-based recreational-fishing effort as a result of the management arrangements that were introduced in the late 1990s. The subsequent trends in fishing-boat hours varied between that exhibited in the Eastern Gulf where increasing fishing effort followed the re-opening of snapper fishery in 2003 and those of the Denham Sound and Freycinet Estuary, which showed possible signs of increasing fishing effort in 2002. In

Table 6. Percentages (with s.e. in parentheses) of the estimated total numbers of retained or released fish contributed by the six species with the greatest numbers of retained fish across all surveys in the three areas of Shark Bay

The choice of these six species was based on the selection of the five species that had the greatest retained catches in each area

Common name	Scientific name	Denham Sound		Freycinet Estuary		Eastern Gulf	
		Retained	Released	Retained	Released	Retained	Released
Pink snapper	*Pagrus auratus*	22 (2)	59 (4)	43 (4)	66 (9)	6 (1)	43 (3)
Black snapper	*Lethrinus laticaudis*	33 (3)	16 (2)	14 (3)	10 (2)	32 (3)	22 (2)
Whiting species	Sillaginidae	11 (2)	<1 (<1)	1 (<1)	0	26 (3)	2 (<1)
Western butterfish	*Pentapodus vitta*	7 (1)	8 (1)	10 (3)	5 (1)	9 (1)	7 (1)
Blackspot tuskfish	*Choerodon schoenleinii*	<1 (<1)	1 (<1)	6 (1)	4 (1)	4 (<1)	5 (1)
Tailor	*Pomatomus saltatrix*	3 (1)	<1 (<1)	7 (2)	<1 (<1)	2 (<1)	<1 (<1)
Other species		23 (2)	14 (1)	19 (3)	14 (2)	21 (2)	20 (1)

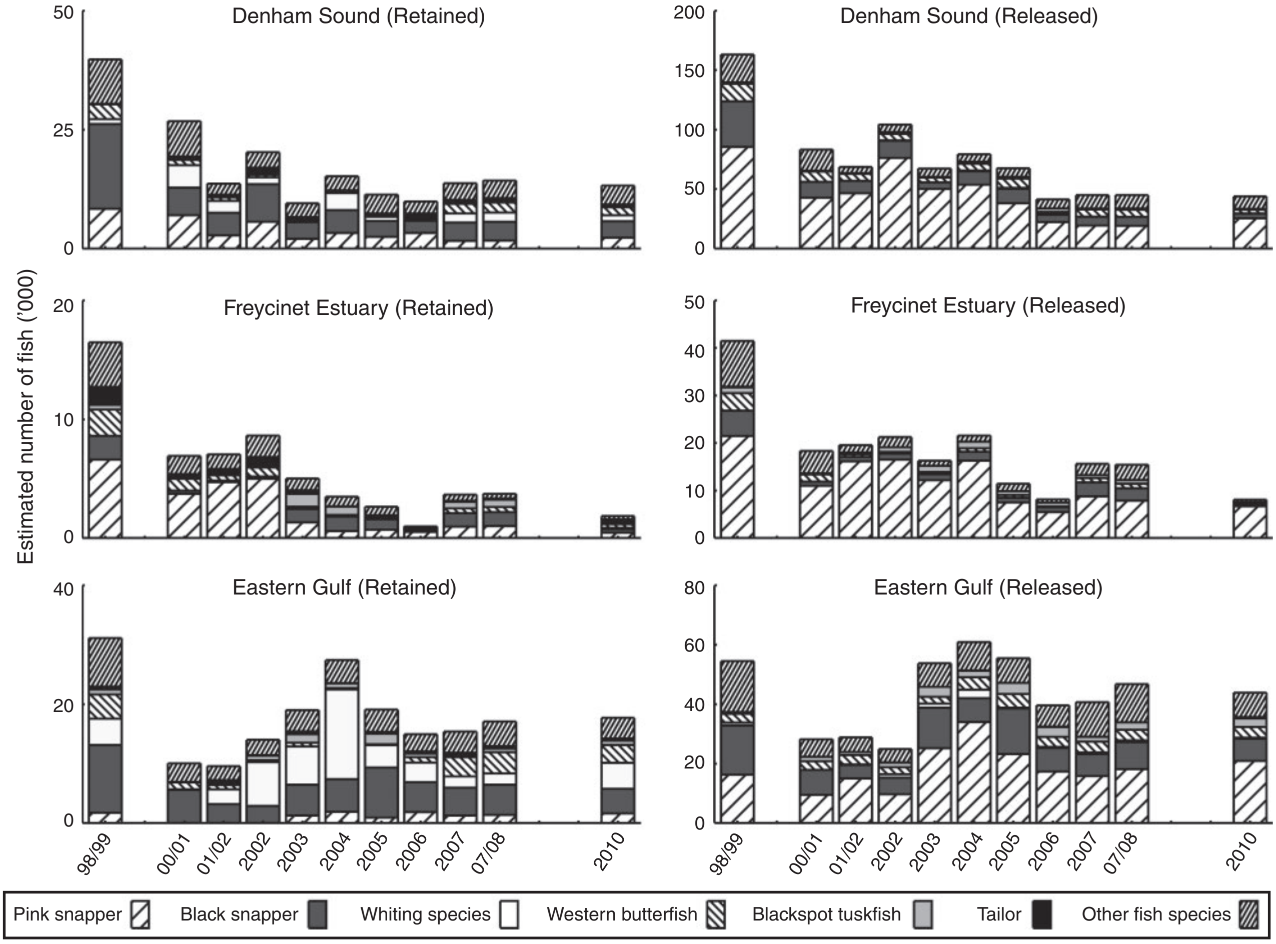

Fig. 4. Estimated number (s.e. not shown) of retained and released fish for the top six species plus other species, in each area in Shark Bay for each survey.

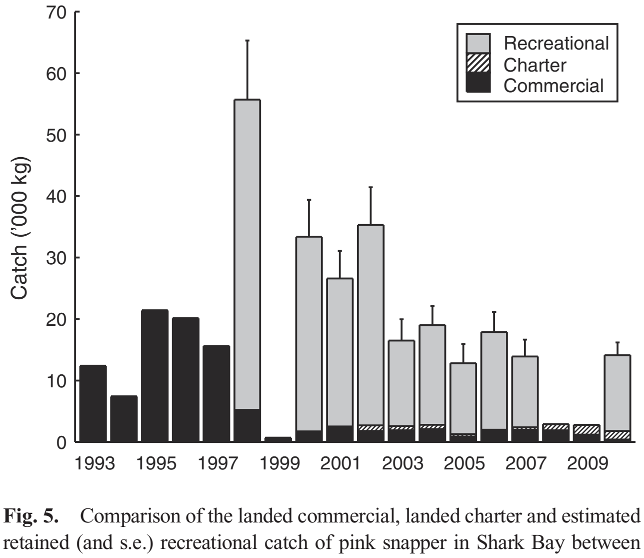

Fig. 5. Comparison of the landed commercial, landed charter and estimated retained (and s.e.) recreational catch of pink snapper in Shark Bay between 1993 and 2010. Charter catches are available only since 2002. Recreational fishing surveys are available only for 1998–1999, 2000–2001, 2001–2002, 2002–2007, 2007–2008 and 2010. Missing years represent lack of catch data rather than the absence of charter and recreational fishing. Note that surveys are matched to the calendar year that contains the majority of the same months.

2003, following the introduction of another series of restrictive management measures, fishing-boat hours in Denham Sound and Freycinet Estuary were observed to decline, before stabilising from 2003 onwards at a level lower than in 1998. In contrast, fishing effort in the Eastern Gulf appeared to also stabilise after 2003, although at a higher level than that in 1998. The changes in boat-based recreational-fishing effort in Eastern Gulf since 2003 resulted in declines in the numbers of pink snapper released compared with the pre-closure levels. The numbers of retained pink snapper from the Eastern Gulf were consistent over time, except during the moratorium. Retained catches of pink snapper from Denham Sound and Freycinet Estuary were consistently higher before the introduction of the restrictive management measures in 2003, after which they declined. The numbers of released pink snapper in Freycinet Estuary and Denham Sound exhibited similar trends over time but were substantially higher than those retained.

Understanding the changes in boat-based recreational-fishing effort and catch between 1998 and 2010 has allowed regulations to be adapted to account for changes in the behaviour of recreational fishers, that arose in response to the implementation of management measures (Metcalf *et al.* 2010). More importantly, the present study has demonstrated the value of ongoing monitoring programs, not only to understand the immediate localised impact of the management measures, but also, by ensuring that monitoring covers longer time frames over broader areas, to assess the long-term impact of the management changes over the entire region (Henry and Lyle 2003; Cooke and Cowx 2006). The design of the surveys of boat-based recreational fishing, used in the present study, was able to accommodate both scales. In Shark Bay, it was important to understand both the local scale for management of the separate pink snapper stocks in Denham Sound, Freycinet Estuary and Eastern Gulf, and also to understand the regional scale for management of multiple stocks within the whole system. Had the survey been designed for only the large regional scales, it would not have been able to provide information at the fine-scale resolution often necessary to assess fisheries at more local scales, or detect dynamic shifts in fishing effort.

The status of pink snapper in Shark Bay is determined from independent assessment of each of the three discrete stocks in the inner gulfs (Stephenson and Jackson 2005). The most recent assessments have indicated that the Eastern Gulf and Denham Sound stocks have recovered, whereas the Freycinet stock continues to slowly recover from low levels (Jackson and Moran 2012). These assessments utilise fishery-independent estimates of stock size and catch estimates from all fishing sectors, and in particular, the recreational sector that dominates the catch (Stephenson and Jackson 2005). For assessments to be reliable, it is essential to include all fishing mortality experienced by each stock, where such removals include the retained catch and estimates of the released fish that suffer mortality as a consequence of capture and release (National Research Council 2006; Lenanton *et al.* 2009). Because of the shallowness of the inner gulfs of Shark Bay, where the average depth of water is 9 m, with a maximum of 29 m (Jackson 2007), the mortality of released fish as a result of barotrauma is likely to be negligible (Lenanton *et al.* 2009). However, further research in determining mortality of released fish is critical, given the large proportion of released fish.

The implementation of ecosystem-based fisheries management (EBFM) into Western Australia requires consideration of risks to all species in these systems (Fletcher *et al.* 2010). Results of the boat-based recreational-fishing surveys in Shark Bay clearly indicate that recreational fisheries are dynamic and that pink snapper management produced regional-scale responses in the spatial distribution of recreational fishing-boat effort and the species that were targeted. This has important implications for managing World Heritage Areas because, although pink snapper is a key recreational species targeted by recreational fishers and is the dominant species released in all areas of the inner gulfs of Shark Bay, it dominates the retained catches of species only in Freycinet Estuary. Black snapper represents the highest proportion of the retained catches in both Denham Sound and the Eastern Gulf and this most likely relates to the management measures implemented, specifically, to limit the number of pink snapper retained (Jackson and Moran 2012).

In addition to pink snapper and black snapper, several other species, including whiting species, western butterfish, blackspot tuskfish and tailor, are commonly retained and released by boat-based recreational fishing in Shark Bay. A considerable number of other species were also recorded, particularly in Denham Sound and the Eastern Gulf compared with the Freycinet Estuary, possibly reflecting the higher species diversity that exists in those areas (Travers and Potter 2002). The composition of species that were retained and released varied over the study period; for example, in the Eastern Gulf, whiting species dominated the retained catch in some years. The issue of differential targeting of species is an important management issue in the inner gulfs of Shark Bay because the regulations are principally designed to restrict pink snapper catches. The recognition, resulting from these surveys, that some boat-based recreational fishers had switched to other species prompted the introduction of additional management measures for the high-risk estuary cod (*Epinephelus coioides*) and blackspot tuskfish species (Jackson and Moran 2012).

Long-term monitoring of recreational catch and effort by using consistent or comparable methods is important for the ongoing management of fish populations, particularly where a large proportion of the catch is taken by the recreational sector (Cooke and Cowx 2006; National Research Council 2006; Granek *et al.* 2008; FAO 2011). Unlike other long-term programs to obtain data relating to recreational fishing, which have used either an offsite approach (e.g. mail or phone diary survey, Pollock *et al.* 1994; Henry and Lyle 2003) or a combination of offsite and onsite methods (e.g. the USA national marine recreational fisheries statistics survey (MRFSS), National Research Council 2006), the present study is one of the first to report on the long-term on-going use of the onsite bus-route survey method. The current study employed consistent methods over all surveys, with only minor changes to improve design, and with essentially the same interviewing personnel. A benefit of onsite surveys, such as the bus-route survey, is the presence of interviewers at the ramp. The willingness of the recreational sector to cooperate with interviewers was demonstrated by low non-response rates (Essig and Holliday 1991) which were observed throughout the study and measured as a very low non-response rate in 2010.

A possible limitation of the boat-based recreational fishing survey was that only 7 h of a day could be surveyed. At the finishing time of 1800 hours, there were negligible numbers of vehicles and associated trailers remaining at the boat ramps, so the ending time of the daily survey period was considered appropriate. However, a considerable number of vehicles and associated trailers were present before the daily survey period in some survey years, possibly indicating fishing activity before the survey period. The implementation of an adjustment factor attempted to account for some of the fishing activity before the start of the daily survey period, which was considerable in earlier surveys. In recent years, as the numbers of vehicles and associated trailers at the start of the survey day decreased, the adjustment factor has reduced slightly. This was further improved in 2010, with the shift of the time of commencement of the daily survey period 1 h earlier, to 1000 hours. These results indicated that estimates obtained from recent surveys of boat-based recreational fishing are likely to represent the total fishing-boat effort and associated catch for the three ramps in Shark Bay.

Because recreational fishers can be highly selective in their fishing practises, it is important to understand variations in their behaviour. The restrictive bag limits, size limits, closed seasons, protected areas and the use of management quota tags have resulted in complex management arrangements for pink snapper in the inner gulfs of Shark Bay (Jackson and Moran 2012). However, the long-term monitoring of boat-based recreational fishing has demonstrated that, with management arrangements remaining unchanged since 2006, catch and fishing effort has been relatively stable. The present study has demonstrated that long-term monitoring of recreational fisheries provides both immediate and longer-term data on the responses by the recreational fishers to the implementation of management changes, thereby leading to the ability to adapt management measures as necessary, to ensure broader EBFM objectives to deal with the cumulative impacts within a World Heritage Area.

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