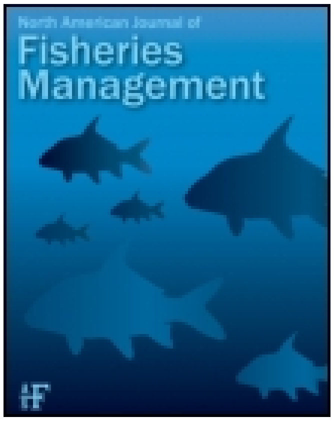

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Recreational Fishing Effort, Catch, and Harvest for Murray Cod and Golden Perch in the Murrumbidgee River, Australia

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ARTICLE

Recreational Fishing Effort, Catch, and Harvest for Murray Cod and Golden Perch in the Murrumbidgee River, Australia

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Abstract
Recreational fishery management aims to prevent species decline and provide sustainable fisheries. Overfishing has been frequently suggested as a cause of historic fishery declines within the Murray–Darling Basin (MDB), Australia, but there have been few quantitative surveys for providing fishery-dependent data to gauge status. The Murray Cod *Maccullochella peelii* and the Golden Perch *Macquaria ambigua* are important species targeted by recreational fishers across the MDB. The fisheries are controlled by size and bag limits and gear restrictions (both species) as well as a closed season (Murray Cod only). A complemented fisher survey design was used to assess the recreational fishery for both species in a 76-km reach of the Murrumbidgee River in 2012–2013. Progressive counts were used to quantify boat- and shore-based fishing effort. Catch and harvest rate information was obtained from shore-based fishers via roving surveys and from boat-based fishers via bus route surveys. Murray Cod catch rates (fish/angler-hour) were 0.228 ± 0.047 (mean ± SE; boat based) and 0.092 ± 0.023 (shore based), and harvest rates (fish/angler-hour) were 0.013 ± 0.006 (boat based) and 0.003 ± 0.001 (shore based). Golden Perch catch rates were 0.018 ± 0.009 (shore based) and 0.002 ± 0.001 (boat based), and harvest rates were 0.006 ± 0.002 (shore based) and 0.001 ± <0.001 (boat based). The Murray Cod fishery had maximal catch and harvest during the 5-month period after the closed season ended. The closed season aims to protect spawning Murray Cod, but this strategy's effectiveness may have been influenced by high fishing effort and deliberate bycatch during the closure period. To sustain and improve these MDB fisheries, we suggest quantification of catch-and-release impacts on spawning Murray Cod, provision of fish passage, re-stocking of Golden Perch, and education on fishing techniques that minimize Murray Cod bycatch during the closed season.

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Fishery exploitation has become a global management issue, with recreational and commercial fishers contributing to harvest in marine and inland waters. Commercial fishing has been suggested as a reason for fish population declines in marine fisheries (e.g., Fromentin and Powers 2005; Hilborn and Litzinger 2009). However, recreational fishing can also have a negative impact, with an estimated 12% contribution to global fish harvest (Cooke and Cowx 2004). Recreational fishing is also thought to contribute to declines in inland fish species, such as the Rainbow Trout *Oncorhynchus mykiss*, Walleye *Sander vitreus*, Northern Pike *Esox lucius*, and Lake Trout *Salvelinus namaycush* in Canada (Post et al. 2002) and the Striped Bass *Morone saxatilis* in North America (Boreman and Austin 1985). Measurement of angler impact within a fishery requires knowledge of recreational catch, harvest, and fishing effort, but such data are often lacking (Cooke and Cowx 2004).

Recreational fisher surveys of sound design and implementation are essential tools for effective fisheries management (Pollock et al. 1994). Trends derived from long-term, probability-based surveys are often used to assess exploited recreational fisheries and to determine whether management interventions are effectively rehabilitating fish populations (Kozfkay and Dillon 2010). Fisher surveys can also be used to evaluate angler attitudes toward fishing regulations (e.g., fishing closures and bag limits) and management programs (e.g., stocking and habitat restoration), thus providing information on the economic value of fishing to anglers and communities (Henry and Lyle 2003; Campbell and Murphy 2005; Wilberg 2009). If well designed, fisher surveys can also be used in conjunction with fishery-independent data to determine the contribution of recreational fishing to fish mortality (e.g., Douglas et al. 2010; Kozfkay and Dillon 2010).

The Murray–Darling Basin (MDB) is Australia's largest catchment, covering over 1 million km^2 (Barrett 2008). Fisheries within the MDB have declined markedly over the past 100 years, and native fish communities are estimated to be as low as 10% of pre-European-settlement levels (Murray–Darling Basin Commission 2003). Commercial exploitation and recreational exploitation are thought to have been major contributors to declines in many large-bodied species (Rowland 1989; Murray–Darling Basin Commission 2003). However, recovery of some MDB fish populations is evident. For example, data collected from 28 long-term monitoring sites across New South Wales (NSW) indicated that the abundance of Murray Cod *Maccullochella peelii* increased by 740% between 1994 and 2011 (D. Gilligan, NSW Department of Primary Industries, unpublished data [cited by Rowland 2013]).

Management strategies that are thought to assist recovery efforts include closure of commercial fisheries, recreational harvest restrictions, re-stocking programs, habitat restoration, restoration of fish passage, and closures to protect fish during the breeding season (see Allan et al. 2005; Lintermans et al. 2005; Barwick et al. 2014). Despite recognition that assessment of fishery sustainability is critical for management, there have been few angler surveys on MDB recreational fisheries (Hunt et al. 2011). Fishing regulations (e.g., bag limits, minimum sizes, or harvest slots) can be implemented without quantitative data to support decision making; however, the absence of data from the recreational fishery makes it difficult to ascertain whether the desired management outcomes have been achieved (Jones and Pollock 2013).

Fisheries in the MDB contribute an estimated AU$1.3 billion (i.e., 1.3×10^9) annually to the Australian economy (Ernst and Young 2011); the two main recreational target species are the Murray Cod and the Golden Perch *Macquaria ambigua* (Rowland 2005; Allen et al. 2009; Brown 2010; Hunt et al. 2010). The Murray Cod is listed by the Commonwealth of Australia as "vulnerable" under the Environment Protection and Biodiversity Conservation Act of 1999; the species is also listed as "critically endangered" according to the International Union for Conservation of Nature (Wager 1996; Ingram et al. 2011). Despite this, angling for Murray Cod is permitted throughout the species' range. Traditionally, fishers preferentially targeted Murray Cod (Rowland 1989), but effort toward Golden Perch has recently increased via activities such as species-specific fishing tournaments and due to changing angler attitudes toward catch and release (Ye 2004; Hall et al. 2012).

An Australian national survey undertaken in 2000–2001 estimated the annual catch of Murray Cod at 483,000 fish, with 77.6% of those individuals released (Henry and Lyle 2003). The same survey also estimated the annual catch of Golden Perch at 1,858,000 fish, with 44% of those individuals released (Henry and Lyle 2003). Recently, a series of surveys focusing on Murray Cod in the Murray, Goulburn, and Ovens rivers has provided annual estimates of recreational fishing effort, catch, and harvest (Brown 2010). Nevertheless, few studies have utilized fisher survey data for riverine Murray Cod and Golden Perch populations; this represents a key knowledge gap in the management of these important native species. Accordingly, our objectives were to (1) provide estimates of recreational harvest, catch, harvest rate, catch rate, and effort for Murray Cod and Golden Perch; and (2) investigate the implications of fishing activity that occurs during the closed season for Murray Cod within a river reach that is popular for recreational fishing and has previously experienced declines in native fish stocks.

METHODS

Study Site

The Murrumbidgee River is one of 23 subcatchments comprising the MDB and extends for 1,690 km from the Great Dividing Range near Canberra to its confluence with the Murray River near Boundary Bend. Discharge in the Murrumbidgee River is regulated by two large impoundments and seven weirs (Baumgartner and Cameron 2012). The study area was selected because (1) it is popular for recreational fishing; (2) it is close to the regional centers of Wagga Wagga (population 60,000), Narrandera (population 4,000), and Leeton (population 7,000); and (3) biological survey data have determined declines in native fish stocks there (Gilligan 2012). The survey reach was declared an endangered ecological community in 2001 under the NSW Fisheries Management Act of 1994, and it extends for 76 river kilometers between Berembed Weir (34°52′48″S, 146°50′13″E) and Yanco Weir (34°42′12″S, 146°25′00″E). The fisheries within these bounds were governed by size and bag limits for Murray Cod and Golden Perch; gear restrictions; and a 3-month period (September–November) during which Murray Cod harvest is prohibited (NSW Department of Primary Industries 2014).

Survey Design and Sampling Protocols

Stratified random sampling methods were used, with day (calendar date) being the primary sampling unit for all strata. The survey year extended from May 1, 2012, to April 30, 2013, and was stratified into three periods: (1) a 4-month period (May–August) prior to the implementation of the annual fishing closure for Murray Cod (hereafter, "preclosure period"); (2) a 3-month period (September–November) when the fishery for Murray Cod was closed (hereafter, "closed season"); and (3) a 5-month period (December–April) after the re-opening of the Murray Cod fishery (hereafter, "postclosure period"). The Murray Cod closed season is not a complete fishing prohibition, as other species can be harvested during this period. However, fishing methods targeting Murray Cod and the harvest of Murray Cod are prohibited during this period (NSW Department of Primary Industries 2014). Day-type stratification (weekend and weekday strata) within each of the three survey periods was also used. Public holidays were included as part of the weekend day stratum.

Three separate survey components were used: (1) progressive counts (a roving survey method) were used to quantify shore- and boat-based fishing effort originating from all public and private access points within the study reach; (2) a roving survey was used to obtain catch rate and harvest rate information from shore-based fishers; and (3) an access-point survey (i.e., two bus routes within the river reach) was used to obtain catch and harvest rate information from boat-based fishers. Two weekdays and two weekend days were surveyed per month for each survey component. Each survey day covered the period from sunrise to sunset.

The scheduling of progressive counts was independent of sample day selection for the roving and access-point surveys. Progressive count and roving survey start locations and travel direction through the study reach were selected randomly, as recommended by Hoenig et al. (1993). Progressive counts and roving surveys were performed from a boat. The time required to travel through the fishery by boat (and between boat ramps by vehicle) was determined during a pilot study. Checkpoints were used to segment the study reach into seven sub-areas. Each sub-area was allocated 45 min for the clerk to travel and count or survey fishers. To ensure even temporal coverage of progressive counts or roving surveys throughout the day, clerks stopped the counts or surveys at the end of each sub-area for a designated time (which varied according to day length) before recommencing counts or surveys in the next sub-area. Boats that were traveling along the river and fishers that were moving along the shore were specifically excluded from effort counts when it was not possible to determine their destination or their immediate intent to engage in any recreational fishing activity.

A bus route design (Pollock et al. 1994; Jones and Pollock 2013) was used to obtain unbiased estimates of the boat-based catch and harvest rates for the fishery. Two bus route surveys were used to cover the whole study reach. The first bus route encompassed four boat ramps, and the second bus route included two boat ramps. The wait time at each boat ramp (within a bus route) was assigned using estimates of expected usage that were based on the physical features of the site and prior fishery knowledge (Forbes and Asmus 2006, 2007). The six major access points used in this study do not represent the entire boat-based fishery, as fishers also used private access points and public access areas with no formed boat ramp. It was not cost effective to assess all public and private access points in the study reach, and thus it was assumed that catch and harvest rates were similar between the major access points used in our bus routes and the other, infrequently used, access points. Starting site and travel direction between boat ramps for each respective bus route were selected at random. A boat ramp on the second bus route was damaged by floodwaters and closed from May 1, 2012, to January 11, 2013, during which time no sampling was performed at that access point. No adjustment for waiting time was made to the other access point on the second bus route during that period.

All fishing parties that were encountered during the roving and bus route surveys were asked to provide information about their fishing trip and catch. Fisher catch data were defined as the total number of fish that were retained for harvest or discarded. Harvested fish were identified and measured (FL, mm) by creel clerks. Any refusal to provide information or to show harvested fish was recorded.

Estimation Procedures

Fishing effort.—The equations used are based on statistical methods and equations from Pollock et al. (1994), and are reproduced in the Supplement (available in the online version of this article). Fishing effort (angler-hours) was estimated separately for the boat-based fishery and the shore-based fishery (Pollock et al. 1994; Steffe and Chapman 2003). Daily progressive counts were multiplied by the length of the survey day to estimate the fishing effort for each survey day sampled. Fishing effort for each day-type stratum within each survey period (i.e., preclosure period, closed season, and postclosure period) was estimated by multiplying the number of possible sample days in each stratum by the mean of the daily effort estimates. Fishing effort estimates for each survey period were obtained by summing the effort estimates for the day-type strata. Annual estimates were calculated by summing the estimates for the survey periods. Variances were calculated by dividing the sample variance by the sample size and were additive when combining strata; SEs were calculated as the square root of the variance.

*Catch and harvest rates.—*The mean-of-ratios estimator was used to estimate catch and harvest from interviews based on incomplete trips for the shore-based fishery (Jones et al. 1995; Hoenig et al. 1997; Pollock et al. 1997). The mean of ratios has been shown in simulations to have a large variance when calculations include high harvest rates resulting from very short incomplete fishing trips (Hoenig et al. 1997). The truncation of short incomplete trips is recommended to reduce the variance without inducing an appreciable bias (Hoenig et al. 1997). We examined the relationship between the catch and harvest rates and the fishing trip duration for the shore-based interviews and found that the appropriate level of truncation was 20 party-minutes. Adoption of this truncation criterion resulted in the loss of 17 (11.0%) usable shore-based interviews from catch and harvest calculations.

The ratio-of-means estimator was used for estimating catch and harvest from interviews based on complete trips for the boat-based fishery (Jones et al. 1995; Pollock et al. 1997). The two bus routes were given equal weighting in the calculations of daily catch and harvest rates.

Catch and harvest rates and their variances for each survey period were calculated using weighted mean rates for each day type stratum (this was done to compensate for size differences among the day-type strata). Similarly, weighted mean catch and harvest rates and the associated variances were calculated for the annual survey period by using weighted means for each of the three survey periods (Pollock et al. 1994).

*Catch and harvest.—*Catch and harvest estimation for boat- and shore-based fisheries was performed by multiplying fishing effort by an appropriate mean daily catch or harvest rate for each base-level stratum (Pollock et al. 1994; Steffe and Chapman 2003). Catch and harvest totals for each of the three survey periods were obtained by summing the appropriate estimates across day-type strata. Annual catch and harvest were estimated by summing the estimates from the survey periods. Variances were additive when combining strata, and SEs were calculated as the square root of the variance.

*Statistical comparison.—*Differences between boat- and shore-based fisheries and differences among survey periods were tested to determine whether the observed variability was statistically significant. We used the standard method described by Schenker and Gentleman (2001),

$$\mathrm{INT} = Q_1 - Q_2 \pm 1.96\sqrt{\mathrm{SE}_1^2 + \mathrm{SE}_2^2},$$

where INT is the calculated interval; Q_1 and Q_2 are survey parameter estimates; and SE_1 and SE_2 are the standard errors of Q_1 and Q_2. Differences were considered significant ($P < 0.05$) when the INT did not contain zero.

RESULTS

In total, 440 effort observations encompassing 941 fishers were made during the survey period. Roving surveys led to successful interviews of 155 shore-based fishing parties comprising 318 fishers. Bus route surveyors successfully interviewed 81 boat-based fishing parties and 194 fishers: 27 boat-based fishing parties and 67 fishers from bus route 1; and 54 boat-based fishing parties and 127 fishers from bus route 2. One shore-based fishing party and one boat-based fishing party refused to be interviewed.

Fishing Effort

We estimated that 77,267 ± 9,333 angler-hours (mean ± SE) of daytime recreational effort were expended in the study reach, with similar effort between boat-based (52%) and shore-based (48%) fishers. Effort distribution was not uniform across periods: effort was 9,645 ± 1,580 angler-hours during the preclosure period; 19,017 ± 2,819 angler-hours during the closed season for Murray Cod; and 48,605 ± 8,756 angler-hours during the postclosure period (Table 1).

Catch Rate

The annual Murray Cod catch rate was significantly greater (standard method: INT = 0.033–0.239, $P < 0.05$) for boat-based fishers (mean ± SE = 0.228 ± 0.047 fish/angler-hour)

TABLE 1. Effort estimates (angler-hours; with SEs) for boat- and shore-based fisheries on the Murrumbidgee River, Australia, between Berembed Weir and Yanco Weir, 2012–2013.

	Boat based		Shore based		Total	
Day type	Mean	SE	Mean	SE	Mean	SE
Effort, preclosure period						
Weekday	2,036	786	1,749	643	3,785	1,015
Weekend	3,809	903	2,051	806	5,860	1,211
Total	5,845	1,197	3,800	1,031	9,645	1,580
Effort, closed season						
Weekday	1,791	526	8,264	2,249	10,055	2,310
Weekend	4,781	1,014	4,181	1,257	8,962	1,615
Total	6,572	1,142	12,445	2,577	19,017	2,819
Effort, postclosure period						
Weekday	8,583	6,036	7,685	3,822	16,268	7,144
Weekend	19,093	2,765	13,244	4,240	32,337	5,062
Total	27,676	6,639	20,929	5,708	48,605	8,756
Effort, annual						
Weekday	12,409	6,110	17,699	4,481	30,108	7,577
Weekend	27,683	3,080	19,476	4,495	47,159	5,449
Total	40,092	6,843	37,175	6,347	77,267	9,333

TABLE 2. Recreational catch rate and harvest rate estimates (fish/angler-hour; with SEs) for Murray Cod and Golden Perch taken by boat- and shore-based fishers on the Murrumbidgee River between Berembed Weir and Yanco Weir, 2012–2013.

	Murray Cod				Golden Perch			
	Boat based		Shore based		Boat based		Shore based	
Day type	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Catch rate, preclosure period								
Weekday	0.017	0.014	0.000	0.000	0.000	0.000	0.000	0.000
Weekend	0.049	0.018	0.134	0.049	0.000	0.000	0.007	0.005
Weighted average	0.026	0.011	0.038	0.014	0.000	0.000	0.002	0.001
Catch rate, closed season								
Weekday	0.030	0.035	0.051	0.033	0.000	0.000	0.000	0.000
Weekend	0.157	0.056	0.119	0.039	0.011	0.005	0.111	0.078
Weighted average	0.068	0.029	0.071	0.026	0.003	0.002	0.033	0.023
Catch rate, postclosure period								
Weekday	0.225	0.117	0.106	0.054	0.002	0.002	0.026	0.023
Weekend	1.010	0.238	0.229	0.109	0.007	0.005	0.012	0.009
Weighted average	0.490	0.112	0.147	0.051	0.004	0.002	0.021	0.016
Catch rate, annual								
Weighted average	0.228	0.047	0.092	0.023	0.002	0.001	0.018	0.009
Harvest rate, preclosure period								
Weekday	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Weekend	0.004	0.003	0.011	0.008	0.000	0.000	0.004	0.004
Weighted average	0.001	0.001	0.003	0.002	0.000	0.000	0.001	0.001
Harvest rate, closed season								
Weekday	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Weekend	0.000	0.000	0.000	0.000	0.000	0.000	0.049	0.028
Weighted average	0.000	0.000	0.000	0.000	0.000	0.000	0.014	0.008
Harvest rate, postclosure period								
Weekday	0.024	0.019	0.001	0.001	0.002	0.002	0.002	0.001
Weekend	0.043	0.025	0.012	0.006	0.000	0.000	0.012	0.009
Weighted average	0.031	0.015	0.005	0.002	0.001	0.001	0.005	0.003
Harvest rate, annual								
Weighted average	0.013	0.006	0.003	0.001	0.001	<0.001	0.006	0.002

than for shore-based fishers (0.092 ± 0.023 fish/angler-hour). There was no statistical difference between boat-based (0.068 ± 0.029 fish/angler-hour) and shore-based (0.071 ± 0.026 fish/angler-hour) catch rates for Murray Cod during the closed season. Boat-based (0.490 ± 0.112 fish/angler-hour) and shore-based (0.147 ± 0.051 fish/angler-hour) catch rates for Murray Cod during the postclosure period were greater than catch rates estimated for the closed season (Table 2). However, significant differences in Murray Cod catch rates were only found (1) between the closed season and postclosure period for the boat-based fishery (INT = 0.195–0.649, $P < 0.05$) and (2) between the boat- and shore-based fisheries (INT = 0.194–0.644, $P < 0.05$). The annual shore-based catch rate of Golden Perch (0.018 ± 0.009 fish/angler-hour) was not significantly different from the boat-based catch rate (0.002 ± 0.001 fish/angler-hour; INT = −0.002 to 0.034, $P > 0.05$; Table 2).

Harvest Rate

For Murray Cod, the annual boat-based harvest rate of 0.013 ± 0.006 fish/angler-hour (mean ± SE) was not significantly different from the shore-based harvest rate of 0.003 ± 0.001 fish/angler-hour (INT = −0.002 to 0.022, $P > 0.05$). The harvest rate for Murray Cod during the closed season was zero, as all captured fish were released (Table 2). For Golden

Perch, the annual harvest rate was significantly greater for shore-based fishers (0.006 ± 0.002 fish/angler-hour) than for boat-based fishers (0.001 ± <0.001 fish/angler-hour; INT = 0.001–0.009, $P < 0.05$; Table 2).

Catch Estimates

Estimated annual catch of Murray Cod was 27,276 ± 5,812 individuals (mean ± SE), and significantly greater catch was estimated for boat-based fishers (22,231 ± 5,525 fish) than for shore-based fishers (5,045 ± 1,814 fish; INT = 5,788–28,584, $P < 0.05$). Murray Cod catch during the closed season was 1,727 ± 473 fish, representing 6% of the total catch (Table 3). Annual catch of Golden Perch was estimated at 1,032 ± 420 individuals. Shore-based catch of Golden Perch (828 ± 405 fish) was not significantly different from the boat-based catch (204 ± 108 fish; INT = −198 to 1,446, $P > 0.05$; Table 3).

TABLE 3. Recreational catch and harvest estimates (number of fish; with SEs) for Murray Cod and Golden Perch taken by boat- and shore-based fishers on the Murrumbidgee River between Berembed Weir and Yanco Weir, 2012–2013.

	Murray Cod						Golden Perch					
	Boat based		Shore based		Total		Boat based		Shore based		Total	
Day type	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Catch, preclosure period												
Weekday	35	29	0	0	35	29	0	0	0	0	0	0
Weekend	186	81	276	143	462	164	0	0	15	11	15	11
Total	221	86	276	143	497	167	0	0	15	11	15	11
Catch, closed season												
Weekday	54	61	423	283	477	290	0	0	0	0	0	0
Weekend	751	306	499	215	1,250	374	53	27	462	340	515	341
Total	805	312	922	355	1,727	473	53	27	462	340	515	341
Catch, postclosure period												
Weekday	1,927	1,530	812	542	2,739	1,624	19	17	196	182	215	183
Weekend	19,278	5,299	3,035	1,677	22,313	5,558	132	103	155	124	287	161
Total	21,205	5,516	3,847	1,763	25,052	5,791	151	104	351	220	502	244
Catch, annual												
Weekday	2,016	1,532	1,235	611	3,251	1,649	19	17	196	182	215	183
Weekend	20,215	5,309	3,810	1,697	24,025	5,573	185	106	632	362	817	378
Total	22,231	5,525	5,045	1,804	27,276	5,812	204	108	828	405	1,032	420
Harvest, preclosure period												
Weekday	0	0	0	0	0	0	0	0	0	0	0	0
Weekend	15	10	23	17	38	20	0	0	8	8	8	8
Total	15	10	23	17	38	20	0	0	8	8	8	8
Harvest, closed season												
Weekday	0	0	0	0	0	0	0	0	0	0	0	0
Weekend	0	0	0	0	0	0	0	0	204	126	204	126
Total	0	0	0	0	0	0	0	0	204	126	204	126
Harvest, postclosure period												
Weekday	208	189	6	7	214	189	19	17	15	12	34	20
Weekend	822	482	156	94	978	491	0	0	155	124	155	124
Total	1,030	517	162	94	1,192	526	19	17	170	124	189	125
Harvest, annual												
Weekday	208	189	6	7	214	189	19	17	15	12	34	20
Weekend	837	482	179	95	1,016	491	0	0	367	177	367	177
Total	1,045	518	185	95	1,230	526	19	17	382	177	401	178

Harvest Estimates

Annual harvest of Murray Cod was 1,230 ± 526 individuals (mean ± SE). For Murray Cod, the boat-based harvest (1,045 ± 518 fish) was not significantly different from the shore-based harvest (185 ± 95 fish; INT = −172 to 1,892, $P > 0.05$). No Murray Cod were harvested during the closed season (Table 3). Annual harvest of Golden Perch was 401 ± 178 fish, with significantly greater harvest estimated for shore-based fishers (382 ± 177 fish) than for boat-based fishers (19 ± 17 fish; INT = 14–712, $P < 0.05$). Golden Perch harvest from the shore-based fishery was highest during the closed season at 204 ± 126 fish (Table 3).

Eighteen Murray Cod ranging from 350 to 740 mm FL were harvested; 78% of the harvested fish were above the current minimum legal length of 600 mm. Three of the undersized fish were harvested illegally by a single fishing party, and the fourth undersized fish was harvested by fishers who used an inaccurate measuring device. Sixteen Golden Perch ranging from 300 to 480 mm were harvested, and all were above the current minimum legal length of 300 mm. None of the fishers reached the existing daily bag limits for these species (2 fish/d for Murray Cod; 5 fish/d for Golden Perch).

Fishing mortality rates for Murray Cod are thought to be about 2% under normal recreational fishing conditions (Douglas et al. 2010) and up to 15% during catch-and-release tournaments (Hall et al. 2012). Application of these catch-and-release-associated mortality rates would add 521–3,907 fish to our estimates of Murray Cod harvest, including mortality of 35–259 Murray Cod during the closed season.

Released Component

The annual percentage of Murray Cod that were released was estimated at 95%. All Murray Cod that were caught during the closed season were released. Murray Cod release rates were 92% during the preclosure period and 95% during the postclosure period. The annual percentage of Golden Perch that were released was estimated at 61%; the release rates were 47% for the preclosure period, 60% for the closed season, and 62% for the postclosure period.

DISCUSSION

Our data suggest that an active Murray Cod fishery and a poor Golden Perch fishery exist in this reach of the Murrumbidgee River. The Murray Cod fishery had an annual boat-based catch rate of one fish every 4 h and an annual shore-based catch rate of one fish every 11 h. The Murray Cod catch rates in this reach are approximately double those recorded from similar fisheries in the Murray River (boat-based fishery: 0.12 fish/angler-hour; shore-based fishery: 0.04 fish/angler-hour; Brown 2010) and are approximately four times greater than catch rates from the Goulburn and Ovens rivers (boat-based fishery: 0.07 fish/angler-hour; shore-based fishery: 0.02 fish/angler-hour; Brown 2010). In contrast, the Golden Perch fishery in our study reach had an annual shore-based catch rate of one fish every 56 h and a boat-based catch rate of one fish every 500 h. Golden Perch catch rates were an order of magnitude lower (shore based) and two orders of magnitude lower (boat based) than catch rates recorded from Lake Keepit, NSW (0.43 fish/angler-hour; Battaglene 1985). Golden Perch are reportedly present in high abundance throughout the MDB (Ye 2004), but they did not contribute strongly to angler catches in our study reach.

With regard to Murray Cod, the increased catch rates and similar harvest rates in the Murrumbidgee River compared with the Murray, Goulburn, and Ovens rivers (Brown 2010) suggest a more productive Murrumbidgee River system. Survey observations from the present study indicated that Murray Cod releases were predominantly due to the fish being undersized, thus supporting the idea that the higher catch rates and similar harvest rates may be related to greater numbers of fish below the minimum legal length in the Murrumbidgee River. The undersized fish may be the result of increased spawning and recruitment after cessation of a decade-long drought (Morrongiello et al. 2011) or the augmentation of fish numbers from stocking, as has been observed in North American salmonids (Moring 1993). Research on the source of Murray Cod recruitment in the Murrumbidgee River is required to determine whether local populations are self-sustaining or augmented.

The closed season is intended to protect breeding Murray Cod and was introduced as a result of biological data demonstrating that (1) the handling of Murray Cod prior to spawning results in egg resorption (Rowland 1988) and (2) Murray Cod are more susceptible to capture during the spawning period (Rowland 2005). We found that closed-season catch rates of Murray Cod were moderate, which does not support increased capture susceptibility during the closure. However, there was still a considerable amount of fishing effort during the closed season, which could negatively impact Murray Cod populations. Closed-season effort was less than half that estimated for the postclosure period. However, the closed season attracted more than double the effort associated with the preclosure period. Some closed-season effort could be attributed to fishers preferentially targeting Golden Perch and to an increase in fishing activity because of more favorable (warmer) climatic conditions. However, given the low catch rates of Golden Perch, the increased effort during the closed season was more likely related to fishers' desire to go fishing and practice catch and release of Murray Cod, and they were either unaware of or ignored the negative impacts of this fishing method. To reduce Murray Cod bycatch during the closed season, some fishers may be changing to baits and lures that are better suited to Golden Perch, but a corresponding effort reduction was not evident in our study. Rowland (1983) suggested that male Murray Cod guard their nests from spawning until hatch. Furthermore, when disturbed, males of the closely related Eastern Cod *Maccullochella ikei* abandoned their nests prior to hatch; in some cases, the male did not return to the nest, and the eggs were subsequently consumed by predators (Butler and Rowland 2009). If similar behavior is exhibited by Murray Cod, then deliberate bycatch (even with 100% catch and release) during the closed season could cause reductions in breeding and recruitment success. Given that the levels of fishing effort in our survey reach were similar between open and closed seasons, the catch of Murray Cod is inevitable and could influence breeding success (Douglas et al. 2010; Hall et al. 2012) through nest abandonment. Accordingly, the effectiveness of the closed season for protecting Murray Cod spawners was reduced; therefore, research to quantify the impacts of catch-and-release fishing on spawning Murray Cod is of priority. In addition, targeted programs that educate fishers on the potential impacts of catch-and-release fishing on fish populations may positively influence spawning outcomes for affected species.

Fishing mortality associated with catch-and-release fishing requires consideration for improved management of species with high release rates (Douglas et al. 2010). The percentage of Murray Cod released in our study (95%) was greater than the 77.6% release rate identified during a nationwide survey (Henry and Lyle 2003) and was also greater than the 90.0% release rate reported for the Murray, Goulburn, and Ovens rivers (Brown 2010). Application of Murray Cod fishing mortality rates demonstrated that catch-and-release fishing could generate additional mortality in excess of our harvest estimates. We identified that no Murray Cod were harvested during the closed season, but based on previous work the postrelease mortality during this period could be up to 21% of the harvest estimate (Douglas et al. 2010; Hall et al. 2012). Postrelease mortality associated with recreational fishing has been highlighted as a global concern, with analogies drawn to bycatch discards in commercial fisheries (Cooke and Cowx 2004). Accordingly, it is important for fishery managers to consider this potential additional source of fishing-related mortality, particularly for fisheries with high release rates of target species, such as that observed for Murray Cod in the current study. Future research could extend the current knowledge of fishing mortality rates by quantifying the effects of environmental factors, multiple instances of catch and release, and fish handling behaviors.

The Golden Perch is a migratory species (Reynolds 1983). These fish aggregate below instream barriers (Baumgartner 2007), where they are particularly targeted by shore-based fishers (e.g., Forbes and Asmus 2006, 2007). The low estimates of Golden Perch catch in the present study could be due to a range of factors, such as poor recruitment, overfishing, or impediments to movement (e.g., the Berembed and Yanco weirs; Ye 2004; Baumgartner 2007; Hall et al. 2012). However, the low estimated catch of Golden Perch could also have resulted from anglers' use of methods and equipment that were selective for Murray Cod. Fishery-independent electrofishing data indicated that during the survey period, Golden Perch comprised 18% and Murray Cod constituted 59% of the total number of large-bodied native fish in the survey reach (J. P. Forbes, unpublished data), which indicates that Golden Perch are more abundant than catch estimates suggest. Despite this, Golden Perch are generally found in greater abundance than Murray Cod throughout most catchments of the MDB (Gilligan 2005), thus supporting the view that the study area had a poor Golden Perch fishery. As such, consideration should be given to recovery initiatives, such as re-stocking and provision of fish passage, in order to increase the Golden Perch population.

Based on the present results, we identified that the effectiveness of the closed season in protecting Murray Cod spawners was reduced due to continued fishing effort for and bycatch of this species during the closure. In addition to providing effort, catch, and harvest metrics, we have offered recommendations for sustaining and improving the Murray Cod and Golden Perch fisheries. Specifically, we suggest (1) research to quantify the impacts of catch-and-release fishing on spawning Murray Cod, (2) consideration of additional fishing-related mortality caused by catch-and-release fishing, (3) provision of fish passage in the study area, (4) re-stocking of Golden Perch, and (5) targeted education programs on fishing gear and techniques that minimize Murray Cod bycatch during the closed season.

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