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Implementation of a harvest slot for Murray cod: Initial impacts on the recreational harvest in a manmade reservoir and comparison to riverine fisheries

Jamin Forbes[1], Aldo Steffe[2], Robyn J. Watts[1], Lee J. Baumgartner[1], Paul Brown[3], Jason Thiem[1,4], Nathan G. Miles[4]*

1 Institute for Land, Water and Society, Charles Sturt University, Albury, New South Wales, Australia

2 Fishing Survey Solutions, Kogarah Bay, New South Wales, Australia

3 Fisheries and Wetlands Consulting and La Trobe University, Mildura, Victoria, Australia

4 Department of Primary Industries, Narrandera Fisheries Centre, PO Box 182, Narrandera, New South Wales, 2700, Australia

* Corresponding author. Email: Nathan.Miles@dpi.nsw.gov.au

Abstract

Freshwater reservoirs support valuable commercial and recreational fisheries resources worldwide. Recreational fisheries in reservoirs are commonly managed using length-based harvest regulations, although empirical data is required to ensure these regulations are fit-for-purpose and that any changes do not result in negative population responses. Following a change from a 600 mm minimum legal length to a 550–750 mm harvest slot (HS) limit for both reservoir and river based recreational fisheries for Murray cod, *Maccullochella peelii*, we used a stratified random sampling design to assess the summer recreational fishery in Lake Mulwala, an important reservoir fishery. Specifically, we assessed the immediate effects of the HS on angler effort, catch and harvest in this fishery. Standardised parameters based on data from existing angler surveys were also used to investigate variability among fisheries for Murray cod. We found that (1) in Lake Mulwala, more than 50% of Murray cod harvested after the introduction of the HS were between 550 and 600 mm; (2) boat-based anglers almost exclusively targeted Murray cod and harvested more and larger fish than shore-based anglers; (3) the Murray cod population was severely truncated with high mandatory discard rates (93.7% for boat fisheries and 99.8% for shore fisheries) of fish below the lower HS limit; (4) standardised parameters varied among waterbodies, and comparatively higher effort, discard and harvest densities were observed in the reservoir fishery. The reliance on newly harvestable Murray cod in Lake Mulwala highlights the need for early and ongoing monitoring of regulatory changes across riverine and reservoir environments, encompassing both social and biological aspects of the fishery.

Introduction

The impoundment of rivers and the formation of reservoirs provide a range of unique opportunities for fisheries, leisure activities, aquaculture and irrigation for agriculture (Mosisch and Arthington 1998; Renwick 2001; Hutt et al. 2013). Reservoir based commercial and recreational fisheries are highly valuable both socially and economically in many of regions worldwide (De Silva and Sirisena 1989; Ambak and Jalal 2006; Loomis and Ng 2012). The success of reservoir fisheries is often related to higher growth rates in these artificial habitats than in natural rivers and streams (Wilde and Sawynock 2005; Forbes et al. 2015a). Reservoir fisheries can also alleviate pressure on wild riverine stocks and provide a reliable resource for anglers. However, many reservoirs are constructed for reasons other than recreational fishing and leisure activities, thus creating a conflict between users and stakeholders (Mosisch and Arthington 1998). The quality of reservoir fisheries are often influenced by these conflicting uses and the use of reservoir waters for their intended purposes, such as drinking water or irrigation, which may conflict with fisheries management goals.

A key regulatory tool available for managers of reservoir fisheries are length-based harvest regulations, which are widely used in recreational and commercial fisheries management (Gwinn et al. 2015). Harvest slot (HS; harvest of intermediate sized fish) regulations are considered especially effective at achieving fishery objectives when the harvest numbers and numbers of trophy fish captured are more important to anglers than total yield or harvest of trophy fish (Gwinn et al. 2015). However, changes to harvest restrictions, such as a transition from a minimum legal length (MLL) to a HS, can influence the structure of a fish population in ways that may not be favourable to all angling groups (Allen et al. 2013; Gwinn et al. 2015). Furthermore, a change in legal length may affect the distribution of effort, such that anglers move to or from a particular fishery depending on the perception of angling success (Boxrucker 2002). As a result, sound scientific monitoring is required throughout all stages of regulatory change (Cooke et al. 2015; Arlinghaus et al. 2016). This monitoring requires understanding of initial changes in angler effort and harvest, and how these aspects develop or adapt over time and the subsequent impact on the fishery (Allen and Pine 2000; Stone and Lott 2002).

In Australia's Murray-Darling Basin, Murray cod, *Maccullochella peelii*, is a major recreational target species (Brown 2010; Hunt et al. 2010; Forbes et al. 2015c) because of its large size and edibility (Rowland 2005). Murray cod populations have exhibited a historic decline partly caused by recreational and commercial exploitation, as well as catchment development and river regulation (Rowland 1989; Reid et al. 1997). Despite the previous decline, recovery at the state jurisdictional level is apparent (Rowland 2013; West et al. 2016), and NSW and Victoria agencies continue to support increased opportunities to participate in recreational fishing for this species. Artificial reservoirs are particularly important in the recovery of Murray cod fisheries. In Australia, more than 84 million native and introduced fish were stocked between 2009 and 2015 for recreational benefit, thus resulting in several put-and-take fisheries that are beneficial to the economy in many regional areas (Hunt and Jones 2018). This effort has included removal of state-wide seasonal spawning closures in selected reservoirs (e.g., Copeton Dam, Blowering Dam and Lake Eildon) where Murray cod populations rely on stocking with little or no natural recruitment (Forbes et al. 2015b).

A length-based harvest restriction for Murray cod was re-established in 1992 with a MLL of 500 mm in New South Wales (NSW), Australian Capital Territory (ACT) and Victoria across all river and reservoir environments (Lintermans 2004; Koehn and Todd 2012). This restriction was followed by the additional regulation of allowing harvest of one fish over 750 mm in Victoria and 1000 mm in NSW (Lintermans 2004; Koehn and Todd 2012). The MLL was then changed from 500 to 600 mm in 2010 in NSW. In Queensland, a 600 mm MLL and 1100 mm maximum size limit currently exist, and South Australia has a limited catch-and-release season for Murray cod with no harvest permitted. The states of NSW, ACT and Victoria introduced a 550–750 mm HS in 2014. The change was enacted to provide spawning opportunity before harvest eligibility for smaller fish; to protect larger, more fecund fish; and to decrease truncation in length around the minimum length limit (Nicol et al. 2004; Koehn and Todd 2012; Gwinn et al. 2015).

Information collected from fishery dependent surveys, such as effort, discard and harvest, are commonly used to inform aspects of fishing quality and the relative success of management strategies such as length-based harvest regulations imposed on recreational fisheries (Kozfkay and Dillon 2010; Hunt et al. 2011). Combining these basic fishery metrics with the behavioral dynamics of anglers (e.g., species targeted fishing, preferences for harvest or catch-and-release, and fishing gear used) increases the understanding of factors that drive variability and change within recreational fisheries, thus potentially leading to improved management (Johnston et al. 2012; Arlinghaus et al. 2013). In this regard, it is important to compare effort, harvest, discard and targeting preference/proportion of harvest from each species across different waterbody types to determine variability in the fishery over larger geographical areas. However, creel surveys are seldom conducted for Australian freshwater recreational fisheries, thus hindering examination of change before and after HS introduction. Nevertheless, collection of baseline fishery data at the onset of regulatory change are valuable and contribute to quantifying long-term effects (Cooke et al. 2015).

In this regard, the objectives of this study were to (1) quantify the levels of daytime shore-based and boat-based fishing effort, harvest and discard, targeting practices, fishing methods and reasons for releasing/discarding fish in Lake Mulwala after the introduction of the HS; (2) evaluate the HS effectiveness to sustain recreational harvest in Lake Mulwala, given the biology of Murray cod and the management of the reservoir; and (3) examine aspects of the recreational fisheries (catch, effort and harvest practices) in Lake Mulwala, Murrumbidgee River and Murray River using standardised parameters to evaluate variability among these fisheries. This study will also provide harvest and catch rate information on which future comparisons can be made.

Methods

Study site

Lake Mulwala (36º00'22"S; 146º00'11"E) is an impoundment on the Murray River in south-eastern Australia, which was formed in 1939 by the construction of Yarrawonga Weir. Lake Mulwala covers an area of 3,561 ha, and has a capacity of 118,000 ML (Murray-Darling Basin Commission 2004). Habitat within the lake includes large amounts of dead standing and fallen hardwood trees, extensive beds of *Egeria densa*, macrophytes and remnant (inundated) river channels (Koehn 2009), as well as wetlands around the lake margins (Howitt et al. 2004). The lake forms part of the state border between NSW and Victoria, and it is used to store and resupply water for irrigation (Howitt et al. 2004). The lake has become an important recreational area supporting waterskiing, swimming, boating and recreational fishing (Howitt et al. 2004). The management of the lake for irrigation purposes and the lowering of water levels has raised community concerns about its impact on amenities and recreational uses (Howitt et al. 2004).

Lake Mulwala is one of Australia's premier recreational fisheries for Murray cod, hosting regular fishing tournaments that attract thousands of anglers (Kearney and Kildea 2001; Howitt et al. 2004; Koehn and Clunie 2010; Hall et al. 2012). The Murray cod population in the lake showed evidence of decline under a minimum legal size of 500 mm (Howitt et al. 2004). The impoundment is thought to be an important nursery ground for cod populations in surrounding rivers (Howitt et al. 2004).

Survey design and sampling protocols

To quantify fishery metrics for Murray cod within Lake Mulwala, we used a stratified random sampling design with day (calendar date) as the primary sampling unit (PSU) for all strata. Each survey day covered the period from sunrise to sunset. Night fishing (sunset to sunrise) was not included in the sampling design. The temporal survey frame was the three month summer season; 1 December 2014 to 28 February 2015. The season was stratified into two periods: (1) the month of December, during which the Murray cod fishery opens after a three month fishing closure (termed summer-early period); and (2) a two month period (January and February; termed summer-late period) to accommodate the expected high fishing effort and catch resulting from the reopening of the Murray cod fishery in December and subsequent school holidays. Thus, our survey covered the most intensively fished part of the year. Day-type stratification (weekend and weekday strata) within each survey period was also used. Public holidays were included as part of the weekend day stratum. Thus, the base-level strata were day-type (weekday, weekend), within period (summer-early, summer-late) and within season (summer). Four weekdays and four weekend days were sampled in summer-early, and three weekdays and three weekend days were sampled in summer-late. Sampling days were randomly selected within each survey period.

Progressive counts from a boat were used to quantify the shore- and boat-based fishing effort originating from all public and private access points within the fishery. Progressive count start locations and travel direction through the fishery were randomly selected (Hoenig et al. 1993). A pilot study was used to determine the time required to travel through the fishery, and 3 hours was allocated to complete a progressive effort count. Each survey day was divided into four non-overlapping intervals, and a progressive count was randomly allocated without replacement (within each base-level stratum) to one of the four intervals. We specifically excluded traveling boats and anglers moving along the shore from effort counts when their destination or their immediate intent to engage in any recreational fishing activity could not be determined.

A roving survey was used to obtain catch-and-release rate and harvest rate information from shore-based anglers. The roving surveys were undertaken on the same days as the progressive counts for fishing effort, but they did not cover the interval of the progressive count. The roving survey travel direction for each survey day was randomly selected, and the start location was the termination point of the progressive effort count. The roving surveys covered at least one complete circuit of the fishery during each survey day.

An access point survey was used to obtain catch-and-release rate and harvest rate information from boat-based anglers. Eleven access points (public boat ramps) were identified. Information about the physical features of the access points; prior knowledge of the fishery; and the expert opinions of maritime and fishery compliance officers, local fishing guides and tackle store owners were used to categorize each access point as either high or low usage. Unequal probability sampling was then used to allocate two access points for coverage on each survey day; with the exception of 6 December 2014, when three ramps were sampled to improve coverage of a large boat-based fishing tournament. The daily selection probability for each of the three high usage access points was 0.3, and each of the eight low usage access points was assigned a daily selection probability of 0.0125. It was not cost effective to cover private access points during the survey. We assumed that the behaviors of anglers using private and public access points were similar.

All fishing parties interviewed during the roving and access point surveys were asked to provide information about their fishing trip and catch. These data included (a) trip duration, (b) primary target species of the fishing party, (c) the number and species that were caught-and-released, (d) the reason why those fish were released and (e) the fishing method. 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

All calculations for determining estimates of catch and effort were based on statistical methods and equations from Pollock et al. (1994) and (Forbes et al. 2015c).

Fishing effort

Fishing effort (party hours) was estimated separately for boat- and shore-based fisheries. Daily progressive counts were multiplied by the length of the survey day to estimate the fishing effort for each day sampled. Fishing effort estimates for each base-level stratum were made by multiplying the number of possible sample days in that stratum with the mean daily effort estimate for that stratum. Fishing effort estimates for each survey period were obtained by summing the day-type stratum effort estimates. Seasonal estimates were calculated by summing the survey periods.

For comparisons among studies, the estimates of fishing effort were converted from party hours to fisher hours. This procedure was performed separately for boat- and shore-based fisheries for each base-level stratum by multiplying the fishing effort (party hours) and the daily average of the mean number of anglers per fishing party. Variances were additive when strata were combined. Standard errors (SE) were calculated as the square root of the variance.

Catch-and-release rates and harvest rates

The mean of ratios estimator was used for estimating shore-based catch-and-release rates and harvest rates, because interviews were based on incomplete trips (Jones et al. 1995; Hoenig et al. 1997; Pollock et al. 1997). The mean of ratios has a large variance when high harvest rates resulting from very short, incomplete fishing trips are included in calculations (Hoenig et al. 1997). Plots of party-based catch-and-release rates, harvest rates and the length of the incomplete trip were examined to identify an appropriate level of truncation for these shore-based interviews (Hoenig et al. 1997). Twenty party minutes was used as the truncation criterion, thus resulting in the removal of six (2.4%) shore-based interviews.

The ratio of means estimator was used for estimating catch-and-release rates and harvest rates for the boat-based fishery (Jones et al. 1995; Pollock et al. 1997). Each access point that was sampled on a survey day was given equal weighting in the calculation of daily catch-and-release rates and harvest rates.

Catch-and-release rates and harvest rates and their variances for each survey period were weighted to compensate for the different sizes in day-type strata. Similarly, weighted mean catch-and-release rates and harvest rates and their variances were calculated for the summer season by using weighted means that compensated for the different sizes of the two survey periods (Pollock et al. 1994). These weighting procedures were applied to data from both the shore- and boat-based fisheries.

Catch-and-release and harvest

Catch-and-release and harvest estimation for both boat- and shore-based fisheries were undertaken by multiplying fishing effort (party hours) with the mean daily catch-and-release rate or harvest rate (fish/party-hour) for each base-level stratum (Pollock et al. 1994; Steffe and Chapman 2003). Catch-and-release and harvest totals for each survey period were obtained by summing the appropriate day-type stratum estimates. Seasonal estimates of catch-and-release and harvest were made by summing the survey periods. Variances and SEs were then calculated.

Targeting behavior, fishing methods and reasons for catch-and-release

Weighted frequency distributions were constructed to describe the targeting preferences of anglers, the reasons for their catch-and-release practices and the fishing method used. Weighted frequency distributions were initially used for each base-level stratum on data aggregated at the PSU level (i.e., day). Within each PSU, the weighted response from each fishing party was given equal weighting. The fishing party response was derived by giving equal weighting to the responses of individual anglers within that party. Seasonal weighted frequency distributions were constructed by integrating the data from the base-level strata and weighting them to account for the different number of days in each base-level stratum. These weighted frequency distributions were created for each of the boat- and shore-based fisheries. The reasons why anglers practiced catch-and-release were categorised into whether released fish were undersized (below the MLL), oversized (above maximum length limit), legal voluntary (harvest eligible but voluntarily released) or over bag limit (exceeding possession limits). The fishing method used was categorised into bait, lures or a combination of bait and lures (where anglers used multiple methods).

Standardised parameters

To assess variability among fisheries for Murray cod, estimates of effort, harvest and discard were standardised per unit of surface area. The surface area (ha) of the survey area was calculated with ArcMap

(Environmental Systems Resource Institute 2009). Boat-based anglers are able to effectively fish the entire surface area of Lake Mulwala; however, shore-based anglers are restricted to the lake margins and the distance to which they can cast or wade from shore. Therefore, the surface area used to calculate effort, discard rate and harvest density for the shore-based fishery in Lake Mulwala was defined as the area extending between the shoreline and 50 m from the shore. The estimates of effort, discard rate and harvest were divided by the appropriate surface area (either boat- or shore-based) to obtain effort/ha, fish discarded/ha and fish harvested/ha.

The size structure of harvested Murray cod was standardised by calculating the relative stock density for each fishery (Neumann and Allen 2007). The relative stock density was the proportion of Murray cod that we deemed to provide a memorable fishing experience (i.e. > 700 mm, at which length Murray cod are a highly sought-after sportfish; Forbes 2011) in the legally harvested population (i.e., > 550 mm, the lower bound of the existing harvest slot limit).

We propose a new standardised parameter of harvest specificity as the proportion of harvested Murray cod in the total harvest of all species combined, which provides a relative measure of importance. Harvest specificity differs from targeting behavior because it is independent of angler opinion, perceptions and attitudes.

To obtain effort-, discard- and harvest-density; relative stock density; and harvest specificity in these systems, equivalent to those calculated for Lake Mulwala, we reanalysed data from similar surveys of recreational fisheries conducted during 2012–2013 in the Murrumbidgee River between Berembed Weir and Yanco Weir (Forbes et al. 2015c) and during 2006–2008 in the Murray River downstream of Lake Mulwala to the South Australian border (Brown 2010). These standardised data allowed for comparisons among boat- and shore-based fisheries in each waterbody for the three month summer season.

Results

Roving surveys produced 253 successful interviews of shore-based fishing parties, comprising 493 anglers. Access point surveyors successfully interviewed 296 boat-based fishing parties and 627 anglers. A total of 681 Murray cod were recorded as being captured during the surveys, 46 of which were harvested.

Boat-based fishery

Thirty-three Murray cod ranging from 540 to 760 mm were measured during interviews with boat-based anglers in Lake Mulwala, and 94% (31 fish) were within the current harvest slot limit. Of these, 52% of Murray cod (17 fish) retained by the boat-based fishery were ineligible for harvest at the previous 600 mm minimum length limit (i.e., harvested fish were > 550 mm lower slot bound but < 600 mm). One Murray cod was undersized (i.e., < 550 mm), and one was oversized (i.e., > 750 mm; Fig. 1). The boat-based released component (i.e., the number of fish released as a percentage of fish harvested plus those caught-and-released) for Murray cod in Lake Mulwala was 88.1%. Most Murray cod releases in the boat-based fishery were mandatory because the fish were undersized (93.7%); however, 6.2% of harvest eligible Murray cod were voluntarily released, and 0.1% were released because they were oversized (Fig. 2).

Sixty-five percent of the summer fishing effort in Lake Mulwala was expended in the boat-based fishery (Table 1), and 98% of boat-based fishing parties targeted Murray cod (Fig. 3). Boat-based anglers predominantly used lures, and a smaller proportion used bait (Fig. 4). The summer boat-based catch-and-release rate of Murray cod in Lake Mulwala was 0.256 (± 0.064 SE) fish/angler-hour, and the harvest rate was 0.029 (± 0.011 SE) fish/angler-hour (Table 2). The boat-based catch-and-release rates and harvest rates for species other than Murray cod were minimal (< 0.003 fish/angler-hour; Table 2). Subsequently, the boat-based catch-and-release and harvest estimates for species other than Murray cod were low (catch-and-release ≤ 200 fish; harvest ≤ 89 fish; Table 3). The boat-based catch-and-release for Murray cod in Lake Mulwala was 8,486 (± 2,769 SE) fish, and the harvest was 1,145 (± 454 SE) fish (Table 3).

The boat-based fishery in Lake Mulwala had lower effort density (16.6 angler-hours/ha) than did the Murrumbidgee River (20.0 angler-hours/ha) and the Murray River (26.4 angler-hours/ha; Table 4). The discard density varied from 2.4 fish/ha in Lake Mulwala

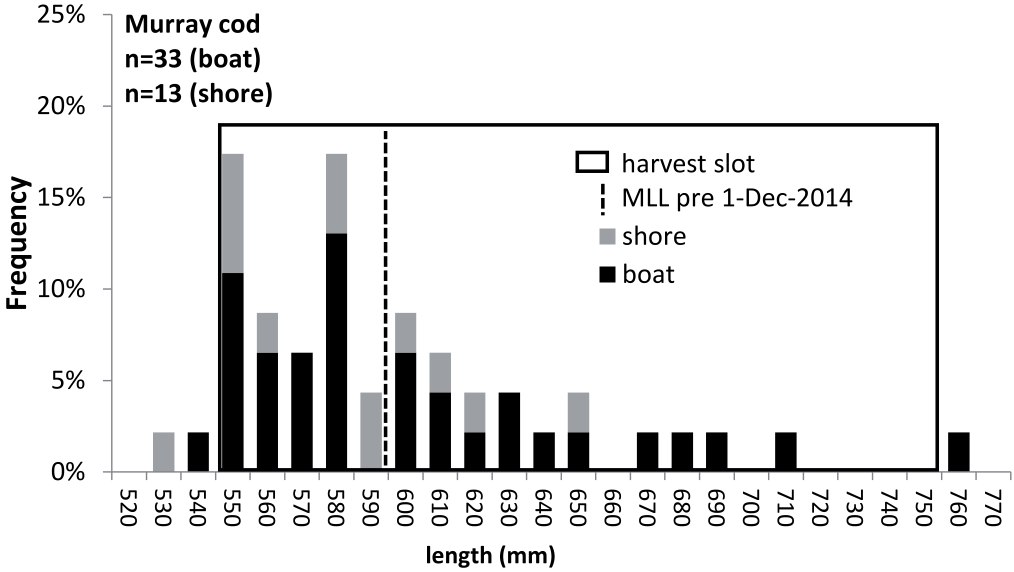

Figure 1: Length frequency distributions for Murray cod harvested by boat- and shore-based anglers from 1 December 2014 to 28 February 2015 in Lake Mulwala. The current 550–750 mm harvest slot is boxed, and pre-December 2014 minimum legal length (MLL) given as a dotted line.

Table 1. Effort estimates (angler-hour; with SEs) for the 2014–2015 summer boat-based and shore-based fisheries in Lake Mulwala.

	Boat		Shore		Total	
Day-type	Total	SE	Total	SE	Total	SE
Weekday	17,259	4,954	17,316	3,924	34,575	6,320
Weekend	41,696	23,590	14,855	3,827	56,551	23,898
Total	58,955	24,104	32,171	5,481	91,126	24,719

Table 2. Murray cod, carp, golden perch, trout cod and redfin release rates and harvest rates (fish/angler-hour, with SE) for (a) boat-based, and (b) shore-based fisheries, taken by recreational anglers during the 2014–2015 survey period in Lake Mulwala.

	a) Boat-based fishery				b) Shore-based fishery			
	Release rate		Harvest rate		Release rate		Harvest rate	
Day-type	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Murray cod	0.256	0.064	0.029	0.011	0.115	0.019	0.011	0.003
Carp	0.003	0.002	0.001	0.001	0.007	0.004	0.037	0.007
Golden perch	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0	0
Trout cod	<0.001	<0.001	0	0	0.001	0.001	0	0
Redfin	0	0	0	0	<0.001	<0.001	0	0

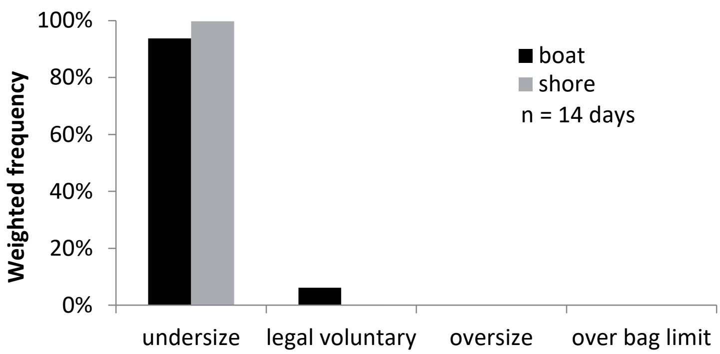

Figure 2: Weighted frequency distribution of reasons for Murray cod catch-and-release for boat- and shore-based fisheries during the 2014–2015 survey period in Lake Mulwala. The total number of sampling days is represented by n.

to 13.8 fish/ha in the Murrumbidgee River (Table 4). Harvest density varied from 0.2 fish/ha in the Murray River to 1.1 fish/ha in the Murrumbidgee River (Table 4). The boat-based harvest specificity in Lake Mulwala (92%) and the Murrumbidgee River (71%) was higher than that in the Murray River (16%; Table 4). The relative stock density for boat-based fisheries varied from 27 in the Murrumbidgee River to six in Lake Mulwala (Table 4).

Shore-based fishery

Thirteen Murray cod ranging from 530 to 650 mm were measured during interviews with shore-based anglers in Lake Mulwala, 92% (12 fish) of which were within the current harvest slot limit. Of these, 62% of Murray

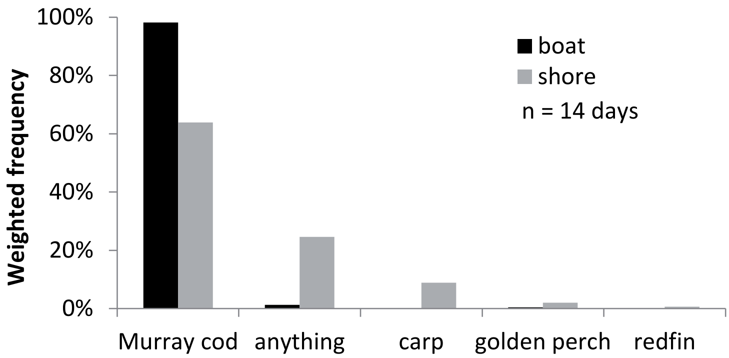

Figure 3: Weighted frequency distribution of angler species-specific target preferences for boat- and shore-based fisheries during the 2014–2015 survey period in Lake Mulwala. The total number of sampling days is represented by n.

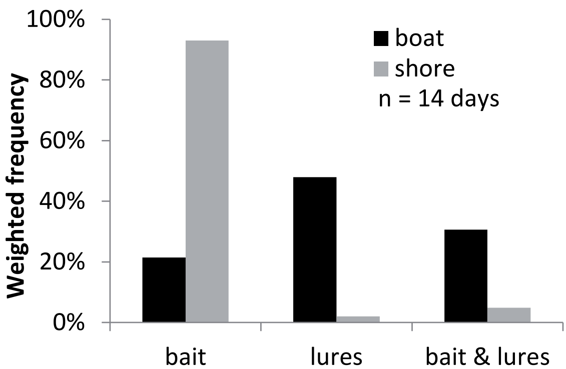

Figure 4: Weighted frequency distribution of the fishing method used by boat- and shore-based fisheries during the 2014–2015 survey period in Lake Mulwala. The total number of sampling days is represented by n.

Table 3. Recreational catch-and-release (a) and harvest (b) estimates (number of fish; with SEs) for Murray cod, carp, golden perch, trout cod and redfin taken by boat-based and shore-based anglers during the 2014–2015 survey period in Lake Mulwala.

	a. Catch-and-release						b. Harvest					
	Boat		Shore		Total		Boat		Shore		Total	
Day-type	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE
Murray cod												
Weekday	4,524	1,742	1,849	656	6,373	1,862	495	221	161	90	656	238
Weekend	3,962	2,152	1,929	674	5,891	2,255	650	397	197	86	847	406
Total	8,486	2,769	3,778	941	12,264	2,924	1,145	454	358	125	1,503	471
Carp												
Weekday	69	57	60	60	129	83	13	13	981	415	994	415
Weekend	15	15	36	32	51	36	76	40	515	179	591	183
Total	84	59	96	69	180	91	89	42	1,496	452	1,585	454
Golden perch												
Weekday	29	20	0	0	29	20	13	13	0	0	13	13
Weekend	171	108	4	4	175	108	0	0	0	0	0	0
Total	200	110	4	4	204	110	13	13	0	0	13	13
Trout cod												
Weekday	0	0	0	0	0	0	0	0	0	0	0	0
Weekend	36	36	38	38	74	52	0	0	0	0	0	0
Total	36	36	38	38	74	52	0	0	0	0	0	0
Redfin												
Weekday	0	0	0	0	0	0	0	0	0	0	0	0
Weekend	0	0	6	6	6	6	0	0	0	0	0	0
Total	0	0	6	6	6	6	0	0	0	0	0	0

cod (8 fish) retained by the shore-based fishery were ineligible for harvest at the previous 600 mm minimum length limit. One Murray cod was undersized (i.e., < 550 mm; Fig. 1). The shore-based released component for Murray cod in Lake Mulwala was 91.3%. In addition, 99.8% of Murray cod released in the shore-based fishery were undersized, and 0.2% of harvest-eligible Murray cod were voluntarily released (Fig. 2).

Thirty-five percent of the summer fishing effort in Lake Mulwala was expended in the shore-based fishery (Table 1). Shore-based fishing parties were more generalist in species targeted than boat-based fishing parties and showed 64% targeting of Murray cod, 25% with no preference (where target species was 'anything') and 9% targeting carp (Fig. 3). Ninety three percent of shore-based anglers used bait, whereas 2% used lures (Fig. 4).

The summer shore-based Murray cod catch-and-release rate in Lake Mulwala was 0.115 (± 0.019 SE) fish/angler-hour. The catch-and-release and harvest rates for other species were ≤ 0.007 fish/angler-hour (Table 2). The shore-based harvest rate of Murray

Table 4. Quantitative characteristics used to assess variability among Murray cod fisheries in Lake Mulwala, the Murrumbidgee River and the Murray River. Data from the Murrumbidgee River were re-calculated from Forbes et al. (2015b). Murray River data were re-calculated from Brown (2010).

	Mulwala boat-based	Mulwala shore-based	Murrumbidgee boat-based	Murrumbidgee shore-based	Murray boat-based	Murray shore-based
Surface area (ha)	3,561	201	1,019	1,019	13,424	13,424
Harvest specificity	92%	19%	71%	3%	16%	3%
Relative stock density	6	0	27	25	21	0
Effort density (angler-h/ha)	16.6	160.1	20.0	10.3	26.4	13.3
Discard density (Murray cod/ha)	2.4	18.8	13.8	2.3	3.2	0.6
Harvest density (Murray cod/ha)	0.3	1.8	1.1	0.1	0.2	0.1

cod was 0.011 (± 0.003 SE) fish/angler-hour. The shore-based catch-and-release of Murray cod in Lake Mulwala was estimated at 3,778 (± 941 SE) fish. The shore-based harvest estimate for Murray cod was 358 (± 125 SE).

The shore-based effort density varied from 160.1 angler-hours/ha in Lake Mulwala to 10.3 angler-hours/ha in the Murrumbidgee River (Table 4). The discard density varied from 18.8 fish/ha in Lake Mulwala to 0.6 fish/ha in the Murray River (Table 4). The harvest density varied from 1.8 fish/ha in Lake Mulwala to < 0.1 fish/ha in the Murray River (Table 4). The shore-based harvest specificity was higher in Lake Mulwala (19%), than in the Murrumbidgee and Murray rivers (both 3%; Table 4). The relative stock density for shore-based fisheries varied from 25 in the Murrumbidgee River to zero in Lake Mulwala and the Murray River (Table 4).

Discussion

The regulatory change from a minimum length limit of 600 mm to a harvest slot of 550–750 mm for Murray cod resulted in a temporary harvest bias toward fish of 550–600 mm in Lake Mulwala. In addition, most Murray cod captures resulted in mandatory release because the fish length was below the existing lower slot limit, and few large fish were captured, a finding consistent with angling surveys for this species in riverine environments (Brown 2010; Forbes et al. 2015c). The role of smaller fish in the recreational fishery was highlighted by previous research indicating that a HS of 400–600 mm may decrease the risk of decline and improve catch rates compared to a range of HSs (including the current HS) and minimum legal lengths (Koehn and Todd 2012). Despite their ability to grow to a large size, small Murray cod (i.e. < minimum legal length) are typical in reservoir and riverine recreational fisheries; thus, the performance of management interventions and the fishery in general may also require evaluation in reference to a recreational fishery dominated by catch and release of Murray cod < 550 mm.

Overall, lowering the minimum length limit to 550 mm initially provided access to more harvest eligible cod in the reservoir examined. However, whether this harvest influences long term sustainability cannot be determined by this study and requires ongoing monitoring. Furthermore, the initial high harvest of Murray cod created a 'gold rush' and likely led to unsustainably high angler expectations in this reservoir. As fish populations adjust to the HS, angler expectations and satisfaction may become unrealistic, because harvest rates of fish 550–600 mm are likely to decline from the initially high rates in the first season after the regulation changes (Connelly and Brown 2000; Arlinghaus 2006). As a result, replication of this survey in Lake Mulwala would be required to provide information on long term impacts and effectiveness of the HS limit in this fishery.

The Murray cod HS was introduced to allow a more natural age structure (Gwinn et al. 2015), because populations truncate at the minimum legal length (Nicol et al. 2004). This truncation was thought to be a result of fishing pressure removing many harvest eligible fish from the population (Nicol et al. 2004). However, the harvest of recently eligible fish in Lake Mulwala also suggest that fewer fish may grow through the slot and attain a protected length (i.e., > 750 mm). In particular, Lake Mulwala is thought to experience reasonable growth rates with fish likely to remain in the HS for approximately 3 years (Anderson et al. 1992; Ye et al. 2000; Nicol et al. 2004). Growth rates in other areas, particularly rivers, are thought to be much slower, and the time in the HS could be more than 5 years in some waters (Anderson et al. 1992; Gooley 1992). As a result, waterbody-specific growth rates and further recreational catch and harvest data are needed to adequately assess the effects of HS introduction over the large scale where the regulation has been imposed.

The sustainability of the initial harvest of 550–600 mm Murray cod and the long term success of the HS will be highly dependent on the ability of the regulation to achieve its goals across multiple state jurisdictions. The ability of the HS to achieve goals across this large scale is especially challenging for Murray cod fisheries, because they are found in waterbodies with varying productivity and fishing pressure (Rowland 2005; Koehn and Todd 2012) as well as reservoirs with management goals, which may conflict with the optimal conditions required for strong recreational fisheries (Kingsford 2000). Similar regulations applied over large spatial scales in other fisheries (e.g., walleye in Alberta, Canada) have had mixed success, with reports of outcomes (e.g., prevention of fishery decline or collapse) not being met on the local scale or in certain waterbodies (Sullivan 2003). In particular, fluctuations in reservoir water levels and the impacts on fisheries may need to be considered in assessing fishery management interventions. These considerations may include the identification of suitable reservoir and riverine sites for ongoing monitoring of the fishery. In instances where monitoring identifies unsustainable practices, managers should consider adaptive management strategies or differing legislation based on local science (Sullivan 2003).

The social trend of voluntarily releasing harvest-legal Murray cod (Douglas et al. 2010) was less apparent in Lake Mulwala as < 10% of harvestable cod were released (Fig. 2). Overall, the percentage of Murray cod released (mandatory and voluntary) in the current study (89%) was less than that reported in the Murrumbidgee River (95%;

Forbes et al. 2015c), greater than that identified during a nationwide survey (77.6%; Henry and Lyle 2003) and similar to the 90.0% release rate reported for the Murray, Goulburn and Ovens rivers (Brown 2010). Mortality of released fish can be a major concern in the sustainability of recreational fisheries. Murray cod are thought to be sensitive to recreational fishing mortality because of their longevity (Allen et al. 2009; Douglas et al. 2010). Murray cod catch-and-release mortality is estimated to range from 2% in the Murray River (Douglas et al. 2010) to 15% in Lake Mulwala during a delayed-release summer fishing tournament (Hall et al. 2012). Such mortality rates and the high incidence of catch-and-release fishing could generate additional mortality in excess of our harvest estimates. Given the high fishing pressure exerted in Lake Mulwala, the high incidence of catch-and-release and the longevity of Murray cod, multiple recaptures are possible, but the rate of recapture and implications of cumulative capture on mortality are not understood (Douglas et al. 2010; Forbes et al. 2015c).

Variability in standardised parameters was evident between Lake Mulwala and the river sites, possibly as a result of fluctuations in abundance, population size structure, shifts in fishing effort or changing length-based harvest restrictions. Harvest specificity varied between Lake Mulwala and the river sites with the reservoir site having very high proportions of Murray cod harvest. The difference in harvest specificity would likely be the result of the recent introduction of the HS but also reflect the importance of Murray cod harvest for this reservoir fishery (Howitt et al. 2004). Murray cod have higher growth rates in reservoirs than rivers, which may contribute to different population structures between these waterbody types (Forbes et al. 2015a). Thus the different growth rates and population structures may contribute to the differences in standard parameters (e.g., relative stock density and harvest density) between Lake Mulwala and rivers. Furthermore, reservoir management practices (e.g., fluctuating water levels) may influence angling effort, harvest, abundance and recruitment (Chizinski et al. 2014; Nagid et al. 2015). Lake Mulwala is subject to excessive aquatic weed growth, which is managed by reducing the lake level to expose banks for a sustained period (~ 3 months) over autumn and winter. The impacts of this procedure on the lake productivity and fishery are not understood, but studies in other regions of the world suggest both positive and negative impacts of drawdown on recreational fisheries (Chizinski et al. 2014; Nagid et al. 2015).

The differences in effort density identified between Lake Mulwala and river sites may be related to the proximity of the reservoir to population centers and the convenient and safe access to angling sites (compared with river sites which were more remote). In Lake Mulwala, most of the total discard of Murray cod came from the boat-based fishery. In contrast, the shore-based fishery in Lake Mulwala was a more diverse, multi-species fishery. Shore-based fishers almost exclusively used bait, an effective method to capture a range of species in the Murray-Darling Basin (Rowland 1989; Brown 2010), whereas boat-based anglers mainly used lures, which can be a selective method for Murray cod (Forbes 2011). In addition, Murray cod are less active during daylight hours in summer months and prefer habitats that include structural woody debris, deeper water and overhanging vegetation

(Koehn 2009; Koehn et al. 2009; Thiem et al. 2018). These habitats are more accessible to boat-based anglers, thus possibly explaining why shore-based anglers were less focused on Murray cod and had increased harvest of less habitat-specific, generalist species such as carp.

This study used fishery-dependent survey techniques to identify the change from a minimum length limit to a harvest slot limit, which resulted in a strong harvest bias toward newly harvestable Murray cod. Analysis of data from this and other surveys for Murray cod also revealed that populations of this species are characterised by an abundance of undersized fish and few large individuals, thus justifying the implementation of the harvest slot limit and its objectives to increase the number of larger fish (Gwinn et al. 2015). In order to provide longer term evaluation of the HS in Lake Mulwala, this survey should be repeated at regular intervals so changes in catch, effort and harvest can be evaluated. However, close monitoring will also be required in both reservoir and riverine fisheries across large areas to ensure that the HS achieves the desired outcomes, particularly which fish survive harvest, grow beyond the upper slot limit and provide enhanced angling opportunities and reproductive advantages afforded by these large fish. Furthermore, managers may need to be responsive to changing angler and fishery needs. Working around lake management will be especially important during times of low inflow or high demand on water resources. Therefore, continued monitoring of recreational fisheries for Murray cod is vital as populations adjust to changing harvest restrictions, fishing effort, reservoir management practices and environmental conditions. Such monitoring should ensure that sampling effort and design are sufficient to separate variability caused by differences among fisheries (as identified in this study) from desired changes caused by the harvest slot limit.

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