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Preliminary Assessment of the Lake Eucumbene summer recreational fishery 2015/16

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Non-technical summary

An assessment of the recreational fishery in Lake Eucumbene over the 2015/16 summer period.

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Objectives

To quantify the recreational fishery in Lake Eucumbene using probability-based survey techniques, and use this data to inform management strategies to govern the recreational fishery in this waterbody.

Key words

Lake Eucumbene, creel survey, fishery management, brown trout, rainbow trout

Summary

Introduction: Fishery independent surveys are used to quantify recreational fisheries and support the development and evaluation of fishery management strategies around the world. Lake Eucumbene is the largest impoundment in the Snowy Mountains region of New South Wales, and contains the principal fishery for rainbow trout, *Oncorhynchus mykiss*, and brown trout, *Salmo trutta* in south-eastern Australia. A state-wide survey identified a 25% decline in catch-rates of trout (all species) from data collected in 2000/01, to comparable information collected in 2013/14. The state-wide reduction in catch-rates has contributed to increasing angler and community dissatisfaction, particularly in the Snowy Mountains region.

Objectives: No standardized fishery-dependent survey data are available to quantify the recreational trout fishery in Lake Eucumbene (for metrics including effort, catch, species composition, length frequency distribution, and percentage of stocked fish) and evaluate the success of the existing management strategies. Therefore, the objectives of the current study were to; (1) quantify boat- and shore-based fishing effort, harvest and release (and their rates) within Lake Eucumbene; (2) collect information from fishers regarding targeting preferences, fishing methods, and release habits; and (3) use these data to discuss the effectiveness of current harvest restrictions and stocking strategies.

Methods: Angler surveys were used to assess the recreational fishery in Lake Eucumbene during the peak fishing season (31 October 2015 to 31 January 2016). Boat- and shore-based fishing effort were quantified using progressive counts. Catch-, harvest- and release-rate information was collected from shore-based fishers using roving surveys, and from boat-based fishers using access point surveys. Resource limitations restricted boat- and shore-based surveys to 34% of Lake Eucumbene's available surface area.

<u>Major outcomes:</u> The shore-based fishery harvested greater numbers of, and significantly larger, rainbow and brown trout, and attracted twice the fishing effort to that of the boat-based fishery. More rainbow trout were harvested or discarded than brown trout.

The catch-rate of rainbow trout (0.12 fish/fisher hr boat-based; 0.15 fish/fisher hr shore-based) was significantly higher than that of brown trout (0.08 fish/fisher hr boat-based; 0.05 fish/fisher hr shore-based) in both fisheries. Size and bag limits were largely ineffectual as anglers voluntarily released most harvest-eligible fish. In this regard, almost all released brown trout (94% boat-based; 73% shore-based) and rainbow trout (96% boat-based; 92% shore-based) were done so voluntarily as they were larger than the existing 250 mm minimum legal size. Conversely, few fish were released because they were undersized. Releasing fish because of bag limit restrictions was very rare (<0.1%).

Over 83% of rainbow trout caught by anglers (i.e. the total harvested plus those released) originated from natural recruitment, rather than stocking. Almost all fishers were non-specifically targeting 'trout'. Most anglers in the boat-based fishery used lures (73%), while bait (53%) or fly (29%), were the most common methods in the shore-based fishery.

<u>Implications for management:</u> Because of its higher catch-ability, rainbow trout are more suitable for stocking to support the recreational fishery in the short-term during periods of recruitment failure.

Catch-rates for both species in the current study appeared considerably lower than catch-rates recorded during tournaments in 2000-2004 (Faragher et al. 2007). This may imply a decline in stocks, however, care has to be taken with this interpretation as survey designs of both studies were markedly different. In particular, a probability-based sampling design was not used in 2000-2004 (which potentially introduces sampling bias), and zero catches were not included, which artificially inflated the historic catch-rates. Well designed, standardized surveys using fishery dependant (e.g. angler surveys) and independent (e.g. electrofishing, trapping) methods are required to assess change and status of trout stocks in Lake Eucumbene. The current survey provides a solid base line to evaluate change in the main characteristics of the recreational trout fishery in Lake Eucumbene.

To ensure sustainability of the recreational fishery in NSW inland waters, the development of harvest strategies including simple and robust ecological, economic and/or social objectives, performance indicators and reference points for trout and other recreational freshwater species (e.g. Murray cod, silver perch and golden perch, Australian bass) is of utmost importance. The need for an appropriate harvest strategy for trout in Lake Eucumbene is illustrated by the high prevalence of voluntarily released legal sized fish that caused existing output controls (size and bag limits) to be largely ineffectual as management tools to control fishing mortality.

Introduction

Fisher surveys are a common research tool to inform strategies for management of recreational fisheries (Henry and Lyle 2003; Hunt et al. 2011; Steffe and Murphy 2011). Management strategies including size and bag limits, closed seasons, closed areas, gear restrictions and stocking, are used to regulate and sustain fisheries around the world (Arlinghaus et al. 2016; Cooke et al. 2015). Such governance can be implemented without being underpinned by sound assessments (Molony et al. 2003; Zukowski et al. 2012), however, a lack of information can lead to ineffective management regimes and fishery decline (Post et al. 2002). It is therefore imperative that data collected from recreational fisheries be used to inform and assess management interventions.

Salmonid fisheries are among the most studied in the world (Wurtsbaugh et al. 2014); being popular recreationally, economically and in a conservation sense (Brownscombe et al. 2014; Cooke and Murchie 2015). Salmonid species have predictable life history stages, often migrating and spawning at similar sites and locations each year (Lisi et al. 2013). They are a popular target of recreational fishers, and as such are susceptible to overfishing (Johnston et al. 2013). It is therefore vital to understand the main stressors on populations in order to manage them effectively. Many salmonid populations are established exclusively for recreational purposes (Miko et al. 1995; Patterson and Sullivan 2013). Thus, to ensure such fisheries are sustainable, the impacts of recreational fishing (particularly effort, catch-and-release, and harvest) need to be quantified. These data can then be used to inform management actions, including harvest regulations and stocking (Pollock et al. 1994).

Rainbow trout, *Oncorhynchus mykiss*, and brown trout, *Salmo trutta*, were introduced to the Snowy Mountains region of New South Wales in the late 1800s to establish stream-based recreational fisheries (Tilzey 1976). The fisheries in this region were expanded following the construction of 16 impoundments during the 1950s, 60s and 70s, associated with the Snowy Mountains Hydroelectric Scheme (Faragher et al. 2007; Snowy Hydro Limited 2016). The impoundment fisheries are considered to be hugely successful, and are now worth an estimated AU$70 million to the NSW economy (Dominion Consulting 2001). However, some of these fisheries are performing poorly, with a 25% downward trend in catch-rates of trout across New South Wales from data collected in 2000/01, to comparable information collected in 2013/14 (Henry and Lyle 2003; West et al. 2016). The regional assessment of the trout fishery did not differentiate species, nor quantify recreational fisheries in specific waterbodies (Henry and Lyle 2003; West et al. 2016). Thus, the results are difficult to use in an adaptive fisheries management context. There is a need for fine-scale surveys to quantify key fisheries within the Snowy Mountains; so that fishery managers can apply the new knowledge to these and other salmonid fisheries. Although some waterbody-specific data exists that was collected during fishing tournaments or self-reported by anglers (Faragher 1993; Faragher and Gordon 1992; Tilzey 1977a; Tilzey 1977b), the absence of a statistically sound sampling protocol restricts use of this information to assess change over time. Therefore, it is necessary to collect additional data using on-site angler surveys to quantify important recreational fisheries for trout within the Snowy Mountains region.

Lake Eucumbene is the largest impoundment in the Snowy Mountains and contains a popular recreational fishery for rainbow and brown trout (Faragher et al. 2007; Tilzey 2000). The Lake Eucumbene fishery is regulated by state-wide harvest restrictions that include; a minimum length limit (MLL; 250 mm total length); a daily bag limit (5 trout per day); and a seasonal closure in streams (June to October) to protect spawning stocks (New South Wales Department of Primary

Industries 2014). Lake Eucumbene is stocked annually with 150,000 rainbow trout fingerlings, whereas the brown trout population is considered to be self-supporting, and are not stocked (Faragher et al. 2007). Rainbow trout are known to have higher exploitation rates than brown trout (Johnson et al. 1995; Pawson 1991). Therefore, it is important to compare statistics for both species as the brown trout population in Lake Eucumbene is generally more stable (Faragher et al. 2007).

The effectiveness of size and bag limits to regulate exploitation is dependent on biological information such as; maturity onset and growth (Forbes et al. 2015); levels of fishing effort, catch and harvest (Munger and Kraal 1997); and understanding the behaviour of anglers within a fishery (Cooke et al. 2013). There is a need to quantify the recreational fishery in Lake Eucumbene to obtain baseline estimates of fishing effort, catch-and-release (discard) and harvest, and use these data to assess existing management strategies. The reasons why anglers discard fish (i.e. voluntary or mandatory because of regulations), angler targeting preferences (i.e. which species are being actively sought), and the fishing methods used (i.e. bait, lure or fly) are important information to inform this process.

The current study used a probability-based on-site 'creel' survey to quantify the summer-time Lake Eucumbene fishery. Specifically, the aims of this study were to; (1) quantify the levels of daytime shore-based and boat-based fishing effort, catch (harvest, release, and their rates), species composition and length distribution; (2) collect information from angling parties regarding their targeting practices, fishing methods, and reasons for releasing fish; and (3) use these data to discuss the effectiveness of current harvest restrictions and stocking.

Methods

Study site

Lake Eucumbene is an impoundment on the Eucumbene River, which lies at an altitude of 1,164 m above sea level in the Snowy Mountains of New South Wales, Australia (36.0918 S, 148.7260 E; Faragher 1993). The impoundment was built in 1957 as part of the Snowy Mountains Hydro-Electricity Scheme, and at 100% capacity has a surface area of 14,542 ha and retains 4,798 GL of water (Faragher 1993; Snowy Hydro Limited 2016). The study site within Lake Eucumbene was restricted to a 3,826 ha reach of the lake because of resource limitations (Figure 1). During the survey period Lake Eucumbene averaged 55% of total volume (11,400 ha; Snowy Hydro Limited, unpublished data). Thus, this survey sampled 34% of Lake Eucumbene's available surface area. The study reach contained a single formed boat ramp and tourist park at Buckenderra, provided ample public access to the shoreline, and was close to Australia's national capital, Canberra (< 2 hour drive; population 356,500).

Figure 1   Location of the study reach (dark shading) within Lake Eucumbene, New South Wales, Australia
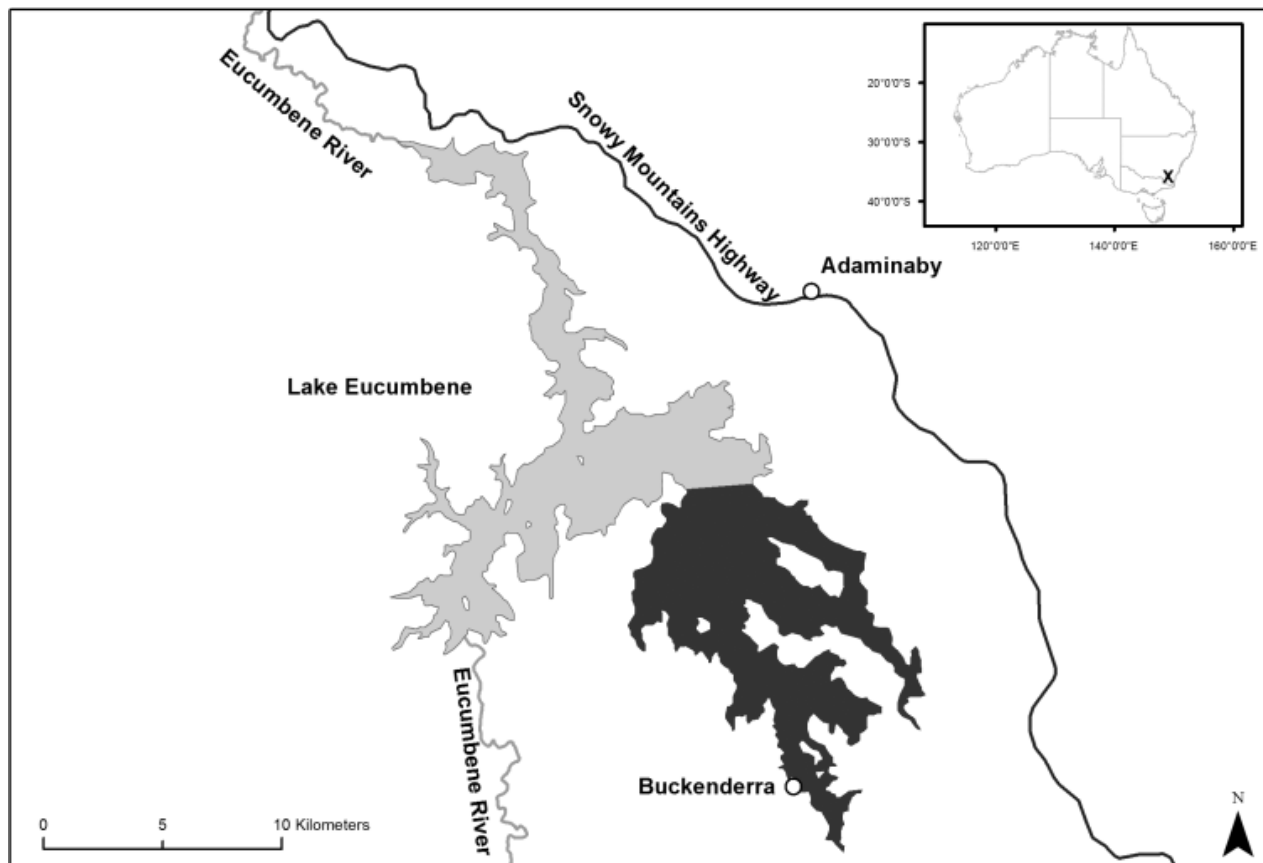
Survey design and sampling protocols

Stratified random sampling methods were used with day (calendar date) being the primary sampling unit for all strata. Each survey day covered the period sunrise to sunset. The temporal survey frame was a three month season; 31 October 2015 to 31 January 2016. The season was stratified into four periods: (1) 31 October 2015 to 6 November 2015, during which a week-long fishing tournament was conducted (termed November-early period); (2) 7 November 2015 to 30 November 2015, (termed November-late period); (3) 1 December 2015 to 31 December 2015 (termed December period); and (4) 1 January 2016 to 31 January 2016 (termed January period). These seasons capture the busiest time for the fishery (from an angling perspective), from

opening date for anglers to fish flowing waters (1st October each year), through the major summer holiday periods whilst capturing the major annual tournament. 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. The base-level stratum is therefore defined as day-type (weekday, weekend), within period (November-early, November-late, December, January), within season (i.e. the temporal survey frame). Two weekdays and two weekend days were sampled in the November-early period (to accommodate the expected high fishing effort and catch resulting from the fishing tournament), and three weekdays and three weekend days were sampled in each of the November-late, December and January periods.

Effort counts

Progressive counts were used to quantify 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 complete a circuit of the fishery with 2.5 hours allocated to complete a progressive count. Each survey day was divided into five non-overlapping 2.5 hr intervals. A progressive count was randomly allocated without replacement (within each base-level stratum) to one of the five intervals.

Shore-based fishery

A roving survey was used to obtain catch-and-release rate and harvest-rate information from shore-based fishers. The roving surveys were done on the same days as the progressive counts for fishing effort, but did not cover the interval of the progressive count. 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.

Boat-based fishery

An access point survey was used to obtain catch-and-release rate and harvest-rate information from boat-based fishers returning to the only formed boat ramp in the survey reach at Buckenderra (Figure 1). It was not cost effective to cover private access points, and it was assumed that the fisher behaviour was similar for public and private access.

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 (i.e. undersize, legal voluntary, over bag limit). Harvested fish were identified, measured (FL, mm), and checked for clipped fins (rainbow trout only; as all stocked fish of this species are fin-clipped) by creel clerks. 25% (37,500) of the 150,000 rainbow trout stocked annually into Lake Eucumbene had a different pectoral or pelvic fin removed prior to release, that corresponds to year of spawning. Thus enabling identification and ageing of stocked fish in the harvest. Any refusal to provide information or to show harvested fish was recorded.

Estimation procedures

The general form of the equations used to calculate fishing effort, catch-and-release, harvest and their rates, can be found in appendix 1, which is based on statistical methods and equations from Pollock et al. (1994) and Steffe and Chapman (2003).

Fishing effort

Fishing effort (units of 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 survey 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 comparative purposes with other studies, the estimates of fishing effort were converted from party hours to fisher hours. This was done 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 fishers per fishing party. The equations used to calculate variances are provided in the supplement. Variances were additive when combining strata. Standard errors (SE) were calculated as the square root of the variance.

Catch-and-release rates and harvest-rates

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). The mean of ratios estimator was used for estimating shore-based catch-and-release rates and harvest-rates as interviews were based on incomplete trips (Hoenig et al. 1997; Jones et al. 1995; Pollock et al. 1997). Simulations have shown the mean of ratios to have a large variance when high harvest-rates resulting from very short, incomplete fishing trips are included in calculations (Hoenig et al. 1997). We examined plots of party-based catch-and-release rates, harvest-rates, and incomplete trip length to identify that the appropriate level of truncation for these shore-based interviews was 0.4 party hour (Hoenig et al. 1997). Use of this truncation criterion resulted in the removal of 6 (1.8%) shore-based interviews.

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 season by using weighted means that compensated for the different sizes of the survey periods (Pollock et al. 1994). These weighting procedures were applied to data from both the shore- and boat-based fisheries. Overall catch-rates were calculated using the same methods as described for catch-and-release rates and harvest-rates, with 'catch' defined as the sum of those fish that were harvested, plus those that were caught and subsequently released.

Catch-and-release and harvest

Catch-and-release and harvest estimation for both boat- and shore-based fisheries were done by multiplying fishing effort (party hours) with an appropriate 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 together. Seasonal estimates of catch-and-release and harvest were made by summing the survey periods. Variances and SEs were calculated as described for fishing effort.

Size, age and origin of harvested fish

The lengths (FL, mm) of harvested rainbow and brown trout were used to create cumulative length frequencies in each of the boat- and shore-based fisheries. Tests for statistical

differences among these cumulative length frequencies were made using a 2 sample Kolmogorov-Smirnov test in SPSS (differences were deemed significant when $P < 0.05$; IBM Corp 2011).

Weighted frequency distributions were constructed to describe the age and origin (stocked or wild) of harvested rainbow trout. Stocked rainbow trout were identified by the absence of a pelvic or pectoral fin. Weighted frequency distributions were initially done for each base-level stratum using data aggregated at the PSU level (i.e. day). Within each PSU a weighted response (finclip observation) for 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. 25% of stocked rainbow trout were fin-clipped, and as such only this number of harvested fish could be identified as stocked, but it was assumed that marked and unmarked fish were equally catchable. It is possible that the overall percentage of stocked fish may have been higher because of the inability to identify all fish of hatchery origin. However, to correct for the detection of only 25% of stocked fish, the weighted frequency distributions of stocked rainbow trout were multiplied by four.

Catch and release: reasons and species composition

The reasons why fishers practiced catch-and-release were categorised into whether released fish were undersized (< 250 mm; the minimum length limit [MLL]), legal voluntary (> 250 mm MLL, but voluntarily released), or over bag limit (exceeded 5 trout of each species/day or exceed possession limit of 10 trout of each species). These categorical data were used to create weighted frequency distributions for each of the boat- and shore-based fisheries. A weighted frequency distribution was also created to categorise brown and rainbow trout that were caught and subsequently released in each of the boat- and shore-based fisheries. The same weighting procedures were used as that described for weighted age and origin distributions.

Fishing method

The method used by fishers was categorised into bait, lure, fly, or combinations of these three techniques. These categorical data were used to create weighted frequency distributions for each of the boat- and shore-based fisheries. The same weighting procedure was used as that described for weighted age and origin distributions. The weighted frequency distributions of fishing method were then applied to the number of fish that were harvested using each fishing method (or combination of methods) to obtain the percentage of fish harvested by fishing method. The weighted frequency distributions were similarly used to obtain the percentage of fish caught-and-released by each fishing method.

Targeting behaviour and fisher origin

The targeting preferences of fishers were categorised by species and used to create weighted frequency distributions for each of the boat- and shore-based fisheries. Similarly, postcode responses provided from fishers were categorised by state and used to create weighted frequency distributions for each of the boat- and shore-based fisheries. The same weighting procedures were used as that described for weighted age and origin distributions.

Statistical comparison

Differences between harvest-rates of brown trout and rainbow trout, and catch-and-release rates of these species, were tested to determine whether the observed variability was statistically significant. We used the standard method described by Schenker and Gentleman (2001),

$$INT = Q_1 - Q_2 \pm 1.96 \sqrt{SE_1^2 + SE_2^2}$$

where INT is the calculated interval; Q1 and Q2 are survey parameter estimates; and SE1 and SE2 are the standard errors of Q1 and Q2. Differences were considered significant ($p < 0.05$) when the INT did not contain zero.

Results

Roving surveys led to successful interviews of 341 shore-based fishing parties, comprising 667 fishers. Access point surveyors successfully interviewed 299 boat-based fishing parties and 553 fishers. One shore-based fishing party refused to be interviewed. There were 54,808 fisher hours (± 4,918 SE) of angling effort expended (Table 1).

Boat-based fishery

Fishing effort was not evenly distributed with a third of total effort expended in the boat-based fishery and two-thirds in the shore-based fishery (Table 1).

Table 1 Effort estimates and standard errors (fisher hours) for boat and shore-based fisheries in Lake Eucumbene (31 October 2015 to 31 January 2016).

Day-type	Boat Fisher hr	SE	Shore Fisher hr	SE	Total Fisher hr	SE
Effort, November-early period						
Weekday	3,180	1,328	3,934	1,814	7,114	2,248
Weekend	1,427	568	1,646	44	3,073	570
Total	4,607	1,445	5,580	1,814	10,187	2,319
Effort,November-late period						
Weekday	2,289	399	6,933	1,154	9,222	1,221
Weekend	2,329	273	5,611	1,215	7,940	1,245
Total	4,618	484	12,544	1,675	17,162	1,744
Effort, December period						
Weekday	3,211	444	8,262	3,310	11,473	3,339
Weekend	984	263	2,821	656	3,805	707
Total	4,195	516	11,083	3,374	15,278	3,413
Effort, January period						
Weekday	3,526	1,477	3,336	1,048	6,862	1,812
Weekend	1,781	692	3,538	594	5,319	912
Total	5,307	1,631	6,874	1,205	12,181	2,028
Effort, total						
Weekday	12,206	2,075	22,465	4,083	34,671	4,580
Weekend	6,521	972	13,616	1,504	20,137	1,791
Total	18,727	2,291	36,081	4,351	54,808	4,918

Almost all boat-based fishers were non-specifically targeting 'trout', rather than focussing on either of the two salmonid species present in the fishery (Figure 2).

Figure 2   Weighted frequency distribution of fisher species-specific target preferences for boat- and shore-based fisheries in Lake Eucumbene, 31 October 2015 to 31 January 2016. The total number of sampling days is represented by n.
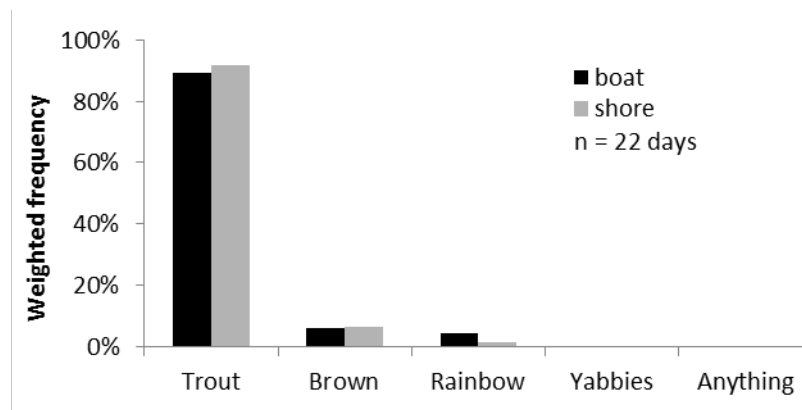
The harvest-rate of rainbow trout was approximately double that of brown trout in the boat-based fishery (rainbow trout 0.106 fish/fisher hr ± 0.030 SE; brown trout 0.049 fish/fisher hr ± 0.005 SE; Table 2). However, this result was not significant (INT = -0.003–0.117, p > 0.05). Similarly, there was no statistical difference between boat-based catch-and-release rates of these species (INT = -0.013–0.037, p > 0.05; rainbow trout 0.055 fish/fisher hr ± 0.008 SE; brown trout 0.043 fish/fisher hr ± 0.010 SE; Table 2). The catch-rate of rainbow trout in the boat-based fishery was significantly larger than that of brown trout (INT = 0.002–0.080, p < 0.05; rainbow trout 0.122 fish/fisher hr ± 0.018 SE; brown trout 0.081 fish/fisher hr ± 0.008 SE; Table 2).

There were more rainbow trout harvested and caught-and-released (harvest 1,790 ± 591 SE; catch-and-release 1,008 ±187 SE), than brown trout (1,016 individuals ± 141 SE; catch and release 727 ± 215 SE) in the boat-based fishery (Table 3).

Table 2   Rainbow trout and brown trout catch-and-release rates, harvest-rates, catch-rates and standard errors (fish/fisher hr) for (a) boat-based, and (b) shore-based fisheries, taken by recreational fishers in Lake Eucumbene, 31 October 2015 to 31 January 2016.

| Day-type	a) Boat-based fishery						b) Shore-based fishery					
	Release rate		Harvest rate		Catch rate		Release rate		Harvest rate		Catch rate	
	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE
Rainbow trout, November-early period												
Weekday	0.026	0.002	0.049	0.017	0.040	<0.001	0.072	0.034	0.032	0.022	0.104	0.056
Weekend	0.038	0.007	0.045	0.001	0.054	<0.001	0.094	0.070	0.116	0.006	0.210	0.076
weighted average	0.029	0.002	0.048	0.012	0.044	<0.001	0.078	0.031	0.056	0.016	0.134	0.045
Rainbow trout, November-late period												
Weekday	0.039	0.034	0.093	0.030	0.128	0.051	0.045	0.015	0.038	0.021	0.084	0.033
Weekend	0.080	0.026	0.044	0.031	0.090	0.026	0.047	0.019	0.064	0.002	0.111	0.018
weighted average	0.053	0.024	0.076	0.022	0.115	0.035	0.046	0.012	0.047	0.014	0.093	0.023
Rainbow trout, December period												
Weekday	0.116	0.026	0.205	0.147	0.206	0.065	0.022	0.017	0.060	0.015	0.082	0.032
Weekend	0.037	0.008	0.099	0.051	0.143	0.056	0.012	0.012	0.044	0.017	0.056	0.021
weighted average	0.095	0.019	0.178	0.110	0.190	0.050	0.020	0.013	0.056	0.012	0.075	0.024
Rainbow trout, January period												
Weekday	0.009	0.009	0.028	0.028	0.056	0.056	0.015	0.015	0.278	0.232	0.294	0.224
Weekend	0.054	0.048	0.163	0.071	0.125	0.030	0.089	0.050	0.098	0.040	0.187	0.076
weighted average	0.024	0.017	0.071	0.030	0.078	0.039	0.039	0.019	0.220	0.158	0.259	0.154
Rainbow trout, total												
Weekday	0.057	0.011	0.108	0.040	0.124	0.023	0.037	0.009	0.107	0.051	0.143	0.051
Weekend	0.053	0.011	0.102	0.034	0.118	0.022	0.038	0.009	0.112	0.057	0.150	0.056
weighted average	0.055	0.008	0.106	0.030	0.122	0.018	0.037	0.007	0.108	0.040	0.145	0.039
Brown trout, November-early period												
Weekday	0.013	0.001	0.071	0.012	0.043	0.007	0	0	0.034	0.018	0.034	0.018
Weekend	0.021	0.010	0.067	0.001	0.053	0.002	0.020	0.020	0.018	0.010	0.038	0.030
weighted average	0.015	0.003	0.070	0.008	0.046	0.005	0.006	0.006	0.029	0.013	0.035	0.016
Brown trout, November-late period												
Weekday	0.080	0.063	0.074	0.017	0.131	0.037	0.004	0.004	0.027	0.022	0.031	0.020
Weekend	0.038	0.013	0.083	0.021	0.118	0.047	0.014	0.007	0.028	0.015	0.041	0.020
weighted average	0.066	0.042	0.077	0.013	0.127	0.029	0.007	0.004	0.027	0.015	0.035	0.015
Brown trout, December period												
Weekday	0.049	0.011	0.060	0.012	0.106	0.010	0.071	0.063	0.052	0.018	0.123	0.079
Weekend	0.047	0.017	0.051	0.014	0.069	0.038	0.008	0.008	0.004	0.002	0.011	0.006
weighted average	0.049	0.009	0.058	0.010	0.096	0.012	0.055	0.047	0.040	0.013	0.094	0.059
Brown trout, January period												
Weekday	0.036	0.036	0.019	0.019	0.055	0.031	0.026	0.026	0.008	0.008	0.034	0.034
Weekend	0.004	0.004	0.003	0.003	0.006	0.003	0.006	0.006	0.005	0.005	0.011	0.006
weighted average	0.026	0.024	0.013	0.013	0.039	0.021	0.019	0.018	0.007	0.006	0.027	0.023
Brown trout, total												
Weekday	0.043	0.013	0.049	0.006	0.081	0.011	0.028	0.018	0.025	0.006	0.053	0.022
Weekend	0.043	0.015	0.048	0.007	0.081	0.012	0.025	0.015	0.024	0.006	0.049	0.019
weighted average	0.043	0.010	0.049	0.005	0.081	0.008	0.027	0.013	0.025	0.005	0.052	0.017

Table 3 Recreational catch-and-release (a) and harvest (b) estimates and standard errors (number of individuals) for rainbow trout and brown trout taken by recreational fishers in Lake Eucumbene, 31 October 2015 to 31 January 2016.

| | a. Catch-and-release | | | | | | b. Harvest | | | | | |
| | Boat | | Shore | | Total | | Boat | | Shore | | Total | |
Day-type	numbers	SE	numbers	SE	numbers	SE	numbers	SE	numbers	SE	numbers	SE
Rainbow trout, November-early period												
Weekday	84	36	150	77	234	85	157	81	72	45	229	93
Weekend	54	24	93	49	147	55	64	25	151	9	215	27
Total	138	43	243	91	381	101	221	85	223	46	444	97
Rainbow trout, November-late period												
Weekday	83	70	353	94	436	117	210	76	272	172	482	188
Weekend	204	86	202	78	406	116	121	87	290	51	411	101
Total	287	111	555	122	842	165	331	116	562	180	893	214
Rainbow trout, December period												
Weekday	420	114	147	102	567	153	749	538	578	256	1,327	596
Weekend	43	17	24	24	67	29	105	57	150	90	255	107
Total	463	115	171	104	634	155	854	541	728	272	1,582	605
Rainbow trout, January period												
Weekday	32	32	34	34	66	47	95	95	1,092	887	1,187	892
Weekend	88	81	262	159	350	178	289	166	249	101	538	194
Total	120	87	296	163	416	184	384	191	1,341	893	1,725	913
Rainbow trout, total												
Weekday	619	142	684	162	1,303	215	1,211	557	2,014	940	3,225	1,093
Weekend	389	121	581	185	970	222	579	197	840	145	1,419	245
Total	1,008	187	1,265	246	2,273	309	1,790	591	2,854	951	4,644	1,120
Brown trout, November-early period												
Weekday	42	18	0	0	42	18	229	100	149	78	378	127
Weekend	31	18	17	17	48	25	95	38	31	7	126	38
Total	73	26	17	17	90	31	324	107	180	78	504	133
Brown trout, November-late period												
Weekday	191	152	28	28	219	154	166	39	150	111	316	117
Weekend	86	31	44	23	130	39	188	27	141	55	329	61
Total	277	155	72	36	349	159	354	47	291	124	645	132
Brown trout, December period												
Weekday	183	60	508	467	691	471	211	39	337	143	548	148
Weekend	58	30	23	23	81	38	60	25	11	7	71	26
Total	241	67	531	468	772	473	271	46	348	144	619	151
Brown trout, January period												
Weekday	130	130	44	44	174	137	63	63	28	28	91	69
Weekend	6	6	23	23	29	24	4	4	18	18	22	19
Total	136	130	67	50	203	139	67	63	46	33	113	72
Brown trout, total												
Weekday	546	209	580	470	1,126	515	669	131	664	199	1,333	238
Weekend	181	48	107	44	288	65	347	53	201	59	548	79
Total	727	215	687	472	1,414	519	1,016	141	865	208	1,881	251

There were 160 brown trout (265 to 613 mm FL; mean 448 mm ± 5 SE) and 173 rainbow trout (260 to 523 mm FL; mean 362 mm ± 5 SE) harvested in the boat-based fishery (Figure 3). Only four of the harvested rainbow trout (395 to 425 mm FL) were finclipped, and each of these fish was 3 years of age. The corrected percentage of stocked rainbow trout in the boat-based fishery was 13.3%.

Figure 3   Cumulative length frequency distributions for brown and rainbow trout harvested by boat- and shore-based fishers in Lake Eucumbene, 31 October 2015 to 31 January 2016.
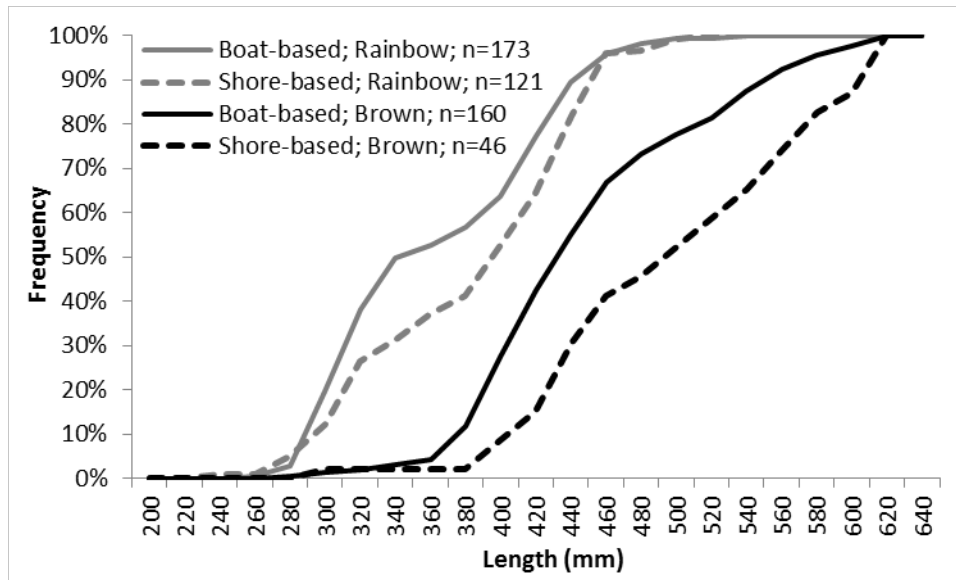
Rainbow and brown trout harvested by boat-based fishers were significantly smaller than those harvested in the shore-based fishery (2 sample Kolmogarov-Smirnov test; rainbow trout: KS = p < 0.05; brown trout, KS = p < 0.05; Figure 3). However, for fish harvested within the boat-based fishery, brown trout were significantly larger than rainbow trout (Figure 3). Of those fish harvested in the boat-based fishery, 55.3% were rainbow trout and 44.7% were brown trout, whereas for those fish that were caught and released, 77.9% were rainbow trout and 22.1% brown trout. Almost all brown (93.8%) and rainbow trout (95.8%) caught-and-released were voluntarily discarded because fish were greater than the existing 250 mm MLL (Figure 4). Few fish were released in the boat-based fishery as they were undersized (rainbow trout 4.1%; brown trout 6.2%), or because anglers had reached their bag limit (rainbow trout 0.1%; brown trout 0%; Figure 4).

Figure 4   Weighted frequency distribution of reasons for catch-and-release of rainbow and brown trout for boat- and shore-based fisheries in Lake Eucumbene, 31 October 2015 to 31 January 2016. The total number of sampling days is represented by n.
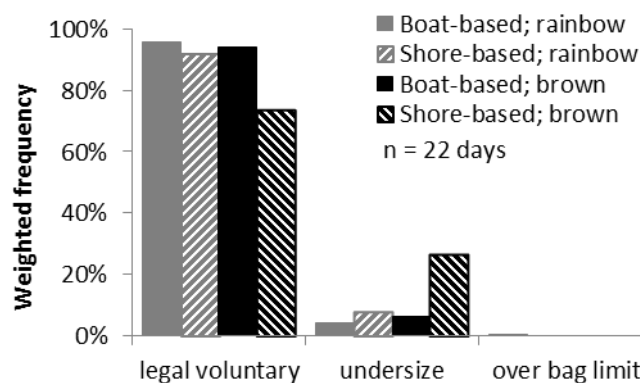
Most anglers in the boat-based fishery used lures (73.4%; Figure 5). Lure fishers were responsible for almost all harvest and catch-and-release of rainbow trout and brown trout in the boat-based fishery (Harvest; rainbow trout 97.5%, brown trout 99.5%; Catch-and-release; rainbow trout 97.1%, brown trout 98.8%; Figure 6).

Figure 5   Weighted frequency distribution of fishing method for boat and shore-based fisheries in Lake Eucumbene, 31 October 2015 to 31 January 2016. The total number of sampling days is represented by n.
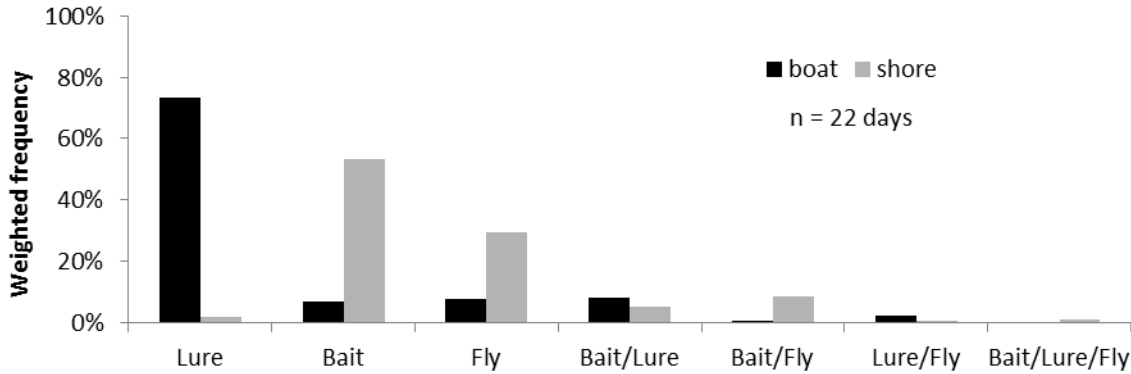
Figure 6   Weighted frequency distributions of fish harvested and fish caught-and released by fishing method for boat and shore-based fisheries in Lake Eucumbene, 31 October 2015 to 31 January 2016. The total number of sampling days was 22.
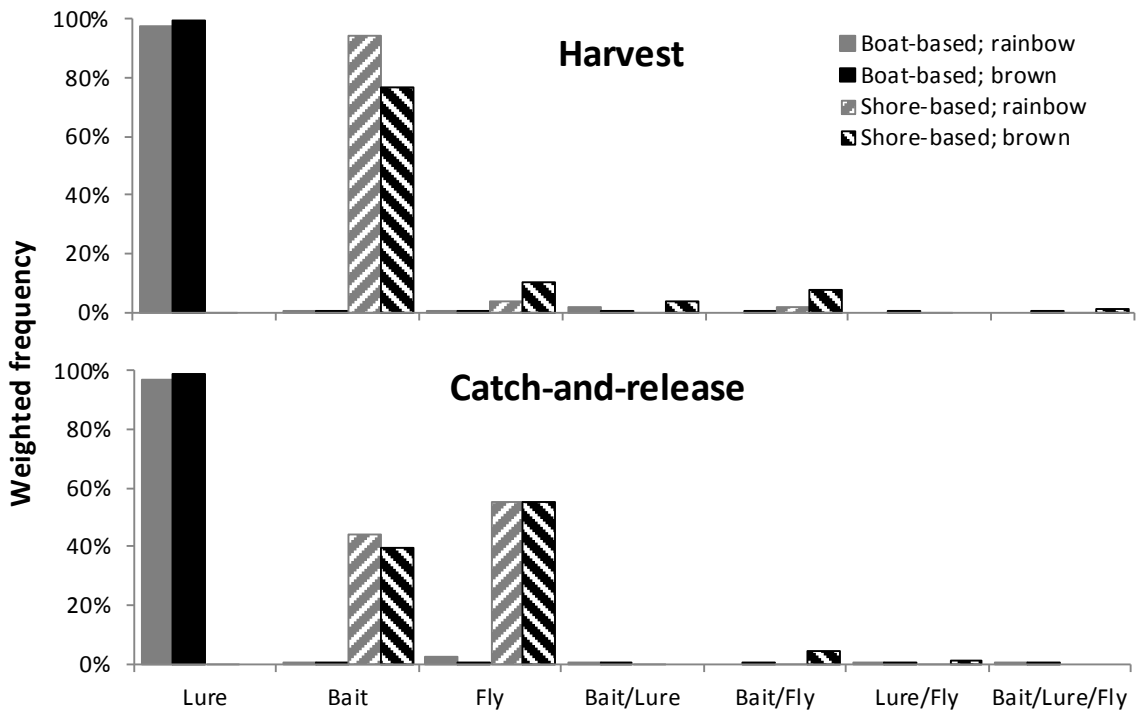
Shore-based fishery

The shore-based fishing effort (36,081 fisher hr ± 4,351 SE) was approximately double that of the boat-based fishery (18,727 fisher hr ± 2,291 SE; Table 1). Most shore-based fishers nominated 'trout' as their target species (91.9%; Figure 2). The harvest-rate of rainbow trout from the shore-based fishery was significantly larger than that of brown trout (INT = 0.004–0.162, $p < 0.05$; rainbow trout 0.108 fish/fisher hr ± 0.040 SE; brown trout 0.025 fish/fisher hr ±

0.005 SE; Table 2). However, shore-based catch-and-release rates of these species were not statistically different (INT = -0.019–0.039, p < 0.05; rainbow trout 0.037 fish/fisher hr ± 0.007 SE; brown trout 0.027 fish/fisher hr ± 0.013 SE; Table 2). The catch-rate of rainbow trout in the shore-based fishery was significantly larger than that of brown trout (INT = 0.010–0.176, p < 0.05; rainbow trout 0.145 fish/fisher hr ± 0.039 SE; brown trout 0.052 fish/fisher hr ± 0.017 SE; Table 2). There were more rainbow trout than brown trout, harvested and caught-and-released, in the shore-based fishery (Harvest; rainbow trout 2,854 individuals ± 951 SE; brown trout 865 individuals ± 208 SE; Catch-and-release; rainbow 1,265 individuals ± 246 SE; brown 687 individuals ± 472 SE; Table 3).

There were 46 brown trout (300 to 620 mm FL; mean 501 mm ± 11 SE) and 121 rainbow trout (233 to 505 mm FL; mean 383 mm ± 6 SE) harvested in the shore-based fishery (Figure 3). Five of the harvested rainbow trout (400 to 451 mm FL) were finclipped, and each of these fish were 3 years of age. The corrected percentage of stocked rainbow trout in the shore-based fishery was 16.1%.

Shore-based fishers harvested significantly larger rainbow and brown trout, than boat-based fishers (2 sample Kolmogarov-Smirnov test; rainbow trout: KS = p < 0.05; brown trout, KS = p < 0.05; Figure 3). Brown trout harvested by shore-based fishers were significantly larger than retained rainbow trout in this fishery (2 sample Kolmogorov-Smirnov test; p < 0.05; Figure 3). Of those fish harvested in the shore-based fishery 70.6% were rainbow trout and 29.4% were brown trout, whereas for those fish that were caught-and-released in the shore-based fishery, 93.3% were rainbow trout and 6.7% were brown trout. Most brown and rainbow trout that were caught-and-released in the shore-based fishery were voluntarily discarded (rainbow 92.2%, brown 73.6%; Figure 4). However, 26.4% of brown trout were released as they were undersized. In contrast, few rainbow trout in the shore-based fishery were released as they were undersized (7.8%), and no fish were released because anglers had reached their bag limit (Figure 4).

The main fishing methods used by shore-based fishers were bait (53.3%) or fly (29.4%; Figure 5). Shore-based fishers using bait harvested the most rainbow trout (94.2%) and brown trout (76.9%; Figure 6). The percentage of fish caught-and-released in the shore-based fishery was greatest for anglers that used fly (rainbow trout 55.4%; brown trout 55.1%), or bait (rainbow trout 44.2%; brown trout 39.4%; Figure 6).

Discussion

Our data suggests that the Lake Eucumbene recreational fishery is comprised mainly of rainbow trout with the estimated harvest and catch-and-release of this species more than double that estimated for brown trout. The shore-based fishery harvested more, and significantly larger, rainbow and brown trout, and attracted twice the fishing effort to that of the boat-based fishery. Harvest- and catch-rates of rainbow trout were higher than those for brown trout in both boat- and shore-based fisheries. These results were not caused by specific targeting preferences of anglers as almost all fishers were non-specifically targeting 'trout', rather than a particular species. Furthermore, the higher catch-rate of rainbow trout by recreational fishers is not necessarily an indication of a higher abundance of rainbow trout in Lake Eucumbene. The most likely explanation is the higher catchability of rainbow trout compared to brown trout with the methods used. This suggestion is supported by historic tagging studies in Lake Eucumbene from 1987, that showed lower exploitation rates of brown trout (Faragher and Gordon 1992). North American and European recreational fisheries also showed evidence of higher catchability of rainbow trout over brown trout (Johnson et al. 1995; Pawson 1991).

Fishery dependant information collected from Lake Eucumbene during fishing tournaments, including the relative contribution and size structure of rainbow and brown trout, can increase understanding of fishery performance (Faragher et al. 2007). For example, data from this study indicated that the relative contribution and size structure of each trout species were generally similar to historic tournament-sourced data (Faragher et al. 2007). However, catch-rates for both species in the current study appeared considerably lower than those recorded during tournaments in 2000-2004 (Faragher et al. 2007). This may imply a decline in stocks, however, such a comparison is invalid, as survey designs of both studies were markedly different. In particular, a probability-based sampling design was not used in 2000-2004 surveys (which may introduce a large sampling bias), and zero catches were not included, which artificially inflated the historic catch-rates. Well designed, standardized surveys using fishery dependant (e.g. angler surveys) and independent (e.g. electrofishing, trapping) methods are required to assess change and status of trout stocks in Lake Eucumbene. The current survey provides a base line to evaluate change in the Lake Eucumbene trout fishery noting that presently, catch rates are quite low. Anglers need to invest substantial hours on the water to catch a trout and, at least during summer months, exceeding the bag limit is rare.

The regulations governing harvest and catch-and-release of trout in Lake Eucumbene (i.e. bag and size limits) were largely ineffective, because of the high incidence of voluntary release of legal sized fish; at least in summer. In contrast, mandatory releases were uncommon as few trout were undersized, and it was rare for fish to be released because of bag limit restrictions as few anglers achieved their personal limit. The high incidence of voluntary discards of harvest-eligible trout in Lake Eucumbene may be reflective of a recent shift in developed countries from fishery management solely by government imposed harvest restrictions to voluntary behaviours of anglers that aim to conserve and protect resources (Cooke et al. 2013). For example, changing catch-and-release behaviours have been shown to reduce the effectiveness of harvest regulations in fisheries for largemouth bass, *Micropterus salmoides*, in North America where increased prevalence of voluntary releases lowered exploitation of this species (Allen et al. 2008). It may also be that the MLL applied to trout fisheries across New South Wales (New South Wales Department of Primary Industries 2014), is inappropriate for Lake Eucumbene because anglers release most harvest eligible fish. If this were true, then the use of waterbody-specific rules that more closely match fishing quality objectives of managers with angler expectations, may be more effective at governing harvest. In this regard, the existing MLL may

be too low to meet the expectations of anglers in this fishery. However, fishery specific regulations are difficult to enforce, as it is impossible for compliance officers to determine where specific fish were harvested, especially in instances where other trout fisheries are located nearby. In any case, considering the high incidence of release, a post-capture survival study would be warranted, to ensure that fish which are released successfully re-enter the fishery.

Regulations that target specific fishing methods used in Lake Eucumbene are a potential tool that could be effective in limiting harvest, should further governance of the fishery be deemed necessary. For example, shore-based fishers that used fly were focussed on catch-and-release, whereas anglers that used bait were more harvest oriented. In this regard, restricting the Lake Eucumbene fishery to artificial fishing methods only (i.e. fly and lure), would likely reduce harvest. However, caution must be taken with discriminatory regulations as angler visitations to a fishery can fall by up to 80%, as fishers have been shown to avoid locations with more restrictive rules (Knoche and Lupi 2016; Olaussen 2016). Thus, fishery managers need to consider whether imposing regulations that restrict certain fishing methods are warranted against the potential loss in angler participation, and the subsequent negative effects to the local economy. The results from this survey in Lake Eucumbene do not suggest that such regulations are necessary at this time.

Electrofishing and trapping surveys estimated that up to 8% of rainbow trout collected from spawning streams flowing into Lake Eucumbene were stocked (Faragher et al. 2007). We found the proportion of stocked fish in Lake Eucumbene was approximately twice this number, suggesting that this lentic rainbow trout population continues to be maintained primarily by natural recruitment; or that wild-fish are more easily captured. However, it is important to note that not all mature individuals spawn in any given year. For example, only 25% of reproductively mature rainbow trout in a North American impoundment migrated into spawning streams (Holecek and Scarnecchia 2013). Therefore, it is likely that the disparity between the proportions of stocked fish in Lake Eucumbene and the spawning run was because some reproductively mature rainbow trout are remaining in the lake, rather than undertaking an annual migration. Additional investigation into quantifying how many mature trout remain in the lake; the reasons why this occurs; and the possible effects that such intermittent spawning may have on sustainability of the fishery, represents an important avenue for further research.

The absence of historic fishery-dependent data collected consistently in Lake Eucumbene, using a probability-based sampling design, prevents assessment of current fishery status (i.e. decline or recovering). Thus, it is difficult to determine if variable catch-rates reflect differing abundances of each species, or simply a broader reflection that rainbow trout are more susceptible to capture than brown trout. Fishery managers have used the high catchability of rainbow trout as a short-term fix to improve fishery quality in underperforming or depleted fisheries (by releasing more hatchery-reared fish), whereas brown trout are considered a longer-term prospect for fishery sustainability (Pawson 1991). Such a strategy could be used in Lake Eucumbene to enhance the fishery during periods where rainbow trout natural recruitment and existing stocking levels are insufficient to sustain the population at current levels of fishing pressure. In this regard, the development of a framework to classify fishing quality in this and other salmonid fisheries should be considered a priority. The framework should include key parameters such as; catch- and harvest-rates; fishing effort; proportion of stocked and wild fish; carrying capacity; and population estimates. Attainment of prescribed levels for each parameter should then trigger additional management and regulation activities to ensure that the fishery is sustainable in the face of variable influences.

Solid conclusions about whether this recreational fishery is in decline or otherwise cannot be drawn from this study alone, or from any comparisons with historic studies. This is because firstly, this was a snapshot survey done over summer months in a particular year. Secondly, only by repeat sampling using a robust study design, can a definitive assessment among years be made. Thirdly, resource limitations allowed only a third of the lake area to be surveyed using the present study design. Accounting for these three variables is essential in assessing angler success moving forward. We recommend annual sampling, with full lake coverage across all seasons to generate substantial data on the two fisheries within this lake.

Management framework development

Management regulations governing the recreational fishery in Lake Eucumbene include input (e.g. maximum two rods; seasonal closures in spawning rivers) and output (e.g. bag/possession limits, minimum size restrictions) controls. In addition, stocking of rainbow trout is used to enhance the Lake Eucumbene fishery. Stocking has been used as a tool to enhance the rainbow trout fishery in Lake Eucumbene since the early 1980s. Since 2001, 150,000 rainbow trout fingerlings have been stocked annually in this waterbody. Additional stocking of rainbow trout could be a strategy to enhance the fishery during periods where natural recruitment and current stocking levels are insufficient to sustain the population at existing levels of fishing pressure. Such decisions should consider negative impacts on trout stocks that are beyond the direct control of fishery managers (i.e. water levels, climate change, and oligotrophic water bodies). For example, Salmonidae in California showed high vulnerability to climate change (Katz et al. 2013).

The DPI Fisheries Snowy Lakes Trout Strategy 2012-2017 aims to manage Lake Eucumbene as the *"premier enhanced wild trout fishery in NSW"* and "*to maximise catches of fish in the range of length from 40 to 50 cm and weights from 1 to 2 kg*" (NSW Department of Primary Industries 2012). No quantifiable indicators and reference points for these two management objectives have been developed. It is therefore impossible to assess the current status of Lake Eucumbene's fishery against the objectives and/or to determine whether changes in management are effective in reaching the objectives. With respect to the period 2001-2004, it was stated that "*catch has remained at satisfactory rates of fish caught per angler hour*" without explaining whether catch-rates were satisfactory from a management or angler perspective (Faragher et al. 2007). Furthermore, no information was provided in this document regarding catch-rate targets or reference points for a fishery to be regarded as satisfactory.

To ensure the sustainability of recreational fisheries in Lake Eucumbene, and in NSW inland waters in general, a framework is required that specifies pre-determined management actions in a fishery for defined species (at the stock or management unit level). Such a framework is necessary to achieve the agreed ecological, economic and/or social management objectives (Sloan et al. 2014). The following key elements should be included in a best-practice harvest strategy framework (Sloan et al. 2014):

- Defined operational objectives for the fishery
- Relate objectives to indicators of fishery performance
- Define acceptable risk in meeting objectives
- Limit, trigger and target reference points for performance indicators
- A monitoring strategy to assess fishery performance
- Assessment of fishery performance relative to objectives
- Decision rules that control the intensity of fishing activity and/or catch

Thus we recommend that the Snowy Lakes Trout Management strategy be reviewed, and the annual monitoring program be adjusted to align with this new approach.

For recreational fisheries in NSW, harvest strategies should be simple, robust and cost-effective. Collecting regular and reliable data on potential performance indicators such as catch per unit effort (CPUE), or mean length for key species and waterbodies would require a large resource commitment. The financial resources required to collect such data using DPI Fisheries staff is not realistic. Anglers play a pivotal role and can make a crucial contribution to data collection by participation in citizen science programmes. An integrated recreational fishery research programme combining state-wide phone-diary surveys for overall trends in participation and catch-rates, surveys of key species and waterbodies (i.e. on-site angler creel surveys), and a well-designed citizen science programme should provide relevant indicators to assess status and trends in recreational fisheries. Additionally, harvest strategies are being developed for NSW marine recreational and commercial fisheries. Close co-operation among cross-disciplinary scientists and managers in NSW, plus those from other state jurisdictions, will assist development of harvest strategies for freshwater recreational fisheries in NSW.

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Appendices

Appendix 1 – Equations for estimating effort and harvest in recreational fisheries

Basic notation

The following notation is used in defining the various estimation methods:

j denotes the stratum being considered ($j = 1,…,J$) ;

J denotes the total number of strata;

i denotes the sample day unit within the stratum ($i = 1,…,N_j$) ;

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

n_j is the sample size in stratum j ;

x_{ij} denotes the value of the i th unit of stratum j ;

$\bar{x}_j$ is the sample mean for stratum j ;

$s_j^2 = \dfrac{\left[\sum_{i=1}^{n_j} (x_{ij} - x_j)^2 \right]}{(n_j - 1)}$ is the sample variance for stratum j

Effort estimation for boat- and shore-based fisheries

Step 1: The progressive counts of boat- and shore-based fishers were calculated separately to estimate effort for each day of sampling.

$$\hat{e}_i = P_i \times T \qquad \text{(Equation 1)}$$

where $\hat{e}_i$ is the estimate of fishing effort for the i th sample day; P_i is the progressive count for the i th sample day (the number of fishing parties counted was used for both boat- and shore-based fisheries); and T is the length of the fishing day (we used the mean day length period in hours).

Step 2: The daily effort estimates were then expanded for each day-type stratum (weekend or weekday) by multiplying the number of possible sample days in each base level stratum by the mean of the daily estimates of effort.

$$\bar{e}_j = \frac{\sum \hat{e}_{ij}}{n_j} \qquad \text{(Equation 2)}$$

where $\bar{e}_j$ is the estimated mean daily fishing effort (fishing parties per day) for the j th day-type stratum within the season; $\hat{e}_{ij}$ is the estimate of fishing effort for the i th sample day in the j th day-type stratum within the season; and n_j is the number of days sampled in the j th day-type stratum within the season. The effort estimates were further expanded by multiplying the mean daily fishing effort by the number of possible sampling days in each stratum.

$$\hat{E}_j = N_j \times \bar{e}_j \qquad \text{(Equation 3)}$$

where $\hat{E}_j$ is the estimate of total effort (party hours) for the j th day-type stratum within the season.

Step 3: We calculated the precision of effort estimates by estimating variances and SEs for each stratum.

$$Var(\overline{e}_j) = \frac{s_j^2}{n_j}$$ (Equation 4)

where $Var(\overline{e}_j)$ is the estimated variance of the mean daily fishing effort for the j th day-type stratum within the season; s_j^2 is the sample variance of the daily estimates of fishing effort for the j th day-type stratum within the season; and n_j is the sample size as described in Equation 2. The SE of mean daily fishing effort was then estimated as

$$SE(\overline{e}_j) = \sqrt{Var(\overline{e}_j)}$$ (Equation 5)

where $SE(\overline{e}_j)$ is the estimated SE of the mean daily fishing effort; and $Var(\overline{e}_j)$ is the estimated variance of the mean daily fishing effort as described in Equation 4. The variance for total effort was calculated as

$$Var(\hat{E}_j) = N_j^2 \times Var(\overline{e}_j)$$ (Equation 6)

where $Var(\hat{E}_j)$ is the estimated variance of total effort for a stratum, and was calculated separately for each day-type (weekday or weekend). SE was subsequently calculated as

$$SE(\hat{E}_j) = \sqrt{Var(\hat{E}_j)}$$ (Equation 7)

where $SE(\hat{E}_j)$ is the estimated SE of total effort for a stratum; and $Var(\hat{E}_j)$ is the estimated variance of total effort for a stratum as described in Equation 5.

Step 4: We calculated total fishing effort separately for boat- and shore-based fisheries. This was done by adding the effort estimates of the strata to obtain seasonal totals.

$$\hat{E}_{Tot} = \sum_{j=1}^{J} \hat{E}_j$$ (Equation 8)

where $\hat{E}_{Tot}$ is the total seasonal effort (party hours), obtained by summing the effort estimates for day-type stratum; $\hat{E}_j$ is the estimate of total effort for the j th stratum as defined for Equation 3.

Step 5: The precision of effort estimates obtained by adding stratum totals was calculated by summing the estimated variances for all strata and calculating the SE.

$$Var(\hat{E}_{Tot}) = \sum_{j=1}^{J} Var(\hat{E}_j)$$ (Equation 9)

where $Var(\hat{E}_{Tot})$ is the estimated total seasonal variance, calculated by combining the estimated effort variances for day-type strata. The SE was determined as

$$SE(\hat{E}_{Tot}) = \sqrt{Var(\hat{E}_{Tot})}$$ (Equation 10)

where $SE(\hat{E}_{Tot})$ is the estimated SE for seasonal effort totals when adding day-type strata; and $Var(\hat{E}_{Tot})$ is the estimated total variance as described in Equation 9.

Step 6: The estimates of fishing effort were converted from party hours to fisher hours. This was done for each of the boat- and shore-based fisheries at the base-level stratum (i.e., day-type within a season) using the equation

$$\hat{E}_{fisher\ h} = \hat{E}_{party\ h} \times \bar{f} \qquad \text{(Equation 11)}$$

where $\hat{E}_{fisher\ h}$ is the new estimate in fisher hours; $\hat{E}_{party\ h}$ is the old estimate in party hours; and $\bar{f}$ is the mean number of fishers per party in that stratum.

Step 7: The precision of the new estimates of effort in fisher hours were determined by

$$Var(\hat{E}_{fisher\ h}) = [\hat{E}_{party\ h}^2 \times Var(\bar{f})] + [\bar{f}^2 \times Var(\hat{E}_{party\ h})] - [Var(\bar{f}) \times Var(\hat{E}_{party\ h})]$$
$$\text{(Equation 12)}$$

where $Var(\hat{E}_{fisher\ h})$ is the estimated variance for the new estimate of effort; $Var(\bar{f})$ was calculated using the general form of Equation 4; and $Var(\hat{E}_{party\ h})$ was calculated by using the general form of Equation 6. The SEs were determined as

$$SE(\hat{E}_{fisher\ h}) = \sqrt{Var(\hat{E}_{fisher\ h})} \qquad \text{(Equation 13)}$$

where $SE(\hat{E}_{fisher\ h})$ is the estimated SE of the new effort estimate; and $Var(\hat{E}_{fisher\ h})$ is described by Equation 12.

Harvest-rate estimator for the boat-based fishery

The ratio of means was used to estimate total harvest, as the boat fishery data were based on completed trips (Jones et al. 1995; Pollock et al. 1997). This estimator is the ratio of mean harvest to mean effort and has been shown to have a statistical expectation equal to total harvest divided by total effort for the population of fishers when applied to access point surveys (Pollock et al. 1997).

$$\hat{R}_1 = \frac{\sum_{k=1}^{n} H_k}{\sum_{k=1}^{n} L_k} \qquad \text{(Equation 14)}$$

where $\hat{R}_1$ is the "ratio of means" an estimated daily harvest-rate (fish per fisher hour) based on complete trips; H_k is the complete harvest for the k th fishing party; L_k is the complete trip length for the k th fishing party; and *n* is the number of fishing parties in the daily sample.

The seasonal mean daily harvest-rates ($\bar{R}_1$) for each day-type stratum were calculated. The estimated variances of the mean daily harvest-rates ($Var[\bar{R}_1]$) were calculated using the general form of Equation 4, and the estimated SEs of the mean daily harvest-rates ($SE[\bar{R}_1]$) were calculated using the general form of Equation 5.

Harvest-rate estimator for the shore-based fishery

The mean of ratios was used to estimate total harvest from the shore-based fishery, as the data were based on incomplete trips (Hoenig et al. 1997; Jones et al. 1995; Pollock et al. 1997). This estimator is the mean of the individual harvest-rates for all fishers interviewed on a given day. The mean of ratios estimator is shown to have a statistical expectation of total harvest divided by total effort for the population of fishing units when applied to incomplete trip interviews taken by roving through the fishery, provided short duration trips are excluded (Hoenig et al. 1997). Given this expectation, the mean of ratios estimator $(\hat{R}_2)$ used on incomplete trips with short trip

exclusion, provides an equivalent measure of fishing success to the ratio-of-means estimator $(\hat{R}_1)$ used on completed trips (Hoenig et al. 1997; Pollock et al. 1997).

$$\hat{R}_2 = \frac{1}{n}\sum_{k=1}^{n}\frac{H_k}{L_k} \qquad\qquad \text{(Equation 15)}$$

where $\hat{R}_2$ is the mean of ratios, the estimated shore-based fishery harvest-rate (fish per fisher hour); H_k is the harvest recorded at the time of interview for the incomplete trip for the k th fisher; L_k is the length of the incomplete trip at the time of interview for the k th fisher; and n is the number of fishers in the daily sample.

The seasonal mean daily harvest-rates $(\bar{R}_2)$ for each day-type stratum were calculated. The estimated variances of the mean daily harvest-rates $(Var[\bar{R}_2])$ were determined using the general form of Equation 4, and the estimated SEs of the mean daily harvest-rates $(SE[\bar{R}_2])$ were calculated using the general form of Equation 5.

Harvest-rate estimation for boat- and shore-based fisheries

The contribution of each day-type stratum to the estimated seasonal harvest-rate was apportioned by the relative size of each day-type stratum within the season (Pollock et al. 1994), as there are more weekdays than weekend days in a season.

$$\bar{R}_{Season} = \left(\frac{N_{wd}}{N_{Season}} \times \bar{r}_{wd}\right) + \left(\frac{N_{we}}{N_{Season}} \times \bar{r}_{we}\right) \text{(Equation 16)}$$

where $\bar{R}_{Season}$ is a stratified seasonal mean daily harvest-rate (fish per fisher hour); The $\bar{R}_1$ estimator described in Equation 14 was used for the boat-based fishery, and the $\bar{R}_2$ estimator described in Equation 15 was used for the shore-based fishery; N_{wd} is the number of weekdays in the season; N_{we} is the number of weekend days (includes public holidays) in the season; N_{Season} is the total number of days in the season; $\bar{r}_{wd}$ is the mean daily harvest-rate for the weekday stratum; and $\bar{r}_{we}$ is the mean daily harvest-rate for the weekend day stratum. Estimates of variance for the stratified mean daily harvest-rates were calculated as:

$$Var(\bar{R}_{Season}) = \left[\left(\frac{N_{wd}}{N_{Season}}\right)^2 \times Var(\bar{r}_{wd})\right] + \left[\left(\frac{N_{we}}{N_{Season}}\right)^2 \times Var(\bar{r}_{we})\right] \text{(Equation 17)}$$

where $Var(\bar{R}_{Season})$ is the estimated variance for the stratified mean daily harvest-rate for the season; $Var(\bar{r}_{wd})$ is the estimated variance for the mean daily harvest-rates for the weekday stratum in the season; and $Var(\bar{r}_{we})$ is the estimated variance for the mean daily harvest-rates for the weekend day stratum in the season. Both $Var(\bar{r}_{wd})$ and $Var(\bar{r}_{we})$ can be calculated by using the general form of Equation 4.

The other terms are described in Equation 16.

Estimates of SE for the stratified mean daily harvest-rates were calculated as

$$SE(\bar{R}_{Season}) = \sqrt{Var(\bar{R}_{Season})} \qquad\qquad \text{(Equation 18)}$$

where $SE(\bar{R}_{Season})$ is the SE of the stratified mean daily harvest-rate; and $Var(\bar{R}_{Season})$ is the variance of the stratified mean daily harvest-rate as described in Equation 17.

Harvest estimation for boat based and shore based fisheries

To estimate total harvest for boat- and shore-based fisheries, the independent effort estimate was multiplied by the appropriate harvest-rate estimate (Hoenig et al. 1997; Pollock et al. 1997; Pollock et al. 1994).

$$\hat{H}_{Boat} = \hat{E}_{Boat} \times \bar{R}_1 \qquad \text{(Equation 19)}$$

where $\hat{H}_{Boat}$ is an estimate of harvest (numbers of fish) for the boat-based fishery (estimation was for each day-type stratum within the season); $\hat{E}_{Boat}$ is the estimate of effort (fisher hours) for the boat-based fishery; and $\bar{R}_1$ is the estimate of mean daily harvest-rate (fish per fisher hour) as described in Equation 14. Likewise for the shore-based fishery,

$$\hat{H}_{Shore} = \hat{E}_{Shore} \times \bar{R}_2 \qquad \text{(Equation 20)}$$

where $\hat{H}_{Shore}$ is an estimate of harvest (numbers of fish) for the shore-based fishery (estimation was for each day-type stratum within the season); $\hat{E}_{Shore}$ is the estimate of effort (fisher hours) for the shore-based fishery; and $\bar{R}_2$ is the estimate of mean daily harvest-rate (fish per fisher hour) as described in Equation 15.

Estimates of variance for harvest in the boat- and shore-based fisheries were calculated, and the base level of estimation was for a day-type stratum within the season using the following equation

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

$$\text{(Equation 21)}$$

where $Var(\hat{H})$ is the estimated variance for the boat-based fishery when using equivalent terms from Equation 19, and the estimated variance of the shore-based fishery when using equivalent terms from Equation 20; $\bar{R}$ is the estimate of mean daily harvest-rate for a stratum (the $\hat{R}_1$ estimator described in Equation 14 was used for the boat-based fishery, and the $\hat{R}_2$ estimator described in Equation 15 was used for the shore-based fishery); $Var(\bar{R})$ is the estimated variance of the mean daily harvest-rate for a stratum and was calculated by using the general form of Equation 4; $\hat{E}$ is the total effort for a stratum, and is described in Equation 3; and $Var(\hat{E})$ is the estimated variance of the total effort for a stratum, as described in Equation 6. The estimated SE of the harvest was calculated as

$$SE(\hat{H}) = \sqrt{Var(\hat{H})} \qquad \text{(Equation 22)}$$

where $SE(\hat{H})$ is the estimated SE of the harvest of the boat-based fishery when using equivalent terms from Equation 19, and the estimated SE of the harvest for the shore-based fishery when using equivalent terms from Equation 20; and $Var(\hat{H})$ is the estimated variance of the harvest, as described in Equation 21.

Harvest estimates for weekday and weekend day strata were combined to give seasonal totals. The general form of the equations used in the effort and harvest estimation and the associated variances and SEs were used for catch-and-release (discard) estimation.

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