Assessment of Recreational Fishing in Three Recreational Fishing Havens in New South Wales

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NON-TECHNICAL SUMMARY

Assessment of recreational fishing in three recreational fishing havens in New South Wales

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NON-TECHNICAL SUMMARY:

Since the declaration of recreational fishing havens (RFHs) in 27% of the estuarine waters of New South Wales (NSW), ongoing assessments of the longevity and spatial extent of changes to the quality of recreational fishing in RFHs have been required. This report documents the findings of the most recent (March–May 2011) assessments of recreational fishing within three RFHs in NSW: Lake Macquarie, St Georges Basin and Tuross Lake. Using a combined access-point and roving survey design, these assessments were aimed at: (i) estimating recreational fishing effort and total harvest in the three estuaries; (ii) estimating the harvest of the five most-harvested species in the three estuaries; (iii) examining the spatial patterns of recreational exploitation within the three estuaries; and (iv) qualitatively assessing overall changes in fishing effort and harvest within Lake Macquarie and Tuross Lake between 1999, 2004 and 2011 for the March–May period.

For the boat- and/or shore-based fisheries of each estuary, effort and total harvest were highest in Lake Macquarie, followed by St Georges Basin and then Tuross Lake, which correlates with their relative size. The surveys provided evidence of substantial recreational fisheries in each estuary and continued monitoring of recreational harvest-rates within them is strongly recommended to ensure the sustainability of their recreational fisheries. The species most harvested by boat-based anglers in Lake Macquarie, St Georges Basin and Tuross Lake were blue swimmer crabs, bream species and dusky flathead, respectively, while those most harvested by shore-based anglers in the first two estuaries were luderick and bream species, respectively. Bream species, dusky flathead and sand whiting consistently occurred among the five most-harvested species in this study, as did luderick where shore-based harvest was surveyed. Given that these four species are classed as fully fished in NSW, the current findings highlight the need for species-specific monitoring programs to ensure sustainable harvest of these iconic recreational species.

The generally deeper and larger lake zones of each estuary yielded among the highest levels of boat-based effort and total harvest/harvest-rate. Spatial patterns of shore-based effort and harvest were slightly more variable between the estuaries studied. To increase the spatial precision of future initiatives aimed at enhancing recreational fisheries in these estuaries, and thus maximise their impact, it is suggested that managers and scientists alike utilise the spatially specific empirical information uncovered here. With the exception of the total number of fish harvested from Tuross Lake, all other temporal comparisons indicated an overall decrease in effort and total harvest between 1999 (3 years before RFHs were introduced) and 2011 (9 years after the introduction of RFHs) during March–May (Autumn). We recommend that future surveys be conducted regularly and during different seasons or at wider temporal intervals to build a clearer and more representative picture of temporal changes in the fisheries within RFHs.

KEYWORDS:

Recreational fishing haven; creel survey; recreational effort; recreational harvest; spatial management.

INTRODUCTION

The purpose of recreational fishing havens – the broad context

Recreational fishers comprise approximately 11.5% of the global population and an estimated 12.0% of the world's fishery harvest is credited to the recreational sector (Cooke and Cowx, 2004; Crowder et al., 2008). Recreational fishing therefore represents a substantial global industry that must be carefully managed in order to meet three important goals: (i) ensure sustainability of recreational fisheries and the provision of high-quality fishing opportunities; (ii) ensure equitable allocation of resources among recreational and commercial fishing sectors; and (iii) enable the conservation of aquatic stocks and the ecosystems that sustain them (Mardle et al., 2002; Pereira and Hansen, 2003; Sutinen and Johnston, 2003).

One strategy that has been employed in some developed countries as a broad-scale measure to meet these goals is the establishment of recreational fishing havens (also known as RFHs or recreational only fishing areas (ROFAs)) (Denny and Babcock, 2004; Schroeder and Love, 2002; Tobin, 2010). RFHs are defined as geographical areas within multi-sector fisheries where commercial fishing is fully or partially excluded but recreational fishing is still permitted (Tobin and Sutton, 2011). In Australia, where 19.5% of the population were estimated to participate in recreational fishing during the early 2000s (Henry and Lyle, 2003), RFHs have been implemented in all states and territories and are particularly common in coastal areas (Tobin, 2010). The two main objectives of establishing these RFHs have been to enhance the quality of recreational fishing and to reduce conflict between commercial and recreational fishers (Steffe et al., 2005b; Tobin, 2010; Tobin and Sutton, 2011). It has also been suggested that RFHs have the potential to conserve aquatic populations by maintaining or improving the biomass some fish stocks (Bucher, 2006; Tobin, 2010).

Recreational fishing havens in New South Wales

In New South Wales (NSW), the introduction of the general recreational fishing fee in March 2001 generated significant funding which was used to implement extensive changes in the management of the state's fisheries. These changes included the declaration of 31 RFHs in NSW during May–September 2002 (Figure 1) and resulted in 27% of the state's estuarine area becoming free of commercial fishing (Steffe et al., 2005a, b). This re-allocation of access to fisheries resources was expected to create additional opportunities for recreational fishers (anglers) in NSW. Various reports following the establishment of RFHs have indeed suggested significant increases in the recreational harvest of highly sought-after species such as yellowtail kingfish and mulloway in Botany Bay (Fletoridis, 2012) and dusky flathead, tailor and sand whiting in Lake Macquarie (Steffe et al., 2005b).

Need and objectives of project

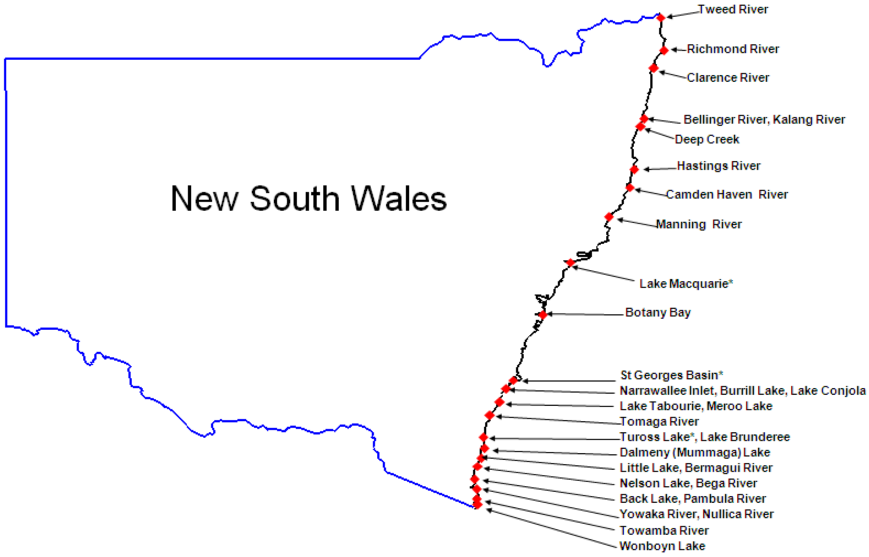
To quantitatively assess the longevity and spatial extent of the reported changes in harvest, regular ongoing creel surveys are required within RFHs. Surveys of this nature can provide empirical point estimates (snapshots) of the performance of RFHs through time and therefore contribute information to assist in the long-term maintenance of high-quality recreational fishing opportunities. Here, we report on the most recent recreational surveys conducted in three RFHs in NSW. The results of this study will enhance our understanding of changes in recreational fishing in RFHs and consolidate trends derived from previous surveys (Steffe and Chapman, 2003; Steffe et al., 2005a, 2005b).

The specific objectives of this study were to:

- estimate daytime recreational fishing effort and total harvest (numbers of fish across all species in retained catch) in Lake Macquarie, St Georges Basin and Tuross Lake for the period inclusive of March–May 2011
- estimate the daytime harvest of the five most-harvested species in the three estuaries during March–May 2011

- examine spatial patterns of recreational exploitation within the three estuaries during March–May 2011
- qualitatively assess overall changes in fishing effort and total harvest within Lake Macquarie and Tuross Lake between 1999, 2004 and 2011 over the March–May period.

Figure 1. Location of recreational fishing havens (RFHs) in New South Wales, Australia



* RFHs surveyed in this report.

MATERIALS & METHODS

Study sites

Three RFHs were examined in this study: Lake Macquarie (33.064˚S, 151.587˚E), St Georges Basin (35.098˚S, 150.588˚E) and Tuross Lake (36.036˚S, 150.112˚E). The physical dimensions of these estuaries are (NSW Office of Environment & Heritage, 2011):

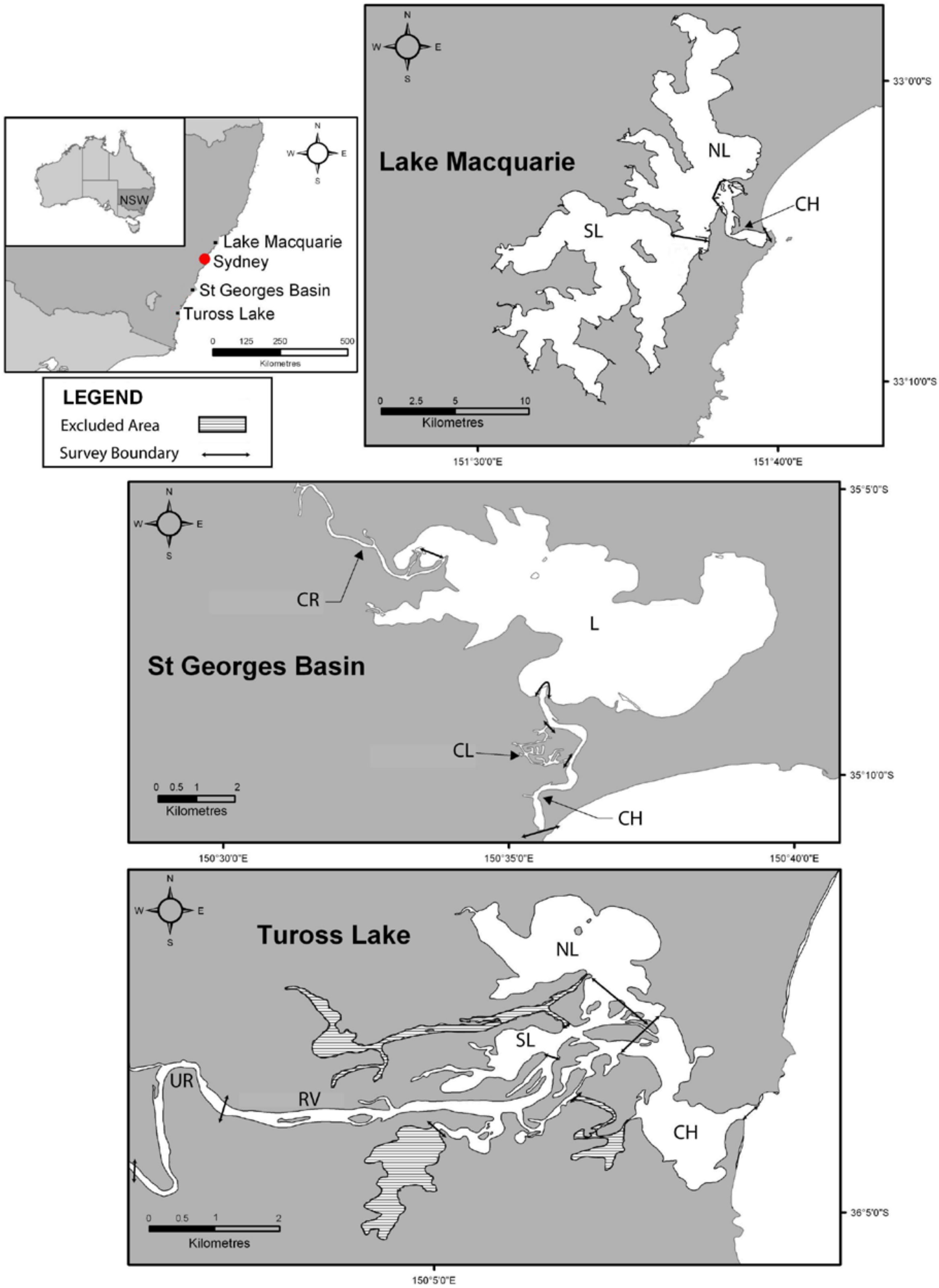
- Lake Macquarie—surface area, 114.10 km^2; catchment area, 604.40 km^2; average depth, 5.70 m
- St Georges Basin—surface area, 40.90 km^2; catchment area, 315.80 km^2; average depth, 5.30 m
- Tuross Lake—surface area, 15.50 km^2; catchment area, 1,813.80 km^2; average depth, 1.20 m.

For the purpose of this report, the three were stratified into distinct survey zones (Figure 2):

- Lake Macquarie—north lake, south lake and channel
- St Georges Basin—lake, channel, canals and creek
- Tuross Lake—north lake, south lake, channel, river and upper river.

The fisheries resources within Lake Macquarie are accessed easily by both boat- and shore-based anglers (Steffe and Chapman, 2003). Prior to the survey period, 35 functioning, public boat ramps (6 in the channel, 15 in the north lake and 14 in the south lake) that were diffusely distributed throughout Lake Macquarie were identified as points from which boat-based anglers could access fisheries resources in each of this estuary's zones. Of these, 8 were classified as major access points based on their size and potential for high boating traffic during busy periods and 27 were classified as minor access points. Points from which shore-based anglers at Lake Macquarie could access fisheries resources were similarly diffuse and numerous, spanning each of this estuary's zones.

Figure 2. The relative location and extent of the spatial zones examined within Lake Macquarie, St Georges Basin and Tuross Lake



Note: CH = channel, CL = canals, CR = creek, NL = north lake, SL = south lake, RV = river, UR = upper river

In St Georges Basin, 9 functioning boat ramps (5 in the lake and 4 in the channel) and 1 boat-hire outlet (in the canals) were identified as access points for boat-based anglers to each of the estuary's zones. Of these, 5 were major access points and 5 minor access points. The shore-based fishery of this estuary spanned each of the zones.

In Tuross Lake, 3 functional boat ramps (1 in the north lake, 1 in the channel and 1 in the upper river) and 1 boat-hire outlet area (in the channel) were identified as points from which boat-based anglers could access fisheries resources in this estuary's zones. Only one of these points was classified as a major access point. The entire shoreline of Tuross Lake comprises dense vegetation and large rural/private properties that preclude shore-line access (Steffe et al., 2005a). We consequently did not assess the shore-based fishery of Tuross Lake.

Temporal sampling frame

A combined survey design, comprising two contact methods to collect data on effort and harvest-rate (access-point or roving), was used to assess recreational patterns of exploitation in each estuary (Pollock et al., 1994, 1997). Table 1 provides a summary of the survey design used for each estuary.

Table 1. Summary of the survey designs used to estimate recreational effort, harvest-rate and harvest in each of Lake Macquarie, St Georges Basin and Tuross Lake

Estuary	Survey design	Effort (E)	Harvest-rate (R)	Harvest	No. survey-days (E)	No. survey-days (R)
Boat-based fishery						
Lake Macquarie	Roving (effort)–Access (harvest-rate)	Expansion using progressive count data	Ratio of means	$E \times R$	9	9
St Georges Basin	Roving (effort)–Access (harvest-rate)	Expansion using progressive count data	Ratio of means	$E \times R$	9	9
Tuross Lake	Access (effort)–Access (harvest-rate)	Direct expansion	Ratio of means	$E \times R$	9	9
Shore-based fishery						
Lake Macquarie	Roving (effort)–Roving (harvest-rate)	Expansion using progressive count data	Mean of ratios with truncation	$E \times R$	9	9
St Georges Basin	Roving (effort)–Roving (harvest-rate)	Expansion using progressive count data	Mean of ratios with truncation	$E \times R$	9	9

The temporal sampling frame of this study spanned 3 months from 01/03/2011 to 31/05/2011. This period was stratified into day-types (weekdays (*WD*) and weekend days (*WE*)). For St Georges Basin and Lake Macquarie, 3 *WD* and 3 *WE* days within each month were randomly selected (without replacement) as survey-days on which effort data would be collected, with selection of survey-days within each day-type stratum occurring separately. For these two estuaries, 3 *WD* and 3 *WE* days within each month were independently selected, using similar methods, as survey-days on which harvest-rate data would be collected. The collection of effort data in St Georges Basin and Lake Macquarie was therefore statistically independent of the collection of harvest-rate data. In Tuross

Lake, however, effort and harvest-rate data were collected on the same 3, randomly selected *WD* and *WE* days within each month. Random selection of survey-days was done independently for each estuary. The primary sampling unit used for each estuary was days and for each data type (harvest-rate or effort data), sampling would therefore occur on $n = 9$ *WD* days and $n = 9$ *WE* days during the 3-month period.

For St Georges Basin and Tuross Lake, recreational effort and harvest-rate data were collected during the sunrise to sunset period. For Lake Macquarie, sampling of effort and harvest-rate data was restricted to between 9:00 am and sunset. Since this estuary was large and had numerous access points, this temporal restriction was applied to the enable cost-effective use of sampling resources while allowing for an adequate level of spatial coverage. Two previous surveys in Lake Macquarie showed that, respectively, only 3.6% and 4.2% of boat- and shore-based fishing trips were completed between sunrise and 9:00 am (Steffe and Chapman, 2003; Steffe et al., 2005b), suggesting that most daytime recreational fishing trips in this estuary that start within this period are completed later in the day and would consequently be covered by a 9:00 am to sunset sampling regime (Steffe and Chapman, 2003).

Collection of boat- and shore-based effort data

On the days selected for collecting effort data, roving progressive counts of all individual boats and individual shore-based persons observed engaged in any fishing activity were used to quantify boat- and shore-based recreational fishing effort in Lake Macquarie and St Georges Basin. To make the progressive counts, a single circuit traversing all zones was navigated by boat. A pilot study was used to determine the time needed to complete a single circuit in each estuary and this allowed the starting times of the progressive counts to be scheduled by randomly selecting one of a set of discrete possible starting times (Hoenig, 1983). On each survey-day, the starting location and direction of travel within the circuit was also randomly selected. For Tuross Lake, effort for the boat-based fishery was quantified using an access-point contact method, whereby the number of all boat parties involved in estuarine recreational fishing activity that returned to the four access points on the survey-days were recorded. This information was collected in preference to harvest-rate information on busy days to provide validated measures of daily effort (Steffe et al., 2005a). Relative to progressive counts recorded independently of harvest-rate data, this method provided a more cost-effective yet accurate way of quantifying boat-based effort in Tuross Lake, given its smaller size, but precluded estimation of effort for the discrete spatial zones (Steffe et al., 2005a).

Collection of boat-based harvest-rate data

In St Georges Basin and Tuross Lake, a trained surveyor was stationed at each of the boat-based access points from sunrise to sunset on each day selected for collection of harvest-rate data. This access-point survey design enabled surveyors to interview all returning, cooperative, boat-based fishing parties (Figure 3). Standardised, machine-readable interview forms were developed to collect data on fishing activities and the following information was recorded for each party: (i) duration of fishing and non-fishing activity; (ii) species targeted (if any); (iii) zones fished and duration of fishing in each zone; (iv) numbers and sizes of species retained as harvest (obtained by the surveyor inspecting and measuring the harvest (Figure 4)) and zones in which they were caught; (v) numbers of species released; and (vi) demographic characteristics of fishing parties. During periods of high recreational fishing activity, when it was not possible to interview all returning parties, it was necessary to systematically subsample every third party.

Although surveyors could be stationed at each major boat-based access point in Lake Macquarie from 9:00 am to sunset to collect harvest-rate data, minor boat-based access points were numerous and it was not cost-effective to station surveyors at each of them. A given number of minor access points was therefore randomly selected, with the selection process renewed for each survey-day, and surveyors placed at each of the selected minor access points from 9:00 am to sunset (Pollock et al., 1994). Sample-size calculations based on a 95% confidence interval as well as the variance in boat-based harvest-rates during March–May and an *a priori* desired margin of error as estimated from a previous survey in Lake Macquarie (Steffe and Chapman, 2003) revealed that the minimum number of minor access points we needed to randomly select for sufficient power was 6 (see Pollock et al., 1994; Quinn and Keough, 2002 for equations). However, to maximise power, we used 12. This type of repeated, simple and random sampling from a defined population of minor access points should, on average, produce representative estimates that do not consistently under- or over-estimate the population parameters of interest (Quinn and Keough, 2002; Underwood, 1997). The same methods and interview forms as those described for St Georges Basin and Tuross Lake were used to interview boat parties in Lake Macquarie.

Figure 3. Returning angler being interviewed by a trained surveyor

Figure 4. Trained surveyors measuring the size of individual fish in recreational catch

Collection of shore-based harvest-rate data

The diffuse nature of the areas from which shore-based anglers could access fisheries resources in Lake Macquarie and St Georges Basin precluded the use of access-point survey methods to estimate shore-based harvest-rates (Pollock et al., 1994; Steffe and Chapman, 2003). A roving survey design that relied on incomplete trip interviews was used instead (Pollock et al., 1994; Steffe and Chapman, 2003). On each day selected for collecting harvest-rate data, trained surveyors travelled by car, boat or foot to traverse all shoreline access areas and attempted to interview all shore-based anglers they intercepted. On each survey-day, the starting location and direction of travel were randomly selected. Interview forms similar to those described for assessing the boat-based fisheries were used.

Estimation methods

The following calculations were performed using the open-source software '*R*' (Ihaka and Gentleman, 1996) and the equations and methods used for all calculations are described in detail in Pollock et al. (1994), Steffe and Chapman (2003) and Steffe et al. (2005a).

Effort

To estimate the boat- and shore-based fishing effort for each sampled day (n = 9 *WD* or *WE* days) in Lake Macquarie and St Georges Basin, the number of boats or shore-based anglers counted in each zone on each day selected for collecting effort data in each estuary was multiplied by the length of a fishing day (we used the mean day length for the season as per Steffe and Chapman (2003)). For each fishery, the daily effort estimates were then expanded for each day-type stratum within each zone of each estuary by multiplying the number of possible days in each day-type stratum with mean daily effort. The subsequent day-type effort totals were combined to obtain a seasonal estimate of total effort. Variances and standard errors associated with each of these estimates were also calculated. For Tuross Lake, the number of fishing-boat parties observed on each scheduled survey-day was totalled across all access points to estimate boat-based effort for each sampled day (n = 9 *WD* or *WE* days) for the whole lake. The daily effort estimates were then expanded to calculate mean effort for each day-type stratum and these estimates were combined to estimate total effort across *WD* and *WE* days, weighted by the relative number of each day-type. Variances and standard errors associated with each of these estimates were also calculated. For Lake Macquarie and St Georges Basin, the units for boat-based effort were boat hours and the units for shore-based effort were fisher hours. For Tuross Lake, the original units for boat-based effort were boat trips and effort estimates were converted to boat hours via multiplication with the average number of hours fished (Pollock et al., 1994).

Harvest

Once the data from the interviews had been checked and validated, expansion methods were again used to estimate total (combined across all species) boat- and/or shore-based harvest-rates in each estuary as well as the harvest-rates of the five most-harvested species by each fishery in each estuary. Since the interview data collected from the boat-based fishing parties were based on complete trip information from an access-point design, the daily harvest-rate estimator used for each sampled day was the 'ratio of means' (Pollock et al., 1994). For all species combined and for each of the five species most harvested through the boat-based fishery in each estuary, estimates of mean daily boat-based harvest-rates, as well as their variances and standard errors, were calculated separately for each day-type in each zone. A seasonal harvest-rate for each fishery in each estuary was then calculated by combining estimates derived from each day-type stratum. The contribution of each day-type stratum to the estimated seasonal harvest-rate was weighted by the relative number of days belonging to each day-type within the season.

In contrast to the boat-based data, the interview data collected from the shore-based anglers were based on incomplete trip information from a roving design. The daily harvest-rate estimator used for each sampled day was therefore the 'mean of ratios' (Pollock et al., 1994). For all species combined and for the five species most harvested through the shore-based fishery in each of Lake Macquarie and St Georges Basin, estimates of mean daily shore-based harvest-rates, as well as their variances and standard errors, were calculated separately for each day-type in each zone. These estimates were again combined to derive an estimate of seasonal shore-based harvest-rate which was weighted by the relative number of *WD*s and *WE*s in the season. Calculations of shore-based harvest-rates were performed on truncated data that excluded very short, incomplete trips (those that lasted <0.5 hour) so that the variance of the estimators would not be influenced by extreme harvest-rates (Pollock et al., 1994). For the shore-based fishery in St Georges Basin, this truncation resulted in the omission of the creek zone as all trips within this zone lasted for <0.5 hour. The units for the boat-based harvest-rates were numbers of fish harvested/boat hour and the units for the shore-based harvest-rates were numbers of fish harvested/fisher hour.

Where effort had been estimated for the different spatial zones within an estuary (Lake Macquarie and St Georges Basin), zonal harvest across all species and for the five most-harvested species was estimated for each fishery by multiplying the estimate of effort for a zone with the corresponding estimate of harvest-rate, and the variances and standard errors for harvest in each zone were calculated using the equations described in Steffe and Chapman, 2003. Whole-lake estimates of harvest and associated variances were then derived by summing the harvest and variance estimates for all the zones in an estuary. Where effort had only been estimated for the whole estuary (Tuross Lake), a whole-lake estimate of harvest across all species and for the five most-harvested species (with associated variances and standard errors) was calculated by multiplying the whole-lake estimate of effort with a whole-lake estimate of harvest-rate. The whole-lake harvest-rate was calculated for all of the data across spatial zones using the same methods described above for the estimation of harvest-rate while ignoring spatial zones (i.e. daily retained catch and trip lengths were derived via summation across all access points).

Qualitative assessment of temporal changes in effort and harvest in RFHs

To assess overall temporal changes in fishing effort and harvest within Lake Macquarie and Tuross Lake, total boat- and shore-based effort as well as total harvest across all fisheries and species were qualitatively compared between 1999 (3 years before the establishment of RFHs), 2004 (2 years after the establishment of RFHs) and 2011 (9 years after the establishment of RFHs) for the March–May (Autumn) period. The 1999 and 2004 estimates of effort and harvest were obtained using data from recreational fishing surveys previously carried out in Lake Macquarie and Tuross Lake. The general methods used in these previous surveys, which are detailed in Steffe and Chapman (2003) and Steffe et al. (2005a, b), were similar to those described here. St Georges Basin was omitted from the temporal comparisons as recreational fishing surveys had not previously been conducted within this estuary.

To enable temporal comparisons of the estimates calculated for Lake Macquarie during this survey with those calculated for 1999 and 2004, effort estimates from the current survey were adjusted to represent the period spanning from sunrise to sunset. These adjustments were made by dividing the current effort estimated for the 9:00 am to sunset period by the proportion of trips reported to have been completed after 9:00 am in the previous surveys in Lake Macquarie (K. Pollock *pers. comm.*) These spanned the period from sunrise to sunset (96.4% and 95.8% for boat- and shore-based fishing trips, respectively (Steffe and Chapman, 2003; Steffe et al., 2005b). Approximations of the variances for the adjusted effort estimates were obtained using the equation for the variance of a quotient from the Taylor series expansions (Mood et al., 1974).

RESULTS

Estimates of effort

Total boat-based and shore-based recreational fishing effort in each estuary are presented in Figure 5. The estimates of total boat- and shore-based effort in each zone within Lake Macquarie and St Georges Basin are given in Table 2 (differentiation between zones was not undertaken for Tuross Lake).

Figure 5. Total (± standard error) boat- and shore-based recreational fishing effort in Lake Macquarie, St Georges Basin and Tuross Lake

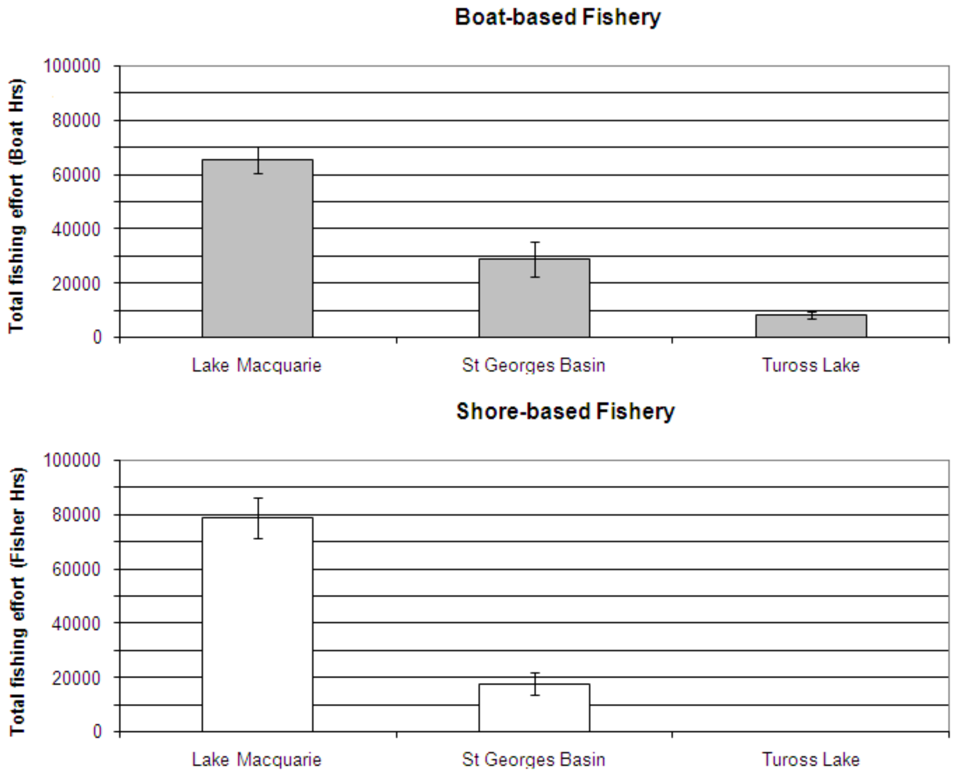


Table 2. Total (± standard error (SE)) boat- and shore-based recreational fishing effort in Lake Macquarie and St Georges Basin

	Zone	Total (±SE)	Proportion of total effort (%)
Lake Macquarie			
Boat-based effort	North Lake	23,784 (2,878)	36
(boat hours)	South Lake	28,738 (3,557)	44
	Channel	12,945 (1,664)	20
Shore-based effort	North Lake	20,566 (3,721)	26
(fisher hours)	South Lake	25,015 (3,513)	32
	Channel	33,140 (5,173)	42
St Georges Basin			
Boat-based effort	Lake	22,597 (6,212)	78
(boat hours)	Canals	335 (198)	1
	Channel	5,660 (1,577)	20
	Creek	286 (161)	1
Shore-based effort	Lake	4,575 (1,951)	26
(fisher hours)	Canals	4,996 (1,758)	28
	Channel	8,147 (3,155)	46
	Creek	38 (38)	<1

Estimates of harvest

Table 3 shows the estimated total harvest (amalgamated among zones) of the five-most harvested species and all species combined for Lake Macquarie from each of the boat- and shore-based. Table 4 gives the estimated total harvest (amalgamated among zones) of the five-most harvested species and all species combined for St Georges Basin from each of the boat- and shore-based fisheries. Table 5 gives the estimated total harvest of the five-most harvested species and all species combined for Tuross Lake from the boat-based fishery. Note that the term "bream species" used in the tables and hereafter refers to the species complex comprised of black bream, yellowfin bream and the hybrids formed by these two species (which are morphologically indistinguishable from black bream (Ochwada-Doyle et al., 2012)).

The boat- and shore-based harvest estimated for each of the zones in Lake Macquarie and St Georges Basin for the five-most harvested species and all species combined are depicted in Figures 6 and 7. Since harvest in Tuross Lake was not estimated at the finer scale of spatial zones (due to the absence of zonal estimates of effort), the harvest-rates that were estimated for each zone for the five-most harvested species and all species combined are reported for this estuary to provide some idea of spatial variation in recreational fishing within Tuross Lake (Figure 8).

Table 3. Total harvest (amalgamated among zones) (number of fish ± standard error (SE)) of the five most-harvested species and all species combined in Lake Macquarie

Species	**Harvest (±SE)**
Boat-based fishery	
Blue swimmer crab	24,435 (5,479)
Bream spp.	14,915 (1,779)
Dusky flathead	8,820 (1,865)
Trumpeter whiting	7,234 (3,179)
Sand whiting	3,282 (523)
All species combined	*73,439 (18,781)*
Shore-based fishery	
Luderick	15,899 (7,141)
Tailor	11,672 (6,675)
Bream spp.	8,518 (2,020)
Dusky flathead	2,524 (710)
Blue swimmer crab	814 (542)
All species combined	*66,338 (14,286)*

Table 4. Total harvest (amalgamated among zones) (number of fish ± standard error (SE)) of the five most-harvested species and all species combined in St Georges Basin

Species	**Harvest (±SE)**
Boat-based fishery	
Bream spp.	7,412 (2,133)
Dusky flathead	6,055 (1,633)
Sand whiting	2,417 (689)
Yellow-finned leather jacket	1,328 (433)
Snapper	868 (334)
All species combined	*23,811 (5,497)*
Shore-based fishery	
Bream spp.	2,349 (951)
Fan-bellied leatherjacket	792 (323)
Dusky flathead	601 (249)
Sand mullet	387 (332)
Luderick	316 (148)
All species combined	*6,564 (1,937)*

Table 5. Total harvest (number of fish ± standard error (SE)) of the five most-harvested species and all species combined in Tuross Lake (boat-based fishery only)

Species	**Harvest (±SE)**
Dusky flathead	3,087 (601)
Bream spp.	999 (309)
Sand whiting	289 (244)
River garfish	289 (244)
Silver trevally	117 (61)
All species combined	*5,139 (1,092)*

Figure 6. Estimated (a) boat-based and (b) shore-based harvest (± standard error) for the five most-harvested species and all species combined within each of the spatial zones in Lake Macquarie

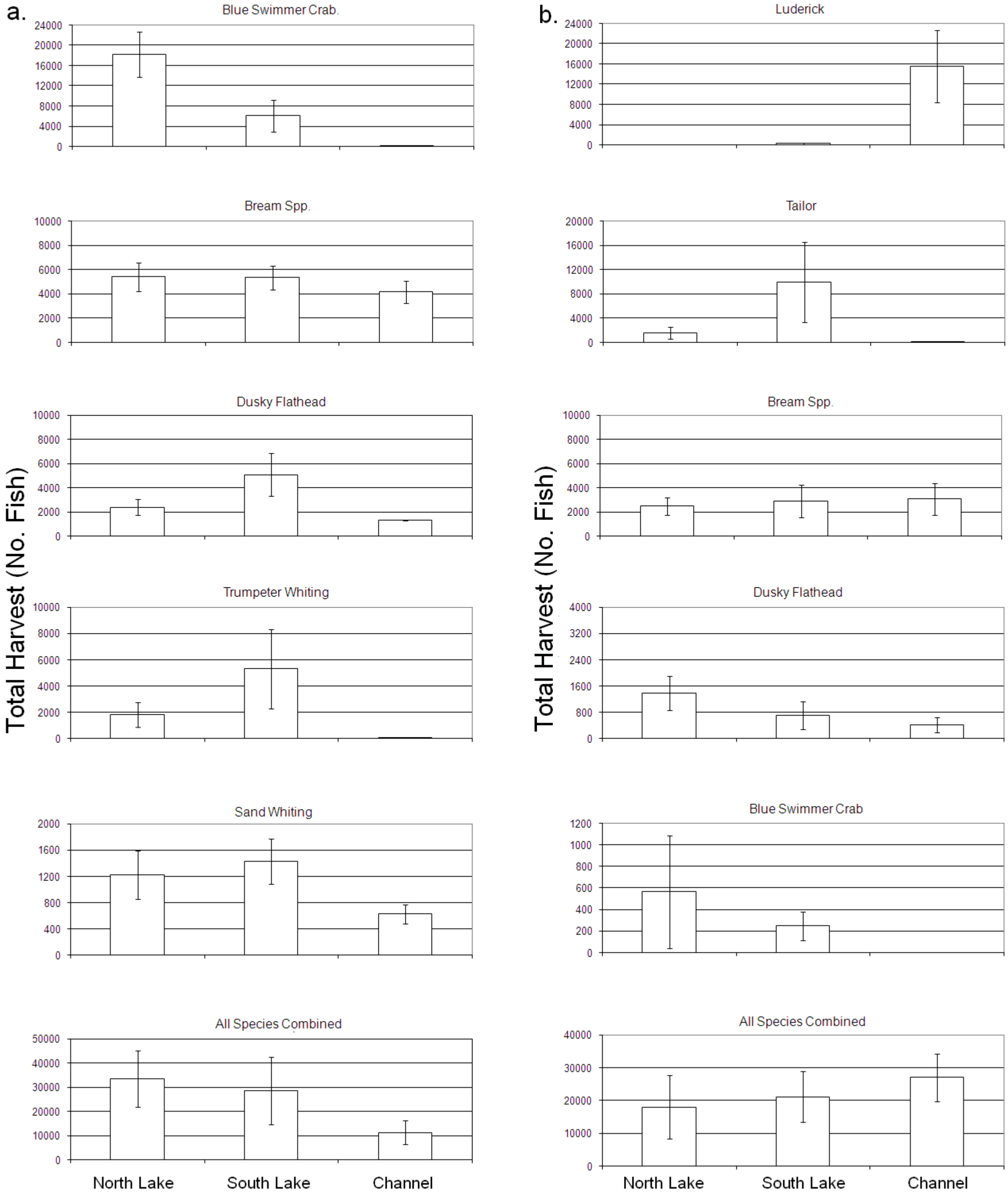


Figure 7. Estimated (a) boat-based and (b) shore-based harvest (± standard error) for the five most-harvested species and all species combined within each of the spatial zones of St Georges Basin

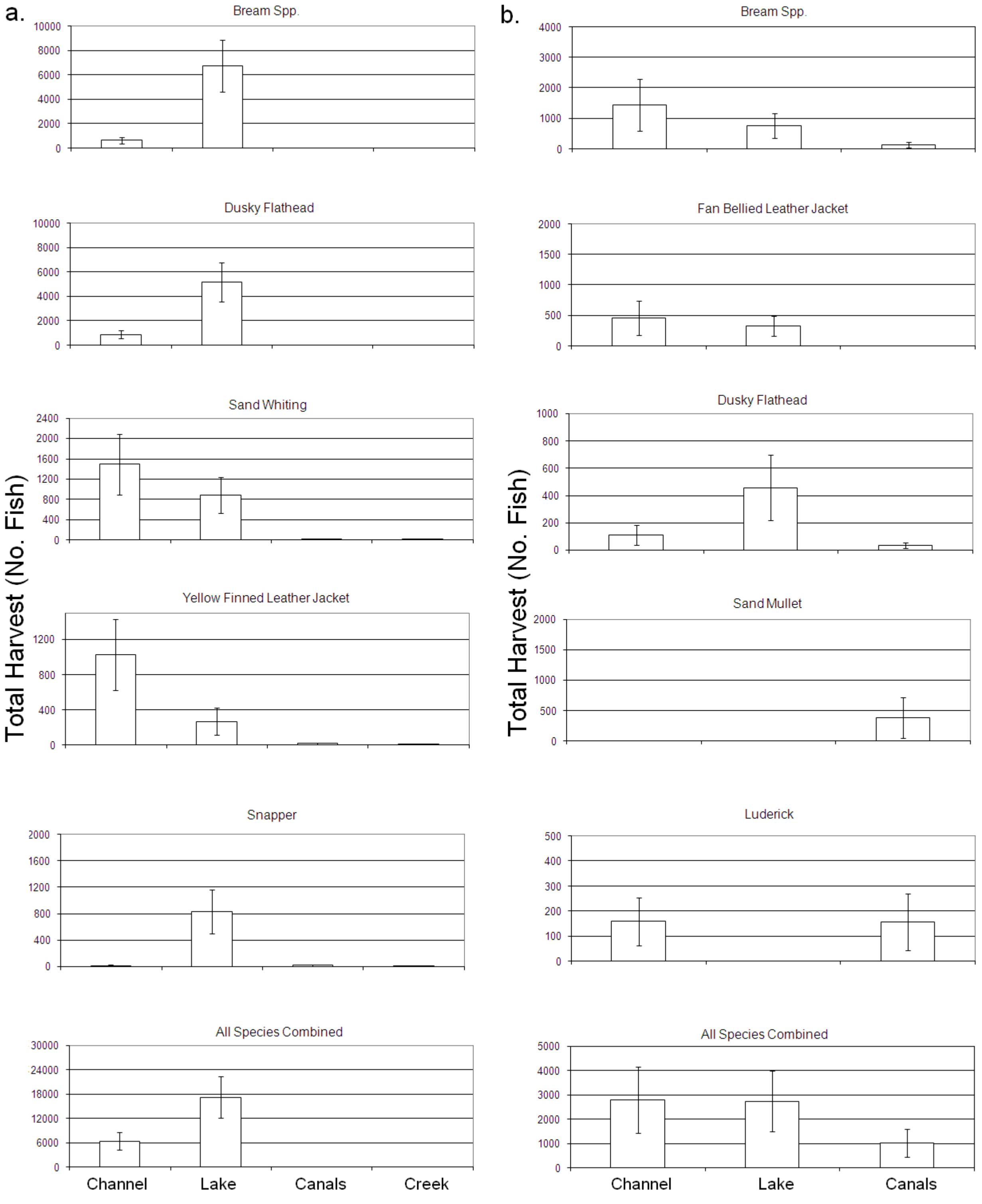
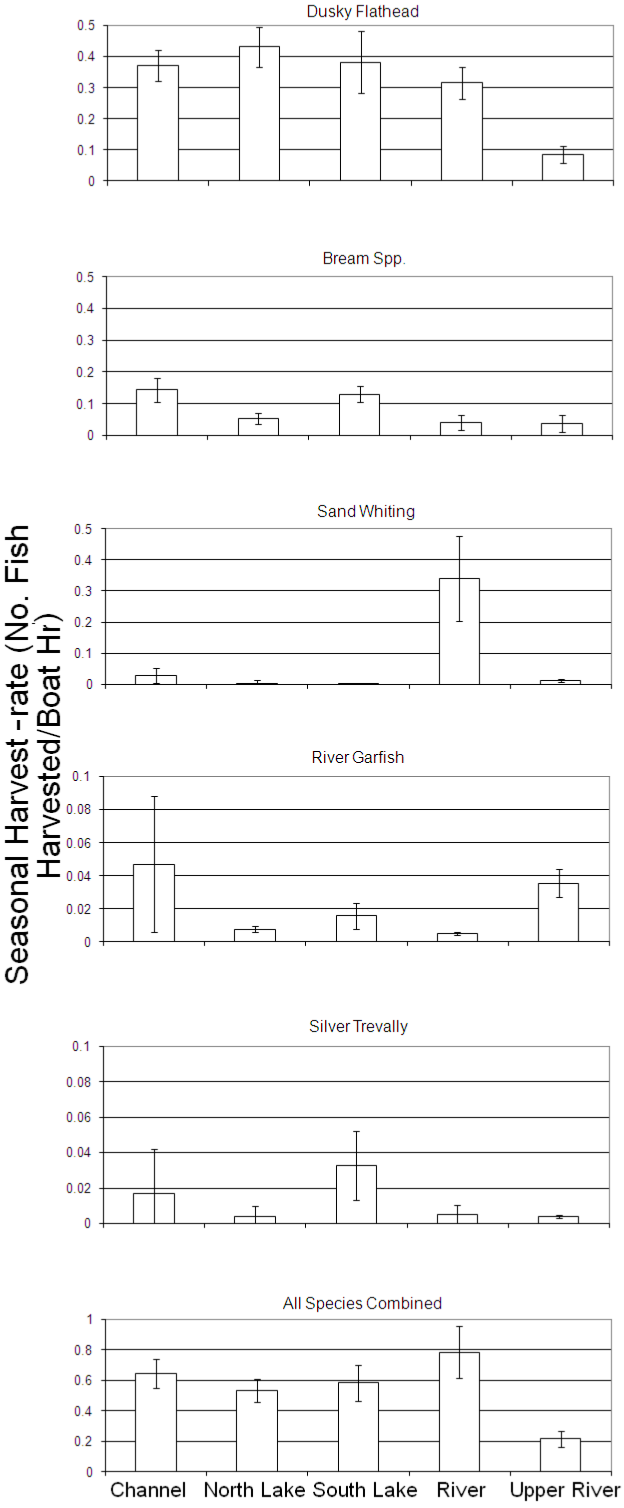


Figure 8. Estimated boat-based harvest-rate (± standard error) for the five most-harvested species and all species combined within each of the spatial zones of Tuross Lake



Temporal changes in effort and harvest in RFHs

Table 6 shows (i) the relative total boat-based effort in Lake Macquarie and Tuross Lake, (ii) the relative total shore-based effort in Lake Macquarie and (iii) the relative total harvest across all fisheries and species in Lake Macquarie and Tuross Lake for the March–May period for 1999, 2004 and 2011.

Table 6. Estimates of effort (boat and/or fisher hours (± standard error (SE)) and total harvest (number of fish (± SE)) across all species and fisheries (boat- and shore-based for Lake Macquarie and boat-based only for Tuross Lake) for the March–May period of 1999, 2004 and 2011

Estuary	**Survey year**		
	1999	**2004**	**2011**
Boat-based effort (boat hours (± SE))			
Lake Macquarie	83,672 (5779)	120,949 (4275)	67,897 (5,050)*
Tuross Lake	9,254 (490)	7,177 (1,198)	8,379 (1,315)
Shore-based effort (fisher hours (± SE))			
Lake Macquarie	83,442 (7,877)	70,081 (4,742)	82,162 (7,596)*
Total harvest (number of fish (± SE))			
Lake Macquarie	187,331 (24,817)	163,861(10,901)	145,401 (34,389)*
Tuross Lake	4,236 (609)	5,470 (434)	5,139 (1,092)

* 2011 effort estimates reported and used for calculating harvest here for Lake Macquarie were adjusted to cover the sunrise to sunset period to make them comparable to previous surveys.

DISCUSSION

Effort and harvest across zones

In terms of total boat-based recreational effort across zones, the levels of activity recorded in St Georges Basin and Tuross Lake, respectively, were about around 44% and 13% of the activity observed in Lake Macquarie. Since all three estuaries represent relatively popular destinations for recreational fishers (Steffe and Chapman, 2003; Steffe et al., 2005a), the differences among them may partly reflect their relative sizes. St Georges Basin and Tuross Lake occupy around 36% and 14%, respectively, of the surface area occupied by Lake Macquarie. These differences may also reflect the estuaries' relative proximity to population centres. Lake Macquarie is surrounded by populated urban centres, is close to the city of Newcastle and is within 2 hours drive of Sydney, the largest city in Australia. In contrast, St Georges Basin and Tuross Lake are located in lightly populated regional areas. The total shore-based recreational effort recorded in St Georges Basin was about 23% of the effort recorded in Lake Macquarie. The lower shore-based effort in St Georges Basin may be attributed to its smaller size and the fact that private ownership of the land adjacent to the southern shoreline of St Georges Basin's lake zone precludes shore-based access to nearly half of this estuary's largest zone.

The most-harvested species by boat-based anglers in Lake Macquarie, St Georges Basin and Tuross Lake were blue swimmer crabs, bream species and dusky flathead, respectively. The most harvested species by shore-based anglers in Lake Macquarie and St Georges Basin were luderick and bream species, respectively. Across all three estuaries, bream species, dusky flathead and sand whiting were consistently among the five most-harvested species by the boat-based fishery. This is not surprising given that all three species are highly sought-after by the recreational sector in NSW and Australia as a whole (Henry and Lyle, 2003; Rowling et al., 2010) and are often recorded as a target species in surveys (e.g. Ghosn et al., 2010; Steffe and Chapman, 2003). The remaining species in the 'top five' harvested by boat-based anglers in each estuary are also regarded as popular recreational targets (Henry and Lyle, 2003; Rowling et al., 2010) and their relative presence or absence among the 'top five' may reflect geographical differences in their distribution and abundance. While bream species and dusky flathead were still among the five most-harvested species from the shores of Lake Macquarie and St Georges Basin, luderick replaced sand whiting in terms of consistent occurrence among the most commonly harvested species from the shoreline. The higher abundance of luderick in the shore-based catch may be attributed to this species' common association with shallow habitats such as rocky reefs and seagrass beds (Ferguson et al., 2013; Henry and Lyle, 2003), where shore-based anglers fish.

The highest total boat-based harvest across all species caught was observed in Lake Macquarie, followed by St Georges Basin and then Tuross Lake, with harvest levels in St Georges Basin and Tuross Lake being around 32% and 7% of the levels recorded for Lake Macquarie, respectively. The total shore-based harvest in St Georges Basin was about 10% of the harvest recorded for Lake Macquarie. The relative total harvest estimates for the three estuaries were, for the most part, similar to the relative amount of total effort that was estimated in the estuaries and their relative sizes.

Spatial patterns of recreational fishing

Overall, zonal patterns of boat-based effort were consistent between Lake Macquarie and St Georges Basin, with effort generally being highest in the lake zones. This pattern is probably due to a combination of a greater variety of habitats within this zone leading to a greater availability and diversity of species, greater boating access and a perceived/expected lack of boating congestion within the lake zones relative to the other narrower and smaller zones. Numerous global studies have previously suggested that ease of access to resources and reduced congestion are major factors influencing the behaviour and site choice of recreational anglers and thus the intensity of fishing effort (e.g. Denny and Babcock, 2004; Gunn and Sein, 2000; Henry and Lyle, 2003; Kent et al., 2010; Lewin et al., 2006; Post et al., 2002; Schuhmann and Schwabe, 2004). For the shore-based fishery in Lake Macquarie, effort was similarly high among the channel, north lake and south lake zones. In St Georges Basin, shore-based effort was highest in the channel zone, followed by the canal zone and then the lake zone. The shore-based patterns observed in both lakes were probably attributable to greater access to the shorelines of the zones that encountered the highest effort. Perceived/expected congestion may have played a lesser role in influencing shore-based effort as suggested by a previous Western Australian study which showed that congestion was not a significant factor in a utility model describing the choice behaviour of shore-based anglers (VanBueren, 1999).

The zonal patterns of harvest for the five most commonly harvested species within Lake Macquarie were generally heterogeneous among species for both fisheries. For the boat-based fishery, bream species appeared to be harvested in fairly similar numbers within the north lake, south lake and channel zones. Blue swimmer crabs, on the other hand, were harvested in the greatest numbers within the north lake, while dusky flathead, trumpeter whiting and sand whiting were harvested in the greatest numbers within the south lake (note, however, that differences between the north and south lake zones for the last two species were probably not statistically different based on our estimates of error). The estimates of boat-based harvest across all species in Lake Macquarie were fairly similar among the zones, after accounting for our estimates of error.

For the shore-based fishery of Lake Macquarie, luderick was the only species that was harvested in the greatest numbers within the channel zone. The number of tailor harvested from the south lake did appear to be greater than that estimated for the other zones, but associated estimates of error would suggest that harvest was not statistically different among the zones. Bream species appeared to be harvested by shore-based anglers in similar numbers within the three zones. Although the estimated shore-based harvest of dusky flathead and the blue swimmer crabs appeared higher in the north lake zone, the measures of error associated with these species' zonal estimates of harvest would suggest statistical homogeneity among the zones. The estimates of shore-based harvest across all species in Lake Macquarie were similar among the zones.

For the boat-based fishery in St Georges Basin, harvest for each of the five most-harvested species was consistently negligible within the canals and the creek and this may be a reflection of the low boat-based effort observed in these zones. Bream species, snapper and dusky flathead appeared to be harvested by boat-based anglers in the greatest numbers within the lake, however differences between the lake and channel for the latter two species were likely to be statistically homogenous based on our estimates of error. For sand whiting and yellow-finned leather jacket, estimated harvest was higher in the channel compared to the lake zone but measures of error again suggest statistical homogeneity among these zones for sand whiting. The estimates of boat-based harvest across all species in St Georges Basin were highest within the lake zone and negligible within the canal and creek zones. With the exception of dusky flathead and sand mullet, which were mainly harvested in the lake and canal zones respectively, obvious peaks in the shore-based harvest of the remainder of the ‘top five’ species were not observed in just one zone. The estimates of shore-based harvest across all species in St Georges Basin were relatively similar between the zones.

With the exception of dusky flathead, the remainder of the ‘top five’ species caught by boat-based anglers in Tuross Lake appeared to be harvested at fairly similar rates among the five spatial zones based on harvest estimates and the errors around these estimates. For dusky flathead, the harvest-rate was similarly high in the channel, north lake, south lake and river zones and lowest in the upper river zone. The spatial patterns of boat-based harvest-rate across all species in Tuross Lake were similar to the patterns observed for dusky flathead.

For each of the estuaries studied here, the heterogeneity among species in spatial patterns of harvest or harvest-rate likely reflect species-specific habitat associations which may have led to a higher abundance, and thus harvest-rate, of specific species in particular spatial zones. Various authors have previously described the rate of recreational harvest (especially, standardised measures of catch per unit effort) as an index of relative abundance (Bannerot and Austin, 1983; Maunder and Punt, 2004; Maunder et al., 2006; Oritiz and Phares, 2002; Williams and Scandol, 2008), linking low harvest-rates to low abundances. However, considerable research is needed to develop accurate and reliable measures of abundance that are derived from recreational harvest-rates.

Temporal changes in effort and harvest in RFHs

While the pre- and post-RFH conditions in Lake Macquarie in 1999 and 2004, respectively, were associated with a 44.6% increase in total boat-based effort during March–May (Autumn), boat-based effort in Lake Macquarie during this season in 2011 showed a 43.9% decrease compared with 2004 and a 18.9% decrease compared with 1999. Lake Macquarie’s shore-based effort on the other hand, decreased by 16.0% from 1999 to 2004 and then increased by 17.2% from 2004 to 2011, compared with an overall 1.5% decrease from 1999 to 2011. Concurrently, there was a 12.5% decrease in total harvest across all species and fisheries between 1999 and 2004. Total harvest in 2011 also showed an 11.3% decrease compared to 2004 levels of harvest and a 22.4% decrease compared to 1999 levels of harvest.

Pre- and post-RFH conditions in Tuross Lake in 1999 and 2004, respectively, were associated with a 22.4% decrease in total boat-based effort during Autumn. Between 2004 and 2011, however, boat based effort in this estuary increased by 16.7%, and there was a 9.5% decrease in effort between 1999 and 2011. Total harvest across species in Tuross Lake showed the opposite pattern, increasing by 29.1% between 1999 and 2004 and then decreasing by 6.1% between 2004 and 2011, and showing an overall 21.3% rise from 1999 to 2011.

CONCLUSIONS & RECOMMENDATIONS

On the basis of the above findings, the following conclusions and recommendations are made with respect to this study's objectives:

1. For the fisheries examined, effort and total harvest were highest in Lake Macquarie, followed by St Georges Basin and then Tuross Lake. These surveys provide evidence of significant and productive recreational fisheries in each of the estuaries studied. Since recreational fishing is now the only potential exploitative pressure affecting these estuaries, there is a strong need to continue monitoring the recreational fisheries within them using surveys such as those described here. Such ongoing monitoring may assist in averting overexploitation of standing fish stocks within these estuaries.

2. The species most harvested by boat-based anglers in Lake Macquarie, St Georges Basin and Tuross Lake were blue swimmer crabs, bream species and dusky flathead, respectively, and those most harvested by shore-based anglers in the first two estuaries were luderick and bream species, respectively. Bream species, dusky flathead, and sand whiting consistently occurred among the five most-harvested species in the current study, as did luderick where shore-based harvest was surveyed. From a broader geographical perspective, they also represent the main taxa/species captured in a number of south-eastern Australian estuarine fisheries (e.g. recreational line-only, commercial gillnet and commercial beach-seine fisheries) and each has attained an exploitation status of fully fished in NSW (Gray et al., 2011; Rowling et al., 2010). The state-wide exploitation status of these key species, and the high rates of harvest recorded for them here, further highlight the need for ongoing monitoring programs for these iconic recreational species to ensure their sustainable recreational (and commercial) harvest in NSW.

3. The lake zones of each estuary generally yielded among the highest levels of boat-based recreational effort and total harvest or harvest-rate. Spatial patterns of shore-based effort and harvest were slightly more variable between Lake Macquarie and St Georges Basin. Future initiatives to enhance recreational fishing opportunities in the estuaries examined in this study would benefit from consideration of the spatially explicit information uncovered here. Our findings on the spatial patterns of boat-based effort and total harvest, for instance, suggest that future measures aimed at enhancing boat-based fishing opportunities would be most beneficial if implemented within the lake zones (e.g. habitat enhancement within the lake zone, stock enhancement of species that use the lake zones, upgrading of boat ramps and fishing facilities proximal to the lake zones).

4. With the exception of the total number of fish harvested from Tuross Lake, all of the other longer-term temporal comparisons indicated an overall decrease in effort and total harvest between 1999 (3 years pre-RFH) and 2011 (9 years post-RFH). However, this long-term temporal trend in the performance of the RFHs in question has only been quantified for Autumn (March to May)—a season typically characterised towards its later months by reduced recreational activity due to fewer sunny days (Underwood and Kennelly, 1990). Future surveys such as those described here should be conducted regularly (every 3-5 years) and during alternating seasons or at wider temporal intervals so that a series of seasonally heterogeneous snap-shots of recreational activity in RFHs can be accumulated. This type of time-series data would be cost effective to collect and would assist in building a clearer and more representative picture of temporal changes in RFHs.

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