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Estimating recreational catch

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Abstract: Understanding recreational catch and effort is important for sustainably managing Queensland's fisheries, especially for species where recreational fishing makes up a large proportion of the total catch. Due to the wide variety of species caught recreationally in Australia, collecting annual, high-resolution, recreational catch and effort data can be cost-prohibitive. As a result, research agencies typically collect data periodically, rather than annually, through statewide surveys. However, Stock assessments typically require annual estimates of catch, and therefore such fragmented survey data present a challenge.

For example, Fisheries Queensland (FQ) conducts Statewide Recreational Surveys (SRS) to estimate the total Queensland recreational catch and harvest every 3-5 years. To obtain estimates for recreational harvest to use in stock assessments, for years where SRS estimates are not available, stock assessment scientists typically interpolate. Such interpolations could be inaccurate if recreational harvest fluctuates between surveys. Therefore, fishery assessments could benefit from a more defensible method for deriving recreational catch and harvest estimates for the in-between years.

In this work, we present new methodology to estimate recreational catch and harvest in years when no statewide surveys were conducted using information from FQ's Boat Ramp Survey (BRS) program, which collects information on the catch and effort of individual recreational fishers at select boat ramps. Using well-established statistical techniques, such as bootstrapping, we first provide an index of catch derived from boat ramp surveys and second, we present an index of the catch for the statewide surveys. The approach adopted is flexible and does not assume any underlying distribution of the data.

These methods were implemented in R statistical language and can be easily used with minimal additional training. Details of the implementation as well as instructions to users are presented. We illustrate with an example for a species with significant recreational catch: snapper (*Chrysophrys auratus*).

Keywords: *Recreational fisheries, statewide surveys, boat ramp surveys, bootstrapping*

1 Introduction

Recreational fishing is a major global sporting and social activity. Understanding the catch and effort and participation rate of recreational fishers has relevance for sustainably managing Queensland's fisheries. For species where the recreational catch component is important, the potential impact of accounting for recreational catch in stock assessments is high. Yet, given the variety of different species recreationally captured in Australia [Griffiths and Fay, 2015], the annual collection of high resolution catch and effort data is expensive and impractical. Therefore, jurisdictional research agencies typically collect data periodically, rather than annually, through statewide surveys [Griffiths and Fay, 2015]. Such fragmented data sets are difficult to use in stock assessment.

For example, Fisheries Queensland (FQ) conducts Statewide Recreational Surveys (SRSs) to estimate the total Queensland recreational catch and harvest of all species, every 3-5 years. Fishery assessments currently interpolate recreational harvest for years where SRS estimates are not available. FQ also conducts an annual Boat Ramp Survey (BRS) program that runs all year throughout Queensland and collects information on the catch and effort of sampled individual recreational fishers. However, this data is typically not incorporated into fisheries stock assessments. Therefore, there is an opportunity to improve fishery stock assessments by developing a method to use this data to derive more accurate and defensible recreational catch and harvest estimates for the in-between SRS years.

The objective of this work was to present a realistic and defensible estimate of species recreational catch and harvest in years when no statewide recreational surveys were conducted. We reconcile data from boat ramp surveys with statewide surveys in geographic regions where both sources of data are available. This reconciliation is done with the help of well-established statistical techniques. These methods were implemented in R statistical language [R Core Team, 2020] and can be easily used by current Fisheries Queensland staff with minimal additional training.

We outline the methodology developed, the implementation as well as instructions to users. We illustrate with an example for a species with significant recreational catch: snapper (*Chrysophrys auratus*).

An overview of the project is in Figure 1. The figure summarises the steps to estimate annual Queensland's fishery recreational catch combining data from statewide survey and boat ramp survey.

2 Recreational catch for years between state-wide surveys

In this section we present a methodology to estimate recreational catch in-between SRS years. The method analyses information from more frequent surveys of recreational catch at selected boat ramps. Using statistical techniques, we provide an index of recreational catch derived from both the infrequent state-wide survey data and the frequent annual boat ramp data. All methods presented can be applied to estimate kept or released catches of fish. We start by describing the new method to obtain an index proportional to the total recreational catch for a specific species through time-based on boat ramp survey data.

Figure 1. Project overview. Summarises the steps to estimate annual recreational catch combining information from Statewide Recreational Fishery and Boat Ramp Surveys, 2014-2019.

2.1 $B-$index for recreational catch based on Boat Ramp Surveys

The proposed method models the number of fish caught in each interview using Bootstrapping, a statistical technique introduced in [Efron, 1979] and popularized by Efron and Tibshirani [1994]. Its underlying principle is that data represent the best available image of the population from which they were sampled. The data are therefore used to reconstruct the population distribution. Bootstrap techniques are seen as having two main advantages over traditional statistical models. First, they are more robust in the sense that they cope better with data that do not conform to standard parametric assumptions and second, they are often simpler to implement, replacing complex derivations with computer power. Bootstrapping is widely used in fisheries science, with many applications in stock assessments [Restrepo et al., 1992; Mohn, 1993; Punt and Butterworth, 1993; O'Neill et al., 2011]. They were also used in recreational fisheries by [Cabanellas-Reboredo et al., 2017; Greiner and Gregg, 2010; Hoyle et al., 2000]. However, to the best of our knowledge they have not been used in the context of reconstructing recreational catch estimates for the SRS in-between years.

In this subsection, the goal is to obtain a distribution for the total recreational catch each year. We do this by breaking catches into two constituent components, the number of boats, and the number of fish caught per boat. In Queensland, the boat ramp data surveyors go out to ramps and count the number of boat trailers. We assume that the number of trailers counted is a proxy for number of boats, and the number of fish caught reported per boat interview is a proxy for catch per boat trip. We treat these two quantities as random variables that can vary from site to site and time to time (e.g. region, weekend/weekday, etc.). More technically, $B-$index is the random variable, denoting the reported number of fish caught, across all interviews at all boat ramps, in any given year. The expectation of B is defined by the following equation:

$$E(B) = E\left[\sum_{j=1}^{n^r}\sum_{i=1}^{n_j^{Tr}} n_{i,j}^C\right], \tag{1}$$

for fixed species and year, where n^r is the number of boat ramps, n_j^{Tr} is the number of trailers at boat ramp j and $n_{i,j}^C$ is the number of fish caught (kept + released) per boat interview at boat ramp j.

The equation (1) captures the estimate of catch using information from the corresponding strata, where each stratum could be defined by a region, season, year and type of day (e.g., week or weekend). Therefore, for each stratum, there is: a distribution for the number of boat trailers and a distribution for the number of fish caught per boat interview. The idea is to compute, for each date at each ramp, the total number of fish caught according to (1) using information from the corresponding stratum. In this work, previous exploration with Generalized Linear Models (GLM) helped define the strata sensible for most species. But these might depend on species-specific characteristics (e.g., spatial distribution or spawning season) hence, the definition of the best strata should be examined for each species.

A pseudocode for $B-$index computation is available in the Appendix. However, our actual implementation vectorises this approach to speed up computation.

As an example, suppose we want to estimate the total number of fish caught in $24/06/2018$ at Wellington Point Ramp. Thus, the first step is to identify to which stratum that date and ramp belong. In this case, Brisbane at a weekend in the winter of 2018. The second step is to draw a number n^{Tr} from the empirical distribution for the number of trailers for that stratum. For instance, we drew $n^{Tr} = 28$, we next resample 28 interviews in that stratum. For each interview we draw n^C from the empirical distribution for the number of fish caught per interview. Finally, summing the catch of all interviews, we obtain a total of 10 fish caught in $24/06/2018$ at Wellington Point Ramp.

In an analogous way, we can estimate the total catch in another ramp. Once all ramps are covered, we will have estimated the total catch for that day. And so for each day of the chosen period. By repeating this process n_{max} times it is straightforward to derive estimates of the mean, standard errors, and confidence intervals. Note that the estimated catch can be aggregated across months, seasons, or years.

2.2 S$-$index for Queensland's recreational catch

Supposed we want to estimate recreational catch in between two SRSs in years t_1 and t_d and, that BRS' period information overlaps. Also, assume that a region and a species have been fixed and that time horizon of interest consists of consecutive years $t_1, t_1+1, \ldots, t_d$. Here, S_t and B_t denote two relevant catch indices in year t, where S_t corresponds to the SRS and B_t to the BRS ($B-$index previously discussed). In the following: B_{t_1}, $\ldots$, B_{t_d} are known from data, S_{t_1} and S_{t_d} are known estimates and $S_{t_1+1}, \ldots, S_{t_d-1}$ need to be estimated.

We explored two cases: (1) When SRS data are available both in years t_1 and t_d and, (2) When SRS data after t_1 is not available. For the first case, we can estimate S_t index by

$$\hat{S}_{t_1+k} = B_{t_1+k}\left[\left(\frac{d-k}{d}\right)\left(\frac{S_{t_1}}{B_{t_1}}\right)+\frac{k}{d}\left(\frac{S_{t_d}}{B_{t_d}}\right)\right], \quad k=0,1,\ldots,d. \tag{2}$$

Note that this method captures the notion that the ratio $\hat{S}_{t_0+k}/B_{t_0+k}$ is at first closer to S_{t_0}/B_{t_0} and then moves closer to S_{t_d}/B_{t_d}. The second case is especially useful when the next survey, at t_d, is not yet available. Ensuring that the forward percentage change in S_t is the same as in B_t we can define

$$\hat{S}_{t_1+k} = S_{t_1+k}\left(\frac{B_{t_1+k}}{B_{t_1}}\right), \quad k=0,1,\ldots,d. \tag{3}$$

Next we illustrate these methods using real data. We considered both cases, when SRS data are available in 2014 and 2019 and when SRS data are only available in 2014.

2.3 Possible modifications

Adjustment for AM/PM trailer count: Boat ramp survey shifts occur in the morning or in the afternoon. Therefore, the number of trailers counted at the boat ramp can be an AM and/or PM observation. Unfortunately, there were systematic differences in AM vs PM sampling from year to year. To account for how these differences might affect $B-$index, the number of trailers variable counts could be made only during a specific shift, AM or PM, depending on whichever is most appropriate for the species in question. Using only PM or AM counts can drastically reduce the amount of data, but it may also reduce systematic bias.

Adjustment for non-fishing boats: The trailer count at each boat ramp includes both fishing and non-fishing boats. Therefore, raw trailer count may not be the best proxy for the number of fishing boats during the survey. Luckily, the number of non-fishing boats encountered during the entire duration of the survey shift is also recorded. One can try to remove non-fishing boat trailers from the computation of $B-$index, by utilising the non-fishing boat data. One way to incorporate this is to compute the ratio of non-fishing boats to the total number of trailers counted,

$$r^{NFB} = \frac{n^{NFB}}{n^{Tr}} \tag{4}$$

when $n^{Tr} > 0$ and 0 otherwise, where n^{NFB} is the number of non-fishing boats and n^{Tr} is the number of trailers. To account for variation in non-fishing boats, one could draw the ratio n^{NFB} from its empirical distribution, and then draw the number of fishing boats from a binomial distribution with probability of success, $1 - r^{NFB}$, and number of trials, n^{Tr}. This value would then replace the number of trailers variable in the preceding $B-$index computation methods. Note that unlike the trailer count, non-fishing boat data includes boats that may not have been present during the trailer count, since it includes boats seen during the entire survey shift. This can lead to ratios in equation (4) bigger than one. To correct for this, one can multiply (4) by $1/\max_i\{n_i^{NFB}/n_i^{Tr}\}$, where i is a given survey, which then bounds r^{NFB} between zero and one.

Converting catch from number to weight: Commercial fisheries generally report the weight by species caught, while recreational surveys report the number caught. As many species are caught by both fishery sectors, for comparison purposes a conversion is required. One option is to use the methodology from Webley et al. [2015], which uses an average fish size for each year, assumes a common mean weight for all and involves the corresponding length-weight relationship to convert from number count to weight. Note that conversions would usually be done inside the stock assessment model.

3 Example: estimation of Queensland recreational catch in 2014 – 2019 using $B-$index for snapper

We developed a function in R called **recFish**, which is species-specific and consists of two stages. In the first stage, a bootstrap is performed to compute $B-$index (index of catch from BRS) according to equation (1) and in the second stage, replicates of S_{14} and S_{19} are generated from a normal distribution with mean and standard deviation equal to the catch and SE estimated in corresponding SRS. With each replicate of S_{14}, S_{19} and $B-$index an annual catch time-series S_t is estimated according to equation (2). Note that the second stage of bootstrapping allows us to propagate error from SRS estimates. The species – snapper – has been selected based on a request by the Department of Agriculture and Fisheries (DAF). At high risk of depletion, recent assessments of snapper have found that the population is between 10-40% of virgin biomass [Wortmann et al., 2018], which is below the future 60% unfished biomass target of the Sustainable Fisheries Strategy [Department of Agriculture and Fisheries, 2017*b*] (see `https://www.daf.qld.gov.au/business-priorities/fisheries/sustainable/sustainable-fisheries-strategy-overview`). As recreational catch appears to form approximately half of the total catch across all years, stock assessment results are very sensitive to changes in recreational catch data. Therefore, robust, annual recreational catch estimates for snapper will support better stock assessments.

The **recFish** code is available on GitHub (`https://github.com/manumendiolar/RecFish`) and needs to be run in R or RStudio [RStudio Team, 2020], following instruction on the GitHub page.

3.1 Fishery data

We use catch data estimated in the last two SRSs, 2013 − 14 and 2019 − 20 obtained from the DAF's Statewide Recreational Survey monitoring program. Both surveys with the same two-phase design. The first phase, gathers background data from a general sample of the population (e.g. number of QLD residents who go fishing in QLD, etc.). The data collected are then used to identify a more focused sub-sample which is then re-sampled in the second phase, providing detailed catch and effort information [Lyle et al., 2010].

Additionally, we use catch data from BRSs collected from 42 boat ramps from January 2016 until December 2019 inclusive. The selection of the boat ramps was restricted to ramps with uninterrupted time series. The main priority of the BRS program is to record data about (1) boating effort and (2) recreational fishing activity. For boating effort, at each survey the number of boat trailers, at the time the survey began, was recorded as well as the launch and retrieval times of interviewed boats. For recreational fishing activity, recreational fishers were interviewed at each ramp upon their return from a fishing trip. For each boat interview, the interviewer collected data on the number of fishers on the trip, primary and secondary target species (if any), fishing location/s, fishing method/s, number of fish kept (counted by the interviewer) and released (reported by the fisher), and length of each retained fish. Details of these surveys can be found in Department of Agriculture and Fisheries [2017*a*].

3.2 Estimates in-between SRSs and after the last available SRS

Figure 2 presents the estimated annual recreational catch for snapper when SRS data are available both in 2014 and 2019 (black solid line) and when SRS data are only available in 2014 (blue dashed line). Simple linear interpolation between the two SRSs (red dotted line) was also included for comparison purposes, as this is a common technique for filling in missing data in recreational catch time series [Greer et al., 2014; Freire et al., 2020]. As we can see, uncertainty increases as we move away from 2014. The method using only information in 2014 (blue dashed line) tends to underestimate catch compared to the black line, which corresponds to the estimation scheme when we have SRS information at the start and end of the period. However, the estimate for 2019 (blue triangle) is within the 95% confidence interval (black error bars), meaning that this second method did predict 2019 catch reasonably well.

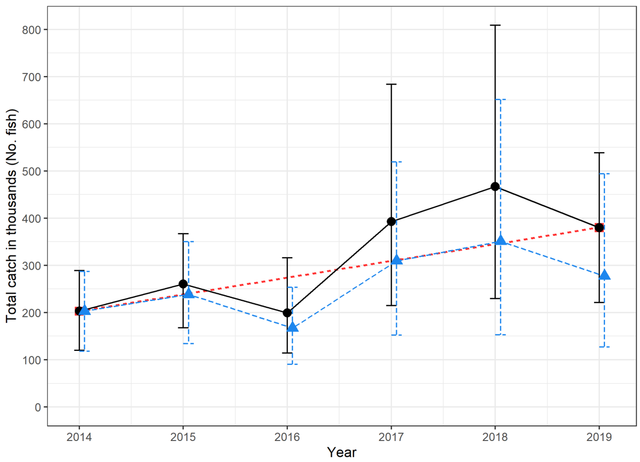

Figure 2. Estimates of Queensland recreational catch (kept released) with 95% bootstrap confidence intervals for snapper (*Chrysophrys auratus*). Comparison between method when 2014 and 2019 SRS information is available (—), when only 2014 SRS information is available (- -) and benchmark scheme (- - -).

4 Discussion

In this project, combining information from statewide recreational (SRS) and boat ramp (BRS) surveys, we provided a method to estimate species recreational catch in-between years $2014 - 2019$ when no SRSs were conducted. Our method proves particularly useful for species for which recreational fishing constitutes a significant proportion of the total catch. Using well-established statistical techniques, such as bootstrapping we were able to provide an index of catch derived from BRS. The approach adopted maximises the use of available data, estimates uncertainty, is flexible and does not assume any underlying distribution of the data. In contrast with the traditional approach which theoretically assumes that the data are normally distributed [Babcock and Skomal, 2008; Farmer and Froeschke, 2015; Sweke et al., 2015].

We also provided a method when only SRS information at the start of the period was known. When using this method, there is a possibility to project recreational catch forward, before the next statewide survey. Similarly, one could think of a scheme to "fill the gaps" in the previous period where there was no BRSs. In the case of species like snapper where the recreational catch comprises nearly 50% of total fishery catches for most years, the possibility of having estimates for earlier periods could substantially influence assessment results.

It is important to acknowledge that our approach assumes that strata capture the main variability in catch. An important source of variability not considered in our case study is variability in catch between individual fishers. In future analyses, incorporating a strata related to fisher ID could account for this variability, particularly if there are frequently surveyed fishers. Additionally, an interesting extension of this work would be to perform the analysis with less or more strata and see how the index changes with respect to the choice of the strata. Moreover, our methodology can be tailored to specific species, and the approach could be adapted to obtain an index of recreational catch per unit effort. Finally, although methods were developed in R these can be easily implemented in other languages following the pseudo-code provided.

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Appendix

In this appendix, we present a pseudocode for $B-$index computation.

Algorithm 1: Pseudocode $B-$index computation

Input : n_{max}, d_{max} and r_{max}
// total number of iterations, days and boat ramps, respectively.
Output: matrix A
// $A[i, j]$ corresponds to the number of fish caught at simulation i and day j.

$s_r = 0$; // Total number of fish caught in day (d) at boat ramp (r)
$s_d = 0$; // Total number of fish caught in day d (across all boat ramps)
for n = 1,n_{max} **do**
    for d = 1,d_{max} **do**
        for r = 1,r_{max} **do**
            Draw n^{Tr} from distribution according to date (d) and ramp (r) stratum.
            Sample with replacement n^{Tr} interviews from corresponding stratum:
            for i = 1,n^{Tr} **do**
                Draw n_i^C from corresponding distribution.
                $s_r = s_r + n_i^C$;
            $s_d := s_d + s_r$;
        $A[n, d] = s_d$;
    // reset
    $s_r = 0$;
    $s_d = 0$;
End of algorithm

References

Babcock, E. A. and Skomal, G. [2008], 'Indices of blue, mako and thresher shark abundance derived from US Atlantic recreational fishery data', *Collect. Vol. Sci. Pap. ICCAT* **62**(5), 1405–1416.

Cabanellas-Reboredo, M., Palmer, M., Alos, J. and Morales-Nin, B. [2017], 'Estimating harvest and its uncertainty in heterogeneous recreational fisheries', *Fisheries Research* **188**, 100–111.

Department of Agriculture and Fisheries [2017*a*], 'Monitoring Queensland's boat-based recreational fishing: Baseline report for Fisheries Queensland's recreational boat ramp survey program'.

Department of Agriculture and Fisheries [2017*b*], 'Queensland Sustainable Fisheries Strategy, 2017–2027'.

Efron, B. [1979], 'Bootstrap Methods: Another Look at the Jackknife', *The Annals of Statistics* **7**(1), 1–26.

Efron, B. and Tibshirani, R. J. [1994], *An introduction to the bootstrap*, CRC press.

Farmer, N. A. and Froeschke, J. T. [2015], 'Forecasting for recreational fisheries management: what's the catch?', *North American journal of fisheries management* **35**(4), 720–735.

Freire, K. M. F., Belhabib, D., Espedido, J. C., Hood, L., Kleisner, K. M., Lam, V. W., Machado, M. L., Mendonça, J. T., Meeuwig, J. J., Moro, P. S. et al. [2020], 'Estimating global catches of marine recreational fisheries', *Frontiers in Marine Science* **7**, 12.

Greer, K., Harper, S., Zeller, D. and Pauly, D. [2014], 'Evidence for overfishing on pristine coral reefs: reconstructing coastal catches in the Australian Indian Ocean Territories', *Journal of the Indian Ocean Region* **10**(1), 67–80.

Greiner, R. and Gregg, D. [2010], 'Considering recreational catch and harvest in fisheries management at the bio-regional scale', *Fisheries Management and Ecology* **17**(4), 336–345.

Griffiths, S. and Fay, G. [2015], 'Integrating recreational fisheries data into stock assessment: implications for model performance and subsequent harvest strategies', *Fisheries Management and Ecology* **22**(3), 197–212.

Hoyle, S., Brown, I., Dichmont, C., Sellin, M., Cosgrove, M. and McLennan, M. [2000], 'Integrated fish stock assessment and monitoring program. FRDC Project No. 94/161.'.

Lyle, J. M., Wotherspoon, S. and Stark, K. [2010], 'Developing an analytical module for large scale recreational fishery data based on phone-diary survey methodology. FRDC Project No. 2007/064'.

Mohn, R. [1993], 'Bootstrap estimates of ADAPT parameters, their projection in risk analysis and their retrospective patterns', *Canadian Special Publication of Fisheries and Aquatic Sciences* pp. 173–184.

O'Neill, M., Leigh, G., Martin, J., Newman, S., Chambers, M., Dichmont, C. and Buckworth, R. [2011], 'Sustaining productivity of tropical red snappers using new monitoring and reference points. FRDC Project No. 2009/037'.

Punt, A. and Butterworth, D. [1993], 'Variance estimates for fisheries assessment: their importance and how best to evaluate them', *Canadian Special Publication of Fisheries and Aquatic Sciences* pp. 145–162.

R Core Team [2020], *R: A Language and Environment for Statistical Computing*, R Foundation for Statistical Computing, Vienna, Austria.

Restrepo, V. R., Hoenig, J., Powers, J. E., Baird, J. W. and Turner, S. C. [1992], 'A simple simulation approach to risk and cost analysis, with applications to swordfish and cod fisheries', *Fishery Bulletin* **90**(4), 736–748.

RStudio Team [2020], *RStudio: Integrated Development Environment for R*, RStudio, PBC., Boston, MA.

Sweke, E. A., Su, Y., Baba, S., Denboh, T., Ueda, H., Sakurai, Y. and Matsuishi, T. [2015], 'Catch per unit effort estimation and factors influencing it from recreational angling of sockeye salmon (*Oncorhynchus nerka*) and management implications for Lake Toya, Japan', *Lakes & Reservoirs: Research & Management* **20**(4), 264–274.

Webley, J., McInnes, K., Teixeira, D., Lawson, A. and Quinn, R. [2015], 'Statewide recreational fishing survey 2013–14'.

Wortmann, J., O'Neill, M. F., Sumpton, W. D., Campbell, M. J. and Stewart, J. [2018], 'Stock assessment of Australian east coast snapper, *Chrysophrys auratus*, Predictions of stock status and reference points for 2016'.