1 **19th century narratives reveal historic catch rates for Australian snapper**
2 **(*Pagrus auratus*).**

3

4 *Alternative title 1:* Using archival records to construct historic catch rates for
5 Australian snapper (*Pagrus auratus*), 1871-1939.

6

7 *Alternative title 2:* Constructing catch rates for Australian snapper using archival
8 records: insights into a developing fishery.

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ABSTRACT

Snapper (*Pagrus auratus*) is widely distributed throughout subtropical and temperate southern oceans and forms a significant recreational and commercial fishery in Queensland, Australia. Using data from government reports, media sources, popular publications and a government fisheries survey carried out in 1910 we compiled information on individual snapper fishing trips that took place prior to the commencement of fishery-wide organised data collection, from 1871-1939. In addition to extracting all available quantitative data, we translated qualitative information into bounded estimates and used multiple imputation to handle missing values, forming 287 records for which catch rate (snapper fisher⁻¹ hour⁻¹) could be derived. Uncertainty was handled through a parametric maximum likelihood framework (a transformed trivariate Gaussian), which facilitated statistical comparisons between data sources. No statistically significant differences in catch rates were found among media sources and the government fisheries survey. Catch rates remained stable throughout the time series, averaging 3.75 snapper fisher⁻¹ hour⁻¹ (95% confidence interval, 3.42 - 4.07) as the fishery expanded into new grounds. In comparison, a contemporary (1993-2002) southeast Queensland charter fishery produced an average catch rate of 0.4 snapper fisher⁻¹ hour⁻¹ (95% confidence interval, 0.31 - 0.58). These data illustrate the productivity of a fishery during its earliest years of development and represent the earliest catch rate data globally for this species. By adopting a formalised approach to address issues common to many historical records – missing data, a lack of quantitative information and reporting bias –

50 our analysis demonstrates the potential for historical narratives to contribute to
51 contemporary fisheries management.

52

53 **Keywords:** catch per unit effort, historical ecology, multiple imputation,
54 narrative accounts, qualitative data.

55

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INTRODUCTION

Many marine fisheries have been intensively exploited for generations, yet detailed fisheries data rarely extend further than three or four decades into the past (Eero and MacKenzie 2011). Lack of data from the developmental stages of a fishery is problematic for stock assessment and can lead to bias in estimates of key parameters, both in quantities relating to the productivity of the stock and in those responsible for its potential overall magnitude. In addition, as our awareness of long-term data has grown, increasing numbers of historical ecology and marine environmental history studies have shed light upon the magnitude of changes that have occurred to marine species, communities and ecosystems as a result of human impacts (Jackson et al. 2001; Christensen et al. 2003; Pandolfi et al. 2003; Lotze et al. 2006; Fortibuoni et al. 2010; Kittinger et al. 2011). The issue of shifting environmental baselines, where intergenerational changes are forgotten or dismissed, has also been quantified across different generations of fishing communities (Pauly 1995; Sàenz-Arroyo et al. 2005; Lozano-Montes et al. 2008). Appreciating change through time is of value to decision-makers as it provides temporal context to more contemporary data, enables more appropriate exploitation or recovery targets to be set, and aids the prioritisation of management goals (McClenachan et al. 2012).

Previous studies have been successful in providing quantitative information on past fisheries. These include Rosenberg et al. (2005), who reconstructed the biomass of Scotian Shelf cod prior to the industrialisation of fishing using early fishing logbook records, and Poulsen et al. (2007), who used early catch rate data

to calculate the historical abundance of ling in the Skagerrak and north-eastern North Sea. Both of these studies used catch and effort data extracted from early archival documents to provide biomass reference points not previously available to fisheries management. MacKenzie et al. (2011) extended analytical time series of eastern Baltic cod spawner biomass and recruitment back to the 1920s to inform contemporary management reference points, whilst early catch rate trends have also been determined for the southern hemisphere. For example, Klaer (2001) used previously unexamined steam trawl haul records to determine trends in catch rate and species composition in southeast Australia from 1918-1957. He found that initially high catch rates of target species declined throughout the time series and that fishing effort expanded to more distant fishing grounds and deeper depths. Archival data have also revealed cases where a species' range has contracted, signalling declines in abundance or loss of spawning components (Ames 2004; McClenachan and Cooper 2008; Zu Ermgasson et al. 2012).

Whilst some of the above studies were able to compare different sources of historical data, or contrast historical with contemporary records, this is not always possible. Historical sources of data are often dissimilar or are incomplete, hence their use in contemporary fisheries management are limited unless approaches are adopted that evaluate disparities among data sources, assess the extent of bias in the available historical data, and address levels of uncertainty surrounding the techniques used to determine historical proxies of change. In this paper we examine historical data sourced from a range of documents, including archival fishery reports, early fishing publications, newspaper articles

and an early government line fishing survey to extend our temporal perspective of an east coast Australian fishery. Using methods drawn from different fields of research, we use a formalised approach to address the issues of missing data and reporting bias, and to identify areas of uncertainty in our data and statistical approach. In doing so, we deliver quantitative data from historical narratives that may be of use for contemporary fisheries assessment and management. Our approach also provides an avenue for other work addressing missing data and disparate sources.

Snapper (*Pagrus auratus*, Sparidae) is a commercially important species that is widely distributed throughout the coastal waters of Australia, New Zealand, China and Japan. In Australia its range extends from central Queensland, along the south coast to northern Western Australia. The IUCN Red List classes snapper as data deficient, and there are concerns about population declines throughout its range (Carpenter et al. 2012). In Queensland, snapper is an iconic recreational species and is also commercially exploited. It is the only fin fish species to be classed as overfished in Queensland (Campbell et al. 2009), a finding that has divided public opinion. A statutory authority responsible for fish marketing provides the earliest ‘official’ history of snapper catches with records dating back to the end of the Second World War (Allen et al. 2006). This period also marks the beginning of the fishery in the two stock assessments conducted to date; however, it is widely appreciated that snapper were targeted in offshore waters many decades prior to this. The few official reports that exist prior to 1939 suggest that levels of fishing were significant (Marine Department Report 1905). Furthermore, the iconic nature of the Australian snapper fishery means

that management approaches are unlikely to be successfully implemented without an understanding of the social and cultural perspectives surrounding it (Urquhart et al. 2013). Thus, examination of the early snapper fishery provides information relevant both to future stock assessments and fishery management strategies.

In this paper we use multiple types of quantitative and qualitative information to produce a 69-year (1871-1939) timeline of catch per unit of fishing effort, thus extending current available data on the snapper fishery by an additional seven decades back to 1871. Critical to the generation of a robust time series were the following three steps. Firstly, available information was maximised by translating narrative accounts into bounded quantitative estimates. Secondly, a further boost to the overall sample size was achieved by performing multiple imputation on records for which one of the three key variates was completely missing. Finally, a parametric maximum likelihood estimation framework was utilised to provide a principled approach to quantifying uncertainty and making statistically valid comparisons on this somewhat challenging (small sample size, skewed, unbalanced) data set. A key aspect of the estimation framework is its robustness under management restrictions on trip limits, which facilitated a comparison between the archival data and a contemporary data set collected during a period when bag limits were in operation. These archival data provide critical insights into the productivity of the coastal offshore fishery during its initial years of development, as well as social-cultural perspectives on early recreational fishing activities. Such data on the *Pagrus auratus* fishery have

never been examined in detail before and provide some of the earliest catch rate data globally for this species.

METHODS

Study area and the Queensland fishery since World War II

East coast snapper live up to 30 years and can weigh in excess of 10kg (Campbell et al. 2009). Along the east coast of Australia, snapper reach their northerly distribution limit in the sub-tropical waters around Proserpine (latitude 20.4°S; Ferrell and Sumpton 1997). In Queensland they are most abundant in the rocky reef systems south of the northern tip of Fraser Island (latitude 25.2; Figure 1) and the majority of Queensland snapper landings are from this region (Ferrell and Sumpton 1997). In Queensland snapper are targeted by both recreational and commercial fishers from depths of 10-200m (Allen et al. 2006), with both fisheries currently restricted to operating with 3 lines and 6 hooks total, per person (*Fisheries Regulation 2008* (Qld) s189, s397 and s405). Charter boats (a fishing platform for recreational fishers operated by a professional skipper) also operate under recreational limits. Commercial fishers target snapper as part of the rocky reef fin fish fishery, a mixed fishery which also targets pearl perch (*Glaucosoma scapulare*, Glaucosomatidae), teraglin (*Atractoscion aequidens*, Sciaenidae) and cobia (*Rachycentron canadum*, Rachycentridae), among other species. Prior to 1990 both recreational and licenced commercial fishers could sell their catch of snapper and there were no restrictions on the number of fish

recreational or commercial fishers could take (Allen et al. 2006), although snapper less than 25 cm in total length could not be landed. In 1990 recreational selling of catch was stopped (Anderson et al. 2005) and in 1993 the minimum size limit for snapper increased to 30 cm total length with recreational fishers limited to 30 snapper in possession per fisher. In December 2002 the recreational limit was reduced to 5 snapper and the minimum size (commercial and recreational) was increased to 35 cm. In September 2011 the recreational limit was further reduced to 4 snapper, with only 1 fish over 70 cm allowed to be kept (Queensland Government 2012). Catch statistics indicate that the contemporary recreational fishery catch is two to three times larger than the commercial fishery (Allen et al. 2006).

Historical data sources

Major Queensland newspapers are digitally archived by the State Library of Queensland spanning the years 1803-1954 (National Library of Australia 2013) and the majority of historical data used in this study were sourced from this collection (Table S1). We conducted standardised searches using key words and phrases to describe early snapper fishing activities, for example, 'snapper fishing', 'snapper excursion', 'snapper trip'. During the late 19th and early 20th century, snapper in Queensland were known as 'schnapper' or 'squire', depending upon their size and/or the presence of a bony protrusion on their forehead. Hence we also conducted searches including these terms. We also manually searched a number of non-digitised Queensland newspapers; these

231 included the *Redland Times* (1931-1942), the *South Coast Bulletin* (1929-1963)
232 and the *Tweed Herald* (1898-1910).
233
234 In addition to newspaper articles, we also searched popular publications
235 dedicated to snapper fishing. A major source of data came from a publication by
236 Welsby (1905), which described the author's fishing experiences for snapper off
237 the southeast Queensland coast during the late 19th and early years of the 20th
238 century. As well as providing qualitative information on the early snapper
239 fishery, the book also records catch and effort data from chartered and private
240 fishing trips.
241
242 We also sourced the official report of the *Fisheries Investigation Ship (F.I.S.)*
243 *Endeavour* (Dannevig 1910), which completed fishery surveys in Queensland in
244 1910. Whilst the *Endeavour's* main objective was conducting bottom trawl
245 surveys to determine the suitability of Queensland waters for trawl fishing, she
246 also undertook line-fishing surveys between July and October 1910, for which
247 catch and effort were recorded.
248
249 Other sources of information searched included the annual reports of the
250 Queensland Marine Department, which was responsible for reporting on
251 Queensland fisheries until 1935 when the responsibility for the sale and
252 distribution of Queensland fisheries was transferred to the Fish Board. The
253 Queensland Fish Board recorded statewide landings data of snapper from 1946-
254 1981, which comprised a mixture of commercial and recreationally landed fish.
255 However, these data are incomplete as not all fish were marketed through the

Fish Board. Unknown quantities of fish were also sold directly to fish retailers and individuals, for which no records exist. Upon the closure of the Fish Board in 1981, Queensland fishery statistics were unavailable until 1988 when a compulsory logbook system was implemented to record daily catch and effort data of commercial fishers (Allen et al. 2006). Separate recreational catch statistics have been collected sporadically from 1994 onwards.

Extracting catch rates from quantitative and qualitative data

We extracted all available quantitative (for example, hours fished, number of fish caught, number of fishers) and qualitative data (for example, location of fishing ground, departure location, vessel name) from each individual archival record. To arrive at catch rates in snapper fisher⁻¹ hour⁻¹, we used a multivariate approach that maximises the information contained in the data and is more robust than simpler ratio estimators. A probability density (a trivariate Gaussian) was estimated for three variables: number of snapper caught, S , number of fishers, F , and hours spent fishing, H . Our approach is an extension of an analysis performed by Richards and Schnute (1992); details are contained in the Supplementary Material (Figures S1-S6). The medians of the three variables were denoted by the terms S^* , F^* and H^* , and the estimated medians by $\widehat{S}^*$, $\widehat{F}^*$ and $\widehat{H}^*$. The catch rate, U , was calculated as

$$\widehat{U} = \frac{\widehat{S}^*}{\widehat{F}^* \widehat{H}^*}$$

Confidence intervals were established using the profile-likelihood based approach (see details in Supplementary Material).

279

280 Where records did not provide all the necessary quantitative data to enable us to
281 directly extract catch rate, we dealt with missing values using a two-level
282 procedure. First, where available, we used qualitative descriptions ('narratives')
283 from individual records to construct a range of plausible quantitative estimates.
284 These estimates were constructed using comparable data from other records
285 (Tables 1 and 2). Estimates of numbers of fishers were defined by vessel, and
286 were only included if other records existed for that vessel that provided
287 quantitative data on the numbers of fishers on board. From these records an
288 average value for number of fishers was derived, which was applied to records
289 that explicitly named the vessel in question and where data on number of fishers
290 were missing. This enabled us to account for the different sizes and carrying
291 capacity of the vessels throughout the time series. Narrative estimates for
292 proportion of snapper and hours fished reflected available historic data and
293 were consistent across the historical time period (Table 1).

294

295 Secondly, we used multiple imputation (Rubin, 1987) on records for which one
296 of the three variables was still (after the narrative step) missing. Multiple
297 imputation is a technique where missing values are replaced m times by
298 simulated values to form m simulated complete datasets (Schafer 1999). It is a
299 principled approach to capturing the uncertainty arising from missing values
300 and is widely used across the economic, behavioural, social and health sciences.
301 We assumed missing values were missing at random, that is, the mechanism
302 causing values to be missing was assumed to not be systematically related to
303 catch rate. This assumption is a potential weakness in our approach. Multiple

304 imputation takes into account true randomly missing data, but here it is possible
 305 that missing data are biased towards zero catches, and catch rates may be
 306 correlated due to another, unknown factor that changes over time.

307

308 For each record with a missing value for one of the three variables, we drew ten
 309 samples from the modelled trivariate distribution, providing us with ten
 310 complete data sets, indexed $j = 1, 2, \dots, m$. The overall estimate of catch rate was
 311 calculated as:

$$\bar{U} = \frac{1}{m} \sum_{j=1}^m \hat{U}_j$$

312 For the overall variance, T , we calculated

$$T = \bar{V} + \left(1 + \frac{1}{m} B\right)$$

313 where V and B are the within-imputation variance and the between-imputation
 314 variance respectively. $\bar{V}$ is the average of the variances associated with each
 315 imputed sample, $\hat{U}_j$, which were estimated using a bootstrap (1000 re-samples).
 316 Confidence intervals were obtained by taking the overall estimate plus or minus
 317 a number of standard errors, where that number is a quantile of Student's t-
 318 distribution with degrees of freedom

$$df = (m - 1) \left(1 + \frac{m \bar{U}}{(m + 1)B}\right)^2$$

319

320 We ran multiple imputations on each of the three narrative levels (Table 1) to
 321 generate an upper and lower envelope of plausible catch rates from 1871-1939.

322

We assigned four time periods to the historic data (1870-1887, 1888-1904; 1905-1922; 1923-1939), which broadly represented different stages in the fishery: from trips to nearby fishing grounds (1870-1887), to the expansion and exploration of new grounds further afield (1888-1904), to a rapid rise in the popularity of snapper fishing and further expansion of fishing grounds (1905-1922) to the introduction of motor launches and a subsequent increase in the number of amateur fishing parties along the coast (1923-1939).

Investigating potential data source bias

88% of our catches were sourced from newspaper reports (1871-1939), 3% from a book by *Welsby* (1905) and 9% from the *F.I.S. Endeavour* surveys (Dannevig 1910). An immediate criticism of media reports as a data source is the bias arising from the most successful trips being more likely to make the papers. The Government survey data (the *Endeavour*) provide an opportunity to test this criticism formally and for this we used two approaches. Firstly, we considered the existence (or not) of overlap in confidence intervals constructed using the methodology described previously. The non-overlap of 83.4% confidence intervals corresponds to a statistically significant difference at the $p=0.05$ level (Knol et al. 2011). Using this method we explored differences in catch rates between sources and between vessels, comparing catch rates from the *Endeavour* with other major sources of data (*The Brisbane Courier*, *Courier Mail*, *Queensland Times*, *The Queenslander*, and *Welsby*) and comparing records where the vessel identify was known (*Beaver*, *Endeavour*, *Greyhound*, *Kate* and *Otter*). Secondly, we conducted two-sample Welsh t-tests to identify differences in

catch rates between newspaper and non-newspaper sources on a) catch rates from the *Endeavour* (n=26) and the *Queensland Times* (n=50) and b) catch rates from *Welsby* (n=8) and *The Queenslander* (n=8). These comparisons were chosen because the sample sizes were more balanced than other combinations, with tests conducted on the log scale.

Comparisons with contemporary data

Contemporary catch rate data were sourced from the southern offshore Queensland charter boat industry (data provided by Ray Joyce, Pacific Marinelife Institute), which recorded numbers of snapper and other fish species landed by charter boats fishing out from the Gold Coast from 1993–2013. The advantages of this particular contemporary data source as a basis for comparison are that it has a reliable measure of fishing effort in number of hours and number of fishers, and the historical data also relate primarily to charter fishing. However there are also some strong caveats for such a comparison, which we later discuss.

In order to facilitate this comparison we adjusted the contemporary data set in three ways. Firstly, only trips between May and September were considered as 94% of historic trips took place during these months. Secondly, we disregarded catches in the period 2003-2010, when the bag limit for snapper was further reduced to 5 snapper angler⁻¹ (in possession) as it was widely reported by contemporary recreational fishers that such restrictions affected their targeting behaviour for snapper. As the contemporary data set does not distinguish between trips targeting snapper and trips targeting other species, contemporary

catch rates of snapper may be underestimated by erroneously including trips that were targeting species other than snapper. So thirdly, to limit the impact of this targeting issue, we restricted the analysis to trips where more snapper were caught than other species.

Calculating rate of spatial expansion

We used the number of new fishing grounds documented each year in archival records and the maximum distance travelled as proxies for spatial expansion of the fishery. We calculated the rate of spatial expansion as the number of new fishing grounds documented per year and the increase in the furthest distance travelled each year, measured as distance travelled to the fishing ground from port of departure.

RESULTS

Table 2 provides examples of the archival records collated with quantitative information used to construct catch rates highlighted in bold. In total, 307 individual archival records provided quantitative data on fishing parties targeting snapper, spanning a period of 69 years from 1871-1939. These were collated from newspaper reports (n = 272) from twelve Queensland newspapers, 58% of which were sourced from one newspaper, *The Brisbane Courier*; Welsby (1905) (n = 8) and the results of the 1910 *Endeavour* line fishing surveys (n = 27). 307 records state the total number of 'fish' (i.e., mixed fish including snapper) caught, and 100 records state the number of individual snapper caught.

199 records provide the numbers of fishers present, whilst 91 record the numbers of hours fished. While only 47 records were complete (i.e., provided data on the number of snapper caught, number of fishers and hours fished), using the narrative and imputation techniques increased our sample size to 278 (Table 3).

The pre-World War II snapper fishery

The earliest quantitative record we were able to source comes from a newspaper article published in 1871, which spoke of the growing popularity of offshore snapper fishing (*The Brisbane Courier*, 7 Sep 1871). For the next four decades articles on the catch of 'schnapper parties' from the offshore grounds of southeast Queensland slowly increased, although the small number of boats capable of regularly reaching the outside grounds limited total fishing effort. The 307 records collated provide quantitative data on the catches of fishing parties and in many cases qualitative information on the methods, gear and vessels used and descriptions of fishing activities (Table 2). In 1905 it was reported that a total of 10 to 12 steamboats regularly took snapper parties to the offshore grounds from Brisbane (Marine Department Report 1905), ranging from 8 to 50 anglers in number. During fishing activities the boat would steam onto the fishing mark, at which point lines would be cast and the boat would drift with the current until fish stopped being caught and it was time to steam back onto the fishing mark. If fish could not be found after a few drifts, the boat would travel to an alternative fishing ground. Lines were made of cord and were weighted with lead and comprised one or more large hooks; these lines would be hauled in by

hand. Whilst a number of other species were caught in addition to snapper including tuskfish (*Choerodon* spp., Labridae), rock cods and large grouper (*Epinephelus* spp., Serranidae), snapper were the iconic species to catch and excursions to offshore fishing grounds were labelled as ‘schnapper excursions’ (Figure 2). In 1910 a line fishery survey conducted by the *Endeavour* showed that snapper averaged 77% of the catch (by number) from the 27 southeast Queensland rocky reef environments they surveyed, with snapper comprising 95% or more of the catch of fish in 12 surveys (Dannevig 1910).

Even though the parties that travelled to the snapper grounds were not always regular fishers it was rare for snapper fishing parties to arrive back in port with fewer than 200 fish (Marine Department Report 1905, Table S2 in Supplementary Materials). Throughout the time series, the number of snapper landed per trip ranged from fewer than 10 to more than 1000 individuals, with 13 trips recording 500 or more individual snapper caught. 94% of trips took place during the winter months, between May and September, a time when snapper are known to aggregate to spawn and the weather and currents are generally more favourable for deep water line fishing trips. As few commercial fishers operated in open water during this period these recreational catches were almost the sole sources of supply of deep-water fish (Marine Department Report 1905).

Historic catch rates

Median catch rates over the time series equalled 4.165 snapper fisher⁻¹ hour⁻¹ (95% confidence interval, 3.364 - 5.104) for the narrative data set and 3.753 snapper fisher⁻¹ hour⁻¹ (95% confidence interval, 3.419 – 4.086) for the imputed data set. We report median values rather than mean to reduce the influence of occasional very high catch rates. Median catch rates and associated confidence intervals were calculated for four periods (1870-1887, 1888-1904, 1905-1922 and 1923-1939), and for each of the three narrative assumptions (Figure 3). No statistically significant time series trend was identified within the historical period, regardless of the narrative assumptions. Individual catch rates broken down by data source are depicted in Figure 4. The Brisbane Courier presents the longest unbroken series of catch rates, between 1871-1933. On two occasions reported catch rates exceeded 37 snapper fisher⁻¹ hour⁻¹.

Fishing grounds expanded greatly during the period covered by the newspaper reports, as did the skill and knowledge of the skippers of many of the vessels that regularly visited the fishing grounds (Marine Department Report 1903). From 1879-1938 the cumulative number of named fishing grounds reported in popular media increased from 3 to 46 (Figure 5a), a rate of 0.7 new fishing grounds documented year⁻¹. The maximum distance travelled from port also increased from 22 to 88 nautical miles (Figure 5b), a rate of 1.5 km year⁻¹ from 1871-1915 as the fishing grounds most commonly accessed from Brisbane shifted north and south (Figure 1; Figure 5c).

Investigating data source bias

Confidence interval analysis indicated the only significant difference across the six main data sources was between the *Courier Mail* and *Welsby* (Figure 6a). No significant differences were found across the five most reported vessels (Figure 6b). The Welch two-sample t-test showed no significant difference between catch rates reported by the *Endeavour* (median $\pm$ SD, 1.3 ± 0.96 snapper fisher⁻¹ hour⁻¹) and in the *Queensland Times* (1.29 ± 0.59 snapper fisher⁻¹ hour⁻¹; Welch 2-sample t-test on log catch rates, $t = -0.026$, $df = 35.05$, $p = 0.98$). Catch rates reported in *The Queenslander* (1.55 ± 0.45 snapper fisher⁻¹ hour⁻¹) and those of *Welsby* (2.27 ± 0.96 snapper fisher⁻¹ hour⁻¹) were much more distinct, with the difference approaching significance ($t = -1.91$, $df = 9.97$, $p = 0.085$).

Contemporary catch rates

The catch rate of snapper in the contemporary data set ($n=1,751$) averaged 0.40 snapper fisher⁻¹ hour⁻¹ (95% confidence intervals, 0.3087 - 0.5760); roughly one ninth of the historical catch rates (Figure 3).

DISCUSSION

Snapper has a long history of exploitation in southern temperate and sub-tropical oceans, but quantitative data on the early history of these fisheries are lacking. We collated data from a variety of historical data sources and analysed quantitative and narrative information to generate catch and effort data up to seven decades prior to the commencement of official data collection. We then

497 assessed levels of bias across data sources to evaluate the reliability of the
498 historical data used in our study.

499

500 *Analysis of catch rate*

501

502 Despite the crude fishing technology of the time, catches of snapper and other fin
503 fish species frequently ran into the hundreds of fish per trip when targeted from
504 early charter boats. Our analysis indicates that historical catch rates remained
505 stable over time; however, it is likely effective fishing effort increased over the
506 period of the study. The stable catch rates reflect the information available to us,
507 but changes in technology, number of vessels able to reach the fishing grounds,
508 increasing spatial coverage of the fishery and increasing skill of boat pilots may
509 have masked any declines that occurred. This would potentially impact our
510 results by overestimating catch rates later in the time series. In addition, spatial
511 expansion of the fishery further from port and into southern regions indicates
512 there may have been localized depletion (Hilborn et al. 2003). This is further
513 supported by anecdotal evidence that indicates popular fishing grounds were
514 seasonally depleted during these early years of the fishery,

515

516 *“Captain Bedford, having spent a lot of time prospecting for ground, enabled the*
517 *vessel to do much better in numbers [of fish caught] than she would otherwise have*
518 *done, having had so many grounds to try; the old grounds were all worked out, but*
519 *owing to the speed of the ‘Greyhound’ it was possible to change grounds quickly*
520 *and get a deal more fishing in the time. Towards the end of the season it was quite*

521 *impossible to get a good catch anywhere at the Cape or Flat Rock grounds"*
522 (Marine Department Report 1903).
523
524 The evidence for local depletion (in space and/or time) indicates anthropogenic
525 influence was already at work in these early years.
526
527 Although historic catch rates remained stable, contemporary catch rates were
528 significantly different. However, this difference must be interpreted with caution
529 for a number of reasons. Firstly, the spatial location of fishing differs between the
530 two data sets, with the contemporary data coming exclusively from the southern
531 region of the fishery. While there is some spatial overlap between the data sets, a
532 strict statistical comparison is not possible as snapper populations exhibit some
533 degree of spatial persistence and there is potential for localised depletion.
534 Tagging and recovery studies demonstrate that some snapper may occupy the
535 same reef for years (Willis et al. 2001), and anecdotal evidence from historic data
536 sources (Parsons et al. 2009) suggest that snapper populations may be
537 susceptible to localised depletion. Taken together, this evidence suggests effort
538 on different grounds may be acting on potentially different snapper populations.
539
540 Secondly, a related but distinct issue is the changing spatial nature of the fishery
541 itself. During the historical period, vessels first expanded from nearby more
542 accessible grounds to those further north, and then to fishing grounds in the
543 south (Figure 5c). Expansion of the fishery still occurs today, as fishers continue
544 to move to less exploited grounds further offshore (Campbell et al. 2009).
545 Systematic changes to fishing locations throughout a time series has strong

implications for the interpretation of catch rates, as spatial shifts may mask localised depletion and maintain catch rates at an artificially high level (Hilborn and Walters 1992).

Thirdly, many additional aspects of the fishery have changed over time. Fishing technology has advanced, increasing fishing power. In addition, changing economic and social patterns mean contemporary charter operations may substantially differ from historical expeditions in terms of their fishing ethic and targeting behaviour (Policansky 2002). Together, these obstacles to a strict statistical comparison should be weighed against the magnitude of the decline in catch rates observed, although some (e.g., changing fishing effort) indicate the magnitude of decline may be greater.

Can archival data provide robust estimates of catch rate?

Many fisheries time series suffer from incomplete or unrepresentative data, and rarely do time series extend to the beginnings of a fishery (Lotze and Worm 2009). Historical ecology provides an opportunity to explore alternative sources of information that can expand our temporal depth of understanding (Schwerdtner Máñez et al. 2014). However, historical sources of data and their potential biases must also be subjected to critical examination if we are to use these as proxies for past fisheries productivity. Our archival data were sourced from three main areas: popular literature, newspapers and a government survey. The main challenges to the validity of our study were missing data, the related

statistical challenge of small sample sizes, and the question of whether our records provide catch rates representative of this time period.

Missing data and small sample sizes were dealt with through a combination of narrative interpretation, multiple imputation, and a parametric maximum likelihood approach to the estimation of medians and construction of confidence intervals. The representativeness of the archival data were assessed by comparing different data sources. Newspaper data were relatively plentiful, but had the problem of potential bias towards reporting of higher catches or catch rates; data sourced from *Welsby* (1905) were scarce and potentially consisted of the same upward bias as newspaper data; *Endeavour* survey data were scarce, but as a scientific survey were considered a reliable source of catch rates.

Our comparisons showed that whilst catch rates sourced from *Welsby* were significantly higher than other sources, the newspaper sources did not show significantly different catch rates from the *Endeavour* surveys. Further indications that newspaper records are reasonable proxies for this period of time (zero catches excluded) come from several unbroken series of trips by either a vessel or fishing club (see Table S2, supplementary materials), which show that high (if variable) catches were maintained from trip to trip. Whilst *Welsby* might be disregarded as a representative source, we note that these records are useful for recording maximum catch rate data.

Application to management

595 In fisheries science, and in particular stock assessment, modellers are often faced
596 with the challenge of incorporating data sets that do not fit easily into traditional
597 quantitative approaches. Historical data sets are particularly challenging due to
598 their (usually) small sample size, potential bias and a lack of independent data
599 from the same time period with which to cross-reference. The potential payoff
600 for using such sources, however, is significant. Observations of a system during
601 periods of change (as in the development of a fishery) can contain far more
602 relevant information for models (*sensu*. Shannon 1948) than observations during
603 a period of stasis. In other words, the sample size may be small but the impact
604 on parameter estimates may be significant.

605

606 Specifically, archival data, as examined in this work, may contribute to fisheries
607 assessment outcomes in several ways. On a most basic level, they may impel
608 modelling to start from an earlier stage in the fishery. That is, they can reveal
609 significant fishing began prior to a date previously assumed to coincide with a
610 virgin stock. Archival data can indicate likely total catch during these early years,
611 which may corroborate or contradict previous total catch estimates in the model.
612 Excerpts from the early snapper fishery, for example, speak of the number of
613 steamers fishing each weekend and the total quantity of fish landed,

614

615 *"...The fact of outside deep-fishing as a sport should not be lost sight of [...], as many*
616 *as ten or twelve steamers, with large parties on board, engaging in it each weekend*
617 *[...]. I am able to account for, say, 25,000 fish so landed from pleasure steamer trips*
618 *during the last winter..."* (Marine Department Report, 1905)

619

620 *“Approximately 21,000 fish have been caught [...] the total weight represented is*
621 *something over twenty-eight tons.”* (The Brisbane Courier, 17 Jul 1905)

622

623 More ambitiously, the data may be used as an index of abundance for the period
624 over which they were collected. This requires sufficient data, both in terms of
625 raw sample size and data richness (for example, effort information and
626 covariates, such as vessel identifiers and spatial information). If they are of
627 sufficient quality – for example if potential biases can be calibrated against
628 historical surveys – data may augment contemporary indices of abundance and
629 extend the index back in time. These applications provide a more accurate
630 baseline of overall stock productivity. Critical to these abundance indices is the
631 ability to quantify both the rate of spatial fishery expansion and the spatial
632 mixing of the fish (i.e., to what extent individuals or populations interact), to
633 account for possible localised depletion effects. Alternatively, they may
634 contribute to contemporary catch rate standardisation, for example, through
635 information about changes in fishing technology and locations fished (Hoggarth
636 et al. 2006).

637

638 All the above measures (and they are by no means exhaustive) have the potential
639 to aid in better parameter estimates from stock assessment models, and hence
640 more informed management. Perhaps more important than these technical
641 advances are the conceptual implications for stock assessment. Archival data
642 tends to be descriptive first and quantitative second, and descriptive information
643 can force a reconsideration of previously unquestioned assumptions, both

644 historic and contemporary. In our case the question of quantifying hours of
645 fishing effort came in for re-examination:
646
647 *“The dangerous nature of the ocean bed at Flat Rock renders it impossible to*
648 *anchor near the fishing ground; the Kate, as fast as she is brought near the desired*
649 *sports, drifts back again, and, as the fish are only to be had near the rocks, the*
650 *moral enforced upon us is that we must make the most of our time...”* (The
651 Brisbane Courier, 16 Jun 1877).

652
653 While the phenomenon of “drifting” is timeless, and could in principle be
654 examined without recourse to 19th century newspaper articles, it was through
655 this data set that it was brought into focus for the authors, and has led to a re-
656 consideration of effort quantification in contemporary recreational fishing
657 surveys.

658
659 Ecosystem-based fisheries management (EBFM) is of growing interest around
660 the world as it focuses on broader issues than stock assessment, including social,
661 cultural and wider ecosystem impacts (Pikitch et al. 2004). In EBFM, historical
662 data can be of use in making decisions about which ecological or social indicators
663 are most appropriate for tracking past and future ecosystem change (Tallis et al.
664 2010). Historical literature also provides insights into human interactions with
665 marine species and how these have altered with time. For example, our data
666 provides clues on the extent of fishing activities and the locations where fishing
667 occurred in the past, which could be referenced against levels of fishing effort
668 and known grounds today. Also important is the potential for historic data to be

used for understanding the social-cultural aspects of a system - for example why species such as snapper are perceived to be more iconic than many other recreationally targeted species – and changes in these phenomena through time. Finally, EBFM tends to have a high level of stakeholder involvement (Fletcher et al. 2011) and historical data similarly appears to engage fishers and the wider community far more than the standard stock assessment and management communication channels. Popular media narratives are of particular relevance here. Stakeholder-relevant science communication is a critical and often under-appreciated aspect of the overall management picture, and this may ultimately be the most powerful contribution of historical ecology to the fisheries management process.

This study not only provides important insights into the historic snapper fishery and changes in the fishery over time, but also presents a multidisciplinary approach that could be adapted to other historical ecology studies as well as broader fields of research. For example, many contemporary ecological data sets suffer from similar issues to our historical data, including missing data and methodological bias, and thus could benefit from a similar approach to formally assessing levels of uncertainty (Chevenet et al. 1994). Natural resource managers also have to regularly make decisions based on limited or disparate data sources. Formalised approaches that assess biases and uncertainty may thus encourage the use of unconventional data sources that may previously have been discarded by decision-makers (Anderson et al. 1999).

CONCLUSIONS

Previous assessments raised concerns about the status of east coast Australian snapper stocks, but were limited to data that were collected many decades after initial exploitation commenced. This study provides new insights on the earliest period of the Queensland snapper fishery, up to seven decades prior to the recording of state landings data. These data place modern day catch rates into a long-term perspective, and deepen our understanding of the early fishery. Beyond direct contributions to quantitative assessment models, archival data have important implications for the modelling process in general, for stakeholder engagement and wider ecosystem based considerations. Despite the significant challenges associated with archival data, our approach demonstrates that at least some of these challenges are surmountable and lays the foundations for future quantitative analyses.

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