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Nineteenth century narratives reveal historic catch rates for Australian snapper (*Pagrus auratus*)

Ruth H Thurstan[1], *Alexander B Campbell*[2] *& John M Pandolfi*[1]

[1]Australian Research Council Centre of Excellence for Coral Reef Studies, School of Biological Sciences, The University of Queensland, St Lucia, Qld, 4072, Australia; [2]Agri-Science Queensland, Department of Agriculture, Fisheries and Forestry, Ecosciences Precinct, PO Box 267, Brisbane, Qld, 4001, Australia

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 fisherywide organized data collection, from 1871 to 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} h^{-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} h^{-1} (95% confidence interval, 3.42–4.09) as the fishery expanded into new grounds. In comparison, a contemporary (1993–2002) south-east Queensland charter fishery produced an average catch rate of 0.4 snapper fisher^{-1} h^{-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 formalized approach to address issues common to many historical records – missing data, a lack of quantitative information and reporting bias – our analysis demonstrates the potential for historical narratives to contribute to contemporary fisheries management.

Keywords Catch per unit effort, historical ecology, multiple imputation, narrative accounts, qualitative data

Correspondence:
Ruth H Thurstan, School of Biological Sciences, The University of Queensland, Gehrmann Building, St Lucia, Qld 4072, Australia
Tel.: +61 (0) 450 586 263
Fax: +61 (0) 7 3365 47-55
E-mail: r.thurstan@uq.edu.au

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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 prioritization 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 industrialization 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 south-east Australia from 1918 to 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 Ermgassen *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 formalized 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 to both 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 maximized 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 utilized 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 *P. 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 10 kg (Campbell *et al.* 2009). Along the east coast of Australia, snapper reach their northerly distribution limit in the subtropical 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; Fig. 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 10–200 m (Allen *et al.* 2006), with both fisheries currently restricted to operating with three lines and six hooks total, per person

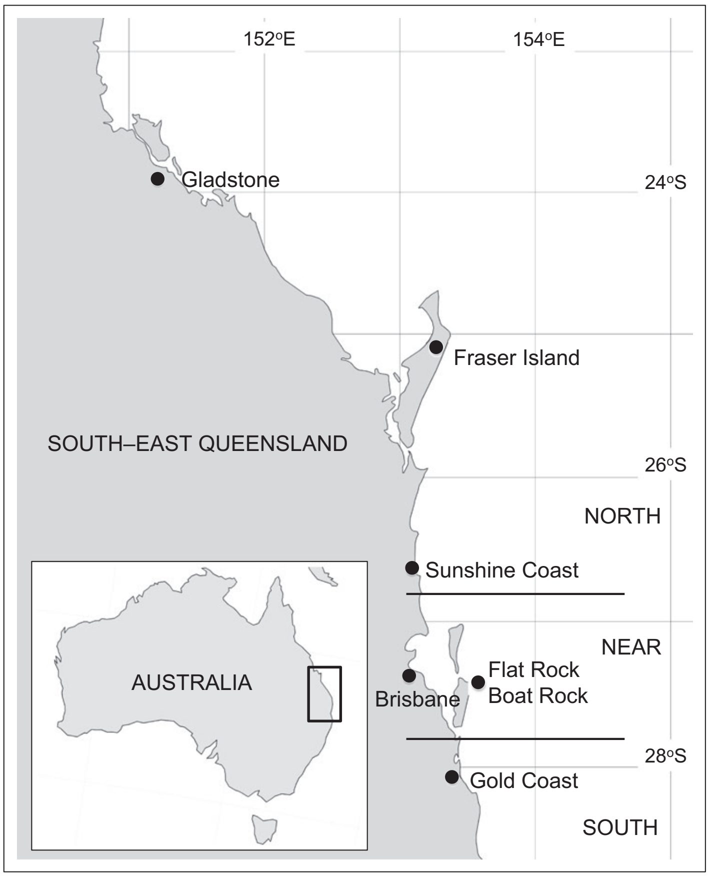

Figure 1 Map showing the coastline adjoining the contemporary Queensland snapper fishery. During the earliest period of the offshore fishery, Brisbane-based boats were mainly recorded as fishing in the 'near' grounds marked on the map. Throughout the pre-war period, fishing grounds accessed from Brisbane expanded north to the Sunshine Coast and south to the Gold Coast.

[*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 licensed 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 <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 five snapper and the minimum size (commercial and recreational) was increased to 35 cm. In September 2011, the recreational limit was further reduced to four snapper, with only one 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 standardized searches using keywords and phrases to describe early snapper fishing activities, for example 'snapper fishing', 'snapper excursion' and '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-digitized Queensland newspapers; these included the *Redland Times* (1931–42), the *South Coast Bulletin* (1929–63) and the *Tweed Herald* (1898–1910).

In addition to newspaper articles, we also searched popular publications dedicated to snapper fishing. A major source of data came from a publication by Welsby (1905), which described the author's fishing experiences for snapper off the south-east Queensland coast during the late 19th and early years of the 20th century. In addition to providing qualitative information on the early snapper fishery, the book also records catch and effort data from chartered and private fishing trips.

We also sourced the official report of the *Fisheries Investigation Ship (F.I.S.) Endeavour* (Dannevig 1910), which completed fishery surveys in Queensland in 1910. Whilst the *Endeavour's* main objective was conducting bottom trawl surveys to determine the suitability of Queensland waters for trawl fishing, she also undertook line fishing surveys between July and October 1910, for which catch and effort were recorded.

Other sources of information searched included the annual reports of the Queensland Marine Department, which was responsible for reporting on Queensland fisheries until 1935 when the responsibility for the sale and distribution of Queensland fisheries was transferred to the Fish Board. The Queensland Fish Board recorded statewide landings data of snapper from 1946 to 1981, which comprised a mixture of commercial and recreationally landed fish. 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} h^{-1}, we used a multivariate approach that maximizes 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 Supporting Information (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 Supporting Information).

Where records did not provide all the necessary quantitative data to enable us to directly extract catch rate, we dealt with missing values using a two-level procedure. First, where available, we used qualitative descriptions ('narratives') from individual records to construct a range of plausible quantitative estimates. These estimates were constructed using comparable data from other records (Tables 1 and 2). Estimates of numbers of fishers were defined by vessel and were only included if other records existed for that vessel that provided quantitative data on the numbers of fishers on board. From these records, an average value for number of fishers was derived, which was applied to records that explicitly named the vessel in question and where data on number of fishers were missing. This enabled us to account for the different sizes and carrying capacity of the vessels throughout the time series. Narrative estimates for

Table 1 Assumptions used to construct quantitative values from narrative data.

Category	Qualitative statement (example)	Assumption (mean)	Assumption (max)	Assumption (min)	Source from which values are derived
Hours fished	Fishing begins in the morning. Vessel returns that evening	5 h fishing	7 h fishing	3 h fishing	Newspaper extracts that state hours fished for similar length trips
Hours fished	Vessel fishing for a short period of time	3 h fishing	5 h fishing	2 h fishing	Newspaper extracts that state hours fished for similar length trips
Proportion of snapper in the catch	Snapper makes up the majority of fish caught	75% snapper	90% snapper	60% snapper	Newspaper extracts; Endeavour survey data
Proportion of snapper in the catch	Snapper part of a mixed-species catch	40% snapper	50% snapper	30% snapper	Newspaper extracts; Endeavour survey data

Table 2 Quantitative data sourced from narrative accounts. Bold type shows data used to construct catch rates.

Source and date reported	Description
The Queenslander 24 May 1879	At a little before 7 [am] we steamed up to the Boat Rock, down went about **twenty-four lines**; in two minutes the cry rose 'schnapper'; in three minutes more, at least a dozen splendid fish were flapping on the deck [...]. For **four hours and a quarter** the sport was sustained [...]. We were found to have lessened that particular tribe of schnapper by about **735 individuals**...
The Queenslander 13 June 1885	The Lady Musgrave left Brisbane on Saturday evening [...] the party comprised **thirty gentlemen** [...]. Flat Rock was reached at **9.30** [am][...] fish were hauled over the side with tremendous speed until about **half-past 1 o'clock**, when the fishermen ceased their labours. On heads being counted, it was found that **901 fish** – chiefly schnapper, and several gropers, had been taken in **four hours**
The Brisbane Courier 16 August 1889	The steamer Alice returned to town at half past 7 o'clock yesterday evening from a schnapper fishing excursion to Flat Rock. She left Simon's wharf on Wednesday evening, and anchored in the South Passage for the night, reaching the fishing ground at **7 am yesterday**. The sport then began in real earnest and continued up till **1 o'clock**, when a start was made for home. Although only **8 lines** were out no less than **210 fine large fish** were caught
The Brisbane Courier 23 June 1905	A private party of **eight** [...], the party only fished for **about an hour**, at a spot about two miles to the eastward of [Flat] rock. The depth of water was between thirty-five and forty fathoms, but excellent sport was obtained, and some fine fish were caught. The total catch was **slightly over 100, all schnapper**
The South Coast Bulletin 12 July 1929	Next day a party of **nine** visited the [seven-mile] reef, in Mr H Lahr's launch, and after **five hours fishing** returned with **280 schnapper**, some of which weighed up to 12 lb. A cod turned the scale at 29 lb
The Courier Mail 9 June 1939	...the Ivy May, with **5 men** on board, returned after **three hours fishing** with a catch of **53**, mostly snapper and nannygai, aggregating 116 lb. The biggest snapper weighed 8 lb

proportion of snapper and hours fished reflected available historic data and were consistent across the historical time period (Table 1).

Secondly, we used multiple imputation (Rubin 1987) on records for which one of the three variables was still (after the narrative step) missing. Multiple imputation is a technique where missing values are replaced *m* times by simulated values to form *m*-simulated complete data sets (Schafer 1999). It is a principled approach to capturing the uncertainty arising from missing values and is widely used across the economic, behavioural, social and health sciences. We assumed missing values were missing at random, that is the mechanism causing values to be missing was assumed not to be systematically related to catch rate. This assumption is a potential weakness in our approach. Multiple imputation takes into account true randomly missing data, but here, it is possible that missing data are biased towards zero catches, and catch rates may be correlated due to another unknown factor that changes over time.

For each record with a missing value for one of the three variables, we drew 10 samples from the modelled trivariate distribution, providing us with 10 complete data sets, indexed $j = 1,2,\ldots,m$. The overall estimate of catch rate was calculated as:

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

For the overall variance, T, we calculated:

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

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

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

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

We assigned four time periods to the historic data (1870–87; 1888–1904; 1905–22; 1923–39), which broadly represented different stages in the fishery: from trips to nearby fishing grounds (1870–87), 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 (1905–22) and to the introduction of motor launches and a subsequent increase in the number of amateur fishing parties along the coast (1923–39).

Investigating potential data source bias

Eighty-eight percent 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 (i) catch rates from the *Endeavour* ($n = 26$) and the *Queensland Times* ($n = 50$) and (ii) 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 to 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.

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 2003–10, 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 to 1939. These were collated from newspaper reports (n = 272) from 12 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). Three hundred and seven records state the total number of 'fish' (i.e. mixed fish including snapper) caught, and 100 records state the number of individual snapper caught. One hundred ninety-nine records provide the numbers of fishers present, whilst 91 records provide the numbers of hours fished. Whilst 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 September 1871). For the next four decades, articles on the catch of 'schnapper parties' from the offshore grounds of south-east 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 10–12 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' (Fig. 2). In 1910, a line fishery survey conducted by the *Endeavour* showed that snapper averaged 77% of the catch (by number) from the 27 south-east Queensland rocky reef environments they

Table 3 Sample sizes of the data at the three stages of analysis.

Category	Sample size	Description
Complete	47	All 'Snapper', 'Fishers' and 'Hours' present and taken directly from quantitative sources
Narrative	106	'Snapper', 'Fishers' and 'Hours' present and taken from quantitative or narrative sources
Imputation	278	Two of 'Snapper', 'Fishers' and 'Hours' present from quantitative or narrative sources; the missing variate generated through multiple imputation

Figure 2 Catch from a snapper fishing trip on the Steam Ship Tarshaw, south-east Queensland, ca. 1900. Source: Welsby (1905).

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). 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. Ninety-four percent 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} h^{-1} (95% confidence interval, 3.364–5.104) for the narrative data set and 3.753 snapper fisher^{-1} h^{-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 (1870–87, 1888–1904, 1905–22 and 1923–39) and for each of the three narrative assumptions (Fig. 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 Fig. 4. The Brisbane Courier presents the longest unbroken series of catch rates, between 1871 and 1933. On two occasions, reported catch rates exceeded 37 snapper fisher^{-1} h^{-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

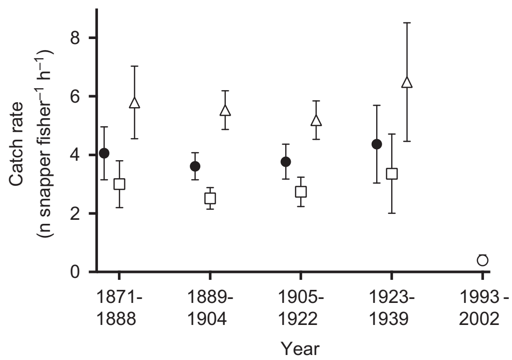

Figure 3 Median and 95% confidence intervals for catch rate (snapper fisher^{-1} h^{-1}) through time. Within each of the four historical time periods (1870–87, 1888–1904, 1905–22 and 1923–39), three intervals are displayed corresponding to three assumptions during the 'narrative' step: mean assumption (filled circle); minimum assumption (open square); and maximum assumption (open triangle). Contemporary data are shown by an open circle.

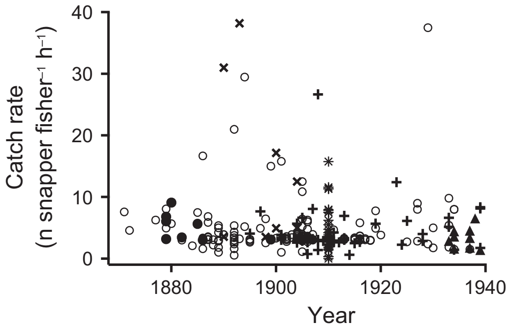

Figure 4 Scatterplot of catch rate (snapper fisher^{-1} h^{-1}) showing the contribution of different data sources (imputed data set, mean narrative assumption, n = 278). The largest data source, the Brisbane Courier (n = 160), is labelled with an open circle. The other five data sources are depicted as follows: the Queensland Times (n = 50) labelled '+'; Endeavour (n = 26) labelled '*'; the Courier Mail (n = 12) labelled with a closed triangle; Welsby (n = 8) labelled 'X'; and The Queenslander (n = 8) labelled with a closed circle. Together, these six data sources account for 95% of the data set.

the vessels that regularly visited the fishing grounds (Marine Department Report 1903). From 1879 to 1938, the cumulative number of named fishing grounds reported in popular media increased from 3 to 46 (Fig. 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 (Fig. 5b), a rate of 1.5 km year^{-1} from 1871 to 1915 as the fishing grounds most commonly accessed from Brisbane shifted north and south (Figs 1 and 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* (Fig. 6a). No significant differences were found across the five most reported vessels (Fig. 6b). The Welch two-sample t-test showed no significant difference between catch rates reported by the *Endeavour* (median ± SD, 1.3 ± 0.96 snapper fisher^{-1} h^{-1}) and in the *Queensland Times* (1.29 ± 0.59 snapper fisher^{-1} h^{-1}; Welch two-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} h^{-1}) and those of *Welsby* (2.27 ± 0.96 snapper fisher^{-1} h^{-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 = 1751) averaged 0.40 snapper fisher^{-1} h^{-1} (95% confidence intervals, 0.3087–0.5760), roughly one-ninth of the historical catch rates (Fig. 3).

Discussion

Snapper has a long history of exploitation in southern temperate and subtropical 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 assessed levels of bias across data sources to evaluate the reliability of the historical data used in our study.

Analysis of catch rate

Despite the crude fishing technology of the time, catches of snapper and other fin fish species

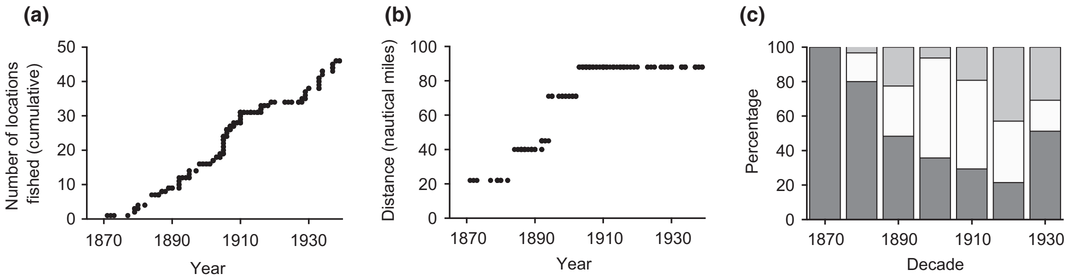

Figure 5 Rate of spread and location of fishing grounds. (a) Cumulative number of locations recorded in historical sources by year. (b) Maximum distance to fishing grounds by year. (c) Relative frequency of trips to near (dark grey), north (white) and south (medium grey) fishing grounds (see Fig. 1 for boundaries of these grounds).

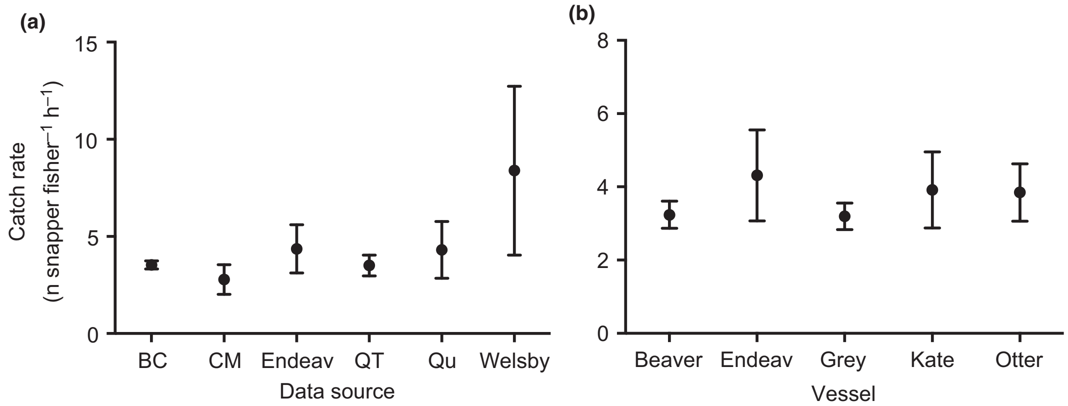

Figure 6 Median and 83.4% confidence intervals for catch rate (snapper fisher^{-1} h^{-1}) across (a) data sources and (b) vessels. BC, Brisbane Courier; CM, Courier Mail; Endeav, Endeavour; QT, Queensland Times; Qu, The Queenslander; Grey, Greyhound.

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

> Captain Bedford, having spent a lot of time prospecting for ground, enabled the vessel to do much better in numbers [of fish caught] than she would otherwise have done, having had so many grounds to try; the old grounds were all worked out, but owing to the speed of the 'Greyhound' it was possible to change grounds quickly and get a deal more fishing in the time. Towards the end of the season it was quite impossible to get a good catch anywhere at the Cape or Flat Rock grounds (Marine Department Report 1903).

The evidence for local depletion (in space and/or time) indicates anthropogenic influence was already at work in these early years.

Although historic catch rates remained stable, contemporary catch rates were significantly different. However, this difference must be interpreted with caution for a number of reasons. Firstly, the spatial location of fishing differs between the two data sets, with the contemporary data coming exclusively from the southern region of the fishery. Whilst there is some spatial overlap between the data sets, a strict statistical comparison is not possible as snapper populations exhibit some degree of spatial persistence and there is potential for localized depletion. Tagging and recovery studies demonstrate that some snapper may occupy the same reef for years (Willis *et al.* 2001), and anecdotal evidence from historic data sources (Parsons *et al.* 2009) suggest that snapper populations may be susceptible to localized depletion. Taken together, this evidence suggests effort on different grounds may be acting on potentially different snapper populations.

Secondly, a related but distinct issue is the changing spatial nature of the fishery itself. During the historical period, vessels first expanded from nearby more accessible grounds to those further north and then to fishing grounds in the south (Fig. 5c). Expansion of the fishery still occurs today, as fishers continue to move to less exploited grounds further offshore (Campbell *et al.* 2009). Systematic changes to fishing locations throughout a time series have strong implications for the interpretation of catch rates, as spatial shifts may mask localized 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 was 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, they 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), 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

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

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

> ...The fact of outside deep-fishing as a sport should not be lost sight of [...], as many as 10 or 12 steamers, with large parties on board, engaging in it each weekend [...]. I am able to account for, say, 25 000 fish so landed from pleasure steamer trips during the last winter...(Marine Department Report 1905).
>
> Approximately 21 000 fish have been caught [...] the total weight represented is something over 28 tons (The Brisbane Courier, 17 July 1905).

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

All the above measures (and they are by no means exhaustive) have the potential to aid in better parameter estimates from stock assessment models and hence more informed management. Perhaps more important than these technical advances are the conceptual implications for stock assessment. Archival data tend to be descriptive first and quantitative second, and descriptive information can force a reconsideration of previously unquestioned assumptions, both historic and contemporary. In our case, the question of quantifying hours of fishing effort came in for re-examination:

> The dangerous nature of the ocean bed at Flat Rock renders it impossible to anchor near the fishing ground; the Kate, as fast as she is brought near the desired sports, drifts back again, and, as the fish are only to be had near the rocks, the moral enforced upon us is that we must make the most of our time…(The Brisbane Courier, 16 June 1877).

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

Ecosystem-based fisheries management (EBFM) is of growing interest around the world as it focuses on broader issues than stock assessment, including social, cultural and wider ecosystem impacts (Pikitch *et al.* 2004). In EBFM, historical data can be of use in making decisions about which ecological or social indicators are most appropriate for tracking past and future ecosystem change (Tallis *et al.* 2010). Historical literature also provides insights into human interactions with marine species and how these have altered with time. For example, our data provide clues on the extent of fishing activities and the locations where fishing occurred in the past, which could be referenced against levels of fishing effort 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 appear 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. Formalized 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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Conflict of interest

The authors have no conflict of interests to declare.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Figure S1. Scatter plots of the effort data (number of fishers F_i, number of hours fishing H_i).

Figure S2. Scatter plots of the catch and effort data (number of fishers F_i, number of snapper caught S_i).

Figure S3. Scatter plots of the catch and effort data (number of hours fishing H_i, number of snapper caught S_i).

Figure S4. Scatter plot of the data (ξ_i, η_i), transformed from (number of fishers F_i, number of hours fishing H_i).

Figure S5. Scatter plot of the data ξ_i, ζ_i, transformed from (number of fishers F_i, number of snapper caught S_i).

Figure S6. Scatter plot of the data (η_i, ζ_i), transformed from (number of hours fishing H_i, number of snapper caught S_i).

Table S1. Sources from which data on historical snapper fishing trips were derived.

Table S2. Newspaper records where consecutive snapper fishing trips undertaken by an individual fishing club or a vessel, and the total number of fish landed could be identified.