Unique palaeoenvironmental records? An examination of applications and the reliability of fish otoliths in archaeological investigations

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THE UNIVERSITY of ADELAIDE

This thesis is dedicated to my grandfather, who inspired in me a fascination of the natural world, and to my son, whom the world is for.

Declaration

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Morgan C.F. Disspain

1 August 2016

Cover Image: Fish for sale at the Arica fish markets, Chile.

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Abstract

Fish otoliths are bony structures found in the inner ear of teleost fish. Their morphological and chemical properties provide excellent environmental and anthropogenic proxies. Otolith analyses are widely employed in modern fisheries studies, and have been increasing within archaeological and palaeoenvironmental research. This thesis investigates the use of otoliths in archaeological research, and evaluates the reliability of the data obtained from such analyses. The main objectives are to: (1) overview and synthesise the development and future prospects of otolith studies in archaeology; (2) investigate the reliability of archaeological fish otoliths as proxies for environmental change through the use of experimental archaeology; and (3) explore various applications of archaeological otolith analyses by applying experimental, documentary, isotopic, trace element and morphological methods to otoliths, thereby investigating what they can tell us about past environments, fish populations, and people.

The main methods of archaeological otolith analysis are overviewed and discussed; in spite of some limitations, the benefits and unique information that otolith analyses can provide ensure that they should be an important part of archaeological research. Continuing development of methods and technologies within this area will serve to increase the importance and use of otoliths.

An experimental approach is used to investigate the reliability of analyses of archaeological fish remains, specifically the effects that cooking and processing methods have on the morphology and chemistry of hard parts. Analyses of otoliths, vertebrae and scales from mulloway (*Argyrosomus japonicus*) cooked using a range of techniques reveal disparities in the chemistry and morphology of otoliths and vertebrae processed in different ways, while impacts observed in the fish scales were less substantial. Findings highlight the need to conduct palaeoenvironmental reconstructions based on chemistry and stable isotope data of archaeological fish remains with caution.

Otoliths from two archaeological sites in the Atacama Desert, Chile were analysed; species distribution and changes over time were investigated, and fish size was estimated based on relationships between otolith weight and fish total length (TL) determined from modern samples. These analyses provide insights into the subsistence strategies of past site inhabitants, as well as how fish populations in the region have changed over time. Comparisons with a nearby contemporaneous site, suggest that fishing techniques were similar along this section of the Pacific coast.

Fish age, size and growth data obtained from archaeological fish otoliths, historical anecdotes, and contemporary data sources were combined to provide an extended temporal record of mulloway, *A. japonicus,* populations along the eastern coast of South Australia. Data from the three different sources corroborate each other in many aspects, with no significant changes in fish length over time evident, at

least for the time span of the three data sources, demonstrating the benefit of combining data sets from extended time periods to examine fish survival over thousands of years.

Accelerator Mass Spectrometry (AMS) radiocarbon dates on archaeological otoliths extend the known period of occupation of Long Point, Coorong, South Australia. They provide a detailed local chronology for the region, contributing to a more comprehensive understanding of human use of the area, and validate the use of fish otoliths for radiocarbon dating.

The research presented in this thesis reviews the use of otoliths in archaeological research, assesses the reliability of palaeoenvironmental data obtained from fish hard parts, and applies various methods of otolith analysis to archaeological assemblages.

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Chapter 1

General Introduction

Mulloway prepared to cook wrapped in muslin and boiled in seawater at Goolwa Beach, South Australia, as part of the cooking experiment detailed in Chapter 3.

General Introduction

Fish otoliths are bony structures found in the inner ear of teleost fish that act as organs of equilibrium and as direction and sound detectors. They possess unique characteristics that set them apart from other skeletal structures, notably continuous growth deposited on a daily basis. While otolith analyses are widely employed in modern fisheries studies, they have slowly been increasing within archaeological and palaeoenvironmental research. In this chapter I provide the aims and objectives of the thesis and give a brief introduction to each chapter. Further background to the use of otoliths in archaeological research is found in Chapter 2. The overarching aim of this thesis is to investigate the use of otoliths in archaeological research, and to evaluate the reliability of the data obtained from such analyses.

The main objectives of this thesis are to:

Overview, synthesise, and provide critical review of the development and future prospects of otolith studies in archaeology through a review of published literature (Chapter 2)

Investigate the reliability of archaeological fish otoliths as proxies for environmental change by means of an experimental approach (Chapter 3)

Explore various applications of archaeological otolith analyses by applying a wide range of methods to otoliths from archaeological sites, thereby investigating what ancient otoliths can tell us about past environments, fish populations, and ultimately, people. (Chapters 4, 5 and 6)

Thesis Structure

Each chapter within this thesis has been written as an individual scientific paper, all of which have been submitted, accepted, or published by academic journals. They are all co-authored, with details of individual contributions included at the beginning of each chapter. As a result, each chapter contains its own introduction, methods, results, conclusions and references; however, they all relate to the over-arching topic of this thesis – the analysis of archaeological fish otoliths. They are presented here as an entire body of research, and are discussed as a cohesive entity in the General Discussion, Chapter 7. The following is a brief synopsis of each chapter.

Chapter 2: Otoliths in archaeology: Methods, applications and future prospects

This chapter is a critical literature review, which investigates the development and future prospects of otolith studies in archaeology, establishing the field of knowledge, and providing the background information for the following chapters. The main methods of analysis are outlined and major advances and research in each area detailed. In this chapter I recommend that in spite of some limitations, the benefits and unique information that otolith analyses can provide ensures that otoliths should be an important part of archaeological research. I propose that continuing development of methods and techniques within this area will serve to further increase the importance and use of otoliths. This chapter has been published in the *Journal of Archaeological Science: Reports* and as such, is presented here in the format of the published journal article.

Chapter 3: Do fish remains provide reliable palaeoenvironmental records? An examination of the effects of cooking on the morphology and chemistry of fish otoliths, vertebrae and scales

The morphological and chemical properties of fish calcified structures provide excellent environmental and anthropogenic proxies (as detailed in Chapter 2); however, pre-depositional handling may alter these properties, confounding interpretations. This chapter examines the effects of some commonly used processing and cooking methods on the morphological and chemical properties of modern fish otoliths using an experimental approach, and also includes how cooking affects fish vertebrae and scales. Whole mulloway (*Argyrosomus japonicus*) were treated using six traditional cooking methods. Samples were also obtained from untreated fish as controls for comparison. Otoliths, vertebrae and scales from the treatments were subjected to morphological, trace element and stable isotope analyses. The reliability of cooked fish remains in archaeological analyses and palaeoenvironmental reconstructions were evaluated. This chapter has been submitted to the *Journal of Archaeological Science* and is currently under review.

Chapter 4: Pre-Columbian fishing on the coast of the Atacama Desert, northern Chile: an investigation of fish size and species distribution using otoliths from Camarones Punta Norte and Caleta Vitor

The unique morphological properties of fish otoliths can be used to uncover information about people who lived thousands of years ago, as well as the fish species from which the otoliths originated. This chapter presents the results of morphological analysis of fish otoliths recovered from the archaeological sites of Camarones Punta Norte (occupied ca 7000–5000 years ago) and Caleta Vitor (occupied ca 9500–300 years ago) in the Atacama Desert, Chile. The otoliths were used to investigate individual fish sizes and species distribution, as well as how these compare to other contemporaneous sites in the region, and to modern fish populations. In order to determine the individual sizes of the ancient fish, modern fish samples were collected from fish markets in Arica, Chile, and relationships between otolith weight and fish total length (TL) of the predominant species, *Sciaena deliciosa* determined. The patterns evident in the fish otolith assemblages from each site were interpreted in relation to changing environmental conditions and cultural practices. This chapter has been published in the *Journal of*

Island and Coastal Archaeology and as such, is presented here in the format of the published journal article.

Chapter 5: Long-term archaeological and historical archives for mulloway, Argyrosomus japonicus*, populations in eastern South Australia*

Native fish populations have been strongly impacted by fishing, habitat alteration and the introduction of invasive species. Understanding the dynamics of native fish populations prior to industrialised fishing can be problematic, but provides critical baseline data for fish conservation, rehabilitation and management. Fish remains from archaeological sites can be used to circumvent this issue, and extend the temporal record of fish population data. In this chapter, archaeological analysis of fish otoliths was included, along with historical and modern research, to provide data relating to the populations of mulloway (*Argyrosomus japonicus*) inhabiting South Australia. Fish size, age and growth data, as well as month of catch data, were combined from archaeological fish otoliths (1670–1308 cal BP to 409–1 cal BP), historical anecdotes (1871–2000), and contemporary data sources (1984–2014) to examine changes to the fish populations. The data from each source are compared, and the similarities and differences between them are discussed. This chapter illustrates how longer temporal sequences can be obtained by combining data collected in substantially different manners. This chapter has been submitted to the journal *Fisheries Research*, and is currently under review.

Chapter 6: *Direct radiocarbon dating of fish otoliths from mulloway (*Argyrosomus japonicus*) and black bream (*Acanthopagrus butcheri*) from Long Point, Coorong, South Australia*

This chapter presents an example of one way that otoliths can be used in archaeological research – radiocarbon dating. Accelerator Mass Spectrometry (AMS) radiocarbon dates determined on fish otoliths from mulloway (*Argyrosomus japonicus*) and black bream (*Acanthopagrus butcheri*) are reported from five sites at Long Point, Coorong, South Australia. This chapter validates the use of fish otoliths for radiocarbon dating, and reinforces the benefit of directly dating samples, rather than assigning general time spans to artefacts based on associated dates from other material from the same site context/provenance. This chapter has been submitted to the *Journal of the Anthropological Society of South Australia*, and is currently under review.

Chapter 7: General Discussion

This chapter provides a general discussion of the preceding chapters, and examines the wider implications and overall significance of this research as a whole. Future research directions are also discussed.

Chapter 2

Otoliths in archaeology: methods, applications and future prospects

Excavating Long Point midden sites in the Coorong, South Australia.

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Name of Principal Author (Candidate)	Morgan Carol Faith Disspain		
Contribution to the Paper	Conducted research and reviews of literature, wrote manuscript and acted as corresponding author.		
Overall percentage (%)	90%		
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By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);
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Otoliths in archaeology: methods, applications and future prospects

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ABSTRACT

Otoliths are small structures found in the inner ear of teleost fish that act as organs of equilibrium and as direction and sound detectors. They possess unique characteristics that set them apart from other skeletal structures, notably a continuous growth structure deposited on a daily basis. While otolith analyses are widely employed in modern fisheries studies, they have slowly been increasing within archaeological and palaeoenvironmental research. This paper overviews the development and future prospects of otolith studies in archaeology. The main methods of analysis are outlined and major advances and research in each area detailed. In spite of some limitations, the benefits and unique information that otolith analyses can provide ensure that otoliths should be an important part of archaeological research. Continuing development of methods and technologies within this area will serve to further increase the importance and use of otoliths, while raising the profile of this unique resource.

1. Introduction

Otoliths are small structures found in the inner ear of teleost fish that act as organs of equilibrium and as direction and sound detectors (Popper and Fay, 2011). The three pairs of otoliths are termed the 'sagittae', 'lapilli' and 'asterisci', and are each contained within individual vestibules (Fig. 1) (Campana, 2004). They form in the embryonic stages of the fish, grow continuously throughout its life, and are composed of alternating layers of calcium carbonate (usually in the mineral form aragonite) and protein, which are deposited on a daily basis (Campana and Neilson, 1985; Pannella, 1971; Payan et al., 2004).

Otoliths possess unique characteristics that set them apart from all other skeletal structures. Otolith growth is continuous and is maintained even through periods when somatic growth is virtually nonexistent (Campana, 1990; Secor and Dean, 1989). As they form, otoliths absorb elements from the ambient water, which vary in relation to environmental conditions, such as salinity and temperature. They are acellular, meaning that once the material in otoliths is deposited, it is generally not reworked or resorbed (Campana and Neilson, 1985); otolith chemistry is thus a function of the environmental conditions experienced by the fish. This is a very important property of the otolith for palaeoenvironmental and archaeological applications. Their chemical composition affords the possibility of environmental reconstruction that, when matched with otolith biochronologies, can allow the lifetime of an individual fish to be placed retrospectively within time and space (Campana and Thorrold, 2001:37).

A large array of data are able to be recovered from otoliths, including species identification, age and growth studies, seasonality, radiocarbon dating and trace element and isotope analysis, which are discussed in this paper. Information gained from such analyses can address broad and often key archaeological issues. Otolith studies frequently contribute to answering questions focusing on changes in fish population structures, including examining impacts of intense human predation, environmental change and habitat destruction. The determination of ecological baselines is an essential step toward restoring native fish populations to pre-industrialised fishing levels, and as fisheries catch records generally only provide information from the last hundred years or so, otoliths, along with other fish remains, hold vital information frequently used for establishing knowledge of ancient fish stocks. There are some issues intrinsic to using anthropogenically compiled assemblages (Reitz, 2004), and Indigenous populations often had notable impacts on faunal populations (Holdaway and Jacomb, 2000; Mannino and Thomas, 2002; Wragg, 1995); however, it is undeniable that impacts experienced after the industrialisation of fishing have been unparalleled in human history. Otoliths also provide a wide range of information regarding the past occupants of a site; human subsistence strategies, fishing methods and technologies, trade routes, seasonality of site usage, and past human responses to environmental changes can all be examined through the analysis of these small carbonate structures.

Otolith analyses are widely employed in modern fisheries studies (for recent overviews, see Begg et al., 2005; Campana, 2005; Elsdon

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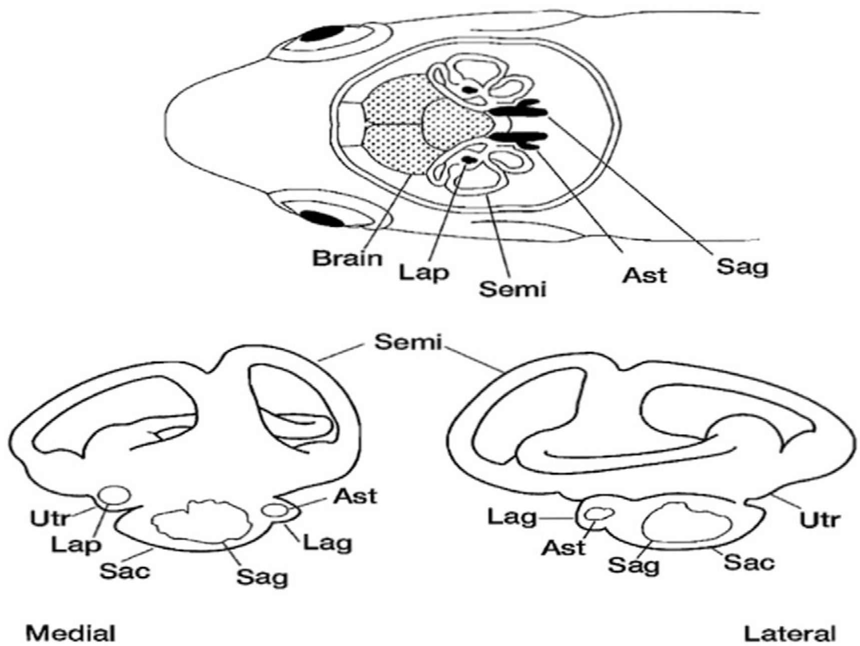

Fig. 1. Schematic of the location of the inner ear and three pairs of otoliths in the skull of a generalized teleost. *Top*, Dorsal view of the inner ear and otoliths in relation to the brain in a cutaway of a fish skull (modified from Secor et al., 1992). *Bottom*, Position of otoliths and otolith chambers in the inner ear of the teleost *Trichogaster* (*modified from* Popper and Hoxter, 1981). Ast, asteriscus; Lag, lagena; Lap, lapillus; Sac, sacculus; Sag, sagitta; Semi, semi-circular canal of labyrinth; Utr, utriculus (used with permission from Campana, 2004:2).

et al., 2008; Sturrock et al., 2012), and have been slowly increasing in archaeological applications. In 1891, otoliths were excavated from an archaeological site in Rio Grande do Sul, Brazil, and identified to species through comparisons with modern samples collected from fish in nearby streams (Ihering, 1891 in Fitch, 1972). Despite these promising beginnings, otolith analysis seems to be absent from archaeological literature until the mid-20th century, when discussions of otoliths from archaeological sites start to re-appear (e.g., Niehoff, 1952; Priegel, 1963; Shumway et al., 1961; Witt, 1960). Initially, these studies focused on species identification based on otolith shape, and size and age of the fish based on otolith size. The development of advanced analytical techniques over the recent past, including trace element and isotope analyses, as well as radiocarbon dating, has encouraged an expansion of these techniques, including archaeological and palaeoenvironmental applications.

A decade ago, Campana (2005) found that papers involving otoliths across all disciplines were being published at five times the rate they were in the 1970s; however, the areas of both environmental reconstruction (modern and ancient) and 'fossil' otoliths each made up <1% of the 862 papers published between 1999 and early 2004. A basic search of online databases, such as Web of Science, shows that while publications focusing on fish otoliths have increased over the past two decades, and archaeological papers within these have also steadily increased, they are still a relatively small area of research.

Despite some earlier reviews of otoliths in archaeology (Campana, 1999, 2005; Casteel, 1976b; Van Neer, 2000; Weisler, 1993) and coverage of otoliths in general icthyoarchaeology texts, no specialist overview on the state of the art of otolith analysis applications in archaeology has appeared for more than a decade. As such, this paper overviews the development of otolith studies in archaeology, building on past reviews and discussing recent technological developments. The main methods of analysis are outlined and major advances and significant studies in each area discussed. There are some limitations to the review; the publications included in this paper are all written in English, therefore, a significant amount of research and developments that have been published in non-English languages have been excluded. In addition, there has been an attempt to avoid "grey literature" (unpublished reports) and focus on peer-reviewed publications, which may have excluded some important research, but such literature is not always widely available. We do not hope to include every publication, but rather provide examples of the type of research that can be undertaken on otoliths. Despite these limitations, this paper provides a broad review of the current state of archaeological analyses of fish otoliths.

2. Sample collection and preservation

While the numbers of otoliths recovered during archaeological excavations can be low, or even non-existent at some sites, others contain significant assemblages from numerous or single fish species (Gabriel et al., 2012; Scartascini and Volpedo, 2013). Otoliths do require certain site conditions to survive in the archaeological record; their aragonite structure makes them more susceptible to deterioration than bone in some situations. The alkaline matrix of shell middens provide some of the best conditions for preservation (Andrus, 2011) and waterlogged sites such as cesspits or large deep refuse pits limit the impact of acid rain percolation, allowing for preservation of the otoliths of some taxa (Van Neer et al., 2002). Well preserved assemblages of otoliths have also been collected from other sites, such as earth mounds (Disspain et al., 2012a), lunettes and hearths (Long et al., 2014).

In order to enhance collecting otoliths from sites, wet sieving methods are advocated (Casteel, 1976a; Ross and Duffy, 2000). The sieve size used during collection will impact the size and number of fish remains collected from a site, and potentially taxa or species identification (James, 1997; Nagaoka, 2005; Ross and Duffy, 2000; Ulm, 2002; Weisler, 1993). Zohar and Belmaker (2005) demonstrated that taxonomic diversity within a fishbone assemblage from Arrawarra-I, a coastal midden site in Australia, was higher when sieved through a 1 mm mesh, as opposed to a 6 mm or 3 mm mesh. As otoliths can vary greatly in size dependent on the species and size of the fish (see Furlani et al., 2007 for examples), Casteel (1976a) advocated wet-sieving samples and sorting with low-power magnification to ensure a comprehensive collection of fish remains.

Sites with large quantities of fish bone can sometimes be devoid of otoliths (e.g., Butler and Chatters, 1994). This can be attributed to a number of factors including discard methods; fish heads may be removed at the time of catch, and returned to the water, or may be removed at the time of cooking and thrown into a fire where burning makes them fragile and more likely to deteriorate completely (Lubinski, 1996). The Indigenous people of the Murray River and Lakes, South Australia, removed the head of the Murray cod and baked it on hot coals, while that of the catfish was cut off and thrown to the dogs (Berndt et al., 1993:105–106). In Kenya (Lake Turkana), fish smaller than 250 mm in length are processed whole while larger specimens (>250 mm) are decapitated (Stewart and Gifford-Gonzalez, 1994). It is also possible for fish heads to be eaten whole, with digestion eroding otoliths sometimes completely, or beyond recognition (Jones, 1986; Nicholson, 1993). Taphonomic processes can contribute to a loss of samples; as they are composed of calcium carbonate in the form of aragonite, which is chemically less stable than the hydroxy-apatite of bones, otoliths can dissolve in acidic conditions (Nicholson, 1996). As well as being eaten, smaller and more fragile otoliths are less likely to survive in archaeological sites than those that are more robust. This can lead to an over-representation of taxa that have more durable otoliths and/or an under-representation of those with small, fragile otoliths. Misidentification may also impact the frequency with which otoliths are recovered from sites; otolith shapes are species specific, and unless researchers are aware of this, some samples may be easily overlooked and misidentified as shell or other material.

3. Species identification

The sagittal otoliths are the largest of the three pairs of otoliths in most fish (in cyprinids, the asterisci are the largest (Macdonald et al., 2012)). Sagittal otolith shape varies widely and is recognised as being species- or genera-specific (see Fig. 2) (Furlani et al., 2007; Maisey, 1987; Weisler, 1993). This is one of the great advantages of otoliths, as shape allows identifications at species level, which is not always possible for the bones of closely related species. Additionally, when species identification is not easily determined using basic observations of otoliths, otolith shape analysis can be employed. This has been used in numerous modern studies (Jolivet et al., 2013; Paul et al., 2013; Vergara-Solana et al., 2013), as well as in conjunction with elemental analyses (Avigliano et al., 2014; Ferguson et al., 2011). It was recently applied to archaeological otoliths as a way to determine species (Chen et al., 2011), and has the potential to be more frequently incorporated into archaeological analyses.

When present at a site, otoliths play an important role in the identification of species within archaeological assemblages, and comprehensive otolith reference collections have been compiled and published (e.g., Campana, 2004; Furlani et al., 2007; Nolf, 2013; Smale et al., 1995; Stinton, 1985; Tuset et al., 2008), or are available online (e.g., http://fishbone.nottingham.ac.uk/, http://hbs.bishopmuseum.org/frc/index.html, http://www.shd-archzoo.co.uk/fishresources.html) in order to assist with these identifications. Species identification is useful because many fish species show marked seasonality of movement, which means that they may only be available for predation by human populations at certain times of the year. Consequently, the presence or absence of seasonal species in the archaeological record may convey information about the way people moved around the landscape throughout the year (Colley, 1990; O'Connor, 2000:141), although it may also indicate cultural choices. Changes over time in the species that are present in, or absent from, archaeological assemblages reflects these changing patterns and allows inferences to be made about the palaeoenvironmental conditions of the region, resource use, cultural preferences and foraging choices of the occupants of the area.

Once a species has been identified at a site, biological information about that species can provide further knowledge about the use of the site. For example, whether a fish is a schooling or solitary species, or their known environmental conditions such as food sources, water temperature, depth and salinity, can inform us about gross changes in environmental conditions surrounding the site, or appropriate technologies for capture e.g., pelagic fish are unlikely to be captured in near-shore stone-walled fish traps.

Examples of these sorts of studies abound in the literature (Disspain et al., 2012b; Fitch, 1969; Rose, 1996; Scartascini and Volpedo, 2013). Fish remains, including otoliths, from hearths dated to between 25,000 and 32,000 years ago at Lake Mungo, were identified as golden perch, *Macquaria ambigua* (Bowler et al., 1970). This species has a high salinity tolerance, but breeding is induced by freshwater flows, which takes place in the spring when floodwaters flow down the Murray–Darling Rivers. At the time the hearths were formed, similar spring floods could have been expected with the annual melt of the periglacial snows in the catchment highlands. It was suggested the presence of immature fish at Mungo might have meant that the site was occupied soon after this spring period (Bowler et al., 1970).

4. Fish size

Fish grow larger the longer they live, though growth capacity is dependent on both internal (nervous, endocrinological and neuroendocrinological) and external ecological factors (salinity, temperature,

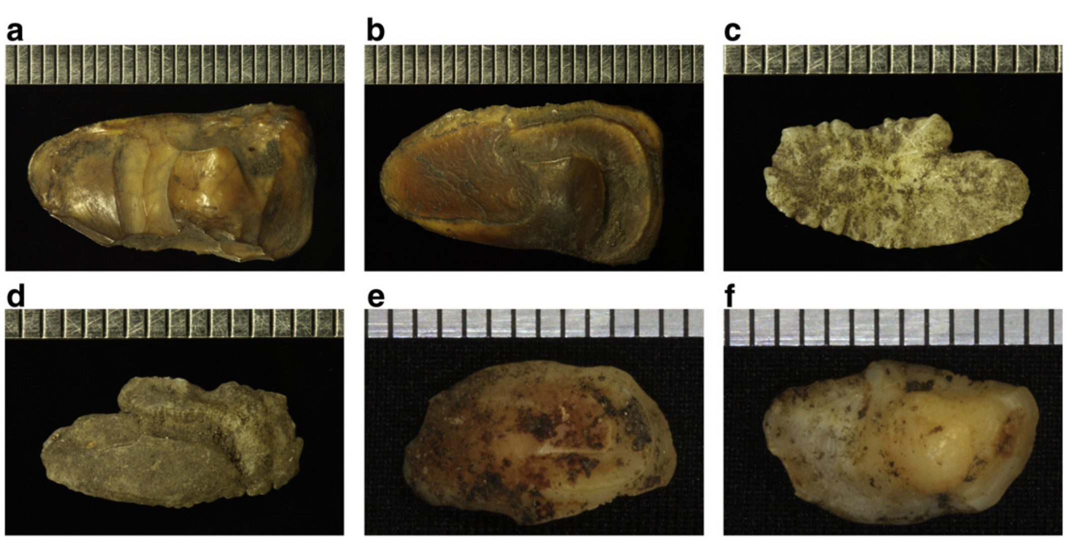

Fig. 2. Archaeological *Argyrosomus japonicus* (mulloway) otolith a, distal and b, proximal surface; archaeological *Macquaria ambigua* (golden perch) otolith c, distal and d, proximal surface; archaeological *Sciaena deliciosa* (lorna drum) otolith e, distal and f, proximal surface. Ruler along top indicates scale with gradations equal to 1 mm.

food) (Boeuf et al., 1999; Boeuf and Payan, 2001; Neuheimer et al., 2011). While somatic growth can be slowed or interrupted, otolith growth is continuous (Campana and Neilson, 1985). Growth is a three-dimensional process, with the length, width and depth of an individual organism all changing over time. This relationship enables the size of a fish at the time of its death to be determined by analysing the weight(s) of its otolith(s) (Quinn and Deriso, 1999:180). Similarly, otolith length can also be used (Casteel, 1974). We acknowledge that numerous other skeletal elements can be used to reconstruct fish size, and may be better suited to the task in some cases; however, as this is a review of otoliths, we will focus solely on research relating to their use in fish size determination. Numerous archaeological studies utilising otolith weight (or length):fish length relations, validated by modern-day samples, have been conducted (e.g., Balme, 1983, 1995; Gabriel et al., 2012; Moss, 2012; Shumway et al., 1961; Witt, 1960). It is important to note that that while there is a strong correlation between otolith size and fish size within species, specific relationships do not correspond between species. Small fish species do not necessarily have small otoliths, and large fish do not always have large otoliths (see Weisler, 1993: Fig. 2 for an example of otolith length:fish length within and across different species). There are some issues with this method, as otolith growth and somatic growth can sometimes become uncoupled (Wilson et al., 2009) because, as mentioned earlier, some constant amount of calcification occurs onto the otolith despite fluctuations in somatic growth rate (Secor and Dean, 1992). In addition, ancient otoliths can experience breakage and deterioration, meaning that calculations based on their size need to be taken as minimum length values only. Despite these complications, otolith size can give a good indication of fish size, which is an extremely valuable attribute of the otolith for use within archaeology and marine science applications.

The size of fish present in the archaeological record may be indicative of the fishing techniques that were employed by local Indigenous populations: spearing in shallow water usually results in the capture of larger specimens, as they are easier to hit; gill nets have a high degree of size selectivity, capturing a narrow size range of fish dependent on the net's mesh size (Balme, 2013); fish traps of stone, netting or wicker-work will catch all fish over a certain size; and hook and line fishing tends to catch predatory fish whose size can be dependent on the size of the hook (O'Connor, 2000:141–3). Past fishing methods can inform about the technological skills and knowledge of a society, and may indicate the relative importance of fish in the diet and community, based on the time and energy involved in fishing (Colley, 1987).

An example of this, comes from sites in the lower Darling River region of western New South Wales, Australia, where the spatial distribution and uniform size of >500 otoliths implied that nets were the most likely fishing technique used at the site (Balme, 1995). From this observation, it was concluded that people must have been able to make string from vegetable fibre, have had a social organisation that allowed them considerable time to make and maintain the nets, and that they were aware of the water conditions under which netting was effective (Balme, 1995). Thus, information about otolith size allows inferences beyond merely fish size, enabling researchers to deduce information concerning Indigenous technologies, subsistence strategies and social structures.

Changes in fish size over time, through comparisons with modern size data, enable investigations into the effects that human predation, habitat alteration and environmental degradation have had on individual species. An early study indicated the mean lengths of present day *Aplodinotus grunnien*, freshwater drum, in the vicinity of a number of archaeological sites along the Mississippi River, Missouri, were generally smaller than those from 3600 to 7000 years ago (Witt, 1960). Estimates of *Maccullochella peelii*, Murray cod, (4250–6410 years BP) size based on otolith weight (Disspain et al., 2012b) were used to suggest that the general size of *M. peeli* has declined over time since very large (>2200 mm TL) fish were found in the archaeological record. Both of these studies suggested habitat alteration and intensive human predation as likely causes for the decreases in fish size and demonstrate that even basic analyses of fish otoliths can result in significant findings concerning past fish population structures.

5. Age structure

Since the late nineteenth century, otoliths have been recognised as accurate indicators of the age of individual fish. The appearance of the aragonite on the organic matrix within the otoliths changes depending on physiological and environmental factors. These variations result in the formation of bands, or annuli, within the otolith's structure. They are defined by two zones; a slow growth zone, that, when viewed under a transmitted light source, appears as thin bands, darker in colour, and a fast-growth zone that appears as thick, lighter-coloured, or hyaline, bands (see Fig. 3) (Casteel, 1972; Pannella, 1971). Aragonite and organic compounds are found in both zones, with greater concentrations of organic compounds in the fast growth zones, and greater concentrations of aragonite in the tight carbonate bandings of the slow growth zones (Jolivet et al., 2008; Schöne and Gillikin, 2013). It is known that development and growth are influenced by both internal and external factors (Boeuf and Payan, 2001), but it is widely accepted that these growth bands in the otoliths of temperate fish coincide with seasonal variations in environmental conditions. Therefore, an examination of a cross-section of an otolith, and counting the annuli, can estimate the age of the fish at the time of its death.

It is important to determine for individual species that the bands are indicative of an annual cycle; this can be done by using modern reference material (Ferguson et al., 2014; Higham and Horn, 2000). It is particularly difficult to age fish from tropical environments using otolith increments, as there is less seasonal fluctuation in tropical waters compared with temperate, meaning that growth cycles are not as strongly related to environmental conditions (Giardina et al., 2014; Green et al., 2009). Validation that one increment equals one year is also required, as not all axes within an otolith show a complete growth record (Campana, 2001). Measures must be taken to avoid distorted results caused by reader bias (Campana, 2001); multiple readers can be used, or one reader can count the annuli more than once with no recollection of previous results. Discrepancies in counts should be reported (for examples, see Disspain et al., 2011; Ferguson et al., 2014). In order to avoid reader discrepancies, another method for determining the age of a fish that has begun to be explored involves using the weight of an otolith to calculate the fish's age; this method also requires validation with modern samples and may result in an underestimate because of taphonomic processes that have caused the otolith's weight to decrease (Matić-Skoko et al., 2011).

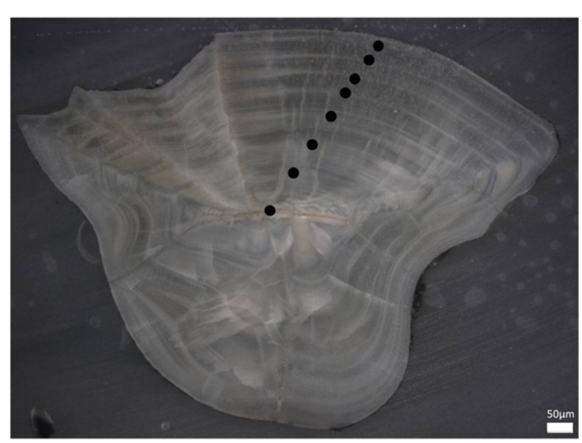

Fig. 3. Transverse section of an archaeological *Argyrosomus japonicus* (mulloway) otolith, with black spots indicating increments. Otolith is aged to 7 years; the edge increment is hyaline, indicating the fish died in the warm season.

As heavy fishing pressure often reduces the size and/or age structure of local or regional populations, temporal changes in the size or age of individuals from a particular species are one of the most common means of assessing changes in human predation pressure and the impacts on aquatic ecosystems (Erlandson and Rick, 2008, 2010; Mannino and Thomas, 2002). One of the great advantages of average size or age studies for zooarchaeological assemblages is that they can be readily compared to palaeontological, historical, and recent ecological data sets to construct relatively long and continuous records of change in marine ecosystems (Erlandson and Rick, 2008:10).

An example of changes in age structure of a population comes from a study on Atlantic croaker, *Micropogonias undulatus*. In this study, otoliths recovered from archaeological sites in Florida, USA showed that ancient Atlantic croaker grew more slowly and lived much longer than those in modern times (15 years versus 7 years) (Hales and Reitz, 1992). Through comparisons of the age and growth of the fish with modern studies, it was determined that the population had changed dramatically over time, perhaps in response to exploitation or habitat alteration. Another study, investigating baselines for the recovery of the Baltic Sea cod fishery, reconstructed demographics from a Neolithic population (4500 BP) to show that the cod were on average larger, older, and had lower total mortality than the heavily exploited modern stocks (Limburg et al., 2008).

6. Edge increment analysis

In addition to providing an estimate of age of death of the fish, the annuli can also provide information about the season of death. By recording the nature of the edge increment, whether it was laid down in a warm (fast growth) or cool (slow growth) season, the season of fish capture can be determined. This in turn, can provide information relating to site occupation and movement of people within the landscape. Analysis of edge increments has, however, been criticized since the outside surface of the otolith may deteriorate through time in archaeological deposits, and a range of factors (e.g. temperature, salinity, geographical location, diet and age of the fish) may influence when increments are formed, as well as the clarity of the edge increment (Carlson, 1988; Plug et al., 2012; Van Neer et al., 2004). The methods can also be problematic, with different results obtained by different readers, but good seasonality estimations can be obtained when a large sample size can be analysed, and when studies of modern samples of the same species have been conducted to demonstrate when edge increments are laid down (Higham and Horn, 2000; Scartascini et al., 2014; Van Neer et al., 1993; Van Neer et al., 1999). The age and season of death were determined for an assemblage of black drum (*Pogonias cromis*) from a late Prehistoric site on the lower Texas coast (Smith, 1983). The seasonality study was enhanced by a comparative study of modern otoliths from the immediate region, and revealed occupation of the site from late fall to early spring. Daily increments can also be used to indicate when fish were targeted; a study analysing daily growth increments from archaeological fish otoliths was conducted on an assemblage from a late Palaeolithic site in Egypt (Van Neer et al., 1993). The well-preserved otoliths at the site had widely-spaced outer growth lines, indicative of fast growth. This fast growth was thought to coincide with the flood season of the Nile. The daily increments showed that the fish were captured after the maximum of the flood.

7. Trace element analysis

Elements are incorporated into the calcium carbonate matrix of otoliths as they grow and can provide information about the environment the fish lived in. This knowledge can in turn be used in palaeoenvironmental reconstructions and examining changes in local conditions. This is possible because concentrations of elements vary, and are influenced by salinity, temperature, ambient water chemistry (Elsdon and Gillanders, 2004; Elsdon et al., 2008; Sturrock et al., 2012), the bedrock type the water is exposed to, and the physiology of the fish (Campana, 1999; Kalish, 1989). Precise relationships are not always clear and species-specific responses to experiments have been found (e.g., Hamer et al., 2006; Morales-Nin et al., 2012; Wells et al., 2003), meaning that caution is required if extrapolating among species. Generally, trace elements incorporated into the surface of the otolith reflect the physical and chemical characteristics of the ambient water. In some systems, such as lakes, open oceans and bays, elemental concentrations can be relatively stable over time (Jarvie et al., 2000). Reconstructing the movements of fish based on otolith elemental concentrations in such stable environments relies on predictable relationships being established between ambient conditions and internal otolith structures. In contrast, in estuaries and coastal regions, elemental concentrations can vary greatly with time, with differences varying over the scales of days to seasons and even over tidal cycles on individual days (Elsdon and Gillanders, 2006; Elsdon et al., 2008). In such regions, information on temporal changes in water chemistry through time can aid interpretation of otolith chemistry patterns.

Numerous researchers have examined how environmental variables influence otolith chemistry and then used such relations to interpret environmental histories of modern fish. The most widely investigated trace elements have been Sr:Ca and Ba:Ca; they appear to reflect environmental parameters either linearly or non-linearly, and as such they are ideal for determining fish movement (Bath et al., 2000; Elsdon and Gillanders, 2005; Gillanders and Munro, 2012; Hamer et al., 2006). Alternate elements, including Mn (Elsdon and Gillanders, 2003, 2006) and Mg (Arkhipkin et al., 2009; Wells et al., 2003), among others (e.g., Campana et al., 2000; Morales-Nin et al., 2012; Tanner et al., 2013) have also been studied for their suitability as environmental indicators, with varying results. Changes in the elemental concentrations within otoliths can only be used to reconstruct past environmental conditions and fish life history patterns, if concentrations of elements within otoliths change in a predictable manner with environmental variables. Although trace element analysis across an otolith can demonstrate potential variation in habitats utilized by a fish throughout its life, it may also demonstrate movement of water masses around a stationary fish. Thus, some information on the life history of the fish and how environmental conditions change is useful to properly interpret such data.

As discussed above, definitive reconstructions often require prior knowledge of the differences in water chemistry within environments (Elsdon and Gillanders, 2004; Elsdon et al., 2008). This is not possible for archaeological studies, and caution is required in identifying fine scale spatial differences in movement of prehistoric fish based on trace elemental analyses. As a result, few studies have analysed trace elements in archaeological otoliths to determine past environmental habitats. One study used modern relationships between ambient water concentrations, salinity and otolith elemental concentrations (sourced from Elsdon and Gillanders, 2004) to analyse data from archaeological *Argyrosomus japonicus* and *Acanthopagrus butcheri* otoliths (Disspain et al., 2011). The assemblage was recovered from mid-to-late Holocene shell middens along the Coorong, an estuary at the mouth of the Murray River, South Australia. The elemental analysis revealed fluctuating levels of salinity in the river and the estuary that were significantly lower than the hypersaline conditions experienced in some areas today (Disspain et al., 2011). This information suggests significant changes in environmental conditions associated with river regulation. Additionally, trace element data from otoliths of two freshwater species (*M. peelii* and *Macquaria ambigua*) from mid-to-late Holocene sites further upstream reinforced that, prior to human interference, water of the Murray River experienced fluctuating salinity levels; however, as a result of historical barrage construction and water management strategies, the river is now predominantly fresh (see Fig. 4) (Disspain et al., 2012b). These studies successfully expanded the examination of archaeological otoliths to include this analysis, although interpretations are generalized and further research is needed into the viability of archaeological otoliths for reliable trace elemental analyses.

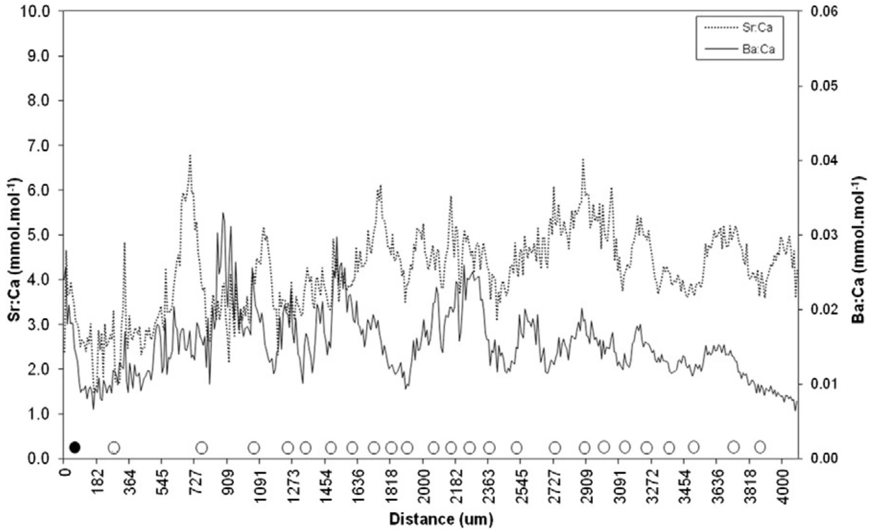

Fig. 4. Trace element data from an archaeological *Maccullochella peelii* (Murray cod) otolith showing fluctuations in salinity levels based on Ba:Ca levels. The spots on the chart indicate the location of the annuli along the profile (modified from Disspain et al., 2012b).

8. Isotope analysis

A range of stable isotopes have been analysed in modern fish otoliths, while the most widely used elements in isotopic studies of archaeological otoliths are oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$), with fewer studies focusing on nitrogen ($\delta^{15}N$) (Rowell et al., 2010). Isotopic analyses of ancient fish remains can provide information on seasonality of site usage (Hufthammer et al., 2010), trade and provenance of fish (for bone and teeth applications, which could be applied to otoliths, see Barrett et al., 2008; Dufour et al., 2007; Lubinski and Partlow, 2012), palaeoenvironmental conditions (Surge and Walker, 2005; Walker and Surge, 2006; Wang et al., 2013), fish migrations, and the effects of human predation and habitat alteration on fish populations (Rowell et al., 2010; Rowell et al., 2008).

Stable isotope analyses of fossilized fish otoliths to examine palaeoenvironmental conditions were investigated in the mid-20th century (e.g., Devereux, 1967); however, archaeologists did not embrace the method until approximately 30 years later (e.g., Andrus et al., 2002; Patterson, 1998). These analyses are becoming increasingly popular and important for understanding past environmental and cultural changes, encouraging the development of new methods, such as the use of a Sensitive High Resolution Ion MicroProbe (SHRIMP II) for detailed fine scale in situ micro-analyses of oxygen isotopes (Aubert et al., 2012). The accretionary nature of otoliths, combined with advances in mass spectrometry and micro-sampling techniques enable the recovery of high-resolution isotope profiles, representing time-specific indices of environmental conditions experienced by individual fish throughout life.

Oxygen isotope ($\delta^{18}O$) ratios in otoliths are determined primarily by water temperature (Rowell et al., 2008; Surge and Walker, 2005), and can consequently provide information on environmental change (Wang et al., 2011; West et al., 2011, 2012; Wurster and Patterson, 2001), seasonality of site usage (Hufthammer et al., 2010), fish location and migration. As water temperatures increase, the uptake of $\delta^{18}O$ in otoliths decreases (Rowell et al., 2008). Oxygen isotopes are robust tracers of the marine stage of life history because large and systematic differences exist between marine and inland water isotope values, and the oxygen isotopic composition of fish otoliths depends upon the temperature, salinity and isotopic composition of the ambient water, not food (Elsdon and Gillanders, 2002; Thorrold et al., 1997). Despite the well defined relationship between temperature and $\delta^{18}O$ ratios, water salinity can also have an effect (Gillanders and Munro, 2012), while temperature and salinity can interact to influence ratios (Elsdon and Gillanders, 2002). Additionally, evaporation increases ocean surface $\delta^{18}O$, whereas precipitation reduces it (Ashford and Jones, 2007). The $\delta^{18}O$ composition of lake waters depends primarily on the $\delta^{18}O$ composition of the precipitation falling on the lake surface and catchment, and on the evaporation/precipitation balance of the water body. A progressive depletion of $\delta^{18}O$ in rain and surface water occurs with increasing latitude, increasing elevation, and increasing distance inland from the ocean (Dansgaard, 1964; Nelson et al., 1989; Stewart and Taylor, 1981).

In contrast with oxygen, carbon isotopes in otolith aragonite are deposited in disequilibrium with the ambient water (Iacumin et al., 1992). The carbon in otolith aragonite is a mixture of carbon derived from ambient dissolved inorganic carbon (DIC) and that derived from diet (metabolic carbon). DIC has a distinct isotopic composition compared to metabolic carbon, and the proportions of each incorporated into otolith aragonite are controlled by the metabolism of the fish (Kalish, 1991; Shephard et al., 2007). Therefore, $\delta^{13}C$ values within otoliths, which reflect levels of metabolically derived carbon, are sensitive to changes in metabolic activity levels, which can allow insights into ontogenic changes in fish metabolism (Ashford and Jones, 2007; Jamieson et al., 2004; Shephard et al., 2007). Carbon isotopes in fish otoliths from the late Holocene have been analysed to examine metabolic rates (Wurster and Patterson, 2003), while comparisons of $\delta^{13}C$ values within and among modern and archaeological otoliths have provided informative trends related to ontogenetic change (Wang et al., 2011).

$\delta^{15}N$ in tissue is commonly used in ecological studies to determine trophic level, trophic structure and food chain length (Post, 2002; Vander Zanden et al., 1997). This is possible, because the ratio of ^{15}N to ^{14}N ($\delta^{15}N$) increases as one moves from lower to higher levels of the food chain (Rowell et al., 2010). Nitrogen isotopes are influenced by species, tissue, type of consumer (e.g., carnivore, herbivore) and habitat type (marine, freshwater or terrestrial) (Vander Zanden et al., 1997). Studies of $\delta^{15}N$ in archaeological otoliths can assist in establishing pre-disturbance ecological benchmarks, or baselines, an essential first step for documenting ecosystem change in response to anthropogenic alterations (Rowell et al., 2010).

The "carbonate clumped isotope thermometer" approach is another method used to investigate past changes in climate, and it can potentially be applied to parts of the geological record where the isotopic composition of water is unknown, eliminating the need to make assumptions regarding these values (Ghosh et al., 2006; Schauble et al., 2006). This can specifically be applied to otoliths from the archaeological record, but to date only modern otoliths have been analysed.

The expanding array of stable isotopic analyses is of great value to icthyoarchaeology, and is more frequently being adopted as a method of choice for researchers examining a wide variety of questions. As with other assays, frequent collaboration with fisheries scientists and geochemists will only serve to increase its applicability to the analysis of ancient samples.

9. Radiocarbon dating

Radiocarbon dating is widely used within archaeology, and, being organic, otoliths lend themselves successfully to this method. As marine organisms exhibit older apparent radiocarbon ages caused by the uptake of carbon that has already undergone radioactive decay through long residence in the ocean (Ulm, 2006), it is important to know the marine carbon reservoir correction, or δR value, for the geographic origin of the samples (for an example, see Higham and Hogg, 1995). Numerous studies have incorporated radiocarbon dating of otoliths (e.g., Favier Dubois and Scartascini, 2012; Hufthammer et al., 2010; Scartascini and Volpedo, 2013). One example is the dating of otoliths collected at sites on the northern coast of the San Matías Gulf, Argentina (Favier Dubois and Scartascini, 2012). Radiocarbon dating places fishing activities between ca. 6000 and ca. 5000 ^{14}C BP at two sites, Bajo de la Quinta, and Bahia Creek, while another site, Bahia de la San Antonio showed greater continuity between ca. 5300 and ca. 890 ^{14}C BP. Calibration of the radiocarbon ages and δR correction of the otoliths pushed the older ages further back and brought forward the more recent. Based on these radiocarbon dates, the past coastal conditions of the area were reconstructed (as demonstrated in simulated digital elevation models (Favier Dubois and Scartascini, 2012)); the sea level was higher, creating small inlets and canals, while today, the coastline has been filled in and straightened as a result of geomorphic evolution. Favier Dubois and Scartascini (2012) propose that these small inlets would have been highly favourable for the use of nets and other mass capture techniques, such as traps.

10. Current issues, challenges and a way forward

Otoliths offer unique and significant information to archaeological research, but they also present some challenges, as detailed throughout this paper. Therefore, there are a number of key methodological issues that require further investigation and refinement. First, such issues are related to factors influencing the presence of otoliths at archaeological sites and also what their elemental/isotopic data actually mean. Discard patterns affect the numbers of otoliths that are initially deposited in archaeological sites; heads (including the otoliths) may be removed from the fish at capture and thrown back into the water, or they may be burnt in campfires to dispose of the sharp bones. In addition, as with any organic remains, specific conditions are required to ensure survival within a site. Otoliths survive best in alkaline sediments, such as those provided by shell middens, and may deteriorate within other more acidic sediments. Numerous studies have examined the effects that taphonomic and diagenetic processes — physical (e.g., trampling, scavenging, temperature, drainage and wave activity etc.), chemical (e.g., sediment pH levels and chemical structure) and biological (e.g., microbial action in sediments) (e.g., Nicholson, 1992; Zohar et al., 2008) have on fish bone preservation in general, but studies focused on otoliths are lacking.

In addition to influencing preservation, taphonomic and diagenetic processes can also alter the morphological and chemical properties of otoliths (Andrus and Crowe, 2002). A number of studies have examined the effects that processing methods (cooking and burning) have on fish bone and flesh (Fernandes et al., 2014; Lubinski, 1996; Nicholson, 1995; Richter, 1986; Willis et al., 2008; Zohar and Cooke, 1997); however, very little has been done to determine the effects that these processes have on the trace element and isotopic information stored within fish otoliths (for an exception, see Andrus and Crowe, 2002). In addition, elements within a site matrix may be post-depositionally absorbed into an otolith's structure, influencing any chemical data that is collected for palaeoenvironmental research from the otolith's edge. In spite of the fact that otoliths are considered chemically inert, handling, preservation and processing methods have been found to impact the integrity of some elements for modern day samples (Milton and Chenery, 1998; Proctor and Thresher, 1998). This impact can be lessened by employing consistent methods of preparation and storage for all samples, but it is difficult to determine processes that otoliths underwent prior to deposition, and what impacts these may have had on their integrity. If relatively minor factors such as how long an otolith remains in a fish's head after death (Proctor and Thresher, 1998) affect its chemical composition, thousands of years of burial and post-depositional modification are likely to have even greater effects. This is significant because assumptions regarding changes in environmental conditions and associated human responses are frequently made based on the isotopic or trace elemental data from archaeological otoliths. Therefore, it is imperative to ascertain whether these data are altered by factors after the death of the fish. This is one area of otolith research that requires further investigation.

As is often the case in archaeological research in general, a key issue is misidentification. As the shapes of otoliths are species-specific, some samples may be incorrectly identified as broken shell, stone or seeds during the sorting process. Even if otoliths are identified, the species they came from may be incorrectly determined. This is where access to large modern-day otolith reference collections and published atlases for individual study regions would be highly beneficial; however, if species distributions have changed, or local extinctions have occurred, this may remain an issue. Hopefully, with the increase of otolith analyses within archaeology, researchers will be more aware of the presence of otoliths within their collection and identification will improve.

Small assemblage size is often problematic; it is much more common to recover a few otolith samples from an archaeological site, than the large assemblages ideally required to conduct environmental reconstructions. When only small sample sizes of otoliths are available, it can be difficult to make substantial claims based on the resulting data set. While small numbers of otoliths can be used to test methodological approaches and make some inferences about site use and fish populations (e.g., Disspain et al., 2011), large assemblages of hundreds of samples can be used to investigate changes over time and to make more significant claims. Compounding this issue is the fact that some analyses are destructive, and as ancient otoliths are fragile, rare and usually subjected to a wide range of morphological and chemical analyses, it is important to examine how multiple applications can be combined on assemblages without too much damage to the collection (Schaerlaekens et al., 2011; Therkildsen et al., 2010), and to carefully plan the sequence of analyses to enable as much data as possible to be collected.

Some of these issues may be circumvented by incorporating developments from within modern fisheries, or other sciences, into archaeological analyses. The ongoing research into how different environmental and physiological factors influence otolith chemistry, or how different fish species are affected by these variables, is highly beneficial in that findings can be incorporated into trace elemental and isotopic analyses of archaeological samples, allowing fewer assumptions to be made regarding fish life history. New techniques for sample acquisition and analyses requiring smaller sample sizes encourage the application of techniques previously deemed too destructive for archaeological specimens (e.g., Shiao et al., 2014).

Ongoing development of comprehensive and readily available reference collections of modern data for comparative analysis regarding all aspects of otolith analysis, and including a wide range of species, would also be advantageous. Some physical collections, online databases and published atlases are available for use by researchers, and continuous additions and updates to these collections only increase their value. In short, open communication and cooperation between the fields of archaeology and modern fisheries science, with the integration of archaeological, historical and modern data sets, and the standardisation of common methods, is highly beneficial to both research areas, with many objectives and outcomes of research overlapping.

11. Conclusion

In spite of the limitations and issues that analysing archaeological otoliths presents, the benefits and unique information that analyses provide suggest that otoliths should be an important part of archaeological research. Otoliths provide information regarding past fish population structures, including changes resulting from human predation, habitat destruction and environmental change, as well as assisting with the establishment of baselines for rehabilitating native species to pre-impact levels. They also provide information on human subsistence strategies, fishing methods and technologies, trade routes, seasonality of site usage, and past human responses to environmental changes. Otoliths from archaeological sites contribute information to palaeoenvironmental studies, with chemical analyses providing significant data about past climates and water conditions. This paper has detailed many of the applications of archaeological otoliths; however, continuing development of methods and technologies within this area will only serve to further increase the importance and use of otoliths, while raising the profile of this unique resource.

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Chapter 3

Do fish remains provide reliable palaeoenvironmental records? An examination of the effects of cooking on the morphology and chemistry of fish otoliths, vertebrae and scales

Sorting, measuring and weighing mulloway at Goolwa Beach (December 2012).

Statement of Authorship

Title of Paper	Do fish remains provide reliable palaeoenvironmental records? An examination of the effects of cooking on the morphology and chemistry of fish otoliths, vertebrae and scales
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Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
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By signing the Statement of Authorship, each author certifies that:

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Do fish remains provide reliable palaeoenvironmental records? An examination of the effects of cooking on the morphology and chemistry of fish otoliths, vertebrae and scales

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Abstract

The morphological and chemical properties of fish calcified structures provide excellent environmental and anthropogenic proxies; however, pre-depositional handling may alter these properties, confounding interpretations. This study examines the effects of some traditional processing and cooking methods on the morphological and chemical properties of modern fish otoliths (ear bones), vertebrae, and scales using an experimental approach. Whole mulloway (*Argyrosomus japonicus*) were treated using a range of techniques, including boiled in freshwater and saltwater; roasted directly on a fire and wrapped in clay; salted; and completely burnt. Samples were also obtained from untreated fish as controls for comparison. Otoliths, vertebrae and scales from the samples were subjected to morphological, trace element (^{7}Li, ^{23}Na, ^{24}Mg, ^{55}Mn, ^{86}Sr, ^{138}Ba, ^{208}Pb, and ^{65}Zn all ratioed to ^{43}Ca) and stable isotope analyses (otoliths and vertebrae – inorganic $\delta^{13}C$ and $\delta^{18}O$; scales – organic $\delta^{13}C$ and $\delta^{15}N$). Results reveal disparities in the chemistry and morphology of otoliths and vertebrae processed in different ways. The otolith and vertebrae carbonate $\delta^{18}O$ values were lower in samples that experienced heating; burnt samples differed significantly from the control samples. Otolith and vertebrae trace elements were largely unaffected by the treatments relative to the controls; however, some individual elements within the burning and salting groups varied significantly. The impacts observed in the fish scales were less substantial. Results provide a basis for evaluating the suitability of archaeological samples for analysis. We recommend avoiding the use of heated samples. Findings highlight the need to conduct palaeoenvironmental reconstructions based on chemistry and stable isotope data of archaeological remains with caution.

Keywords

palaeoenvironmental reconstruction; zooarchaeology; otolith; stable isotopes; experimental archaeology; trace element analysis; icthyoarchaeology.

Introduction

Chemical and isotopic analyses of archaeological fish remains are increasingly used in palaeoenvironmental studies, drawing heavily on methods developed in modern fisheries science (e.g., Disspain et al. 2011, 2012; Long et al. 2014; Wang et al. 2011, 2013). Numerous researchers have examined how ambient environmental variables influence the chemistry of calcified structures, specifically otoliths because of their unique attributes (see Disspain et al. 2016; Elsdon et al. 2008), using such relations to interpret environmental histories of modern fish. The most widely investigated trace elements have been Sr and Ba, which provide information on environmental parameters (Bath et al. 2000; Elsdon and Gillanders 2005a, 2005b; Gillanders and Munro 2012; Hamer et al. 2006). Alternate elements, including Mn (Elsdon and Gillanders 2003) and Mg (Arkhipkin et al. 2009; Wells et al. 2003), among others (Campana et al. 2000; Morales-Nin et al. 2012; Tanner et al. 2013) have also been studied for their suitability as environmental indicators, with varying results.

Stable isotope analysis of fish remains is more widely used and validated than trace element analysis within palaeoenvironmental studies (Disspain et al. 2016). Remains can be analysed for oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) of the inorganic fraction (otolith aragonite and bone apatite) (Wang et al. 2013; West et al. 2012; Zazzo et al. 2006). Nitrogen ($\delta^{15}N$) and carbon ($\delta^{13}C$) stable isotopes from the organic fraction (fish scales and bone collagen) are frequently analysed (Barrett et al. 2011; Robson et al. 2012; Rowell et al. 2010), with others such as sulphur ($\delta^{34}S$), being investigated for suitability as an environmental indicator (Privat et al. 2007). Oxygen isotopes primarily reflect water temperature (Rowell et al. 2008; West et al. 2012), $\delta^{13}C$ in fish remains is a mixture of carbon derived from ambient dissolved inorganic carbon (DIC) and that derived from diet (metabolic carbon) (Kalish 1991), while $\delta^{15}N$ ratios are commonly used to determine trophic level (Rowell et al. 2010). Isotopic analyses of ancient fish remains can provide information on trade and provenance of fish (Dufour et al. 2007; Ishimaru et al. 2011; Orton et al. 2011), seasonality of site usage (Colaninno 2012; Hufthammer et al. 2010), palaeoenvironmental conditions (Surge and Walker 2005; Wang et al. 2013; West et al. 2012), fish migrations, and the effects of human predation and habitat alteration on fish populations (Rowell et al. 2010, 2008).

Despite the vast array of information gleaned from elemental and isotopic analyses of archaeological fish remains, few studies have attempted to determine the effects of pre-depositional processes. Taphonomic processes include human and non-human agents, with many archaeological remains likely to have been exposed to both effects. Of the human impacts, cooking and processing for consumption are primary agents of taphonomic transformations of faunal remains, and can be evidenced by butchery/cut marks, colour changes, crystallization, skeletal element distribution and fragmentation (Nicholson 1993, 1995; Willis and Boehm 2014; Willis et al. 2008). Several studies have examined the effect that processing methods and cooking have on fish remains. Butchering fish was found to leave cut marks primarily on undiagnostic bones (Willis et al. 2008), while differing patterns of bone loss and breakage resulted from different butchering methods prior to salting (Zohar and Cooke 1997). Changes in isotopic values of fish bone collagen and fish flesh, relative to raw flesh, were in general <1‰ after cooking by boiling, grilling and steaming (Fernandes et al. 2014), while morphological changes were observed in the collagen during heating at temperatures as low as 60ºC (Richter 1986). Research has also been conducted into the effects of burning on fish bone, with changes to the surface morphology of burnt bone allowing an approximate indication of the temperature reached by the bone (Nicholson 1995). Additionally, cranial elements were destroyed more quickly than post-cranial vertebrae when burnt, and bone element destruction increased with heating intensity (Lubinski 1996). It is possible that cooking and processing methods may alter the trace element and isotopic composition of fish otoliths, scales and vertebrae. Without prior knowledge concerning how processing and cooking methods and post-depositional influences alter the chemical nature of archaeological specimens, false assumptions regarding palaeoenvironmental changes and diet can be made. Therefore, it is imperative to ascertain whether these data are altered by factors after the death of the fish.

The most detailed study was conducted by Andrus and Crowe (2002), who documented changes in crystallography, $\delta^{18}O$ and $\delta^{13}C$ values, and the elemental chemistry of otoliths from modern fish as a result of different cooking methods (direct burning, roasting over coals, roasting in an oven, boiling in freshwater and boiling in saltwater). They found that burning caused changes in the morphology and isotopic composition of otoliths, proposing that burnt otoliths should not be used in isotopic analyses because of the risk of providing inaccurate palaeoenvironmental information. They also found that the trace elements within the otoliths were readily affected by numerous cooking methods, and proposed that elemental analysis of archaeological otoliths is therefore problematic. The broader application of these results is limited by the small sample size, with only two fish cooked per method tested, not allowing for the identification or control of anomalies in the sample.

The study presented here employs experimental analyses to examine the effects that a range of traditional processing and cooking methods have on the morphological and chemical (elemental and isotopic) properties of modern fish otoliths, vertebrae and scales. A larger sample size than that used by Andrus and Crowe (2002) is used to evaluate individual variation, additional cooking methods are incorporated, and recent technological and analytical advances are utilised. The results provide a standard by which to compare future archaeological analyses, thereby indicating the suitability of individual samples for use in palaeoenvironmental studies, and providing a method of investigating subsistence strategies employed by past inhabitants of individual sites.

Study Species

Mulloway (*Argyrosomus japonicus*: Sciaenidae) is commercially fished in South Australia and was an important species to local Indigenous people. It has large, robust otoliths, which survive well in archaeological sites in the area. *A. japonicus* is a large predatory teleost fish distributed through the Indian and western Pacific oceans. It is a fast growing, relatively long-lived species, attaining a maximum age of ca 30-35 years and size of ~1800 mm. Juveniles inhabit estuarine environments, with sexual maturity of female and male *A. japonicus* in South Australia occurring at 6 and 5 years respectively, after which time they migrate into marine waters (Ferguson et al. 2014). Adult mulloway typically aggregate around estuary mouths during the summer months, attracted by freshwater outflows and an abundance of food.

In order to ensure this research was as realistic as possible, we sourced the fish from the Coorong estuary, an estuarine area that was known to be densely populated by the Ngarrindjeri in pre-European times, owing to the richness of natural resources it provided (Jenkin 1979; Taplin 1879). The species selected was one that the Indigenous population of the region regularly fished (Disspain et al. 2011; Luebbers 1982).

Materials and Methods

Processing and Cooking

Fifty fish (ranging from 860g to 2800g gutted weight) were purchased from a local fisher at Meningie, South Australia in mid-December 2012. The fish were caught in a single net haul from the Coorong, the estuary of the Murray River, in the waters around Pelican Point (35º35'33.34"S 139º01'36.26"E). All fish were gilled and gutted by the fisherman upon capture and were kept on ice for 24 hours, after which time 42 fish were randomly allocated to one of six cooking treatments (Table 1). The remaining eight fish were used as controls. This number of replicate fish was deemed sufficient as previous otolith chemistry studies have found differences between environmental and spatial treatments with similar sample sizes (Dove et al. 1996; Elsdon and Gillanders 2002, 2003); the experimental approach presented here is not likely to be confounded by spatial and environmental effects.

Each fish was allocated a unique code number (e.g. CL1, CL2, etc.), which was inscribed onto a copper tag and attached to its jawbone with wire, such that individual fish could be identified and related back to their specific size data and allocated cooking treatment throughout processing. Fish were then individually photographed and weighed and the standard length of each fish was recorded (Table 1). The fish were kept on ice when they were not being processed. A campfire measuring approximately 1 m x 1 m, was built on a sandy beach using *Eucalyptus* spp. in a 30 cm-deep pit, and monitored by a Centre 309 data logger thermometer with three evenly spaced k-type probes. Different heating devices and fuel types produce different temperatures and consequently, results may vary dependent on these factors (Robins and Stock 1990; Shipman et al. 1984); the temperature was recorded every 30 sec at three locations within the fire.

Table 1: Average fish and otolith length and weight (± standard error) for each cooking method. Abbreviations for cooking method are indicated in brackets.

Cooking method	Standard length (SL) (mm)		Gutted fish weight (g)		Otolith length (mm)		Otolith weight (mg)	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Control (CL)	485.9 ± 81.8	400-595	1707.1 ± 747.1	1000-2730	16.0 ± 1.9	14.2-18.8	748.7 ± 216.8	558.5-1051.2
Boiled Freshwater (BF)	479.3 ± 53.1	400-532	1591.4 ± 388.0	1040-2100	15.8 ± 1.3	14.0-17.1	736.8 ± 185.2	506.9-951.6
Boiled Saltwater (BS)	466.9 ± 85.8	385-601	1545.7 ± 713.4	860-2700	15.6 ± 2.0	13.1-18.3	716.5 ± 232.9	467.0-1051.8
Burnt Completely (BC)	482.8 ± 84.9	400-595	1671.7 ± 811.9	1000-2730	15.9 ± 2.8	12.8-19.4	664.3 ± 245.8	421.5-1040.0
Roasted on Fire (RF)	493.1 ± 67.9	423-610	1750.0 ± 597.9	1300-2800	16.2 ± 1.2	14.9-17.5	789.7 ± 143.3	602.6-1008.8
Salted (SD)	487.3 ± 45.1	427-560	1652.3 ± 347.7	1220-2300	15.8 ± 1.3	14.2-18.0	736.8 ± 158.4	556.9-971.3
Wrapped in Clay (WC)	465.3 ± 62.7	391-560	1498.6 ± 540.9	900-2440	15.7 ± 1.6	13.7-18.2	715.0 ± 175.8	520.8-940.2

Description of cooking methods

Six cooking methods that represent a range of commonly used traditional cooking practices (see Berndt et al. 1993; Homsey et al. 2010; Yankowski et al. 2015) were investigated to document changes in morphology, and elemental and isotope chemistry.

Control (CL). The control fish were kept on ice for 24 h, after which time a single otolith was removed.

Boiled in Freshwater (BF). Each fish was washed in seawater, wrapped in muslin cloth and tied with twine to ensure that the remains of each individual were retained and not mixed. They were then placed in a large pot of boiling freshwater (100ºC) (Figure 1a) on the fire for 20 min until the musculature separated from the bone (Figure 1b). Once cooked, the fish were removed from the water and left to cool until they could be handled.

Boiled in Saltwater (BS). These fish underwent the same procedure as those boiled in freshwater; with the exception that saltwater from the ocean was used.

Burnt Completely in the Fire (BC). These fish were filleted and the frames and heads were placed in the fire to burn. The temperature of the fire ranged from 49–939°C during this time, with a mean temperature of 457±10.4°C. Once the fire had died down, after 140 min, an attempt was made to remove the frames from the ash of the fire. However, this was difficult as the majority of the fish bones had been completely destroyed by the fire, and the coals were too hot to search thoroughly; therefore, no otoliths were obtained. An alternative approach was adopted where one otolith was removed from 6 of the control fish (to use as controls), and a further fish added that had not been used in experiments, which had both of its otoliths intact. We then used these seven fish as the BC group. The fish heads were removed from the frames and placed in a small fire in a brazier for 105 min. The thermocouple was used with two probes to record the temperature of the fire over this time (Figure 1c). Temperatures ranged from 172–892°C, with a mean of 595±6.6°C. After this time, the remains of the heads were removed from the fire and left to cool (Figure 1d). The ash was then sieved to find the remaining otoliths.

Roasted on the Fire (RF). The fish were washed in saltwater and then placed directly on the coals of the fire (Figure 1e). They were cooked on one side, turned and cooked on the other; total cooking time was 33 min (Figure 1f). The temperature of the fire ranged from 397–845 °C during this time, with a mean temperature of 522±23°C.

Salted (SD). The salted fish were washed with seawater and packed tightly into a large plastic tub with 25 kg of sea salt. The salt was packed into the fish's cavities to ensure they were well covered (Figure 1g). After 20 days in the salt, the otoliths were removed from the fish (Figure 1h).

Wrapped in Clay and Roasted on the Fire (WC). Each fish was wrapped in banana leaves and then covered in approximately 1.5 cm thick filtered terracotta clay (Figure 1i). The clay wrapped fish were placed on the coals to cook for 48 min. Once cool enough to handle, one fish (WC4) was broken open; however, it was not completely cooked so the remaining six fish were placed back on the fire for a further 26 min (Figure 1j) (temperature range over the total 74 min: 99–1015°C, mean temperature 553±12°C).

Following their respective treatments, both otoliths were removed from each fish, washed in ultrapure water, and were left to air dry for 48 hours. They were then weighed and stored in plastic vials. In addition to the otoliths, a number of post-cranial vertebrae were removed from each of the carcasses, along with a collection of pectoral scales.

a.

b.

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Figure 1: Documenting the pre- and post-cooking condition of the mulloway. (a) Placing fish wrapped in muslin cloth into boiling freshwater; (b) Removing the flesh and otoliths from boiled fish; (c) Fish heads in the fire with thermocouple probes; (d) Burnt bone and otolith of mulloway after being removed from the fire; (e) Roasting fish directly on the fire; (f) Mulloway after roasting on the fire; (g) Packing the mulloway with salt; (h) Mulloway after salting for 20 days; (i) Wrapping mulloway in banana leaves and clay; (j) Unwrapping mulloway from the clay.

Morphological Analysis

Detailed images of each otolith were acquired to create a comprehensive archival record and for visual comparisons. Both the proximal and distal surfaces of each otolith were photographed using a Canon EOS60D digital camera equipped with a Canon 100mm Macro Lens. Photomicrographs of sectioned otoliths were also acquired using a Leica MZ16A stereomicroscope with a PLANAPO 1.0x lens. Each whole and sectioned otolith was examined for deterioration, breakage and discolouration and compared to the control samples.

Otolith X-Ray Diffraction

To investigate possible recrystallization of the otolith aragonite to calcite, we analysed one otolith sample from each treatment method and one from the control group using X-ray diffraction (XRD). The bulk mineralogy of samples was ascertained by a Bruker D8 ADVANCE Powder XRD with a Cu-radiation source. Prior to analysis, powdered samples mixed in an ethanol slurry were loaded onto silicone wafers fitted in XRD sample holders and allowed to dry. A standard powder sequence was run, involving a Cu-radiation source, with an angle of 3.5–50° 2theta and step sizes of 0.02° with counting times of 1 second. Bruker DIFFRAC.EVA software and Crystallography Open Database reference patterns were utilised for identifying mineral phases.

Otolith and Vertebrae Preparation and Elemental Analysis

One otolith and one vertebra from each fish were embedded in indium spiked epoxy resin (40 ppm), and sectioned (0.35±0.05 mm thick) using a low speed saw (Buehler Isomet). The otoliths were sectioned transversely through the nucleus. All sections (with the exception of the burnt samples, due to their fragile nature) were polished using lapping film and ultrapure water before mounting onto microscope slides with 100 ppm indium spiked CrystalBond™.

Trace element quantification in the sectioned otoliths and vertebrae was conducted on an Agilent 7500s Inductively Coupled Plasma-Mass Spectrometer (ICP-MS) coupled to a Merchantek UP213 (NewWave Research) laser ablation system. Ablations were conducted using a spot size of 30 µm and a pulse rate of 5 Hz, for 150 sec, after pre-ablating to remove contaminants. For the otoliths, spot ablations were located at both the nucleus and at the edge on the final growth increment. Based on marginal increment data from Ferguson et al. (2014: Figures 2 and 3), mulloway otoliths from fish aged 1–4 years increase in size by approximately 10% per month. The average mulloway otolith growth increment measures 402 µm; this is based on 2271 complete otolith increment measurements from mulloway of a range of ages, sizes, and sexes, and equates to growth of approximately 33.5 µm per month (Izzo unpub. data). Therefore, a spot size of 30 µm represents less than one month of mulloway growth. The chemistry data from the edge of the otolith will represent the environmental conditions of the location the fish was caught, while the nucleus chemistry will represent those of the juvenile stage of the fish's life history. All of the fish were captured at the same time in the same location, so edge data would be expected to be similar among samples, and would be the most likely to be affected by the different cooking methods. The spot ablation on the vertebrae targeted the calcified margin.

Nine elements were analysed, which included: ^{7}Li, ^{23}Na, ^{24}Mg, ^{55}Mn, ^{86}Sr, ^{138}Ba, ^{208}Pb, ^{65}Zn and, ^{115}In, as well as ^{43}Ca as an internal standard. To correct for machine drift, a reference sample (National Institute of Standards and Technology, NIST 612) was analysed at the beginning and end of each laboratory session, and after every five to six samples. Prior to each ablation, background gases were measured for 30 sec to allow for background correction and to determine the detection limits of ICP-MS. Raw element mass count data were processed using GLITTER software (www.glitter-gemoc.com). Data were then converted from ppm to mol and normalised to Ca (values in $mmol \cdot mol^{-1}$). The incorporation of elements that substitute for Ca ions within aragonite, which co-vary with elemental levels in the environment, is accurately standardised to the number of Ca ions in the otolith (Thorrold et al. 1998). Normalising data to Ca is a standard protocol in otolith chemistry studies that facilitates direct comparisons among studies (e.g., Elsdon and Gillanders 2005a; Reis-Santos et al. 2013).

Otolith and Vertebrae Stable Isotope Analysis

For stable isotope analyses, approximately 100 µg of otolith material was removed from the edge of each sample to analyse the inorganic component for $\delta^{18}O$ and $\delta^{13}C$. Samples were submerged in 100-105% phosphoric acid and left to dissolve overnight at 70°C. Headspace analysis, measuring $\delta^{18}O$ and $\delta^{13}C$ values, was conducted on a Nu Horizon continuous flow isotopic ratio mass spectrometer (IRMS) following Spötl and Vennemann (2003). Data were corrected to an international standard, LSVEC ($\delta^{18}O$=26.7 $\delta^{13}C$=-46.6), and an internal standard, ANU-P3 ($\delta^{18}O$=-0.32 $\delta^{13}C$=2.24), which were analysed at the start and end of each run, and after every 10 samples.

From each vertebra, 50 mg of material was removed from the outer surface and soaked overnight in 1 ml of 5% NaOCl to remove the organic component. They were then rinsed with ultrapure water, centrifuged and rinsed again until free from NaOCl, and left to dry in an oven at 40ºC. Headspace analysis, measuring $\delta^{18}O$ and $\delta^{13}C$ values, was conducted on a Nu Instruments continuous flow isotopic ratio mass spectrometer (IRMS) following Spötl and Vennemann (2003). Data were corrected to an international standard IAEA CO-8 (marble: $\delta^{18}O$=-22.7 $\delta^{13}C$=-5.76), and internal standards, ANU-P3 ($\delta^{18}O$=-0.32 $\delta^{13}C$=2.24) and UAC-1 (calcium carbonate: $\delta^{18}O$=-18.4 $\delta^{13}C$=-15.0), which were analysed at the start and end of each run, and after every 10 samples.

Scale Preparation and Elemental Analysis

Scales were washed with ultrapure water and left to air-dry overnight. For elemental analysis 10 mg of scale from each fish was weighed, dissolved in ultrapure HNO_3 for 24 h, and diluted to 2% with ultrapure water. Each solution was filtered using 0.45 µm syringe filters to remove any undissolved particles. Serial dilutions (1:50) and undiluted solutions were analysed using an Agilent 7500cs ICP-MS with an Octopole Reaction System. Standards (10 ppm Certified Reference Solution from Choice Analytical) with concentrations of 1 $\mu g \cdot L^{-1}$, 50 $\mu g \cdot L^{-1}$, 100 $\mu g \cdot L^{-1}$ and 500 $\mu g \cdot L^{-1}$ were analysed before and after the samples, as well as intermittently throughout the run. Elements analysed included ^{7}Li, ^{23}Na, ^{24}Mg, ^{55}Mn, ^{86}Sr, ^{138}Ba, ^{208}Pb, ^{65}Zn, ^{115}In, and ^{43}Ca as an internal standard. Raw element mass count data were processed using GLITTER software (www.glitter-gemoc.com). Data were then converted from ppm to mol and normalised to Ca (values in $mmol \cdot mol^{-1}$).

Scale Isotope Analysis

For isotope analysis, 1–2 mg of whole scales from each fish was weighed and the organic component analysed for $\delta^{13}C$ and $\delta^{15}N$ using a EuroVector EA coupled to a Nu Horizon continuous flow IRMS. Standards (glycine ($\delta^{13}C$=-31.2, $\delta^{15}N$=1.32) and glutamic acid ($\delta^{13}C$=-16.72, $\delta^{15}N$=-6.36)) were analysed before and after the samples, as well as intermittently throughout the run.

Statistical Analyses

Elemental data were log(×+1) transformed and fitted to a Euclidean distance dissimilarity matrix. A series of one-way permutational analysis of variance (PERANOVA) and permutational multivariate analysis of variance (PERMANOVA) were used to investigate differences in element composition (both individually and as a multi-element signal) among treatments for all structures. For otolith element data, two-way PERANOVA and PERMANOVA were used to examine the interactive influence of treatment and sampling location (nucleus vs edge) on element composition. We predicted that if the cooking methods affected the otoliths it would most likely affect the edge of the otolith rather than the nucleus. We were not interested in comparisons between the nucleus and the edge in this study as these would be more likely to reflect changing environment via movement or ontogenetic effects rather than cooking methods. Isotopic data were analysed in the same way as elemental data, but were not transformed due to negative values. All analyses were performed using the PRIMER software package, and all tests were carried out using type-III sum of squares and 999 permutations of the data (Anderson and Ter Braak 2003). Where probability (p-) values <0.05 were deemed significant, post-hoc pairwise tests were done. Canonical analysis of principal (CAP) coordinates was used to graphically represent the multi-element data in two dimensions for each structure.

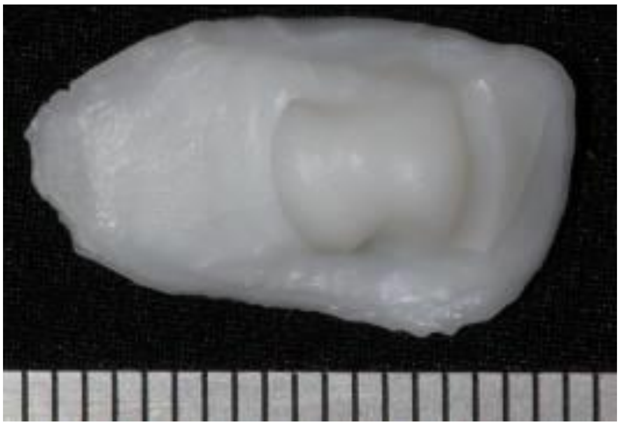
Results

Morphology

The majority of cooking treatments had no obvious effects on the appearance of the otoliths (Figures 2a and b); however, the salted samples had a slightly chalky exterior (Figures 2c and d). The burnt otoliths underwent significant morphological changes; they were carbonised and had a chalky texture, as well as showing numerous cracks and areas of disintegration (Figure 2e). Most of the burnt otoliths were blackened and were noticeably more fragile than unburnt otoliths, with BC1 turning into powdery ash a few days after collection. Once sectioned, these differences in appearance were further evident. The burnt otoliths show carbonization through to the nucleus, and the annuli were very difficult to determine, or were no longer visible (Figure 2f). Three salted samples (SD02, SD04 and SD06) showed a brownish discolouration of small areas close to the nuclei and along small fissures extending inwards from the surface of each sample (Figure 2d). All other treatments appeared to have no effect on the appearance of the otoliths, in terms of discolouration, deterioration or increment clarity, when compared with the control samples (Figure 2a and b).

In addition, the burnt otoliths weighed less after treatment relative to the corresponding control otolith. The mean difference between the burnt otolith and the control otolith from the same fish was 6.3%. It was not possible to assess the effects of cooking methods on otolith weight for other treatments as both otoliths were treated identically.

a.



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c.

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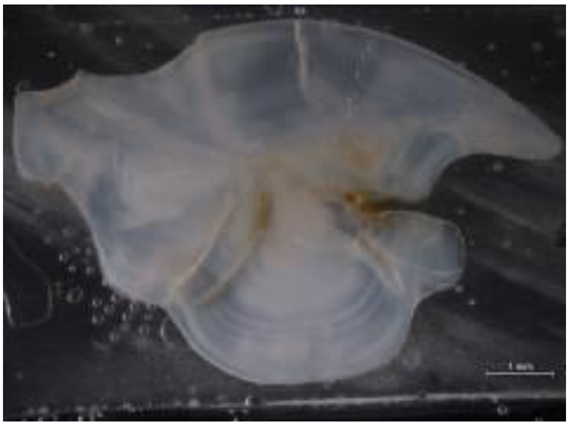


e.

f.

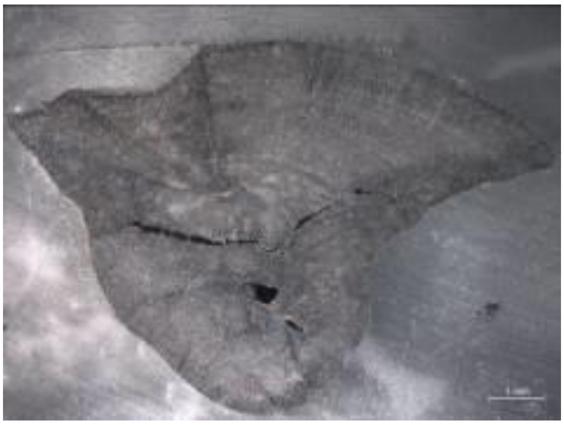


Figure 2: Representative samples of whole and sectioned otoliths. (a) Control otolith whole (CL03); (b) Control otolith section (CL03); (c) Salted otolith whole (SD07); (d) Salted otolith section (SD04); (e) Burnt otolith whole (BC05); (f). Burnt otolith section (BC04).

Morphologies of the vertebrae were affected similarly to the otoliths; the burnt samples were very fragile and highly deteriorated. They ranged in colour from black through to chalky white; presumably dependent on the level of heat they were exposed to. The vertebrae from the salted fish were dehydrated and the adhering tissue was more difficult to remove from the structure in comparison with the other treatments. There were no noticeable differences in the morphologies of the scales from different cooking treatments once they were cleaned; however, no scales were retrieved from any of the burnt samples, so comparisons were unable to be made with that treatment group.

Otolith X-Ray Diffraction

XRD analysis of the otoliths detected the only mineral in all samples to be aragonite, except for the sample from the BC treatment group, which had recrystallised to calcite. No aragonite was detected in the burnt sample.

Trace Element Analysis

Otolith element composition was largely unaltered by most of the cooking treatments relative to the control samples (trace element concentrations for individual otoliths are presented in Appendix A, Table S3.1). There was some variation between the nucleus and edge of the otolith for several elements; however, this is likely reflective of the fish spending time in different environments or an ontogenetic effect, and not a result of cooking (Table 2, Figure 3). However, two treatments (BC and SD) did have noticeable impacts. Burning the otolith significantly ($p<0.05$) increased the Li:Ca, and Zn:Ca concentrations at the edge of the samples (Figures 3a and h), while roasting on the fire and boiling in saltwater also significantly increased Zn:Ca concentrations (Figure 3h). Although Mn:Ca concentrations were increased in burnt otoliths and by wrapping in clay these were not significantly different to controls (Figure 3d).

Unsurprisingly, the Na:Ca concentrations were greatly increased by the salting treatment, both at the edge and the nucleus of the samples (Figure 3b). Salting the fish also appeared to alter Mg:Ca and Pb:Ca concentrations, though these data were highly variable and no significant differences were found. Sr:Ca and Mg:Ca concentrations were relatively similar for all treatments (Figure 3e and c), whereas Ba:Ca and Mn:Ca concentrations only varied between the edge and nucleus of the otoliths and not between treatments (Figure 3f and d). Multivariate analyses of the multi-element data were consistent with these patterns (Table 3, Figure 6a), with the burnt completely and salted fish seen mostly as outliers from the cluster of other cooking treatments and the control fish.

Vertebral elemental concentrations were similarly altered by the salting treatment, with increases in Na:Ca concentrations, while the elemental concentrations of Li:Ca were significantly different between the control and wrapped in clay treatments (Figure 4a and b, Table 2). The Mn:Ca, Ba:Ca, and Pb:Ca concentrations were greater in the burnt completely samples (Figure 4b, f, and g), though statistical analyses indicate that concentrations were not significantly different to the control group (Table 2).

Similar to the otolith results, concentrations of Sr:Ca did not differ significantly among treatments, while in contrast to the otoliths, Zn:Ca was also stable throughout treatments. Differences in the multi-element vertebral signature were largely due to the salting treatment (Table 2, Figure 6b). Trace element concentrations for individual vertebrae samples are presented in Appendix A, Table S3.2.

The elemental concentrations of the scales differed slightly from the other remains. The majority of changes in concentrations were not as dramatic, excluding increases in Na:Ca resulting from salting (Figure 5b), and Mn:Ca resulting from the boiling in freshwater treatment (Figure 5d). The concentrations of Mg:Ca were significantly higher in all treatments compared with the control group (Figure 5c), while Sr:Ca concentrations were higher in all except the wrapped in clay treatment (Figure 5e). Statistical analyses revealed no significant differences in concentrations of Ba:Ca, Pb:Ca, Li:Ca, and Zn:Ca between the scales from the control group and those from any of the treatments. The multi-element scale data were affected by the salted and boiled in freshwater samples (Table 2, Figure 6c). Trace element concentrations for individual scale samples are presented in Appendix A, Table S3.2.

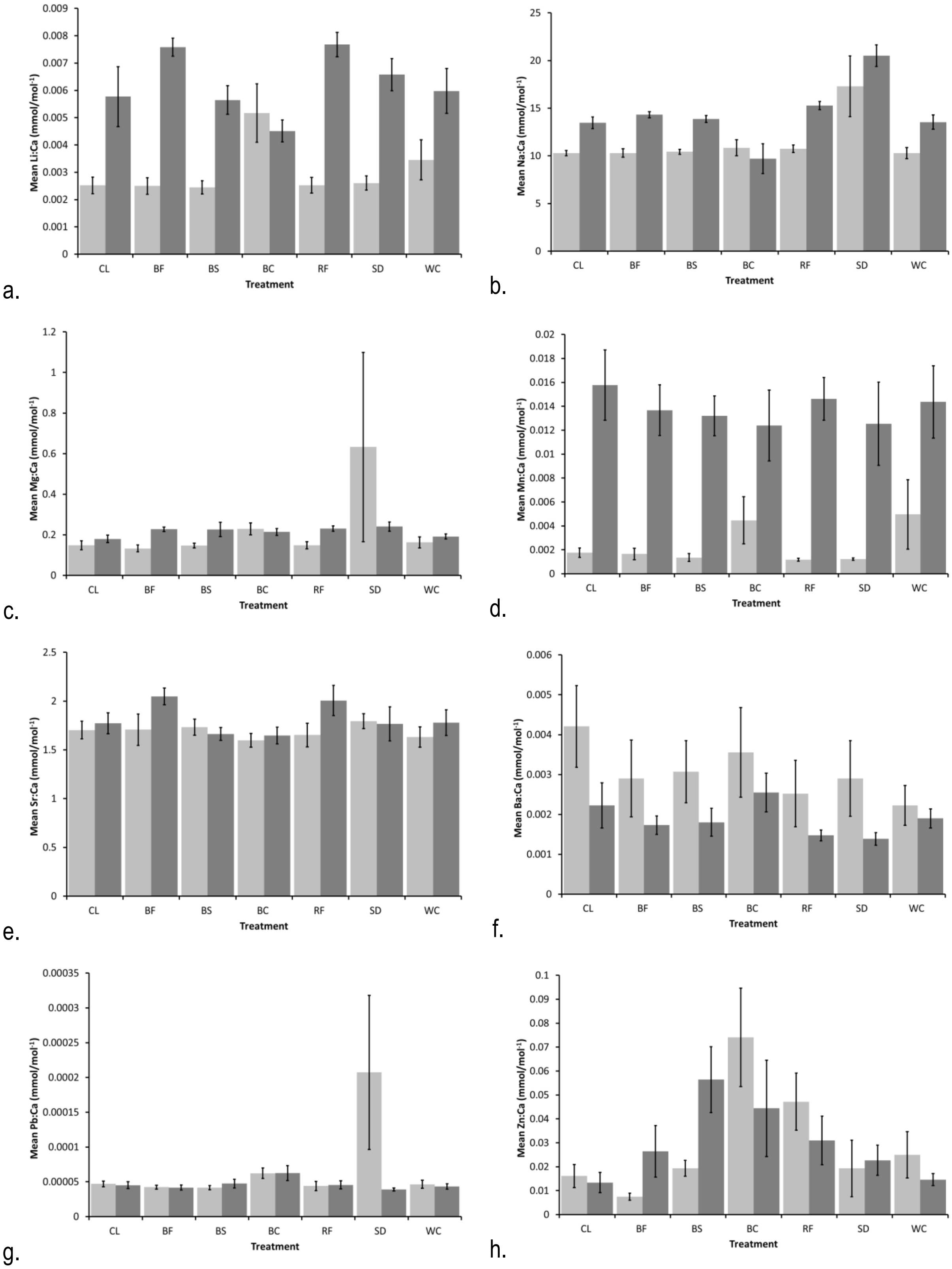


Figure 3: Mean otolith trace element concentrations among seven different cooking treatments (± SE) for the edge (light grey bars) and the nucleus (dark grey bars) (a) Li:Ca; (b) Na:Ca; (c) Mg:Ca; (d) Mn:Ca; (e) Sr:Ca; (f) Ba:Ca; (g) Pb:Ca; (h) Zn:Ca. Codes for cooking treatments are explained in Table 1.

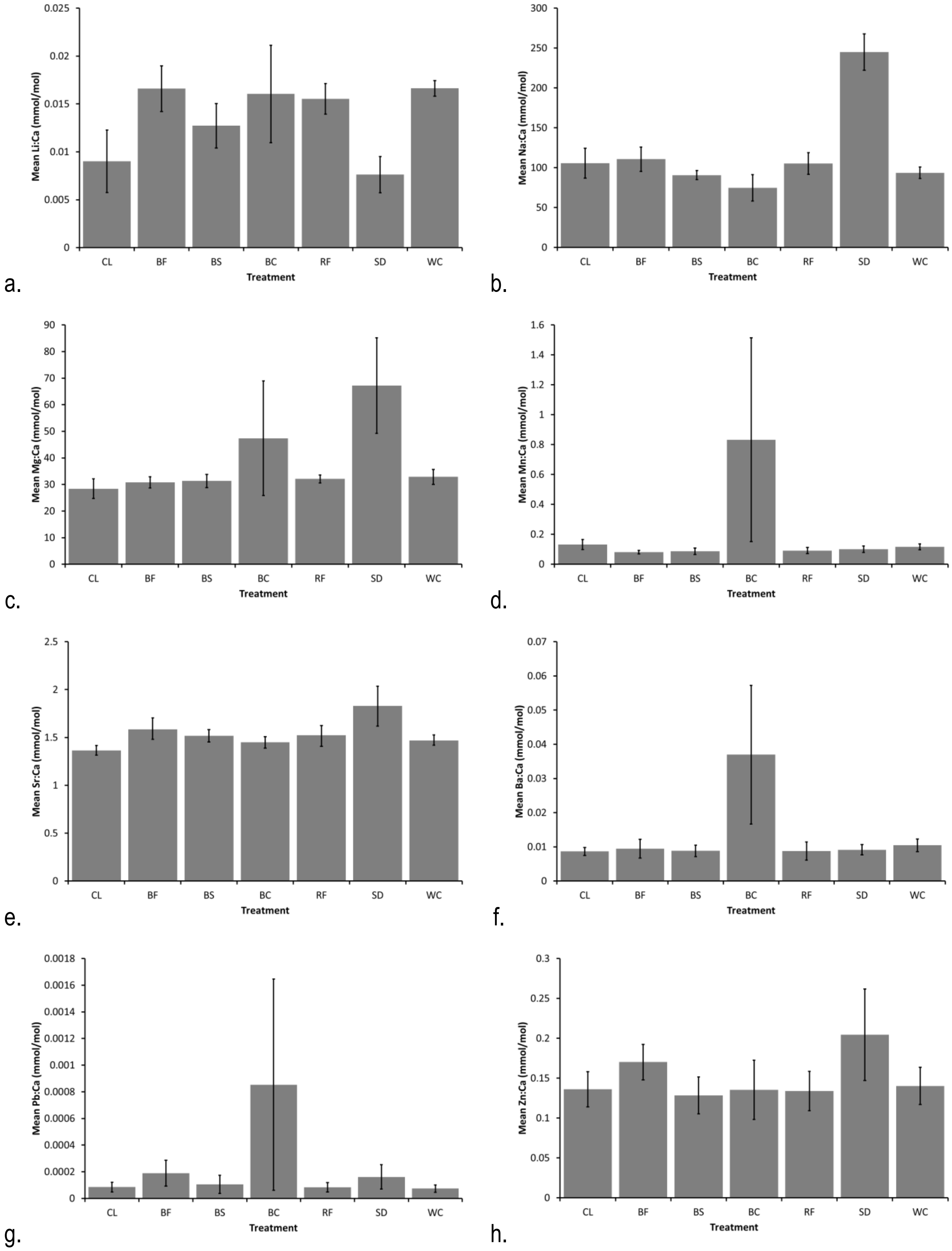


Figure 4: Vertebrae mean (±SE) trace element ratios for different cooking treatments (a) Li:Ca; (b) Na:Ca;(c) Mg:Ca; (d) Mn:Ca; (e) Sr:Ca; (f) Ba:Ca; (g) Pb:Ca; (h) Zn:Ca. Codes for cooking treatments are explained in Table 1.

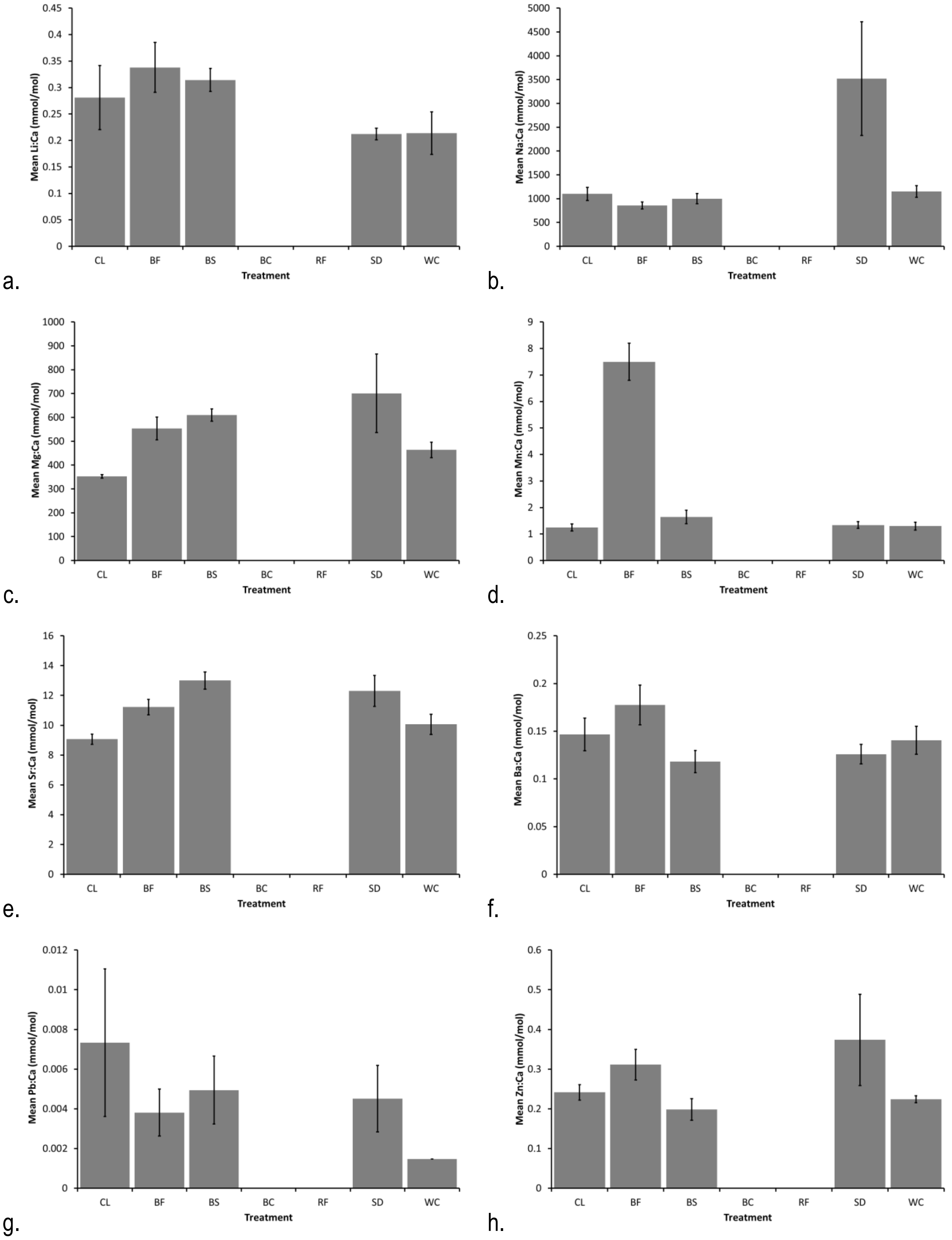


Figure 5: Scale mean (±SE) trace element ratios for different cooking treatments (a) Li:Ca; (b) Na:Ca; (c) Mg:Ca; (d) Mn:Ca; (e) Sr:Ca; (f) Ba:Ca; (g) Pb:Ca; (h) Zn:Ca. Codes for cooking treatments are explained in Table 1. No scale samples were analysed from the burnt completely (BC) and the roasted on fire (RF) treatments.

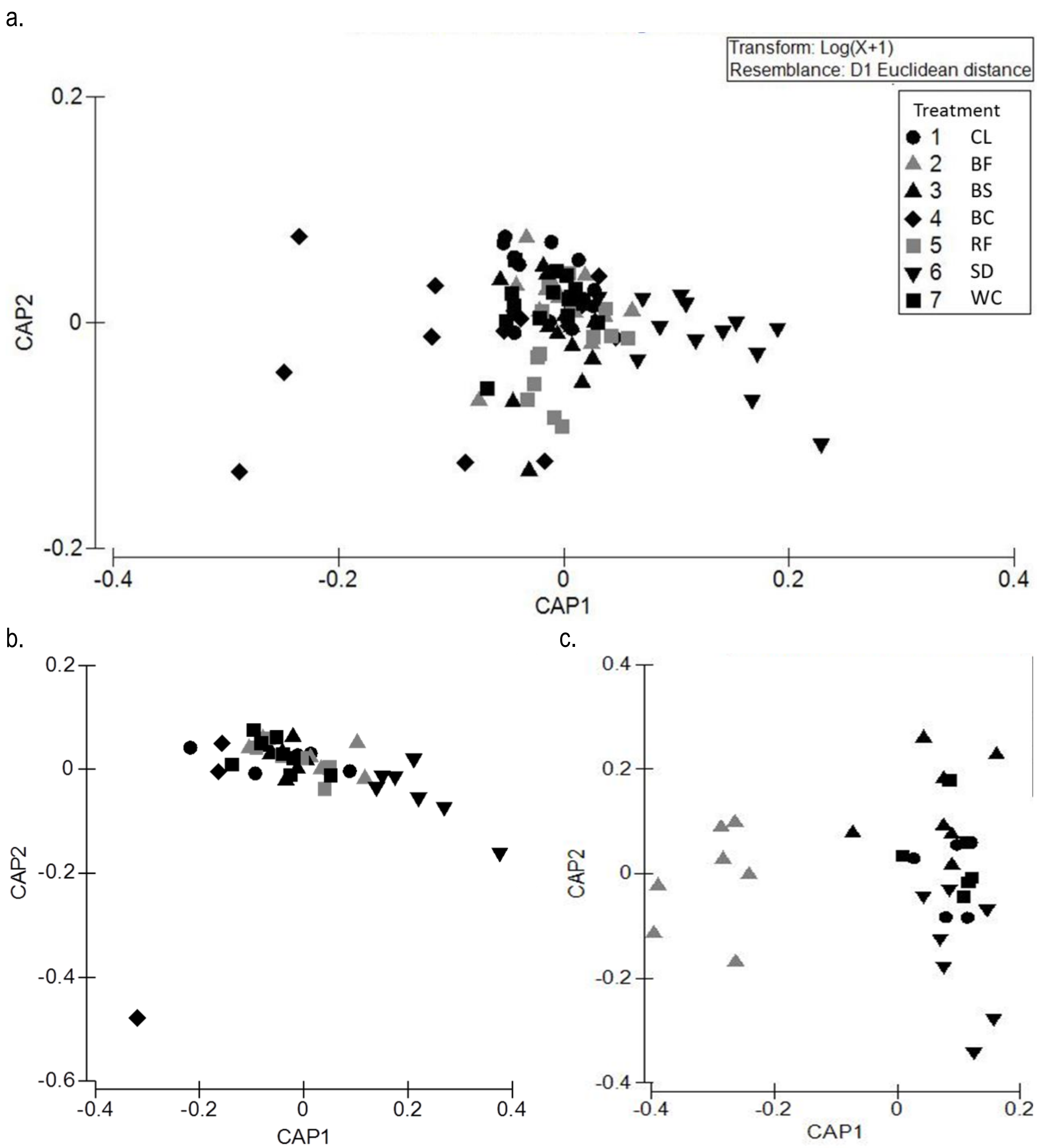


Figure 6: Canonical analysis of principal coordinates (CAP) plots of dissimilarity among cooking treatments for the multi-element signals: (a) otoliths (data for the edge and nucleus included for each treatment); (b) vertebrae; and (c) scales.

Table 2: Permutational ANOVA and MANOVA results comparing element:Ca concentrations in vertebrae and scales among cooking treatments, and for otoliths among treatments and the portion of the otolith (edge vs nucleus). Multi = multi-element signature. The degrees of freedom (df) were the same for each element:Ca ratio and the multi-element signature for each structure.

Otoliths		**Li:Ca**		**Na:Ca**		**Mg:Ca**		**Mn:Ca**		**Sr:Ca**		**Ba:Ca**		**Pb:Ca**		**Zn:Ca**		**Multi**	
Source	**df**	**F**	**P**	**F**	**P**	**F**	**P**	**F**	**P**	**F**	**P**	**F**	**P**	**F**	**P**	**F**	**P**	**F**	**P**
Treatment	6	0.984	0.437	12.952	0.001	1.307	0.290	0.420	0.865	0.771	0.601	1.022	0.422	1.873	0.094	4.550	0.003	6.989	0.001
Position	1	103.740	0.001	34.600	0.001	0.387	0.555	105.360	0.001	4.101	0.050	10.840	0.001	2.088	0.158	0.001	0.967	17.895	0.001
Tr. X Pos.	6	5.152	0.001	2.653	0.022	0.884	0.488	0.510	0.822	1.318	0.276	0.286	0.947	2.203	0.049	2.260	0.040	1.841	0.050
Res	82																		
Vertebrae		**Li:Ca**		**Na:Ca**		**Mg:Ca**		**Mn:Ca**		**Sr:Ca**		**Ba:Ca**		**Pb:Ca**		**Zn:Ca**		**Multi**	
Source	**df**	**F**	**P**	**F**	**P**	**F**	**P**	**F**	**P**	**F**	**P**	**F**	**P**	**F**	**P**	**F**	**P**	**F**	**P**
Treatment	6	2.823	0.023	10.202	0.001	2.813	0.210	3.353	0.013	1.969	0.094	3.820	0.008	2.055	0.086	0.705	0.650	5.441	0.001
Res	37																		
Scales		**Li:Ca**		**Na:Ca**		**Mg:Ca**		**Mn:Ca**		**Sr:Ca**		**Ba:Ca**		**Pb:Ca**		**Zn:Ca**		**Multi**	
Source	**df**	**F**	**P**	**F**	**P**	**F**	**P**	**F**	**P**	**F**	**P**	**F**	**P**	**F**	**P**	**F**	**P**	**F**	**P**
Treatment	4	2.694	0.049	9.723	0.001	4.653	0.008	68.355	0.001	5.055	0.005	2.454	0.075	1.139	0.368	1.672	0.172	14.196	0.001
Res	27																		

Isotope Analysis

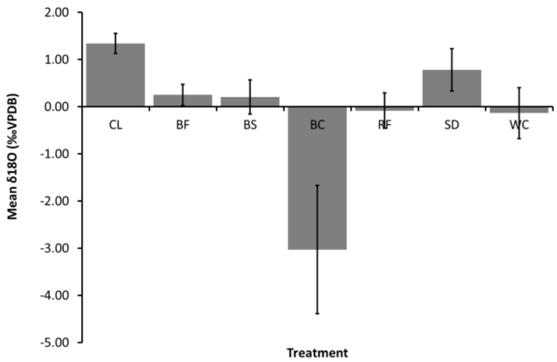
Mean otolith $\delta^{18}O$ values were different among treatments (Table 3, Figure 7a), with samples that underwent heating having lower mean $\delta^{18}O$ values than the control group (Figure 7a). Differences between the control group and the BF, BS, RF and WC treatments range from -1.09‰VPDB to -1.47‰VPDB. The difference between the BC group and the control group mean values is -4.37‰VPDB. Statistical analyses indicated that all treatment groups (excluding the salting treatment with a difference of -0.56‰VPDB) $\delta^{18}O$ values were significantly different to the control group (Table 3). Otolith $\delta^{13}C$ was also different between some of the treatment groups and the control group (Table 3, Figure 7b); the otoliths from the burnt completely (with a difference of -3.74‰VPDB) and the boiled in saltwater (with a difference of -1.24‰VPDB) treatments had significantly more negative values ($p \leq 0.05$), while the other treatments were not significantly different from the controls (Figure 7b).

Table 3: Permutational ANOVA results comparing stable isotope values in otoliths, vertebrae and scales among cooking treatments. Multi = multi-element signature.

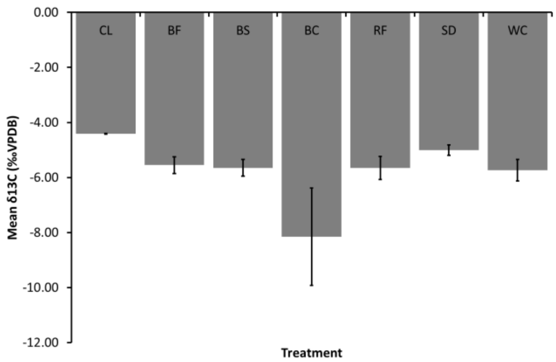
Otoliths		**δ¹⁸O**		**δ¹³C**		**Multi**	
Source	**df**	**F**	**P**	**F**	**P**	**F**	**P**
Treatment	6	5.222	0.001	2.574	0.026	3.662	0.006
Res	43						
Vertebrae		**δ¹⁸O**		**δ¹³C**		**Multi**	
Source	**df**	**F**	**P**	**F**	**P**	**F**	**P**
Treatment	6	19.946	0.001	8.4365	0.001	16.941	0.001
Res	37						
Scales		**δ¹⁵N**		**δ¹³C**		**Multi**	
Source	**df**	**F**	**P**	**F**	**P**	**F**	**P**
Treatment	4	0.699	0.595	0.511	0.744	0.582	0.732
Res	25						

Very similar patterns were seen in the isotope analysis of the inorganic component of the fish vertebrae. All of the treatments that required heating have more negative $\delta^{18}O$ values than the control group, with the BC group having the largest difference (difference of -20.19‰VPDB) (Figure 7c). The differences between the control group and the BF, BS, RF and WC treatments ranged from -1.6‰VPDB to -3.5‰VPDB. Statistical analyses indicated that all treatment groups (excluding RF and SD) $\delta^{18}O$ values were significantly different to the control group (Table 3). The BC treatment was the only group to have any significant difference in δ13C values from the control group (difference of -7.03‰VPDB) (Figure 7d, Table 3).

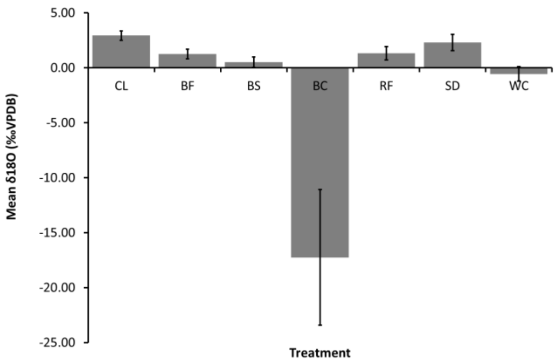
The δ13C and δ15N values of the scales were similar for all treatments (Figure 7e, f, Table 3), with no significant differences observed ($p>0.05$); however, no scales from the burnt completely or roasted on the fire treatments were available for analysis. Stable isotope values for individual otolith, vertebrae and scale samples are presented in Appendix A, Table S3.3.



a.



b.



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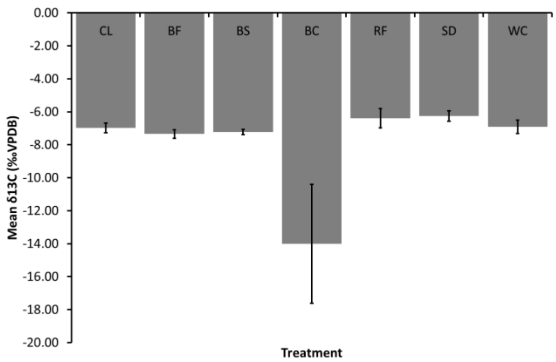

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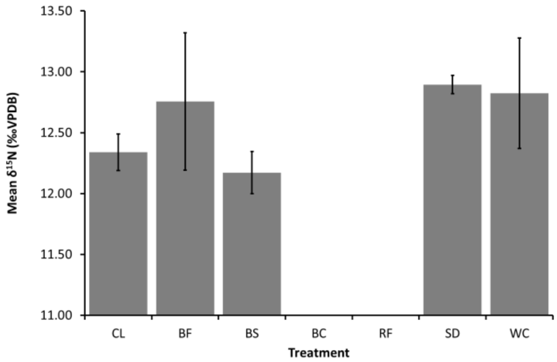

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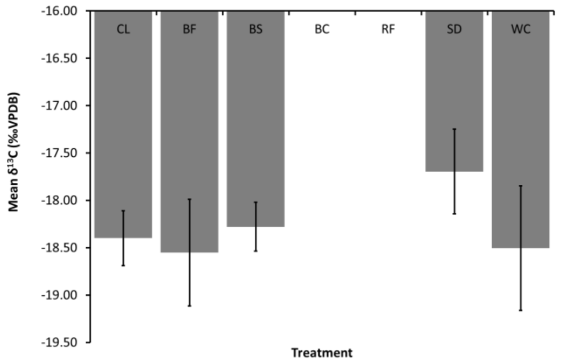

f.

Figure 7: Stable isotope analysis results; (a) otolith δ18O; (b) otolith δ13C; (c) vertebrae δ18O; (d) vertebrae δ13C; (e) scale δ15N; (f) scale δ13C. No scale samples were analysed from the Burnt Completely (BC) and the Roasted on Fire (RF) treatments.

Discussion

The morphology and chemistry of the otoliths and vertebrae were variably affected by the cooking treatments, highlighting the instability of some elements and features, while reinforcing the stability of others. Trace element analysis revealed that the majority of the elements within the treatment groups were similar to those in the control group. Stable isotope analysis indicated that the otolith and vertebrae mean $\delta^{18}O$ values were more negative in the treatment groups that were heated compared to the control groups, while mean otolith and vertebrae $\delta^{13}C$ values were different between various treatments and the control groups, with the majority of treatment groups having no significant difference in values compared with the control group. Trace element analysis of the fish scales revealed differing results compared with the analyses of the hard-parts; stable isotope analysis of the scales indicated that no significant alteration was observed.

The morphology of the hard-parts was largely unaffected by the cooking treatments employed, with the exception of the SD and the BC methods, which caused significant alterations, in agreement with Andrus and Crowe (2002). Morphological alterations seen in the burnt vertebrae and otoliths included changes in colour due to carbonisation (in line with Nicholson 1995), a loss of increment clarity, and a reduction in weight. The reduction of sample weight/density, or "shrinkage" (Shipman et al. 1984), is likely due to the thermal denaturation of the collagen component of the structure at temperatures as low as 60ºC (Richter 1986), while burning has been shown to affect bone microstructure significantly at about 400ºC (Boschin et al. 2015). Given that otolith or vertebrae weight are commonly used to estimate fish size (Disspain et al. 2012; Gabriel et al. 2012; Quinn and Deriso 1999), the use of burnt samples would likely underestimate the fish's actual size, thereby resulting in inaccurate fisheries baseline data or an underestimate of meat yield. Scales were not recovered from the BC or the RF treatments, and no noticeable differences in the morphologies of the scales from the other treatments were observed.

The morphologies of the otoliths and vertebrae from the SD treatment were altered, with samples appearing chalky and dehydrated, and otolith sections revealing the absorption of a substance from the outside surface. This substance is likely a mixture of salt and fish body fluids (e.g. endolymph), which is evidenced by increased levels of Na:Ca in all salted samples (otoliths, vertebrae, and scales) and demonstrates that these structures absorb elements post-mortem. Concentrations of Na:Ca have been found to increase in otoliths when they were left in the skull for long periods after death (Milton and Chenery 1998; Rooker et al. 2001), and are prone to contamination due to handling and preparation procedures (Proctor and Thresher 1998). As the otolith in the salted treatment remained in the fish 20 days after treatment before being removed, this may have had a small additional effect on the concentrations. Although other elements may not be absorbed as readily as Na, this finding suggests that fish remains may be affected by taphonomic processes and absorb elements after burial in other situations as well. Therefore, palaeoenvironmental reconstructions based on chemical analyses need to be conducted with caution. Further research into the post-depositional integration of trace elements into otoliths, bone and scales from sediments would be beneficial. The noticeable absorption of elements from the salt into the structures suggests that if fish have been anthropogenically processed using a salting method, this may be readily detectable through trace element analysis targeting Na:Ca concentrations, however, as salt is water-soluble, these concentrations may decrease post-deposition. Where this method of preservation is suspected, trace element analysis could confirm the practice (e.g., Yankowski et al. 2015).

Other trace elements within otoliths that were significantly affected by treatments were Zn:Ca (affected by BS, BC, RF) and Li:Ca (affected by BC), while Mg:Ca (affected by SD) was the only other element in the vertebrae that was affected. Zinc is a transitional metal present in the otolith protein matrix; its uptake is primarily via the gut (Miller et al. 2006) and it is prone to contamination. Elements, such as Zn, that are under physiological regulation, and are not bound within the aragonite lattice are more likely to leach out of otoliths (Elsdon et al. 2008); however, we found that the three treatments that impacted Zn:Ca had the effect of increasing the concentrations, rather than decreasing them, suggesting a contamination effect. The elements most frequently used in chemical analyses, Sr and Ba, remained relatively stable in the otoliths and vertebrae in comparison to the controls. In otoliths, these elements are incorporated into the structure via substitution for calcium (i.e., as $SrCO_3$) and are likely to reflect environmental parameters (Campana 1999; Doubleday et al. 2014; Elsdon et al. 2008). As such they are assumed to be least affected by post-mortem influences and are relatively insensitive to handling and preparation procedures (Proctor and Thresher 1998). Grupe and Hummel (1991) found that the proportion of Sr:Ca in human bone apatite increased with increased temperature in a predictable fashion, and that Ba was almost completely lost from samples that had been heated above 800°C, suggesting that Sr is one of few trace elements that can be used for palaeodietry reconstructions from burnt bone. We observed other elements that also experienced no significant alteration in otoliths (Mg:Ca, Mn:Ca, Pb:Ca) and in vertebrae (Zn:Ca, Mn:Ca, Pb:Ca). These results differ from those of Andrus and Crowe (2002), who found that all eight elements analysed (Na, Sr, P, Zn, Ba, Mg, Pb, and Mn, reported as ppm) were affected by cooking treatments, with Sr, Zn, Mg, and Mn the most unstable. Their findings may be attributed to anomalies within individual fish, which might have been caused by physiological processes, or slight variations in preparation or storage methods.

The trace element analysis of the fish scales revealed different results relative to the otoliths and vertebrae, whereby Li:Ca, Ba:Ca, Pb:Ca, and Zn:Ca concentrations were not significantly different between the treatment and control groups. Conversely, Mg:Ca concentrations were greater in all treatment groups, and Sr:Ca was greater in all except the WC group. Additionally, Mn:Ca concentrations were greater in the BF group. These data indicate that the chemistry of the hydroxyapatite in the scale structure reacts differently to the other fish hard-parts when heated. The alkaline earth elements, Mg and Sr were greater in the treatment groups, suggesting that the use of Sr as a palaeothermometer in scales is problematic, in agreement with Kalvoda *et al.* (2009), who found that early diagenetic alteration in fish scales is so profound that palaeoecological interpretations are not possible. Differences may also reflect that scales are in direct contact with the environment unlike otoliths and vertebrae.

Stable isotope analysis revealed that values were significantly different in groups that were heated when compared with control data in both the otoliths and the bone carbonate. The findings suggest that the higher the temperature or longer the duration of heating, the lower the otolith and vertebrae $\delta^{18}O$ values are, most notably in the burnt samples. As the SD method did not require heating, the isotope values of samples from this treatment are closest to the control values. The previous otolith cooking study (Andrus and Crowe 2002) also found that isotope values in burnt samples were significantly more negative than the control samples, but reported that no significant effects were observed as a result of the other cooking methods investigated (roasting over coals, roasting in an oven, boiling in freshwater and boiling in saltwater). They proposed that the process that caused the alteration of otolith aragonite to calcite in burnt samples also drove the exchange of oxygen and carbon in the carbonate lattice, indicating that more than structural changes took place. Aragonite is a metastable polymorph of calcium carbonate, which is prone to alteration under increased temperature or pressure (Waite and Swart 2015). This has also been identified in observations of aragonite that have been drilled/micromilled in preparation for isotopic analyses; aragonite was inverted to calcite and in the process $\delta^{18}O$ values were lowered (Waite and Swart 2015). We found, through XRD analysis, that only the burnt otolith had recrystallised to calcite, which supports Andrus and Crowe's (2002) proposition that a complex process takes place when otoliths are burnt, and is in agreement with other research examining the effects of burning carbonates (e.g., Larsen 2015; Zazzo et al. 2012). Oxygen isotopes were significantly altered in the biogenic aragonite of bivalve shells that had recrystallised into calcite after heating to 400ºC for one hour (Larsen 2015). Bone heated to high temperatures has been shown to experience a significant decrease in carbonate content and $\delta^{13}C$ values, with ^{14}C ages of the carbonate fraction of the samples indicating that carbon within the carbonate was replaced with carbon from the atmosphere of combustion (Zazzo et al. 2012). Our results suggest that it is likely this process also occurs within the carbonate of the fish otoliths as they are burnt, but the variations to isotope values in hard-parts that were not calcified, but merely heated, indicates that more research is required into the underlying mechanisms for these changes. While our findings are in agreement with some previous studies, they differ from those reported for fish otoliths, which were roasted at 200, 275 or 350ºC for 1 h, with no significant differences between mean $\delta^{18}O$ and $\delta^{13}C$ isotope signatures from paired experiments with roasted and non-roasted fish otoliths detected (Guiguer et al. 2003).

It can be argued that the observed differences between treatments are a result of environmental variation experienced by the fish; however, we took numerous safeguards to ensure that any environmental or physiological factors did not significantly affect the data. As mentioned above, we selected the location of catch and the species of fish to ensure a realistic research design. In addition, we sampled all of our fish at one time from a single fisher at a single location and randomised fish to different treatments. We sampled both the nucleus and the edge chemistry of the otoliths, and the edge chemistry of the vertebrae. The edge data would be representative of the conditions at the time of fish collection. If there was an issue distinguishing cooking from environmental variation we would expect to see no significant differences among treatments and very large variability, which is not the case.

These findings have implications for palaeoenvironmental and dietary reconstructions based on isotopic analyses of fish otoliths and bones; we observed changes in isotope values as a result of cooking treatments that did not noticeably alter the morphology of the samples. They also have implications for the way otoliths and vertebrae are prepared for analysis via embedding in resin and heating the sample in an oven to cure at temperatures exceeding 55ºC. In order to explore the effects that heating has on estimates of palaeotemperatures, we calculated the differences between temperature estimates based on a 1°C increase in ambient water resulting in a lowering of approximately 0.22‰ $\delta^{18}O$ in otolith aragonite. This relationship has been used by Rowell *et al.* (2005, 2008) to investigate changes in water temperature over time, and was experimentally derived based on the sciaenid *Micropogonias undulatus* (Thorrold et al. 1997). We acknowledge that using an equation based on a fish with a similar physiology and life history to *A. japonicus* is important; however, we are using this equation as an example of potential errors that could eventuate from heating of otoliths. The estimated temperatures increased between 2.54°C and 6.70°C as a result of the different treatments, while the burnt samples resulted in an increase of 19.85±5.21°C (Table 4). Consequently, inaccurate palaeoenvironmental reconstructions could be attained by unknowingly using heated samples. As the morphological attributes of the remains were not affected by most treatments, determining which remains within an archaeological assemblage have been heated is, in itself, a challenge. Fortunately, burnt remains are distinguishable by colour and carbonization and can be avoided (Nicholson 1995; Shipman et al. 1984); exposure to heat for longer periods of time or at higher temperatures causes bone and otoliths to change from dark grey/black through to white (Spennemann and Colley 1989; Stiner et al. 1995). Discolouration of archaeological samples can occur post-depositionally, making them appear burnt, requiring advanced methods of visualizing heat induced change, such as scanning electron microscopy (Shipman et al. 1984), magnetic resonance imaging (Thompson and Chudek 2007) and X-ray diffraction (Andrus and Crowe 2002) to be used. Samples that have been heated but not burnt are more difficult to determine. Boiling for brief periods of time has little distinguishing effect on bone in the short term, but extensive boiling increases porosity and crystallinity as protein is lost, and can mirror diagenetic effects observed in archaeological bone (Roberts et al. 2002). Transition electron microscopy has been used to investigate these changes in bone collagen as it is heated, and can be applied to archaeological remains to ascertain whether they have been cooked or not (Koon et al. 2003, 2010).

Table 4: Estimated temperature increases based on $\delta^{18}O$ values of otoliths.

Treatment	Mean $\delta^{18}O$ (‰)	±	Estimated temperature increase (°C) *x=(control $\delta^{18}O$ - treatment $\delta^{18}O$)/0.22*	±
Control	1.34	0.21		
Boiled freshwater	0.25	0.22	4.95	-0.04
Boiled saltwater	0.20	0.36	5.16	-0.67
Burnt completely	-3.03	1.36	19.85	-5.21
Roasted on fire	-0.08	0.38	6.46	-0.74
Salted	0.78	0.45	2.54	-1.07
Wrapped in clay	-0.13	0.54	6.70	-1.48

Conclusion

This experimental research has revealed complexities in the interpretation of chemical and isotopic analyses of fish remains. While it has highlighted the potential use of trace element analysis to identify salted fish remains, it has shown that other cooking methods can impact samples, thereby potentially leading to inaccurate palaeodietary and palaeoenvironmental reconstructions. In agreement with previous research, we recommend avoiding the use of burnt samples for trace element and stable isotope analyses, and using caution when interpreting data from any fish remains that may have been cooked or heated. Samples need to be prepared and handled using methods that reduce or limit alteration of their isotopic and chemical properties, while data needs to be validated based on individual site processes and conditions.

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Chapter 4

Pre-Columbian fishing on the coast of the Atacama Desert, northern Chile: an investigation of fish size and species distribution using otoliths from Punta Norte and Caleta Vitor

Top: Fish markets at Arica, Chile; Bottom: Looking south across the valley towards Punta Norte, Chile.

Statement of Authorship

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Contribution to the Paper	Conducted research, conducted scientific analyses, analysed data, wrote manuscript and grant applications supporting research. Collected modern samples of fish otoliths from Arica, Chile. Acted as corresponding author.		
Overall percentage (%)	80%		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
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By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);
ii. permission is granted for the candidate in include the publication in the thesis; and
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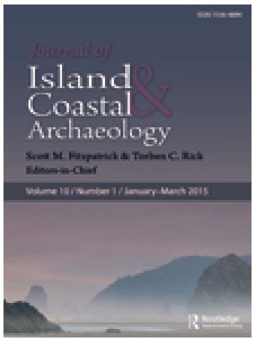

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Pre-Columbian Fishing on the Coast of the Atacama Desert, Northern Chile: An Investigation of Fish Size and Species Distribution Using Otoliths From Camarones Punta Norte and Caleta Vitor

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ABSTRACT

The bountiful marine resources of the northern Chilean coast offset the extreme aridity of the Atacama Desert in pre-Columbian times, underwriting permanent human occupation, and providing the basis for a long tradition of marine subsistence. We analyzed fish otoliths ($n = 549$*) recovered from the sites of Camarones Punta Norte (occupied ca. 7,000–5,000 years ago) and Caleta Vitor (occupied ca. 9,500–300 years ago) to investigate species distribution and changes over time. We also estimated the size of the fish based on relationships between otolith weight and fish total length (TL) obtained from modern samples of the predominant species,* Sciaena deliciosa*. The estimated size range of* S. deliciosa *from Caleta Vitor included fish that were significantly larger than those from Camarones Punta Norte, with the maximum TL (970 mm) almost double the modern maximum length documented. The fluctuating abundance of fish species and other marine taxa from Camarones Punta Norte indicates intense but sporadic use of the site over the span*

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of occupation. In contrast, human occupation of the Caleta Vitor estuary is more continuous. Comparisons of the fish assemblages with a nearby contemporaneous site, Quebrada de los Burros in southern Peru, suggest that fishing technologies were similar along this section of the Pacific coast.

Keywords Caleta Vitor, Camarones Punta Norte, coastal Atacama Desert, fishing, otolith, zooarchaeology

INTRODUCTION

The extreme aridity of the Atacama Desert in northern Chile led to a heavy reliance on marine resources as a source of food, as corroborated by palaeodietry studies (Aufderheide 1993, 1996; Pestle et al. 2015; Petruzzelli et al. 2012; Roberts et al. 2013). Even with the regional advent of agriculture ca. 3,500 years ago, the ocean continued to be essential to local subsistence (Núñez and Santoro 2011; Olguín 2014; Salazar et al. 2015). The Chilean sea, or the area of the Pacific Ocean west of the Chilean mainland, is a highly productive marine ecosystem due to the combined action of coastal upwelling and nutrients transported from the subantarctic region by the Humboldt Current (Bernal et al. 1983; Latorre et al. in press; Montecino and Lange 2009). In contrast to the scarce inland terrestrial and freshwater resources towards the Andes, the nearshore waters offer stable and predictable resources suitable for permanent human occupation. These resources provided pre-Columbian societies with a strong base on which to build a long-term tradition of coastal cultural systems sustained by marine subsistence (Grosjean et al. 2007; Llagostera 1979, 1992; Sandweiss et al. 1996, 1998; Valenzuela et al. 2015). In addition to these coastal resources, freshwater was available from springs that originated in the high Andes. The marine ecosystem had a low diversity of pelagic fish species with abundant but variable stocks, with variability associated with exploitation intensity and changes in environmental conditions (Andrade et al. 2014; Castro et al. in press; Olguín 2014; Olguín et al. 2014; Salazar et al. 2015; Yañez et al. 2001).

Today, the fishing industry remains important to Chile's economy; the western coast of South America produces more fish per unit area than any other region in the world (Montecino and Lange 2009). Stocks fluctuate dramatically, with the El Niño-Southern Oscillation (ENSO) mode of climatic variability having a strong influence on populations (Arellano and Swartzman 2010; Valdes et al. 2008). Investigations concerning past fish populations not only give insight into past occupants and environmental conditions of the area, but they are also essential in gaining an understanding of how fish stocks have changed over time and the impacts of human predation and changing climatic conditions. Documentary sources of fisheries data have limited time depth, whereas archaeological data can provide an indication of fish populations prior to industrialized fishing.

One way to examine the effects that habitat alteration and predation have had on fish stocks is through the analysis of fish otoliths from modern and archaeological samples, and an examination of changes through longer timescales. Archaeological otoliths have been used to determine species identification, season of fish death, and size, age, and growth of individual fish, allowing inferences regarding seasonality of site use, fishing methods, and cultural practices. When compared with modern samples, changes over time in fish population structure and species distribution can be investigated, thus, contributing significant information to the contemporary issues surrounding commercial harvesting of fish species. These data can also be used to better understand the past occupants of a site, their subsistence strategies, and movement within the landscape (for an overview of methods and applications, see Casteel 1976; Disspain et al. 2016). Here we examine species distribution and fish size based on fish otoliths from two sites along the coast of the Atacama, Camarones Punta Norte (CPN) and Caleta Vitor (CV), and investigate changes in fish size over time, as well as differences between the sites.

THE STUDY REGION AND SITES

Camarones Punta Norte and Caleta Vitor are located within the hyperarid coastal strip of the Atacama Desert on the west coast of South America (Figure 1), which stretches approximately 1,150 km from southern Peru to the Copiapó River (~17–27°S). This strip is cut by the mouths of 10 narrow, steep-sided valleys running from the Andes in the east, cutting through the coastal cordillera to meet the sea (see Santoro et al. 2012:fig. 1). The coast is bounded by high cliffs (700–1,000 m above sea level) to the north and south of the coves.

The Atacama ranges to the east ascend from sea level to more than 6,000 m above sea level in a distance of less than 200 km and are characterized by steep landscapes with diverse environmental conditions. The canyons conveying freshwater from the western slope of the high Andes to the coast across the Atacama Desert are today mostly devoid of surface water, with irrigation of the inner valleys consuming much of the subsurface water that would otherwise reach the ocean. The present arid environment of the region seems unlikely to support intensive occupation, but palaeoenvironmental reconstructions indicate that there were plentiful water resources available to support human habitation along the coast during the Archaic period (Arriaza et al. 2001; Marquet et al. 2012; Rivadeneira et al. 2010). Particularly favorable environments were located around the estuaries of valleys, as opposed to the coastline that stretches south of the fertile coast, where minimal freshwater sources are available. Around the estuaries, rich and permanent marine resources are complemented with freshwater, land mammals, birds, freshwater shrimp, and fruits from trees. Vegetation today is mainly limited to valley floors, particularly adjacent to stream beds. These resources allowed for permanent habitation, with the occupants living, and burying their dead, on higher plateaus surrounding river deltas (Arriaza et al. 2001). The initial colonization of the Atacama (11,000–8,000 years ago) coincided with a time of higher humidity and lower sea levels, facilitating habitation in the area, while the fertile coast is argued to have been an ecological refuge around 5,000 years ago during a time of increasing aridity (Arriaza et al. 2008; Gayó et al. 2015; Grosjean et al. 2007; Santoro et al. 2011). At this time, ENSO cycles brought warmer water flows that increased in frequency and magnitude later in the Holocene, which had a profound effect on the available marine biomass and coincided broadly with the appearance of agriculture in the region (Marquet et al. 2012; Rothhammer 2014; Sandweiss et al. 1996; Santoro et al. 2012; Williams et al. 2008).

Camarones Punta Norte is located 90 m above sea level on the northern side of the mouth of one of the valleys conveying freshwater to the coast, the Valle de Camarones (Figure 1). The site is a small shell midden (area ca. 4,000 m^2) representing the accumulation of shell and other marine resources used by the prehistoric coastal population, the Chinchorro, or other socially related groups. Seventeen radiocarbon dates across the period of occupation suggest continuous occupation of the site (see Gayó et al. 2015). People settled there ca. 7,000 years ago (Beta-251625, charcoal 6900 ± 50 BP [Gayó et al. 2015 supp. info.]). The occupation of the site lasted until ca. 5,000 years ago (GaK-7130, charcoal 4950 ± 210 BP [Gayó et al. 2015:suppl. info.]), covering the Middle Archaic Period, which saw the inception of the Chinchorro culture. This occupation coincides with a productive time for the Pacific coast of northern Chile; there was an absence of mega El Niño, resulting in a prevalence of La Niña cold conditions, and an improved coastal marine biomass

Figure 1. *Map of the Atacama Desert showing site locations and places mentioned in the text.*

production. El Niño–like conditions, coinciding with a decrease in marine productivity, occurred from ca. 5040 to 4150 cal. BP (Santoro et al. in review b). Camarones Punta Norte was initially excavated in the late 1970s (Dauelsberg et al. 1971 as cited by Muñoz et al. 1993) and was reinvestigated by Calogero Santoro in 2006. Other sites at the mouth of the valley have also been subject to investigations (Arriaza et al. 2001; Muñoz et al. 1993; Rivera 1984; Rivera et al. 1974; Schiappacasse and Niemeyer 1984). Samples analyzed in this study derive from the 2006 excavation season where a 0.7 m × 0.7 m square was excavated at the site to a depth of 110 cm with 16 excavation units or layers. Excavated material was sieved through a 2 mm screen. Artifacts found at the site include shell and cactus spine fishhooks, knapped lithic material in the form of scrapers and knives, as well as faunal remains from shellfish, sea birds, sea mammals, and fish—including a large number of fish otoliths. The Chinchorro, who occupied the site, were expert craftspeople taking advantage of the rich biomass. They used tools such as fishhooks made of bone, shells, and cactus needles, composite fishhooks, lines, and nets made of reeds and cotton, elongated stone sinkers, bone prying tools, lithic knives, scrapers, awls, and bifacial points (Arriaza et al. 2008; Santoro et al. 2005; Standen and Arriaza 2014).

Compared with Camarones Punta Norte, Caleta Vitor is a very large archaeological site. It is located at the mouth of a valley further north, Quebrada Vitor or Chaca (Figure 1), which consists of a broad sandy beach bounded at the north and south by cliffs reaching 800 m above sea level, and at the east by low sand dunes. The site is geographically and temporally extensive, consisting of different occupation sites, middens, mounds, and burials spanning from the Early Archaic Period to the Late Period (ca. 9500–300 years ago) (see Table 1). The chronology of Caleta Vitor was determined from 65 radiocarbon dates obtained from marine (shell, feathers, and bones) and terrestrial (human bones, plant remains, and charcoal) organic material (Latorre et al. in press; Roberts et al. 2013; Santoro et al. in review b; Swift et al. 2015). Based on chronology, cultural, and physiographical features, this vast site was divided into seven archaeological areas labeled Caleta Vitor 1 to 7 (CV1 to CV7) (Figure 2). It was excavated as part of a larger research program by Chris Carter and Calogero Santoro, and was found to contain shell, bone, plant remains, and otoliths, along with cultural material including (but not restricted to) lithics, ceramics, textiles, metal, and wooden objects. Burials were not targeted but the remains of at least eight individuals were encountered during the excavations (Roberts et al. 2013; Swift et al. 2015). Excavation trenches were restricted to 0.5 m^2 and were spread across six of the site areas. Excavations were undertaken by hand following defined stratigraphic units. Trenches CV4/2, CV4/3, CV4/6, and CV6/2 did not display clear stratigraphy and were excavated in arbitrary 100 mm or 50 mm spits. Excavated material was sieved through a 1.7 mm screen. Areas of the site where otoliths were recovered from are CV1, a broad area shell midden with associated burials, CV2, which contains niche burials and a deep archaeological deposit, CV3, consisting of three artificial mounds with burials, CV4, an area of disturbed deposit with marked burials, and CV6, an extensive shell midden with burials. Table 1 presents minimum and maximum radiocarbon dates available for these individual areas within the site, with CV3 returning the oldest date, and CV6 returning the youngest. The site areas integrate stratigraphically overlapping chronologies rather than isolated and discontinuous periods of occupation.

Isotopic analysis of material from Caleta Vitor has been conducted (Roberts et al. 2013) with results indicating that the diets of occupants of the site were dominated by marine-based foods, predominantly from upper trophic levels (e.g., marine fish, sea lions, sea birds). Roberts et al. (2013) also provide a detailed background of the occupation of the site. Additionally, human remains from the site have been subjected to trace element analysis, revealing elevated levels of arsenic, which was most likely ingested through contaminated drinking water (Swift et al. 2015), and a radiocarbon dating program has been conducted, which investigates regional marine reservoir values (Latorre et al. in press).

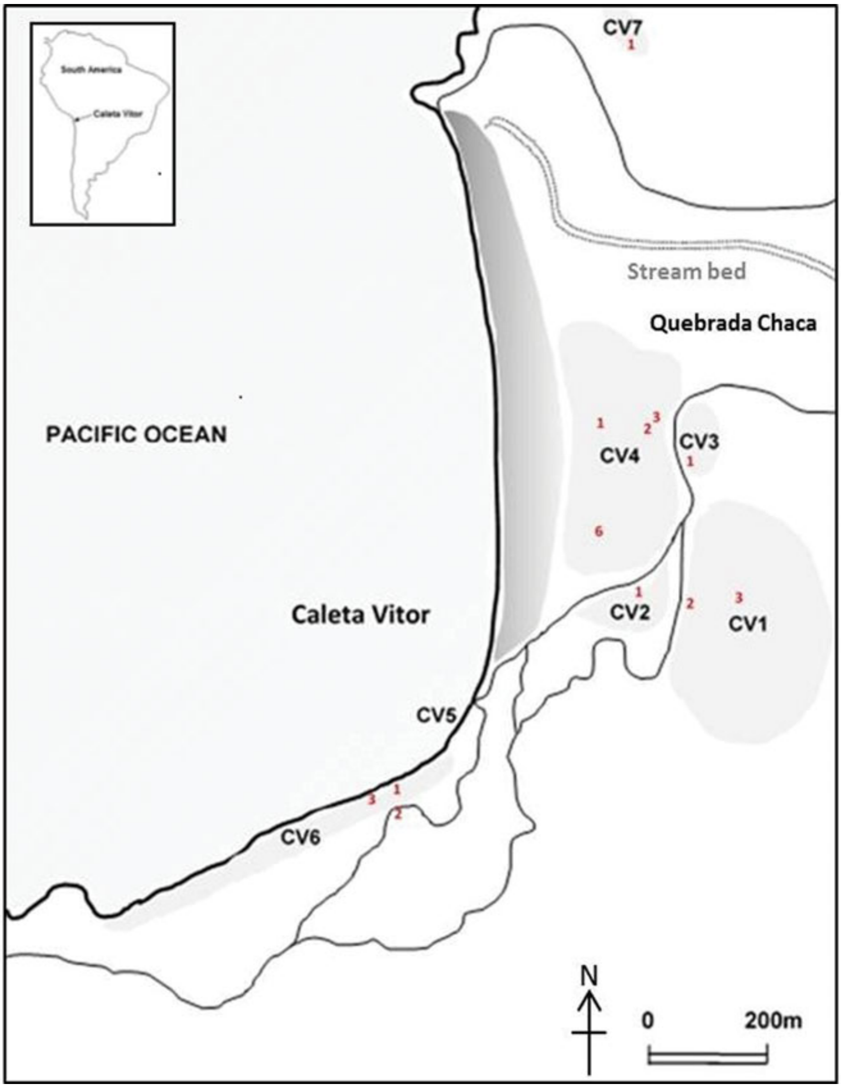


Figure 2. *Caleta Vitor site map. Numbers in red relate to the location of excavation trenches.*

The analysis of otoliths presented here is part of this broader interdisciplinary project.

METHODS

Archaeological Samples

Otoliths ($n = 345$ Camarones Punta Norte, $n = 204$ Caleta Vitor) were extracted from the sieve residue during laboratory analysis. The proximal and distal surfaces of each otolith were photographed using a Canon EOS 50D digital camera equipped with a macro lens to create an archival record. Species identification was carried out based on reference collections.

All otoliths were weighed to a resolution of 0.001 g. While the majority of otoliths were well preserved with no

Table 1. **Minimum and maximum radiocarbon dates available for each excavation location with otoliths within Caleta Vitor, ordered from oldest to youngest site area. Radiocarbon ages were calibrated into calendar years using OxCal (v.4.2.4) (Bronk Ramsey 2009) and the SHCal13 calibration dataset (Hogg et al. 2013) for terrestrial samples and a mixed SHCal13/Marine13 (Reimer et al. 2013) dataset for human bone samples using a local DR value of 367 ± 198 (Latorre et al. in press). For bone samples the % marine was used as reported for each sample by Roberts et al. (2013) and Swift et al. (2015). Calibrated ages are reported at 2-sigma.**

	Maximum radiocarbon date					Minimum radiocarbon date				
Site area	Lab ID	Material	Radiocarbon age (BP)	Calibrated AP (cal. BP)	Cultural period	Lab ID	Material	Radiocarbon age (BP)	Calibrated age (cal. BP)	Cultural period
CV3	ANU-31016[a]	Charcoal	8420 ± 40	9286–9491	Early Archaic	OZN-919[c]	Human bone (65% marine)	2420 ± 35	1591–2280	Formative Period
CV1	UCIAMS-133691[b]	Plant macrofossil	5930 ± 15	6656–6778	Middle Archaic	UGAMS-10507[c]	Algarrobo pod	2470 ± 25	2352–2699	Formative Period
CV2	UGAMS-10515[c]	Charcoal	3820 ± 30	3991–4286	Formative Period	UZP-580[d]	Human bone (74% marine)	1170 ± 30	309–835	Late Period
CV4	OZN-920[c]	Human bone (42% marine)	2575 ± 35	2013–2497	Formative Period	UGAMS-10519[a]	Plant material	420 ± 20	330–500	Late Period
CV6	OZP-069[d]	Human bone (68% marine)	1940 ± 30	1057–1672	Middle Horizon Period	UGAMS-10522[c]	Corn	350 ± 25	500–544	Late Period

[a]Carter (unpublished data); [b]Latorre et al. (in press); [c]Roberts et al. (2013); [d]Swift et al. (2015).

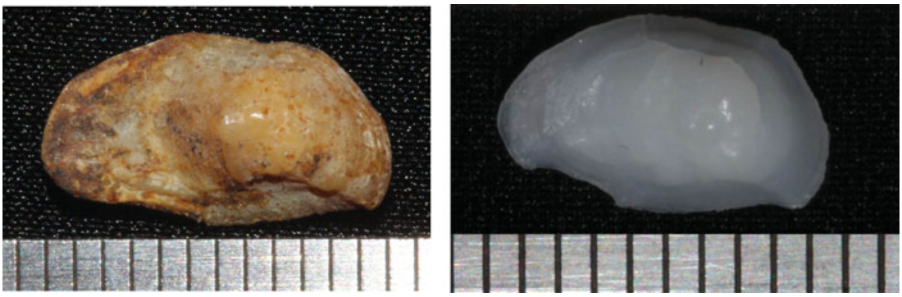


Figure 3. *Examples of archaeological (left) and modern (right)* S. deliciosa *otoliths. Scale bar = mm. The archaeological sample originated from Caleta Vitor, CV1, Square 3, Level 4.*

obvious deterioration (see example in Figure 3), some were broken and incomplete owing to post-depositional processes such as physical weathering and breakage; for the purpose of this study, to avoid inaccurate results, we used only complete samples to estimate fish length. Only one otolith, from Caleta Vitor, showed any signs of burning; this otolith was not included in the analysis because of the likelihood of shrinkage and weight loss (Shipman et al. 1984). Otolith weight was used to estimate fish length (total length, TL or fork length, FL) and fish weight. We acknowledge that otolith length can also be used to estimate fish size, and this method may be less sensitive to the effects of weathering or diagenesis on otolith weight; however, given otoliths are also prone to break, length can also underestimate fish size. We therefore chose to use otolith weight rather than length but acknowledge that fish lengths calculated using either method should be taken as minimum values. Relationships between otolith weight and fish length/weight for *Isacia conceptionis* and *Hemilutjanus macrophthalmos* were sourced from Medina and Araya (2001); values for *Trachurus murphyi* were derived from Araya et al. (2001) (Table 2). No equations for *Cilus gilberti* or *Sciaena deliciosa* were found. Given that *S. deliciosa* was the most abundant species in the archaeological assemblages from both sites, and dominate numerous archaeological assemblages from sites in the region (e.g., Béarez 2000; Sandweiss et al. 1998), modern samples were collected to determine otolith weight versus fish length and weight relationships.

In addition to the data collected from the fish otoliths, other faunal material

Table 2. **Relationships between fish length/weight and otolith weight from the literature (Araya et al. 2001; Medina and Araya 2001).**

	$TL = aOW^b$				$TW = aOW^b$			
Species	**a**	**SE**	**b**	**SE**	**a**	**SE**	**b**	**SE**
Isacia conceptionis	50.947	3.932	0.2861	0.025	2929.5	629.1	1.0977	0.077
Hemilutjanus macrophthalmos	91.532	3.311	0.4926	0.021	16127.8	1515.2	1.8238	0.056
Trachurus symmetricus murphyi	$FL(cm) = ((OW(mg) - 7.508)/0/003)^{1/2.53}$							

in the assemblages (bone, crustaceans, and molluscs), were extracted, counted, and weighed. These remains were not identified to finer taxonomic resolution and are included to contextualize otolith data.

Modern Samples

Seventy-two samples of *S. deliciosa* were collected from fish markets in Arica, Chile. The assemblage represents a range of the smallest to the largest sized fish available at the market over eight days in late April 2013 ($n = 39$) and two days in early October 2014 ($n = 33$). There was no significant difference in the size (TL) of fish sampled in the two periods. Catches originated from the waters off the coast of Arica, Chile. Each fish was weighed, measured, photographed, and the otoliths were removed. The otoliths were weighed (± 0.0001 g) and measured (± 0.01 mm). Measurements of both otoliths were averaged and used to estimate otolith size:fish size relationships. Fish length/weight of *S. deliciosa* archaeological samples was determined using the relationship between otolith weight and fish length/weight from these modern samples.

RESULTS

Modern Samples

The modern *S. deliciosa* samples ranged in size from 218 mm (138 g) to 400 mm TL (887 g), with a mean of 283 mm (304 g). Otoliths ranged from 0.0848 g to 0.2406 g in weight, with a mean of 0.1435 g. The mean difference between left and right otolith weights was only 0.0008 g, indicating that both left and right otoliths can be used for size estimation. The relationships between fish TL and weight and otolith weight both showed a polynomial relationship (see Figure 4a and b).

Archaeological Samples

Species Distribution. Species identified within the Camarones Punta Norte and Caleta Vitor assemblages are all currently found along the coast of northern Chile. The sciaenid, *Sciaena deliciosa*, was the most common fish present at both sites, comprising approximately 87% of the number of identified species (NISP) of each assemblage (Table 3). The other sciaenid, *Cilus gilberti*, which possess much larger otoliths than *S. deliciosa*, was less abundant at Camarones Punta Norte (3.8% NISP) and at Caleta Vitor (3.9% NISP). *Trachurus murphyi* was more abundant at Caleta Vitor (5.4% NISP) than at Camarones Punta Norte (2.9% NISP). Two species of Haemulidae, *Isacia conceptionis* (4.3% NISP) and *Anisotremus scapularis* (2% NISP) were only present in the Camarones Punta Norte assemblage, while the Serranidae *Hemilutjanus macrophthalmos* was only present at Caleta Vitor (3.9% NISP).

The frequency of *S. deliciosa* otoliths fluctuates throughout the excavation levels at Camarones Punta Norte, but exhibits peaks at approximately 6000 BP and 5600 BP (Figure 5a). The other fish species occurred at low abundances such that patterns by excavation level were difficult to ascertain. When the distribution of fish otoliths was compared with other taxa within the site (Figure 5b), molluscs—which include limpets, mussels, and snails—and crustaceans, such as rock crabs and barnacles, a similar pattern emerged.

At the Caleta Vitor site, the majority of the otoliths from all species were found in CV2 ($n = 93$). *S. deliciosa* dominates the assemblages from all of the seven archaeological areas excavated within Caleta Vitor, ranging from 80.0% NISP at CV1 to 91.4% NISP at CV2 (Table 4). *T. murphyi* makes up 5.4% of the total assemblage from Caleta Vitor (Table 3), but is not present at CV2 or CV6. *C. gilberti* and *H. macrophthalmos* occur infrequently, each contributing 3.9% of the total NISP at Caleta Vitor. When compared with other remains at the site, it is evident that the NISP of fish otoliths recovered does not correlate with the percentage weight of fish bone from each trench (Figure 6). Fish bone from CV2/1 constituted 16.4% of the total weight of faunal material, while 85 otolith samples were found in this trench (Figure 6). From CV4/6, only six otoliths

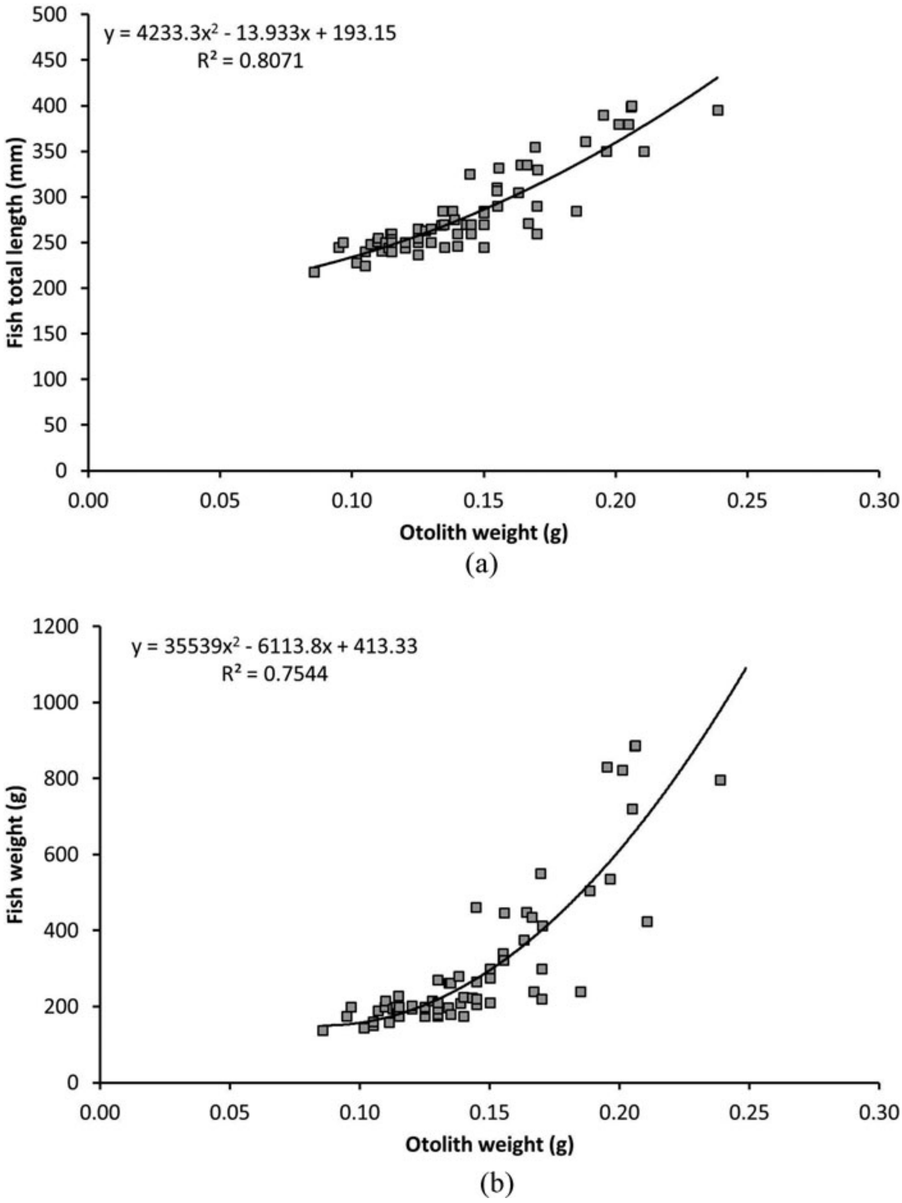


Figure 4. *Relationship between modern* S. deliciosa *fish (a) TL (mm) and otolith weight (g) and (b) weight (g) and otolith weight (g).*

were recovered, while the fish bone made up 30.1% of the weight of the faunal remains from that trench.

Fish Size. The TL of *T. murphyi* from both sites were very similar, with maximum lengths of 529 mm (mean TL = 463 ± 29 mm) from Camarones Punta Norte and 555 mm (mean TL = 462 ± 35 mm) from Caleta Vitor (Table 3). The lengths of *S. deliciosa* from Camarones Punta Norte

Table 3. **Fish species and estimated fish lengths based on otoliths from Camarones Punta Norte and Caleta Vitor.**

Site	Species	Family	Total NISP	% of assemblage	Number of complete otoliths	Fish length measurement	Mean fish length (mm)	SE (fish length) (mm)	Min. fish length (mm)	Max. fish length (mm)	Mean fish weight (g)	SE (fish weight) (g)	Min. fish weight (g)	Max. fish weight (g)
Camarones Punta Norte	*Anisotremus scapularis*	*Haemulidae* (grunts)	7	2.0	0	TL	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Isacia conceptionis	*Haemulidae* (grunts)	15	4.3	12	TL	234	8	181	264	158	19	55	237
	Trachurus murphyi	Carangidae (jacks and pompanos)	10	2.9	5	FL	463	29	356	530	n/a	n/a	n/a	n/a
	Cilus gilberti	Sciaenidae (drums and croakers)	13	3.8	10	TL	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Sciaena deliciosa	Sciaenidae (drums and croakers)	300	87.0	246	TL	287	4	194	555	341	16	338	1688
		Total	**345**		**273**									

(Continued on next page)

Table 3. **Fish species and estimated fish lengths based on otoliths from Camarones Punta Norte and Caleta Vitor. *(Continued)***

Site	Species	Family	Total NISP	% of assemblage	Number of complete otoliths	Fish length measurement	Mean fish length (mm)	SE (fish length) (mm)	Min. fish length (mm)	Max. fish length (mm)	Mean fish weight (g)	SE (fish weight) (g)	Min. fish weight (g)	Max. fish weight (g)
Caleta Vitor	*Hemilutjanus macrophthalmos*	Serranidae (sea basses, groupers and fairy basslets)	8	3.9	7	TL	239	24	125	316	144	41	10	313
	Trachurus murphyi	Carangidae (jacks and pompanos)	11	5.4	6	FL	462	36	308	555	n/a	n/a	n/a	n/a
	Cilus gilberti	Sciaenidae (drums and croakers)	8	3.9	5	TL	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Sciaena deliciosa	Sciaenidae (drums and croakers)	177	86.8	164	TL	358	10	219	970	668	51	152	4356
		Total	204		182									

TL = total length; FL = fork length; SE = standard error.

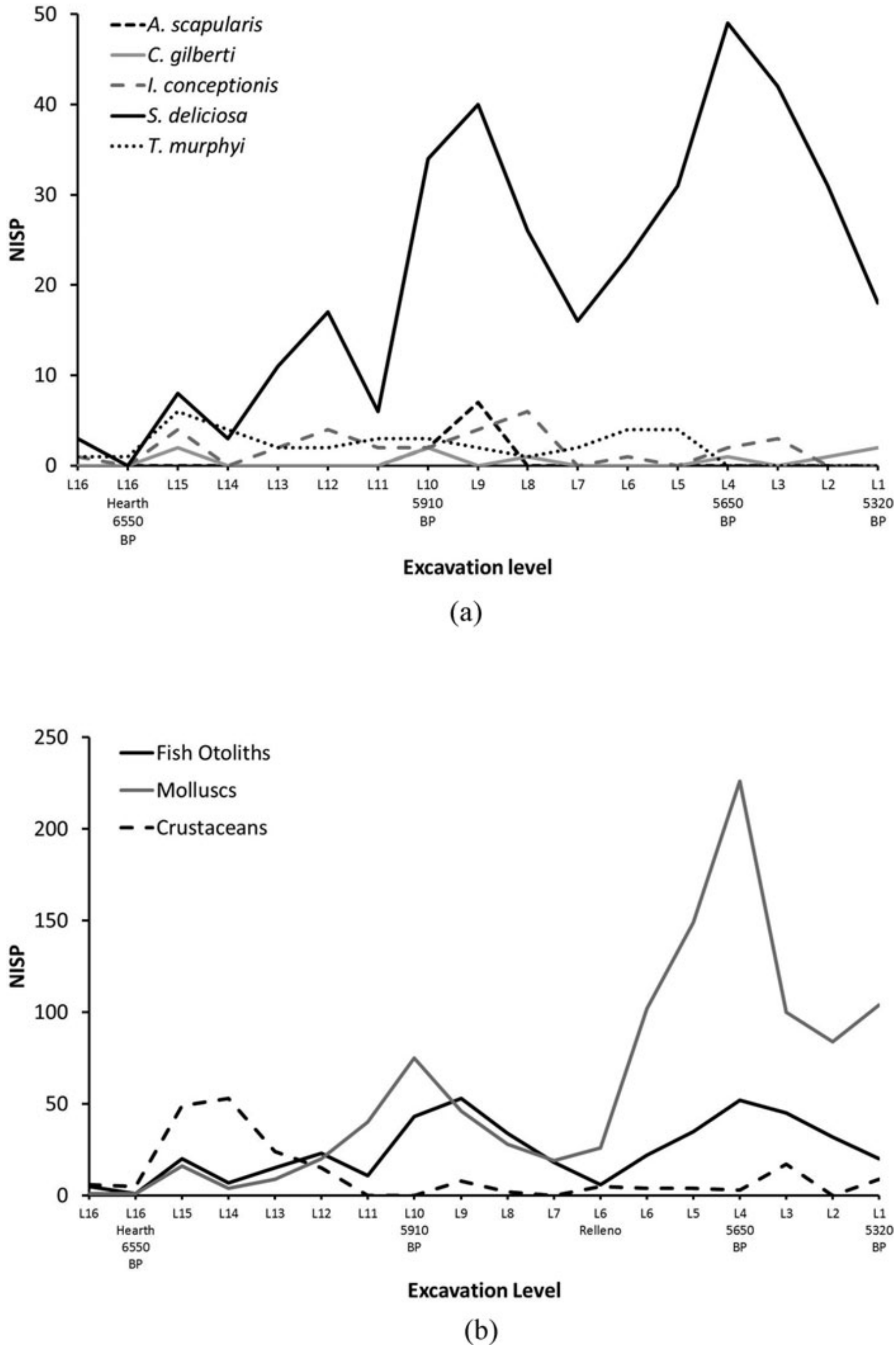


Figure 5. *(a) Fish species distribution for the five most common species at Camarones Punta Norte based on fish otoliths; (b) Taxonomic distribution based on fish otoliths (all species combined), molluscs and crustaceans at Camarones Punta Norte. NISP = number of identifiable specimens.*

Table 4. **NISP (number of identifiable specimens) and % of fish species at Caleta Vitor based on otoliths.**

	CV1		CV2		CV3		CV4		CV5	
Fish species	**NISP**	**%**	**NISP**	**%**	**NISP**	**%**	**NISP**	**%**	**NISP**	**%**
C. gilberti	2	4.0	4	4.3	2	6.3	0	0	0	0
H. macrophthalmos	1	2.0	4	4.3	0	0	1	5.9	2	16.7
S. deliciosa	40	80.0	85	91.4	28	87.5	14	82.4	10	83.3
T. murphyi	7	14.0	0	0	2	6.3	2	11.8	0	0
Total	50		93		32		17		12	

(max. = 554.96 mm, mean = 287 ± 4 mm) were much smaller than those caught at Caleta Vitor (max. = 970 mm, mean = 358 ± 9.52 mm) (Table 3). At Camarones Punta Norte the majority of *S. deliciosa* were estimated to measure <350 mm with weights of <1000 g (Figure 7a and b). In contrast, the majority of the *S. deliciosa* from Caleta Vitor ranged from 200 to 500 mm TL and up to 1500 g weight.

DISCUSSION

The fish species found at both Camarones Punta Norte and Caleta Vitor are a typical representation of the icthyofauna of the coast of modern northern Chile. The majority of the assemblage comprised otoliths from *S. deliciosa*, a medium-sized (up to 500–550 mm TL [Béarez et al. 2015]) predatory fish, living on or near the sandy ocean floor,

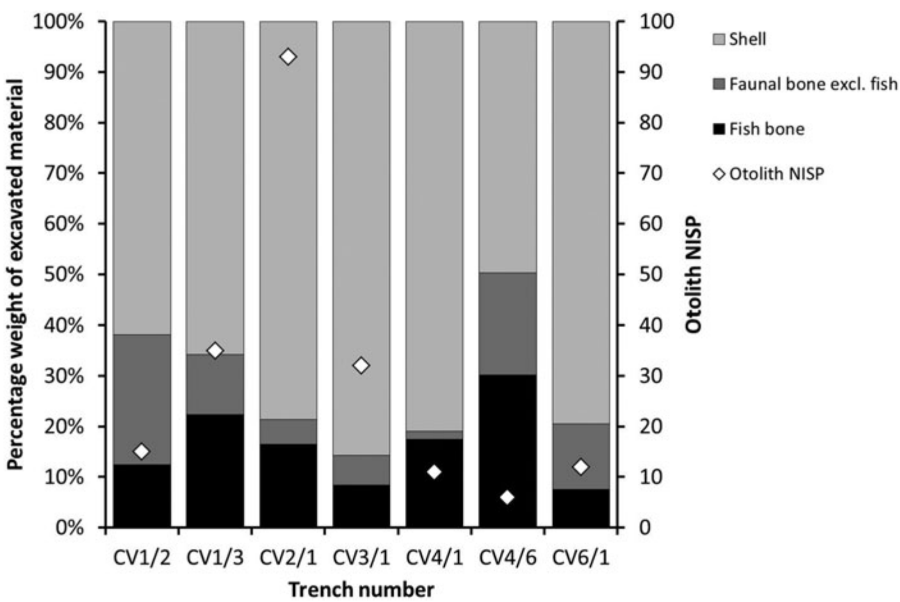
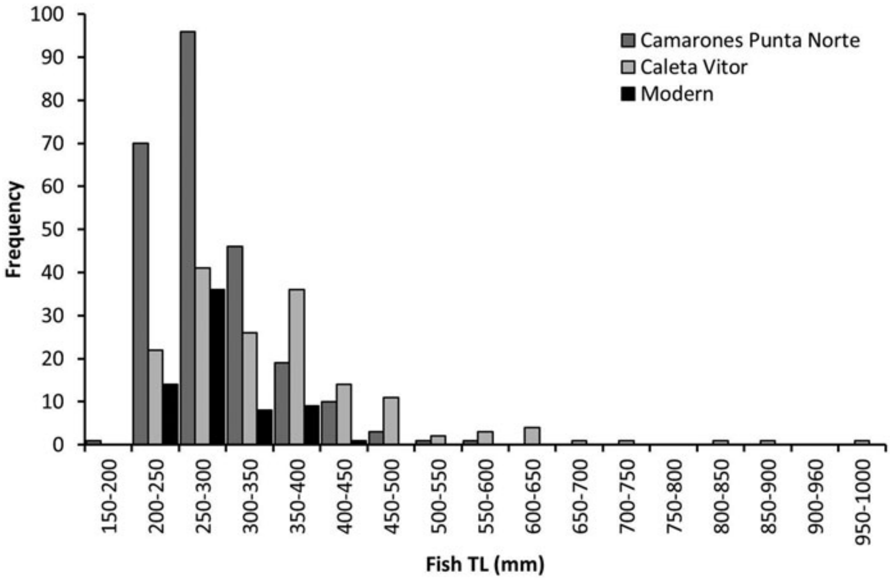
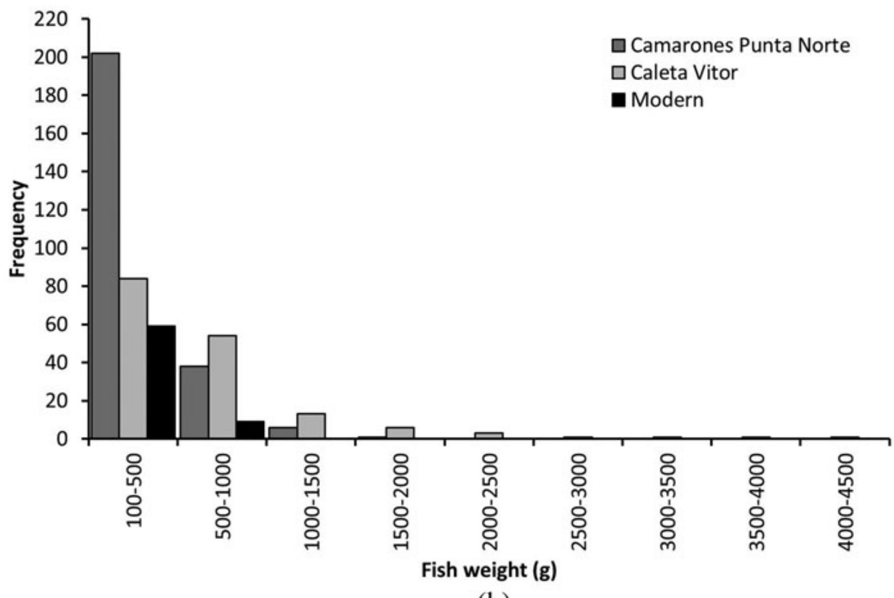


Figure 6. *Taxonomic distribution of broad categories of faunal remains and otolith NISP (number of identifiable specimens) at Caleta Vitor.*



(a)



(b)

Figure 7. *Estimated* S. deliciosa *(a) fish total length (TL) (mm) based on otolith weight:fish length relationships from modern specimens for Camarones Punta Norte, Caleta Vitor and the actual TL for the modern assemblage; and (b) fish weight (g) based on otolith weight:fish weight relationships for modern specimens for Camarones Punta Norte, Caleta Vitor and the actual fish weight for the modern assemblage.*

usually in depths of more than 20 m, but which can often be caught in shallower waters. It matures at a length of approximately 239 mm (Fishbase 2015), and feeds on crustaceans and small fish. It is likely these fish were caught with nets. Although other species were found, they were probably not the focus of the fishing efforts of the sites' occupants; their presence provides some information about past fish populations, as well as fishing strategies and technologies. They are all nearshore coastal species, some of which are highly prized seafood species and are commercially targeted today. *C. gilberti* is a large predatory schooling fish, reaching a TL of up to 1150–1200 mm (Béarez et al. 2015). This species is a prime table fish along the southern Pacific coast in South America, and feeds on small fish and crustaceans along the coast of Chile and southern Peru. *T. murphyi* is a heavily exploited (for fish meal), schooling pelagic fish adapted to both neritic and oceanic environments. They commonly grow to a TL of 450 mm long, but can reach lengths of 700 mm. At both Camarones Punta Norte and Caleta Vitor, maximum lengths were smaller than this modern maximum. Off Chile, the main horizontal migration pattern of the species is an offshore spawning migration in spring, and an inshore feeding migration in autumn and winter (Serra 1991). The presence of this species within the assemblages likely indicates that the sites were occupied during autumn and winter, when the fish were close to shore, and easier to catch. Alternatively, *T. murphyi*, along with the *S. deliciosa*, which also inhabits deeper waters, could have been captured further offshore with the use of watercraft. While watercraft are often found in post-Archaic periods in northern Chile (Llagostera 1990), there is some evidence of fishing for offshore pelagic species from the Middle to Late Archaic periods, which indicates that watercraft may also have been used during these earlier times (e.g., Béarez et al. 2016; Castro et al. in press; Llagostera 1979; Olguín et al. 2015; Olguín et al. 2014). Further analysis of the otoliths, and an examination of the annuli, or growth rings, may reveal the season of death of the fish, and by inference the fishing strategies of the sites' inhabitants. *I. conceptionis* is a benthopelagic fish, inhabiting waters over rocky and sandy bottoms. It can reach lengths up to 600 mm TL and feeds on small crustaceans, polychaetes, and algae. The otoliths within the assemblage at Camarones Punta Norte originated from fish much smaller than this length, with a maximum TL of 264 mm. *A. scapularis* (max. length 400 mm TL) forms schools in open water (usually 3–12 m in depth) above rocky, boulder-strewn reefs, slopes, and hard substrate. It feeds on benthic invertebrates and floating organic matter. *H. macrophthalmos* is found near drop-offs and among rock out-croppings over sand and rock, in depths greater than 10 m. It grows to a maximum length of 500 mm standard length (SL) and feeds on small fishes and crustaceans. Its presence within the assemblage, albeit with a maximum TL of 315 mm, indicates that the people of Caleta Vitor had the skills and tools required to fish in greater depths further from the coast.

The temporal fluctuations of fish species and faunal taxa at Camarones Punta Norte (Figure 5a and b) likely represent increases and decreases in the intensity of occupation at the site. The fish species fluctuate in synchronicity with the other faunal taxa, indicating that there was not a shift away from one species or taxa to another in response to environmental changes or altered resource availability. A significant increase in biomass occurred around 5500 cal. BP (Latorre et al. in press), which may explain the notable increase in faunal remains observed around this time at Camarones Punta Norte, followed by a decline in faunal consumption (Figure 5a and b). This fluctuating pattern may indicate that the site was used more or less intensively at intervals, with other areas in, or around, the estuary of Camarones favored at different times; Camarones Punta Norte is just one small, isolated site, with surrounding sites within the estuary showing occupation since early in the Archaic period, similar to what is seen at Caleta Vitor (Corvalán 2011; Schiappacasse and Niemeyer 1984). It should be noted that preservation and site formation factors may also have impacted the archaeology of the site and contributed to this pattern. Similarly, preservation or differential discard behaviors (butchering practices, activity area use, or carcass transport strategies) may account for the irregular relationship between the frequencies of fish otoliths compared to fish bone at Caleta Vitor (Figure 6).

The high numbers of *S. deliciosa* otoliths recovered from both sites is similar to that seen elsewhere along the coast of the Atacama. At Quebrada Jaguay, most of the terminal Pleistocene and Early Holocene fish bones and otoliths came from sciaenid fish with a mode length of 172 mm (SL) (Sandweiss et al. 1998), while at Quebrada de los Burros, over 50% of the fish remains (NISP), dated to 7735 ± 45 BP, were from *Sciaena spp*. (Béarez 2000). Sandweiss et al. (1998) suggested that the inhabitants of Quebrada Jaguay had a net fishing strategy focused on sciaenids, employing a specialized maritime subsistence strategy while resident at the site. At Quebrada de los Burros the size range of *S. deliciosa* suggested they were also caught with nets (Béarez 2000). At Camarones Punta Norte, the mean TL estimates were similar to that at Quebrada de los Burros (CPN = 287 mm, QdlB = 296 mm); however, the size range at Quebrada de los Burros, from 137 to 388 mm, consisted of smaller sized fish than Camarones Punta Norte (194–555 mm). In all of these sites, evidence for netting is scanty or indirect (i.e., stone sinkers), but today, fishermen along the coast of central Peru still use nets, among other techniques, to catch the same small size fish (Marcus 2008).

The sites of Quebrada de los Burros and Camarones Punta Norte are contemporaneous, although situated 130 km apart. The environmental conditions were likely broadly similar at each site at the time of occupation, allowing comparable suites of fish to be captured. Fishing technologies at the sites may have been shared, with the similar curves of both size frequency graphs (Figure 7a and Béarez 2000:fig. 7) reflecting the selectivity of fishing gear, possibly gill net size. The synchronicity of these sites may support the idea that the Chinchorro moved into the Atacama of northern Chile from similar settlements in southern Peru (e.g., Arriaza et al. 2008; Llagostera 1989, 1992; Rothhammer 2014; Standen et al. 2014; Standen and Santoro 2004; Umire 2013), bringing with them technologies suited to a marine and coastal environment. The use of nets indicates the importance of fish in the diet of the sites' inhabitants; nets require considerable time to make and maintain, suggesting social organization that allows time to be allocated for net making and maintenance (Balme 1995; Colley 1987).

The *S. deliciosa* assemblage from Caleta Vitor was notably different to that from Camarones Punta Norte; the mean size of the fish was significantly larger, at 358 mm TL, with estimated sizes ranging from 219 to 970 mm TL. The majority of fish from Caleta Vitor were in the 200–500 mm size range. These differences may reflect the changing environment in the area. Caleta Vitor was occupied for an extended period of time, and thus would have experienced changes in the marine biomass in line with El Niño/La Niña fluctuations. Along the Atacama coast, there was a swing from the humid early Holocene to fully arid mid-Holocene conditions between ca. 9500 and 8500 cal. BP, ending with the onset of modern climatic conditions around 4000 cal. BP (Betancourt et al. 2000; Grosjean et al. 2003; Grosjean et al. 2007; Latorre et al. 2003; Maldonado et al. 2005). Mollusc shell excavated from Caleta Vitor indicates that marine productivity increased at 5590 and 4380 cal. BP in relation to La Niña–like conditions; El Niño–like conditions may have occurred from 5040 to 4150 cal. BP, which have been linked to periods of lower productivity (Santoro et al. in review b).

The site at Camarones Punta Norte was no longer occupied after ca. 5,000 years ago. The changing environment may have forced site occupants to move completely out of the area or more likely, to relocate their settlement to other sectors of the Quebrada Camarones estuary, where other archaeological sites have been located and studied (Belmonte et al. 1995; Muñoz et al. 1991; Rivera 1984; Schiappacasse and Niemeyer 1984). At Caleta Vitor, more recent archaeological investigations show extensive and prolonged occupations in different locations of the bay throughout the time (Latorre et al. in press; Roberts et al. 2013; Santoro et al. in review a; Swift et al. 2015).

In relation to the sizes of the modern *S. deliciosa* samples, the assemblage from Camarones Punta Norte consisted of fish of a similar mean size and size range, with a maximum size (555 mm TL) in line with the maximum known length of the species (500–550 mm). The majority of the fish (79%) were larger than the modern size at maturity (239 mm), reflecting possible selectivity of harvesting. At Caleta Vitor, where the fish were generally estimated to be larger, 95% of the fish were larger than the size at maturity, likely indicating targeted fishing techniques or technology. The weights of 12 otoliths returned estimates of fish lengths more than the maximum modern length, with one individual, dated to approximately 3000–4500 cal. BP based on associated radiocarbon dates, estimated to be 970 mm long—almost double the modern maximum length. These large fish originate from a range of time periods, and were associated with radiocarbon dates ranging from modern through to approximately 6500 cal. BP (Roberts et al. 2013). Notably, none of the large fish originate from the time of earliest occupation at the site (9286–9491 cal. BP). These larger specimens, scattered throughout the temporal and spatial area of the site, represent the size that *S. deliciosa* could attain prior to commercial harvesting. These large fish could have been prized catches from deeper waters using hook and line technologies, or may have been caught in the nets with the smaller fish in shallower waters.

Over-exploitation of the marine environment is a major global issue (Erlandson and Rick 2008). Commercial harvesting of native fish species has significantly reduced fish stocks and has impacted fish population structures. Prehistoric predation is also acknowledged to affect native fauna, therefore archaeological data may reflect impacted populations, and may not accurately represent pre-exploitation baselines (Butler 2001; Mannino and Thomas 2002; Rivadeneira et al. 2010). In addition, as archaeological ichthyofaunal assemblages result from cultural selection, they will reflect selective processes rather than be direct representations of former fish populations (Reitz 2004). Despite these factors, archaeological fish remains provide a snap-shot of past fish populations. Determining between environmentally and anthropogenically induced changes can be difficult, but fishing mortality can act as a selection pressure producing genetic change, and if larger individuals are more vulnerable to harvesting, then early maturing and slower growth might be favored (Sutherland 1990). Numerous studies world-wide have identified the remains of fish estimated to be significantly or consistently larger than known modern specimens, as is evident at Caleta Vitor, attributing the decline in size to over-fishing and/or environmental degradation (e.g., Disspain et al. 2012; Leach and Davidson 2000; Plug 2008; Rivadeneira et al. 2010). The reverse has also been seen in assemblages, with mean fish size increasing over time (Leach and Davidson 2001), indicating complex processes at play, but it is widely accepted that industrialized fishing pressure and size-selective harvesting have drastically reduced stocks and impacted population structures (Fenberg and Roy 2008).

CONCLUSIONS

Analysis of the fish otoliths from Camarones Punta Norte and Caleta Vitor archaeological sites provides further and finer evidence documenting the reliance of the people of the Atacama Desert on marine resources. Without this bountiful and apparently inexhaustible resource provider, the deep history of humanity in this remote part of the planet would be different. The long-term chronological otolith analysis shows that there were important differential fluctuations in the species production along the coastal ecosystem throughout the Holocene (ca 9,500–300 years ago), and that people likely managed these fluctuations by relocating their settlements either within the estuaries, or by moving out from them.

Based on fish seasonal behaviors, it appears that the coastal enclaves of Caleta Vitor and Camarones Punta Norte were occupied during autumn and winter, which correspond with the inland driest seasons. The large expanse and depth of shell middens along the Pacific coast, and particularly along the Atacama Desert, has been interpreted as a strong proxy to suggest that people maintained a sedentary or semi-sedentary life. This lifestyle was forced, in part, by the scarcity and geographic distribution of inland resources influenced by hyperarid conditions, and the contrasting, plentiful coastal marine resources (Chacama and Muñoz 2001; Marquet et al. 2012; Núñez 1986; Núñez et al. 1974; Zlatar 1983). The assemblages share similarities with contemporaneous sites in the region, containing large amounts of fish remains, providing evidence for the employment of a range of fishing technologies, and reinforcing the importance of fish resources to the occupants of the coast of the northern Atacama Desert. The similarities between assemblages at Camarones Punta Norte and Quebrada de los Burros, further to the north, support the idea that people along the coast from southern Peru to northern Chile employed similar subsistence technologies, which may have been trespassed or exchanged between groups (Lavallée et al. 1999; Lavallée and Julien 2012; Lavallée et al. 2011; Santoro et al. 2012). Further morphological, isotopic, and elemental analysis of the otoliths could provide insights into whether the site was inhabited/fish were targeted continuously or seasonally, while temperatures and upwelling patterns could be investigated through the use of isotopic or trace element analysis (see Latorre et al. in press).

Through estimates of fish size based on weights of otoliths, extremely large specimens of *S. deliciosa* were identified at Caleta Vitor, providing an indication of the size this species was capable of achieving prior to the industrialization of fishing in the region. The over-exploitation of commercial fish species is a major global issue, which requires stocks to be managed and rehabilitated to ensure their survival. Archaeological data indicating significant alterations to a species' individual size can be used as evidence of the profound impact that modern uncontrolled industrialized harvesting could have on fishing biomass reproduction, and provide baseline data for their recovery.

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Chapter 5

Long-term archaeological and historical archives for mulloway, *Argyrosomus japonicus*, populations in eastern South Australia

Mulloway otolith GF121: Top left: proximal surface; Top right: distal surface; Bottom: section through the nucleus showing annuli. Age estimate: 6 years; fish length estimate (TL): 723 mm.

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Overall percentage (%)	80%		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
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iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

Name of Co-Author	Sean Ulm		
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Contribution to the Paper	Conducted community consultation, led the excavation of the archaeological site and its subsequent analysis, and provided otolith samples for analysis. Provided suggestions, comments and feedback on manuscript drafts.		
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Contribution to the Paper	Traditional Owner of the archaeological site; played key role in community consultation for the project. Provided suggestions, comments and feedback on manuscript drafts.		
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Contribution to the Paper	Provided suggestions, comments and feedback on manuscript drafts. Assisted with intellectual development.		
Signature		Date	15 July 2016

Long-term archaeological and historical archives for mulloway, *Argyrosomus japonicus*, populations in eastern South Australia

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Abstract

Native fish populations have been strongly impacted by fishing, habitat alteration and the introduction of invasive species. Understanding the dynamics of native fish populations prior to industrialised fishing can be problematic, but provides critical baseline data for fish conservation, rehabilitation and management. We combined fish size, age and growth data, as well as month of catch data, from archaeological fish otoliths (1670–1308 cal BP to 409–1 cal BP), historical anecdotes (AD 1871–2000), and contemporary data sources (AD 1984–2014) to examine changes to mulloway, *Argyrosomus japonicus*, populations in the waters of the eastern coast of South Australia. We found that the data from the three different sources – archaeological, historical and contemporary – corroborate each other in many aspects. The month of catch data for all three data sets was seasonal, with an increase in catches during the summer months. No significant changes in fish length over time were evident over the time span of the three data sources. Given the impact that the industrialization of fishing in the region is regarded to have had, this may imply that while the maximum recorded sizes of the species have remained stable, the abundance of these large specimens may have declined.

Keywords

Otoliths; archaeology; Kaurna; mound site; historical data, Gulf St Vincent, Trove

Introduction

Anthropogenic impacts have profoundly altered aquatic ecosystems, yet attempting to return native fish stocks to 'baseline states' is difficult because of the shifting baseline syndrome (Hobday 2011; Izzo et al. 2016; Papworth et al. 2009; Pauly 1995). This refers to the concept that fish populations are measured against baselines identified by each consecutive generation of researchers, baselines which themselves may represent significant changes from even earlier states (i.e., before the advent of industrialised fishing). The result is a gradual shift of the baseline, and the establishment of inappropriate reference points for evaluating losses from overfishing, or for identifying rehabilitation targets (Pauly 1995). Systematic collection of fisheries data in most parts of the world only covers a very shallow timeframe, making assessment of long-term population dynamics beyond the industrialised fishing era problematic. Fish remains from archaeological sites can be used to circumvent this issue, and extend the recent record of fish population data (see Galik et al. 2015; Jones et al. 2016; Limburg et al. 2008 for examples). When combined with historical archival information, and modern fisheries data, changes in fish abundance, age and size over time can be examined, thereby addressing the shifting baseline issue (Haidvogl et al. 2015).

Prehistoric fisheries data obtained from archaeological assemblages have limitations. They are reflections of selective processes rather than direct representations of past fish populations (Reitz 2004), undergo various taphonomic processes that impact preservation, and may represent populations already impacted by Indigenous fisheries (Mannino and Thomas 2002). However, they do provide valuable snapshots of past fish populations that would otherwise be near-impossible to determine; as such, they are the best way to obtain prehistoric fisheries baseline data against which to compare more recent data (Butler 2010). Archaeological fish otoliths can be used to identify species, and estimate fish age, size, and season of death. Samples can be radiocarbon dated, assigning timeframes and allowing changes in fish population dynamics over time to be examined. Additionally, archaeological fish remains reveal information about the human inhabitants of an area, with fish otoliths specifically containing large arrays of growth, trace element and isotopic data that can be used to investigate human behaviour and exploitation of their environment (Casteel 1976; Disspain et al. 2016).

Historical records can be used to bridge icthyoarchaeological data with contemporary fisheries records. Historical data sources include archival fisheries reports, early fishing publications, newspaper articles, menus, artworks (Thurstan et al. 2016; Thurstan et al. 2015), archived fish remains (Schaerlaekens et al. 2011; Selleslagh et al. 2016), and early fisheries datasets (Fowler and Ling 2010), which can contain information relating to fish abundance, location of catch, fish size, catch rates, fishing methods and technologies, and species popularity. These sources can be problematic, with the possibility of being exaggerated or biased, and interpreting them can be fraught with challenges. But these data can provide otherwise unknown information regarding past ecological systems, which fill the gap between prehistoric and modern times and address a range of conservation issues, significantly contributing to understanding current fishery status (e.g., Alleway et al. 2016; Fowler and Ling 2010; Klaer 2001; Rosenberg et al. 2005).

Contemporary fisheries reports contain detailed information about commercial, recreational and Indigenous fisheries species, including species biology, catch rates, catch and effort data, population structure (fish age and size), fishing methods and technologies, month and location of catches, analysis of performance indicators, and appraisals of the state of the species/fishery (Earl and Ward 2014; Flood et al. 2014; Giri and Hall 2015). These data, although limited to commercially desirable species, can provide a snapshot of current fish population structures, which can be compared with historical and archaeological data, allowing investigations into changes over time and the impact of industrialised fishing. This information can also be contained in fisheries research or marine science publications, which may provide more detailed analyses and greater insight into the biology of species and the sustainability of stocks (Ferguson et al. 2014; Griffiths and Hecht 1995).

Our aim was to obtain a long-term record of ecological data on mulloway (*Argyrosomus japonicus*) such that changes to populations of the species could be examined. We combined fish size, age and growth data from archaeological fish otoliths from a mound site at Greenfields, South Australia (1670–1308 cal. BP to 409–1 cal. BP), historical anecdotes from the National Library of Australia's database, Trove (AD 1871–2000), and contemporary data sources (AD 1984–2014) to examine changes to *A. japonicus,* populations in the waters of eastern South Australia.

The Study Region and Site

The eastern coast of South Australia encompasses Spencer Gulf, Gulf St Vincent, Yorke and Fleurieu Peninsulas, the Coorong, and the coastline continuing south to Nelson, just past the current border of Victoria (Figure 1). The Port River-Barker Inlet, the closest waterway to the Greenfields mound site, is the largest and most speciose estuary in the Gulf St Vincent, with 61 fish species identified (Gillanders et al. 2008). The inlet has become severely degraded since the arrival of Europeans to the region in the 1800s, with much of the formerly intertidal land drained for agricultural and industrial purposes, including salt evaporation ponds, industrial estates and large areas of landfill (Thomas 2010). Less impacted areas of the inlet are characterised by seagrass meadows, adjoining mudflats, mangrove woodlands and intertidal samphire wetlands (Thomas 2010); these environments are ideally suited as fish nursery areas supporting fisheries in Gulf St Vincent and beyond (Jones et al. 1996). Areas of Port River-Barker Inlet are now aquatic reserves.

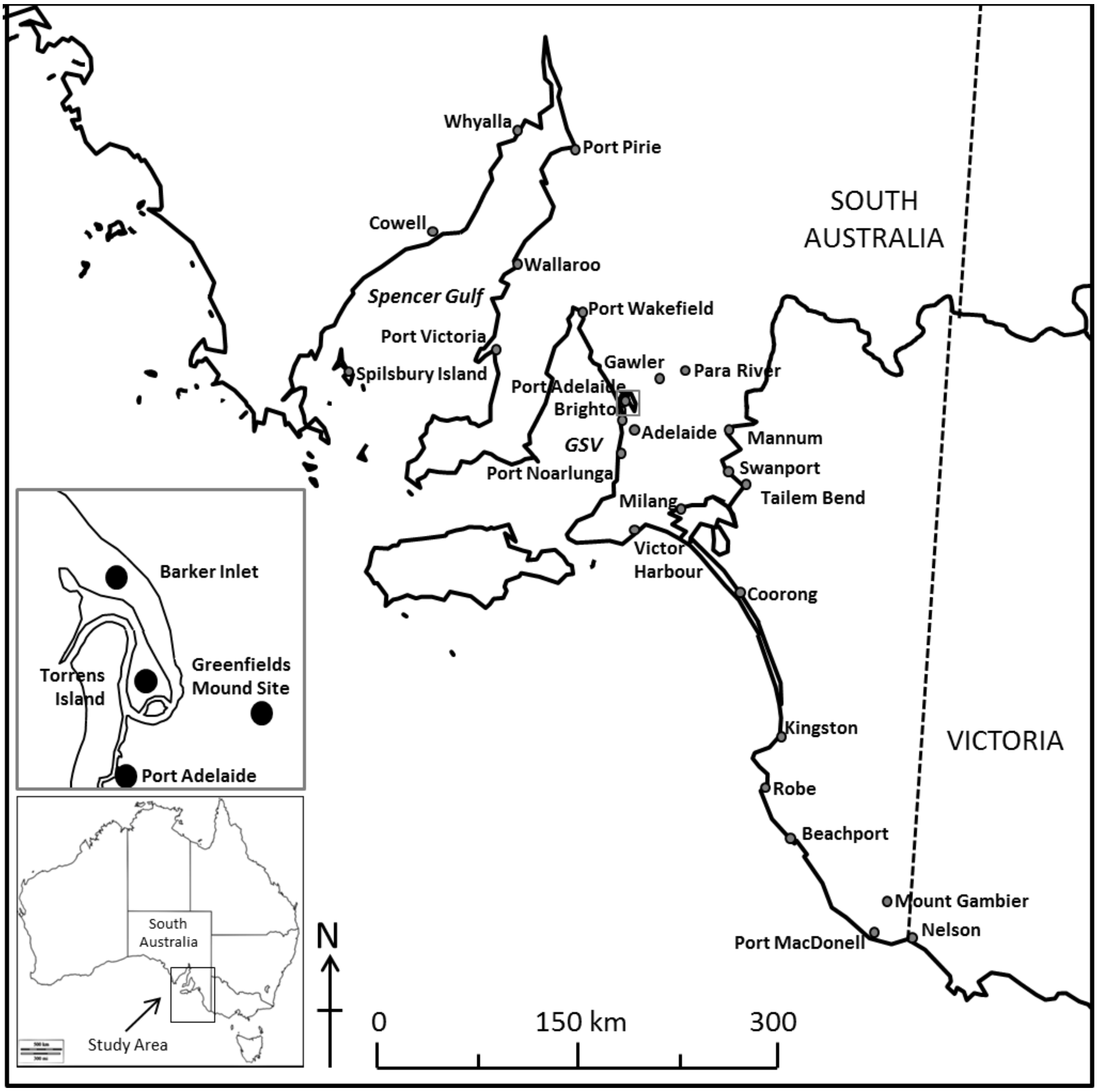

Figure 1: Map of eastern South Australia showing places mentioned in the text.

The Greenfields mound site is located on the flood plain of Dry Creek approximately 5 km from the current lower reaches and constructed wetlands of Barker Inlet, and approximately 10 km from the current coastline of the Gulf St Vincent. The site is a low mound (ca 80 m in diameter and up to 1 m high) composed of an accumulation of ash, charcoal, burnt heating stones from cooking ovens, stone tools, burials, food remains, decomposed plant material and earth. Draper et al. excavated the site in 1992 after development uncovered cultural remains. At the time of excavation, faunal remains were very well preserved and included skeletal parts of various species of bird, mammal, and fish; a large number of fish otoliths (n=522) were recovered during the salvage excavation, 81 of which were identified as mulloway (*A. japonicus*). The assemblage also contained otoliths from whiting (*Sillaginodes punctatus*, *Sillago schomburgkii* and *Sillago flindersi*) and snapper (*Pagrus auratus*).

*Mulloway (*Argyrosomus japonicus*)*

The mulloway, *A. japonicus*, is a large, predatory, teleost fish belonging to the sciaenid family. It is often associated with estuaries, and is distributed throughout the Indian and western Pacific Oceans. The species is fast growing and relatively long-lived, attaining a maximum age of ca 41 years and size of ~1800 mm (Ferguson et al. 2014). Juveniles inhabit estuarine environments, with sexual maturity of female and male *A. japonicus* in South Australia occurring at 6 and 5 years respectively, after which time they migrate into marine waters (Ferguson et al. 2014; Scott et al. 1974). Adult mulloway typically aggregate around estuary mouths during the summer months, attracted by freshwater outflows and an abundance of food. Currently, this is when most of the commercial and recreational catch is taken in areas within South Australia; predominantly at the mouth of the River Murray (adults) and in the Coorong lagoons (juveniles) (Earl and Ward 2014; Giri and Hall 2015; Jones et al. 2005). Mulloway are also targeted in the Port River-Barker Inlet by recreational fishers, primarily using rod and reel (Giri and Hall 2015). Measures, such as bag and minimum length limits, are in place in an attempt to sustainably manage stocks in South Australia; the minimum legal length for mulloway within the Coorong, including the channel of Murray mouth is 46 cm TL, whereas outside Coorong waters, it is 75 cm (PIRSA 2015). Similarly to other sciaenid species, mulloway are vulnerable to anthropogenic impacts because of certain life history characteristics including estuarine association, high age/size at maturity and high maximum age (Ferguson et al. 2014). As a result of intensive harvesting since the arrival of Europeans in the area, populations of *A. japonicus* have been reported as overfished in eastern Australia (Silberschneider et al. 2009). There are noted differences in biological parameters between mulloway from different regions (Farmer 2008; Ferguson et al. 2014; Silberschneider and Gray 2008), with such variation suggesting that locally specific information concerning the species should be collected to ensure appropriate management (Silberschneider et al. 2009).

Methods

Archaeological Samples

Nineteen mulloway otolith samples with known excavation locations within the site were radiocarbon dated at the ANTARES AMS facility at the Australian Nuclear Science and Technology Organisation (n=5) (Fink et al. 2004; Hua et al. 2001), and the Radiocarbon Laboratory, Australian National University (=14) (ANU) (Fallon et al. 2010). Conventional radiocarbon ages were calibrated using the CALIB (v7.0.2) program (Stuiver and Reimer 1993), and the Marine13 calibration dataset (Reimer et al. 2013) with a ΔR value of 61±104 as calculated for the nearby Gulf St Vincent (Ulm 2006). Although it is likely that the life histories of the fish included periods of fresh, marine and mixed environment habitation,

$\delta^{13}C$ values (Table 1) average 2.5, which is close to the marine water value of 0±2 reported by Stuiver and Polach (1977). However, if there was more freshwater influence, the reservoir age would likely be less, meaning that the calibrated ages here are likely a minimum age. Calibrated age ranges are reported at two-sigma.

Total fish length (TL), defined as the length from the tip of the snout to the extended longest caudal finray, was estimated from otolith weight. While the majority of otoliths were very well preserved, some otoliths were broken and incomplete owing to post-depositional processes such as physical weathering and breakage; therefore, weights recorded for these specimens are minimum values only, and thus calculated fish lengths should be considered underestimates. Only those otoliths >50% complete (i.e. large enough to be sectioned) were included in the size determination analysis; all otoliths were weighed to a resolution of 0.01 g. The relationship between otolith weight and fish length was obtained from measurements of recently collected fish in which both otolith weight and total fish length were measured [Linear Regression: Ln(Total length)=0.5611xLn(Otolith wt)+6.4761; r^2=0.981 (Greg Ferguson, SARDI Aquatic Sciences, unpublished data)].

For age determination, otoliths with a nucleus were rinsed using ultrapure water and left to air dry. They were embedded in resin, and placed in an oven at 54.5°C to harden overnight. Otoliths were then sectioned transversely through the nucleus using a Buehler Isomet low speed saw (speed 2.5) equipped with twin diamond edge blades with spacers (0.35 ± 0.05mm). The sections were mounted on glass slides using crystal bond and labelled, but were not polished because of their fragility.

The visible annuli of each sectioned otolith were counted to estimate the individual age of each fish at the time of death. Sections were viewed under a Leica MZ16FA stereomicroscope illuminated by incidental light. Ages were estimated from counts of opaque zones along the posterior axis of the sulcus following Ferguson et al. (2014). The annuli were counted from the nucleus to the outer edge of each otolith by two readers. Where the two counts differed, a third count was made by the primary author. The relative precision of the age estimates was calculated, using an index of the average percentage error (IAPE), as 5.88%. The edge annulus was also recorded as being translucent or opaque, as this information indicates the season during which the fish was caught. The wide, translucent band is laid down during periods of fast growth during the warmer months, while the narrower, opaque bands are laid down during periods of slow growth during the cooler months.

Historical Data Collection

We collected historical anecdotes from the National Library of Australia's database, Trove, conducting searches of the database using the keywords “mulloway OR butterfish”. Searches were limited to South Australian newspaper records mentioning mulloway catches, and including fish size (length or weight), and location of catch. Records date from 1847 up to and including 1999, the date of the final available record on mulloway. Where one anecdote mentioned a range of sizes, the maximum size was recorded. Where lengths of fish were recorded in feet or inches, these measurements were converted to centimetres and used in statistical analyses; however, the majority of the anecdotes recorded only weights of fish (pounds). These weights were converted to kilograms, then fish TL was estimated using the logarithmic relationship between fish length (TL) and fish weight (Fish length TL (cm) =21.303*ln(weight(kg))+47.41 (R^2 = 0.976, n=50) (Disspain unpublished data)

Contemporary Data

Fisheries reports and publications on *A. japonicus* in South Australian waters were reviewed to obtain data on modern maximum and average weights and lengths, age and growth of the species.

Results

Radiocarbon Dating

The calibrated radiocarbon ages of the mulloway otoliths range from 1670–1308 cal BP to 409–1 cal. BP (Table 1). The dates are spread consistently over the period of occupation, with no distinctive clustering of dates. All of the otolith samples with known provenances were dated, as well as three samples from one of the disturbed areas of the site, the Office Garden. The ages of the three samples from the Office Garden were spread over the span of the site's occupation period, a reflection of the extent of the disturbance, and an indication that identifying patterns and changes over time in the icthyofauna for which direct dates were not determined, within the disturbed areas of the site may be problematic.

Archaeological Otolith Morphology

Of the 81 *A.japonicus* otoliths identified from the Greenfields assemblage, 73 were more than 50% intact, (complete n=51, broken tip n=22) enabling estimates of fish TL and age to be estimated. The estimated fish TL, based on otolith weight, ranged from 501 mm to 1155 mm. The estimated ages ranged from 4 to 15 years (n=68), with the majority between 6 and 10 years old (82%, n=56) (Figure 2). The majority of the fish were caught during the warmer months, with 68 of the 69 samples analysed (98%) possessing translucent edge increments. All archaeological otolith data is presented in Appendix B, Table S5.1.

Table 1: Radiocarbon dates from the Greenfields Mound site

Otolith Number	Square	Unit	AMS LAB number	δ13C	Conventional Radiocarbon Age (Years BP)	Calibrated Age (cal. BP)
GF377	Office Garden	n/a	ANU-29930	1.0±0.8	495±25	unable to be calibrated
GF286	Scrape 3	F10	ANU-29924	7.4±1.2	660±30	409-1
GF101	D8	1C	ANU-29917	-4.7±2.2	680±45	435-1
GF121	D9	1C	ANU-29933	5.0±1.2	685±30	436-1
GF306	Scrape 5	A9	ANU-29927	8.2±1.2	685±30	436-1
GF112	D9	1C	ANU-29918	6.6±1.1	790±30	502-246
GF391	Office Garden	n/a	ANU-29932	7.6±1.2	780±30	504-231
GF080	C8	1D	OZO781	-2.0±0.1	835±30	520-273
GF028	B10	1C	ANU-29913	9.3±2.1	850±40	534-275
GF301	Scrape 3	S9/E10	ANU-29925	7.1±1.5	975±35	654-403
GF007	B7	1C	OZO779	-2.2±0.2	1020±35	668-449
GF122	D9	1D	ANU-29920	2.5±0.9	1495±30	1166-817
GF379	Office Garden	n/a	ANU-29931	1.0±1.1	1735±30	1369-1057
GF195	H9	1B	OZO783	-2.4±0.2	1780±40	1460-1087
GF196	H9	1B	ANU-29921	1.6±1.2	1805±30	1478-1151
GF302	Scrape 3	S9/E10	ANU-29926	4.2±1.3	1910±35	1561-1256
GF044	C7	1B	ANU-29924	5.2±1.0	1925±30	1571-1269
GF020	B9	1A	OZO780	-2.3±0.1	1975±40	1647-1293
GF108	D9	1A	OZO782	-0.6±0.3	1990±40	1670-1308

Historical Data Collection

A total of 257 historical anecdotes (1871–1999), which mentioned mulloway or butterfish, and provided information about the location of catch and individual size of the fish, were found (see Appendix C Table S5.2). Of these, the highest number (n=64, 25%) recorded catches from the waters near Nelson, in the state's far south (now part of the state of Victoria) (Table 2). From the Coorong and Lower Lakes region, 54 (21.1%) anecdotes were recorded, with quotes such as the following:

> Large Haul of Fish Near Milang. A big school of mulloway was noticed in the vicinity of the Milang Jetty on Friday. Fisherman had never seen big fish so close to the shore before, and were at first sceptical; but quickly realised that something extraordinary was apparent, and nets were set. Large sprays could be seen from the shore and the sight attracted many towns' people. The fishermen worked at high pressure for four hours, and the catch was estimated at many tons. Some of the fish weighed from 60 to 70 lb. Fish of that size have never been caught in great numbers here before (*The Advertiser* 16 March 1936).

The Port Adelaide area (n=41, 16%) and Victor Harbour (n=37, 14.5%) had the next highest numbers of anecdotes (Table 2), while Barker Inlet – within the Port Adelaide area – was mentioned once in 1954, referred to as ‘the back of Torrens Island’.

> Further confirmation has been received of mulloway taken at the back of Torrens Island. One catch consisted of eight mulloway of seven to 15 pounds. The location was between the old cattle station jetty and the red post at the cutting (Hook and Line, *The Mail*, 3 April 1954).

The maximum individual size of the fish recorded in the anecdotes ranged from 2.5 lb. (equivalent to 1.13 kg and 500 mm TL) on 23 April 1953 at the Glenelg River, Nelson to 46.2 kg (equivalent to 102 lb. and 1290 mm TL) on 22 October 1998 at Goolwa. Although the size range of fish from historic anecdotes generally spanned the range of sizes found from archaeological middens, there was a greater frequency of larger fish from historical anecdotes, presumably reflecting the approach used whereby the largest fish mentioned was recorded (Figure 2). Despite the wide range of sizes recorded, no significant change over time was evident within the time span of the historical anecdotes (Figure 3).

The highest percentage of historical anecdotes were recorded during the warmer months of the year, with 37% of all anecdotes recorded in February and March, at the end of summer in the Southern Hemisphere (Figure 4). The lowest number of anecdotes was recorded in September, at the start of spring.

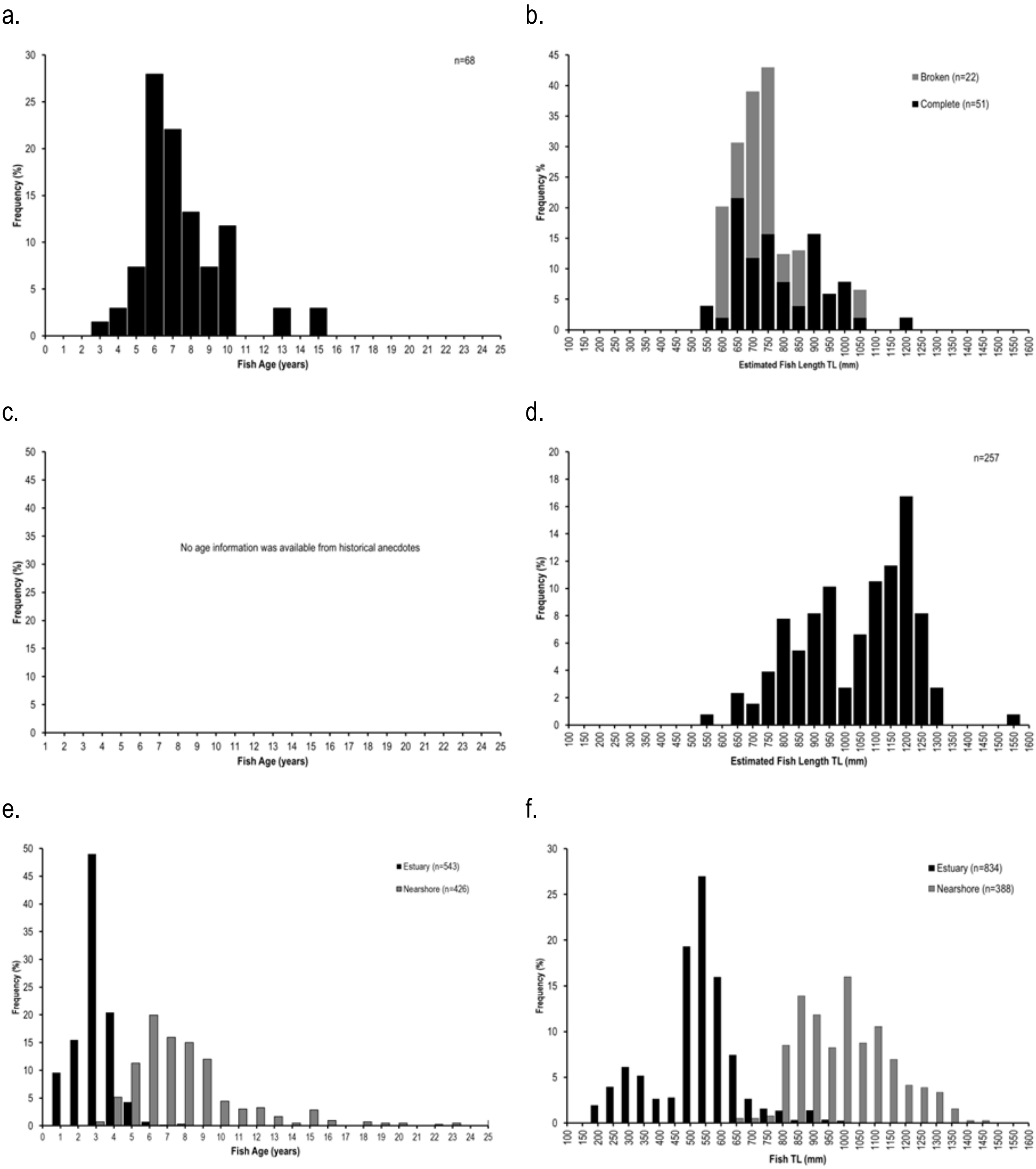

Figure 2: Age (left) and length (right) frequency plots for mulloway based on (a and b) the otoliths from the Greenfields mound site, South Australia, (c and d) fish sizes mentioned in historical anecdotes in South Australian newspapers available in Trove (1873-1999), and (e and f) fish age and size as compiled from modern fisheries reports (Earl and Ward 2014). Modern fisheries data originates from the following years: Age and TL (LCF) 2000/2001, 2002/2003, 2013/2014; (MSF) 2000/2001, 2001/2002, 2009/2010 (no length data), 2010/2011 (no length data), 2011/2012, 2012/2013 (no age data), 2013/2014, 2014/2015 (no length data). Recreational and commercial catch data reported in Earl and Ward (2014) have been combined. Note differing values on the y axes. Data are from two key fisheries in South Australia: LCF, Lakes and Coorong fishery data – Estuary; MSF, marine scalefish fishery data – Nearshore.

Table 2: Locations mentioned in historical anecdotes from South Australian newspaper records (1873-1999) available on Trove. See Figure 1 for a map of the locations.

Location	**Frequency**	**%**
Nelson	64	25.0
Coorong (Hindmarsh Island, Goolwa, Lower Lakes, Murray Mouth, Pelican Point, Point Sturt, Poltalloch, Ram Island)	54	21.1
Port Adelaide (Outer Harbour, Osborne Wharf, Torrens Island, Largs Bay, Semaphore, Grange Jetty)	41	16.0
Victor Harbour (Granite Island, Encounter Bay, Waitpinga, Port Elliot, Horseshoe Bay, Basham Beach, Middleton, Chiton Rocks)	37	14.5
Fleurieu Peninsula (Port Noarlunga, Onkaparinga River, Sellicks Beach, Port Willunga)	15	5.9
Milang	4	1.6
Port MacDonell (Blackfellows Caves, Cape Douglas)	4	1.6
Port Pirie/Port Germein	4	1.6
Beachport	3	1.2
Kingston	3	1.2
Brighton/Seacliff	3	1.2
Robe incl. Botswain Point	3	1.2
Adelaide	2	0.8
Cowell	2	0.8
Gawler	2	0.8
Mount Gambier	2	0.8
Port Wakefield	2	0.8
Swanport	2	0.8
Wallaroo	2	0.8
Gulf (near Whyalla)	1	0.4
Mannum	1	0.4
Para River, South of Tanunda	1	0.4
Port Victoria	1	0.4
Spilsbury Island	1	0.4
Tailem Bend	1	0.4
West Coast	1	0.4
Total	**256**	**100.0**

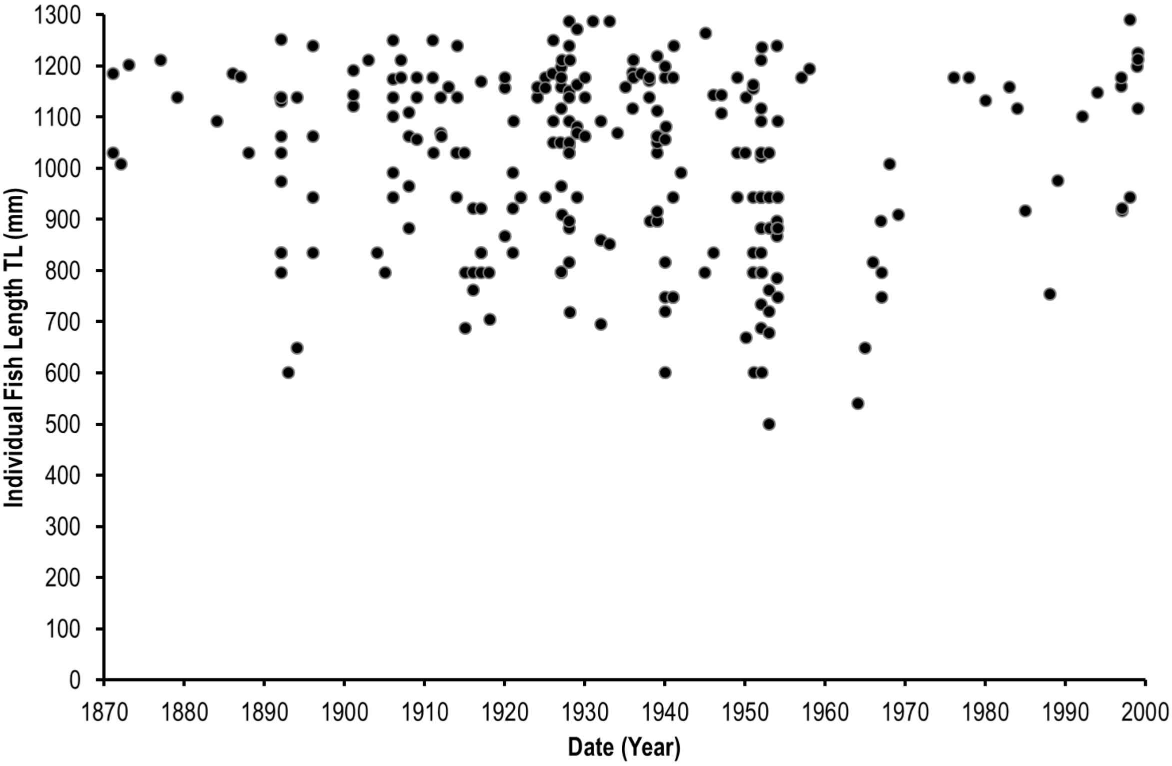

Figure 3: Individual *Argyrosomus japonicus* TL (cm) over time from 1873–1999 in eastern South Australia based on historical anecdotes from newspaper records available on Trove (n=258).

Contemporary Fisheries Data

Fisheries reports provide commercial and recreational catch data from 1984 to 2014 including total annual catches, catch and effort, gear type, average monthly catches, and population size and age structure for both the Lakes and Coorong Fishery (LCF) and the Marine Scalefish Fishery (MSF) (Earl and Ward 2014; Ferguson and Ward 2003; Giri and Hall 2015). The catch data suggests that, while the most recently reported total annual catches (2013/2014) of 68.3 t (LCF) and 1.1 t (MSF) have decreased from previous years, this is a result of a decrease in fishing effort, rather than a decline in fishable biomass (Earl and Ward 2014).

Age structures from catches within the Coorong estuary over the last 15 years range from 1 year to 8 years, but are dominated by 3 year olds (Figure 2e). Nearshore populations in eastern South Australia ranged in age from 4 to 23 years, with the majority of fish aged less than 10 years (Figure 2e).

Within the Coorong estuary, size structures ranged from 150–1000 mm, but were dominated by fish between 450–650 mm (Figure 2f). In the nearshore marine environment the size structures range from 650–1500 mm (Figure 2f), with a modal size of approximately 1000 mm; fish >1200 mm are rarely recorded (Earl and Ward 2014; Ferguson et al. 2014).

Within both the LCF and the MSF, higher monthly commercial catches between 1984/84 and 2013/14 occurred in summer (Figure 5). December and January had the highest catches for the LCF, with the lowest in August. On average, 68% of the annual catch within the LCF was taken from November to March. Within the MSF, the catches were also seasonal, with on average, 42% of the annual catch taken from November to February. Catches in the MSF were highest in December/January as in the LCF, and are lowest in September (Ferguson et al. 2014).

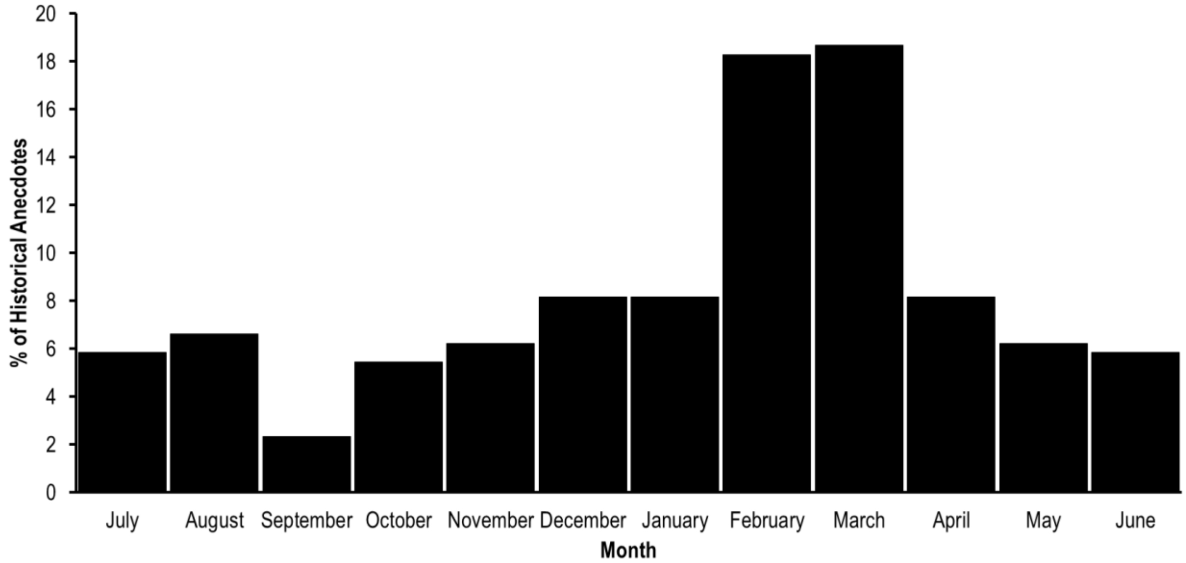

Figure 4: Month of catch of *Argyrosomus japonicus* (1873–1999) in eastern South Australia based on historical anecdotes from newspaper records available on Trove, expressed as a percentage of total number of anecdotes (n=258).

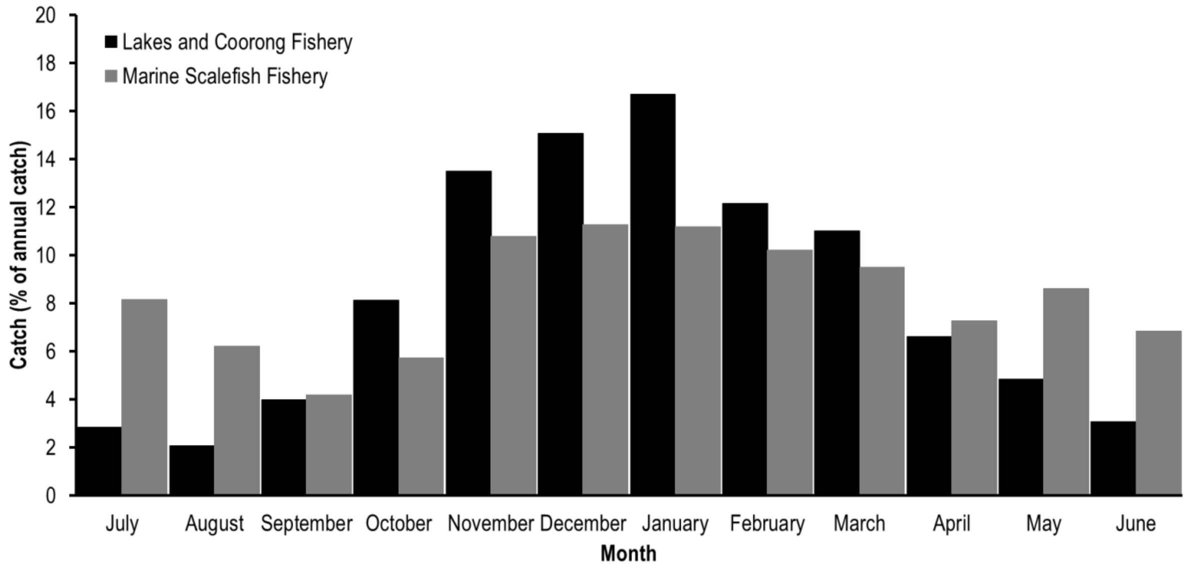

Figure 5: Average monthly catches of mulloway from the LCF and MSF from 1984/1985 to 2013/2014, expressed as a percentage of annual catch. Compiled from modern fisheries data (Earl and Ward 2014).

Fish Growth

A von Bertalanffy growth curve was fitted to the age-length data for the archaeological *A. japonicus* data:

$Lt = L_{inf}(1 - \exp^{-K[t-t_0]})$

where L_{inf} is the mean asymptotic maximum length predicted by the equation, K is the growth coefficient and t_0 is the hypothetical age at which fish would have zero length if growth had followed that predicted by the equation. The asymptotic size (L_{inf}) based on archaeological *A. japonicus* otoliths was 1577 mm TL and the growth rate (K) was 0.0548 y−1. In comparison, the asymptotic size of modern mulloway from eastern South Australia was estimated to be 1377 mm, with a growth rate of 0.136 y-1 (Ferguson et al. 2014) (Figure 6).

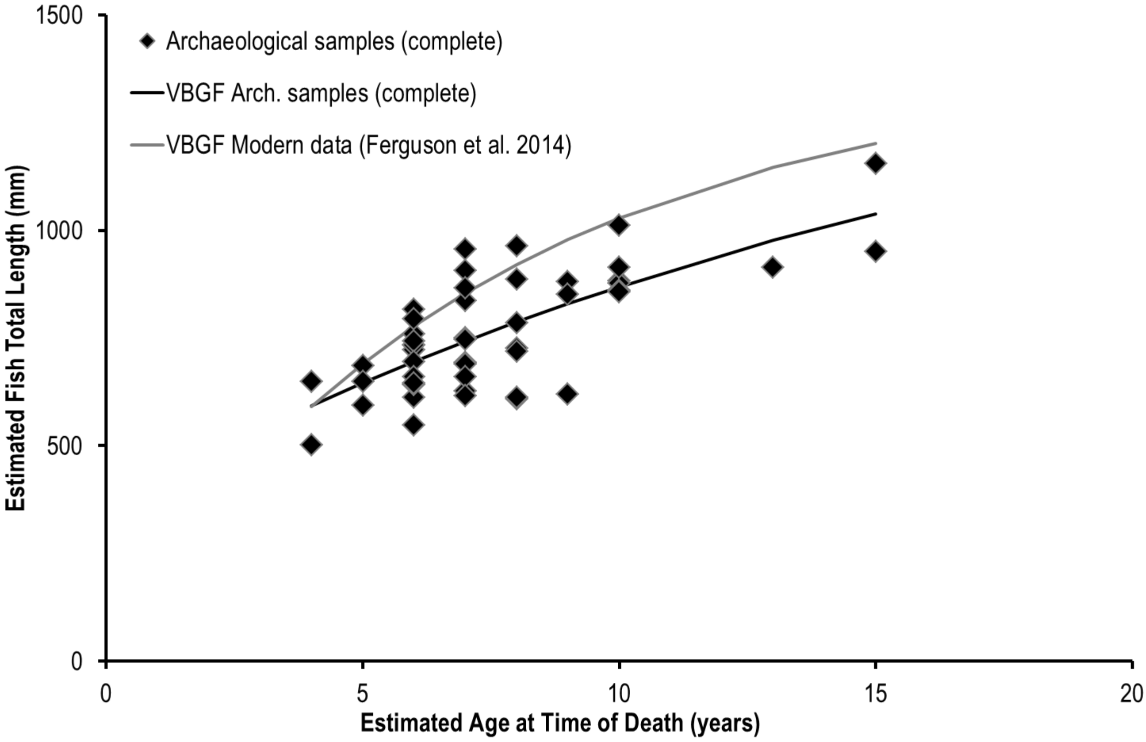

Figure 6: Von Bertalanffy growth function fitted to age-length data for complete archaeological samples from Greenfields, South Australia (n=48), compared with Von Bertalanffy growth function using parameters of modern *Argyrosomus japonicus* (male, female, and unsexed) from eastern South Australia (Ferguson et al. 2014).

Discussion

The data from the three different sources, archaeological, historical and contemporary, are similar in many aspects, with only minor differences. The range of sizes recorded from the contemporary data

(150–200 mm to 1450–1500 mm) was broader than those from the historical (500–550 mm to 1500–1550 mm) and archaeological (500–550 mm to 1150–1200 mm) data, although these latter two data sources may target larger fish through fishing or data collection approaches. The archaeological assemblage may also be influenced by the sieve size used in excavations. Internationally, *A. japonicus* has been recorded at a maximum TL of 1800 mm and weight of 75 kg (South Africa, Griffiths 1996), while in Australia, individuals up to 1690 mm TL have been recorded (Silberschneider et al. 2009). The smallest fish TL came from the archaeological assemblage, and largest from the historical anecdotes. While the majority of fish from the Greenfields site were estimated to be 550–800 mm TL, the fish mentioned in the historical anecdotes were typically larger than this size range. Contemporary LCF fish were generally smaller than this range, while those from the MSF are generally larger than this range, which can be attributed to the presence of juvenile or adult fish in their respective environments. These differences are likely due to the nature of the data rather than major changes in the populations over time. The sizes estimated from the archaeological otoliths are minimum estimates owing to taphonomic processes such as breakage or weathering. Furthermore, the analysis of a small assemblage of fish otoliths from one site cannot mirror the entire fish population of a region (Carder and Crock 2012) – a broader spatial examination would be beneficial in gaining a more comprehensive view. The lengths recorded in the historical anecdotes are likely the larger individuals as ordinary events do not usually gain media attention; as such, the historical anecdotes are biased towards larger fish. Additionally, where a range of sizes was reported in the records, the largest size was used in analyses. The contemporary data will be influenced by the methods used to catch the fish, as well as minimum catch sizes. Fishers operating in the Coorong use mainly large-mesh gill nets (115–150 mm mesh), while the MSF fishers use gill nets, haul nets and rod and lines to target mulloway (Earl and Ward 2014).

While there were no significant changes in fish TL over time within the historical anecdotes from 1871 to the end of 1999, this does not necessarily mean that the abundance of large fish has not changed. Given the impact that the industrialisation of fishing in the region has had, it is likely that the biases in the historical data and the nature of newspaper recording has affected these statistics. These data imply that the size structures of the species have remained stable. Other characteristics, such as growth or population numbers may have been affected. While the lack of young and old fish in the archaeological assemblage possibly means that the t_0 value is unrealistic, the L_{inf} values can be compared between the two equations. The von Bertalanffy growth curves for the modern (Ferguson et al. 2014) and archaeological samples suggested that fish present in the archaeological assemblage grew at a slower rate, but to a larger asymptotic size than their modern counterparts. Determining the cause of population structure change in faunal populations can be complex, with numerous other factors such as data source and collection methods, species ecology, environmental change, and cultural behaviour also having an impact (Butler 2010). In addition to biomass reduction, populations usually experience some degree of size and age alteration that reflects the targeting of larger, older individuals, with some species more susceptible to long term impacts, based on their ecological characteristics (Berkeley et al. 2004; Fowler and Ling 2010). Growth overfishing alone does not always impact the ability of a population to replenish itself, but can lead to recruitment overfishing by reducing egg production (Fowler and Ling 2010; Silberschneider et al. 2009). Additionally, the removal of higher trophic level predators can impact on the balance of the ecosystem.

The month of catch data for all three data sets is seasonal, with an increase in mulloway catches during the summer months. This is likely due to the ecology of the species, with adults migrating closer to the shore during the warmer seasons to spawn and take advantage of the abundance of food produced by freshwater outflows from river mouths (Ferguson et al. 2014). It may also be a reflection of the weather conditions and the ease with which the fishing grounds can/could be accessed. The majority of the fish from the archaeological and contemporary MSF assemblages were older than 5/6 years (the age at which the species migrates to marine environments from within the nursery of the estuary (Ferguson et al. 2014)), and both possess similar age structures (Figure 2), albeit with the archaeological assemblage returning a lower maximum age (arch=15 years, modern MSF=23 years). This suggests that the majority of the fish from the Greenfields site were likely caught in a nearshore environment of the GSV, as opposed to in the nearby Barker Inlet estuary. These ages are in comparison to the maximum recorded age of *A. japonicus* at 42 years in South Africa (Griffiths and Hecht 1995), and 41 years in Australia (Ferguson et al. 2014); fish that have attained these ages are rare, and lower maximum ages have also been recorded of 24 years (Silberschneider et al. 2009) and 32 years (Farmer 2008).

The *A. japonicus* otolith assemblage from the Greenfields site is comparable to that from a midden site complex further south at Long Point in the Coorong, which was used by Ngarrindjeri people from 2500 cal BP through to modern times (see Chapter 6 and Disspain et al. 2011). This Coorong site contained 20 *A. japonicus* otoliths; the majority of the fish at both sites were captured during the warmer months, while both the size and age ranges estimated from otoliths at the Long Point site were slightly broader (337–1265 mm TL and 3–19 years (Disspain et al. 2011)) than those at Greenfields. Given the similarities seen in both assemblages, it is probable that technologies and fishing methods were similar or perhaps shared between the two groups, the Ngarrindjeri and the Kaurna, who, in early historical times, were reported to meet regularly to trade various commodities (Berndt et al. 1993). Historical records detail fishing techniques used by the Kaurna; netting was a commonly used technique (Campbell 1979), and nets have been excavated from a cave further south along the coast (Tindale and Mountford 1936). Spearfishing was also recorded as being used during historical times (Hemming 1985), while the use of hook and line is questioned (Radford and Campbell 1982). The Ngarrindjeri of the Coorong and Lower Lakes region are known to have utilised an extensive array of technologies and techniques to harvest fish, including hooks (Gerritsen 2001), netting and baskets, spearing from canoes and watercraft (Berndt et al. 1993; Clarke 2002), and the construction and use of intricate fish traps, some of which still exist today (Ross 2009).

Fishing techniques used to harvest *A. japonicus* during the three time spans compared here would have been vastly different. The mulloway from the Greenfields site may have been captured using any of the abovementioned methods; the large size and predatory nature of adult mulloway makes it an ideal target for spearing or hook and line methods, while the schooling nature of juveniles means that nets would also be an ideal catch method. During historical times, techniques for mass capture developed, enabling greater distances to be travelled and larger catches to be harvested. These advances, along with the exploration of new fishing grounds and developing fisheries regulation, mean that historical data represents efforts beyond the capabilities of Indigenous people prior to European settlement of the region. Modern fisheries data represent an industry regulated and enforced in a different manner to earlier times, with technologies that enable significant distances to be travelled and specific size or species of fish to be targeted. As such, the data presented here corresponds to different eras in the development of fishing in eastern South Australia, and is influenced by the associated technologies. Despite this, the data provides snapshots of *A. japonicus* populations that would otherwise be unobtainable.

Conclusions

Evaluation and comparison of three sequential eras of mulloway fishing along the eastern coast of South Australia have revealed only minor differences in size, age, and growth of the species over the studied timespan. While the data indicate size continuity from prehistoric times through to the modern day, they must be interpreted with caution, owing to the nature of the data. The historical anecdotes are filled with mentions of the boundless availability of giant fish, and while these may be exaggerations and 'fishermen's tales' it is in stark contrast to the current state of the fishery, with catch rates for the MSF in 2013/2014 at the lowest recorded level, attributed to a decline in targeted fishing effort (Earl and Ward 2014), possibly as fishers move away from mulloway, to other, more profitable/abundant species. Interestingly, no significant changes in the maximum size of mulloway were indicated throughout the historical period. Further research into the effects of increased predation on mulloway would be beneficial – or perhaps the South Australian population of this species is more robust than their eastern equivalent (Silberschneider et al. 2009), and less impacted by the industrialisation of fishing. While this study did not highlight a significant change in fish age or size through time, it did demonstrate the benefit of combining data sets from extended time periods to examine fish survival over thousands of years.

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Chapter 6

Direct radiocarbon dating of fish otoliths from mulloway (*Argyrosomus japonicus*) and black bream (*Acanthopagrus butcheri*) from Long Point, Coorong, South Australia

Long Point, Coorong, South Australia with a backfilled excavation trench in the foreground.

Statement of Authorship

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Contribution to the Paper	Assisted with excavation of archaeological site to obtain samples, conducted research, analysed data, wrote manuscript and grant applications supporting research. Acted as corresponding author.		
Overall percentage (%)	80%		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	21 June 2016

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);
ii. permission is granted for the candidate in include the publication in the thesis; and
iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

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Contribution to the Paper	Developed original Long Point archaeological project and secured funding for that project, conducted community consultation, obtained ethics approval, led the excavation of the archaeological site and its subsequent analysis, and provided otolith samples for analysis. Provided suggestions, comments and feedback on manuscript drafts. Assisted with intellectual development.		
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Contribution to the Paper	Conducted radiocarbon dating, provided specialist advice on data analysis, provided suggestions, comments and feedback on manuscript draft.		
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Contribution to the Paper	Traditional Owner of the archaeological site; played key role in community consultation for the project and in obtaining ethics approval. Provided suggestions, comments and feedback on manuscript drafts.		
Signature	Signed by Morgan Disspain on behalf of co-author. Permission and acceptance received verbally and via email (April 2016)	Date	25 July 2016

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Contribution to the Paper	Assisted with the excavation of the archaeological site and its subsequent analysis. Provided suggestions, comments and feedback on manuscript draft.		
Signature		Date	28 June 2016

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Contribution to the Paper	Assisted with excavation of archaeological site and provided suggestions, comments and feedback on manuscript draft.		
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Contribution to the Paper	Assisted with data analysis, provided suggestions, comments and feedback on manuscript drafts. Assisted with intellectual development.		
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Contribution to the Paper	Co-wrote grant applications supporting the research, provided suggestions, comments and feedback on manuscript drafts. Assisted with intellectual development.		
Signature		Date	30 June 2016

Direct radiocarbon dating of fish otoliths from mulloway (*Argyrosomus japonicus*) and black bream (*Acanthopagrus butcheri*) from Long Point, Coorong, South Australia

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Abstract

Accelerator Mass Spectrometry (AMS) radiocarbon dates (n=20) determined on fish otoliths from mulloway (*Argyrosomus japonicus*) and black bream (*Acanthopagrus butcheri*) are reported from five sites at Long Point, Coorong, South Australia. The dates range from 2938–2529 to 326–1 cal. BP, extending the known period of occupation of Long Point. Previous dating at the sites indicated intensive occupation of the area from 2455–2134 cal. BP. Results provide a detailed local chronology for the region, contributing to a more comprehensive understanding of human use of Ngarrindjeri lands and waters. This study validates the use of fish otoliths for radiocarbon dating.

Keywords: AMS radiocarbon dating, otolith, midden, Coorong

Introduction

The Coorong is a shallow saline lagoon, >100 km in length, at the terminus of the largest river in Australia, the Murray. This water body is separated from the Southern Ocean by a narrow strip of sand-dunes and with Lakes Alexandrina and Albert located at its northern extremity (Figure 1). In its natural state, prior to European alteration and the construction of barrages, the Coorong estuary comprised fresh, brackish and saline environments influenced by both marine and freshwater (river) inflow. Increased human regulation of the Murray has resulted in significantly increased salinity ranges, with hypersaline conditions existing in some areas of the Coorong (Jones et al. 2002; Scheltinga et al. 2006). Together, the Coorong and Lower Lakes support 78 species of fish, including mulloway, *Argyrosomus japonicus*, and black bream, *Acanthopagrus butcheri* (Geddes 2000).

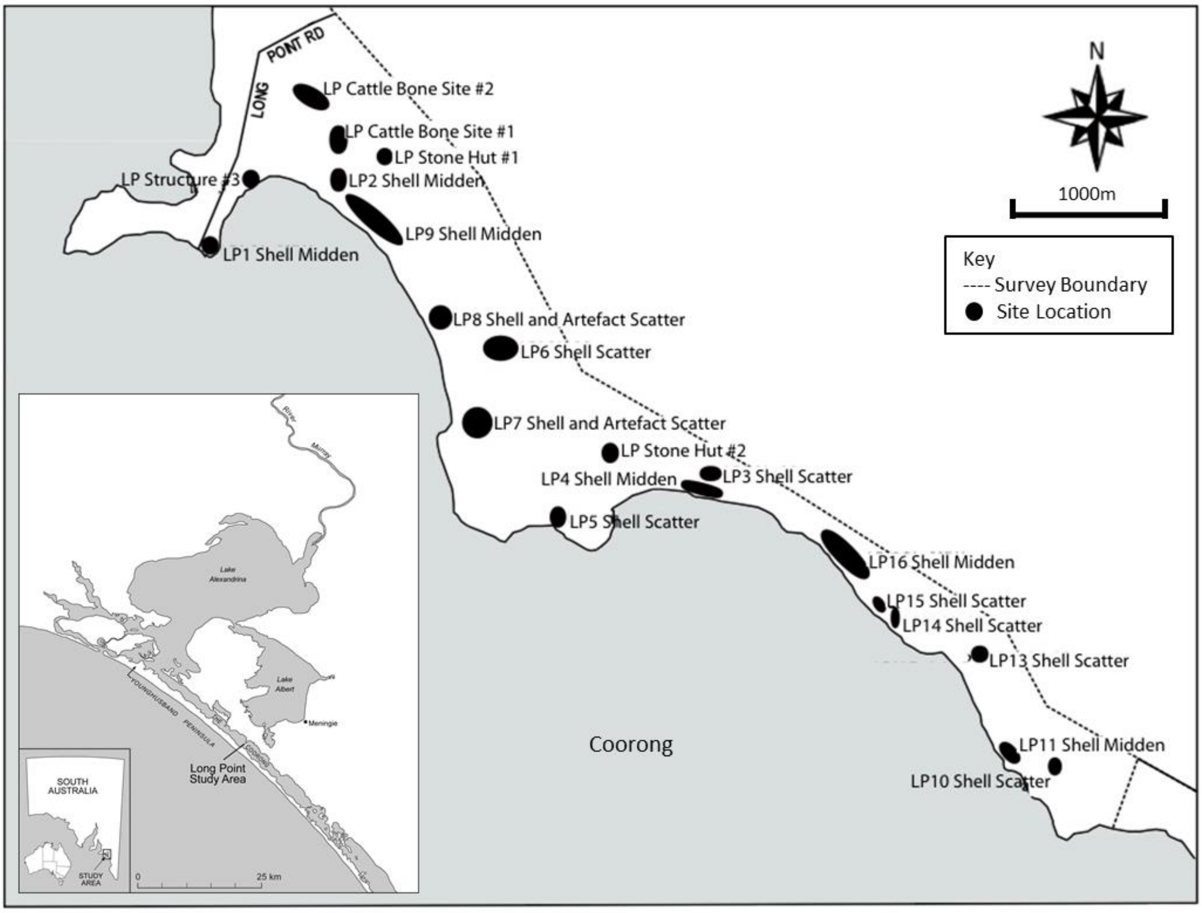

Figure 1: Map of Long Point showing the location and general extent of recorded sites.

A. japonicus is a large predatory teleost fish belonging to the Sciaenid family. It is a fast growing, relatively long-lived species, attaining a maximum age of 41 years and size of ~1800 mm (Ferguson et al. 2014; Scott et al. 1974). Juveniles inhabit estuarine environments, and adults typically aggregate around estuary mouths during the summer months, attracted by freshwater outflows and an abundance of food (Ferguson et al. 2014). *A. butcheri,* a member of the Sparidae family, is common in river mouths and estuaries where it prefers overhanging banks, snags and dead trees on the bottom of low salinity pools (Norriss et al. 2002). It is a slow growing, relatively long-lived species, reaching a maximum age of 29 years and length of 400 mm (Cashmore et al. 2000).

For thousands of years the area of the Lower Lakes and Coorong in South Australia (SA) has comprised the traditional *ruwe* (country) of the Ngarrindjeri people (Ngarrindjeri Tendi et al. 2007). At the time of European invasion, 1836, it is reputed to have been among the most densely populated areas in Australia owing to the richness of natural resources (Jenkin 1979; Taplin 1879). Archaeological research in the area has documented hundreds of middens, testament to thousands of years of Ngarrindjeri resource use and occupation in the region (Luebbers 1978,1981,1982; St George 2009; St George et al. 2013; Wallis 2007a, 2007b; Wallis and Disspain 2008; Wilson et al. 2012). Luebbers (1978, 1981, 1982) suggested that the Coorong experienced an intensive settlement phase from 2000 BP–AD 1840s. St George et al. (2013) supported this theory with 29 radiocarbon dates (charcoal and shell) from sites at Long Point, which suggested continued use from post-2500 cal. BP to the recent past.

Temporal shifts in fish populations in the Lower Lakes and Coorong are expected to offer important information about fluctuating human subsistence, with archaeological otoliths providing useful environmental proxies. However, these studies were originally temporally constrained by the use of dates on associated materials (shell and charcoal) from the same sites (Disspain et al. 2011; Disspain et al. 2012). Despite a strong preference for using shell or charcoal samples for radiocarbon dating in archaeology, fish otoliths have been successfully dated in numerous studies (e.g., Favier Dubois and Scartascini 2012; Hufthammer et al. 2010; Scartascini and Volpedo 2013). Here we present the results of direct radiocarbon dating of Long Point otoliths, and compare them with charcoal and shell dates reported by St George et al. (2013).

Methods

In 2008, four middens in the Long Point area of the northern Coorong were excavated: LP4, LP9, LP11 and LP16 (Figure 1) (see St George 2009; St George et al. 2013; Wallis and Disspain 2008, for details). Additional surface material was collected from a deflated cultural lens in a sand dune blowout (LP8). All four middens were excavated to culturally sterile sediment using arbitrary 5 cm spits (unless otherwise dictated by a stratigraphic change). The excavated materials from each spit were weighed and passed through 7 mm and 3 mm nested sieves, with the retained sieve residues examined to recover cultural materials. A total of 23 otoliths from *A. japonicus* and *A. butcheri* were recovered from the aforementioned five sites. Of these, 20 were selected for radiocarbon dating; two samples (otoliths LP09 and LP19) were not dated because they were small fragments that could not be identified to species (Disspain et al. 2011).

Approximately 10 mg of material was removed from the margin of each otolith with a Dremel® rotary tool and stored in a clean glass vial. At the Australian National University Radiocarbon Dating Laboratory, samples were ground to a powder, transferred to evacuated (<10^{-3}Torr) Vacutainer® tubes and acidified with phosphoric acid (0.5 ml, 85%, 80ºC) until the reaction was complete. The CO_2 generated was collected and purified cryogenically before reaction with H_2 over an iron catalyst at 570ºC. Water was removed during the reaction by Mg $(ClO_4)_2$. The graphite was pressed into a target and analysed for ^{14}C using a Single Stage Accelerator Mass Spectrometer (Fallon et al. 2010). Radiocarbon values were calibrated using CALIB (v7.0.2) program (Stuiver and Reimer 1993), using the Marine13 calibration dataset (Reimer et al. 2013) with a ∆R value of 61±104 as calculated for the nearby Gulf St Vincent (Ulm 2006). Although it has been shown that the life histories of the fish include periods of fresh, marine and mixed environment habitation (Disspain et al. 2011), $\delta^{13}C$ values (Table 1) average -2.0 (range -5.9–1.9), close to the value of marine water of 0.0±2 reported by Stuiver and Polach (1977). If there was more freshwater influence, the reservoir age would probably be less, meaning that the calibrated ages here are probably a minimum age. Calibrated age ranges are reported at two-sigma.

Results

The radiocarbon dates obtained from the fish otoliths from Long Point range from 2938–2529 to 326–1 cal. BP (Table 1). Two distinct clusters of dates are evident, one from ca 500 cal. BP to present, and another ca 2000 cal. BP (Figure 2). From site LP4, only one otolith (otolith LP01) was recovered; this originated from approximately 16–20 cm below the surface, and was dated to 523–280 cal. BP. Eleven otoliths from site LP9 were dated, with maximum age of 2295–1917 cal. BP (otolith LP02), and a minimum of 401–47 cal. BP (otolith LP10). From site LP16, two otoliths (otoliths LP16 and LP17) were recovered from the same spit (21–25 cm below surface), and dated to 566–291 cal. BP and 601–314 cal. BP, respectively. Dating of the otoliths recovered from site LP11 showed it to have the longest span of occupation, from 2938–2529 (otolith LP20) to 326–1 cal. BP (otolith LP18). The two otoliths from the LP8 surface scatter site both returned similar dates, 468–134 cal. BP (otolith LP14) and 442–70 cal. BP (otolith LP15).

Table 1: Radiocarbon ages for fish otoliths from Long Point based on direct dating of otoliths and dating of charcoal or shell material (St George et al. 2013). * indicates no radiocarbon determination was available from the same excavation unit, and an age range was assigned based on the nearest available ages.

										St George et al. 2013		
Otolith code	**Lab number**	**Site**	**Square**	**Spit**	**Depth Below Surface (cm)**	**Species**	**δ13C**	**Uncalibrated age (BP)**	**Calibrated age (cal. BP)**	**Lab number**	**Material**	**cal. Years BP**
LP18	ANU-16725	LP11	A	4	16-20	*A. japonicus*	-1.0±0.5	620±30	326-1	ANU6629	Charcoal	490–318
LP10	ANU-16716	LP9	AD	1	0-5	*A. butcheri*	-0.8±0.4	655±30	401-47	ANU6619	Charcoal	Modern
LP15	ANU-16721	LP8	E1	M2	Surface	*A. japonicus*	-2.1±0.3	690±30	442-70	Wk-21217	Shell	276-modern
LP14	ANU-16720	LP8	E1	M1	Surface	*A. japonicus*	0.9±0.5	730±30	468-134	Wk-21217	Shell	276-modern
LP22	ANU-16729	LP11	C	5	21-25	*A. japonicus*	-2.3±1.1	725±35	471-124	ANU6633	Charcoal	499–322
LP01	ANU-16706	LP4	AK14	4	16-20	*A. japonicus*	-3.9±0.6	845±30	523-280	ANU6614	Charcoal	321–modern
LP16	ANU-16723	LP16	L8	5	21-25	*A. japonicus*	-5.0±0.6	890±30	566-291	ANU6627	Charcoal	491–298
LP17	ANU-16724	LP16	L8	5	21-25	*A. japonicus*	-0.6±0.4	910±30	601-314	ANU6627	Charcoal	491–298
LP21	ANU-16727	LP11	B	2	6-10	*A. japonicus*	-4.5±0.6	1620±35	1265-951	ANU 6632	Shell	<930-671*
LP07	ANU-16713	LP9	AD	4	16-20	*A. japonicus*	-2.7±0.4	2125±30	1829-1456	ANU6620	Charcoal	1816–1569
LP03	ANU-16709	LP9	Y	2	6-10	*A. japonicus*	1.2±0.4	2140±30	1848-1486	ANU6617	Charcoal	<1951-2306*
LP04	ANU-16710	LP9	Y	5	21-25	*A. japonicus*	1.9±1.0	2155±35	1864-1501	ANU6617	Charcoal	2306–1951
LP11	ANU-16717	LP9	AD	1	0-5	*A. japonicus*	-0.8±0.5	2165±30	1864-1515	ANU6619	Charcoal	Modern
LP13	ANU-16719	LP9	AY12	11	51-55	*A. butcheri*	-5.9±0.4	2325±30	2067-1687	ANU6623 and ANU6625	Charcoal	1822-modern*
LP06	ANU-16712	LP9	AD	4	16-20	*A. japonicus*	-4.9±0.4	2395±30	2146-1768	ANU6620	Charcoal	1816–1569
LP12	ANU-16718	LP9	AY12	12	56-60	*A. japonicus*	-0.7±0.4	2400±30	2151-1772	ANU6623 and ANU6625	Charcoal	1822-modern*
LP05	ANU-16711	LP9	Y	5	21-25	*A. japonicus*	-5.4±0.9	2310±35	2171-2161	ANU6617	Charcoal	2306–1951
LP08	ANU-16714	LP9	AD	5	21-25	*A. japonicus*	-1.1±0.5	2490±30	2283-1894	ANU6620 and ANU6621	Charcoal	1569-2121*
LP02	ANU-16707	LP9	Y	2	6-10	*A. japonicus*	-1.0±0.4	2510±30	2295-1917	ANU6617	Charcoal	<1951-2306*
LP20	ANU-16726	LP11	B	2	6-10	*A. japonicus*	-1.8±0.5	3035±35	2938-2529	ANU 6632	Shell	<930-671*

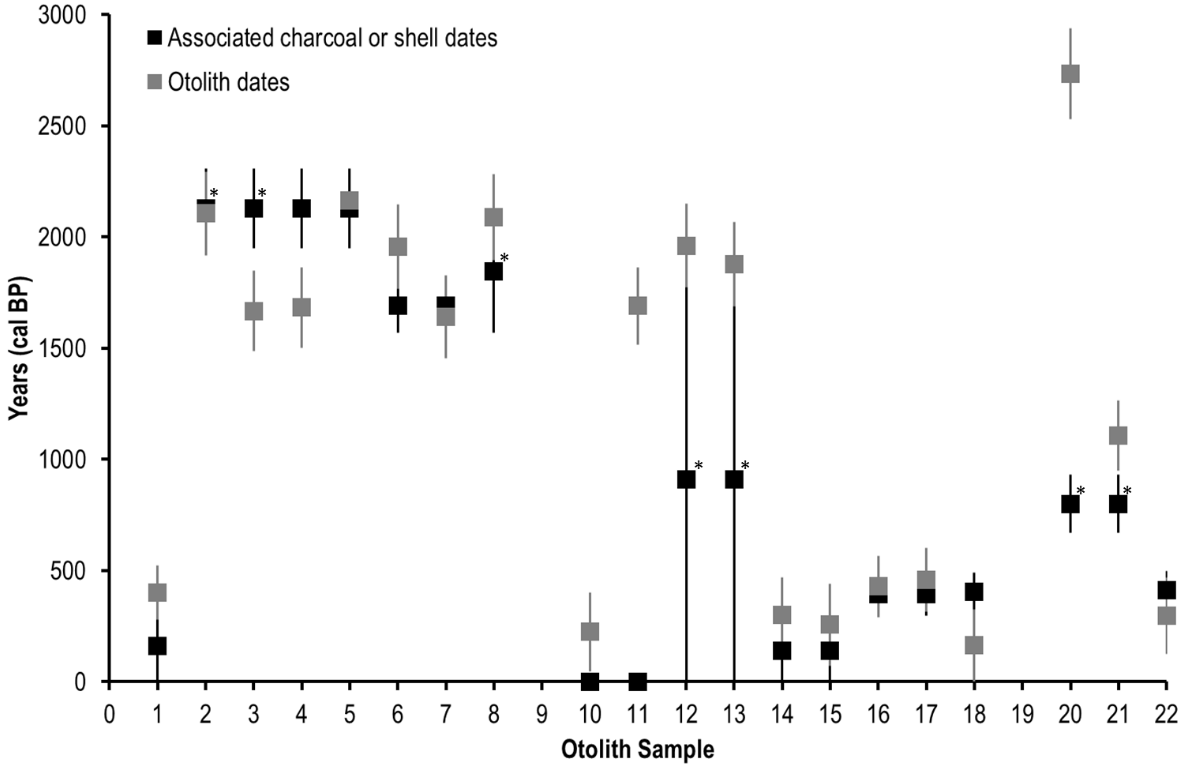

Figure 2: Direct otolith dates vs associated charcoal or shell dates (St George et al. 2013) from Long Point. * indicates no radiocarbon determination was available from the same excavation unit, and an age range was assigned based on the nearest available ages. Note that otoliths LP09 and LP19 were not dated.

The majority of otolith dates are within ca 300 years of the original associated charcoal and shell dates from the same provenance (Table 1, Figure 2). Considering the complexity of shell midden taphonomy and the small size of otoliths and charcoal fragments this consistency is surprising. Two anomalies/inversions were observed. Otolith LP11 from site LP9, Square AD, Spit 1 was directly dated to 1864–1515 cal. BP, while the associated charcoal date from the same provenance was dated as modern (St George et al. 2013). A charcoal sample from Spit 4 (20 cm below surface) of the same test pit was dated to 1816–1569 cal BP (S-ANU6620) (St George et al. 2013). This is most probably due to contamination of the lower levels of the site with modern surface material during excavation, or possibly site disturbance or reworking of the top 20 cm of sediment. The other inverted date was that of otolith LP20 (2938–2529 cal. BP), from the LP11 test pit (Square B, Spit 2). This sample was stratigraphically positioned above a shell sample (site LP11, Square B, Spit 3), which was associated with the lowest cultural material from the test pit and dated to 930–671 cal. BP (S-ANU6632) (St George et al. 2013). This anomaly may be the result of bioturbation, where the shell or otolith may have moved within the site matrix.

Discussion

Based on the new radiocarbon chronology established from the Long Point otoliths, occupation at the site, while still confined to the late Holocene, may extend several hundred years earlier than was indicated by shell and charcoal dates (St George et al. 2013). Unfortunately, no otolith samples were excavated from the same provenance as the oldest associated material date (LP9/Y/10 2455–2134 cal. BP ANU6618 2340±55 (St George et al. 2013)). All previous dates fell after the range of these values, while in this study, one otolith—otolith LP20—from site LP11 was dated to 2938–2529 cal. BP. Conservatively, at two-sigma, this otolith is between 74 and 804 years older than the oldest charcoal/shell date; this value is broad owing to the lack of a local marine reservoir correction value. The regional value used had wide error margins, resulting in a broad calibrated age-range. One outlying date may not provide sufficient evidence to confidently extend the antiquity of the site. Considering that another otolith (otolith LP21) from the same spit was dated to 1265–951 cal. BP, taphonomic site processes may contribute to this inconsistency, and further dating of samples from this square could help to confirm this finding. Should this otolith be a remnant of anthropogenic activities, its presence in the site could indicate that this location was occupied during the initial coastal settlement phase (4500–2000 BP) of the suggested phases of occupation in the region (Luebbers 1978,1981,1982).

The pattern of date clusters, one at <500 cal. BP and another ca 2000 cal. BP, differs from the pattern evident in the associated charcoal and shell dates (St George et al. 2013), which spread consistently over the period of occupation. These clusters could be artefacts of taphonomic site processes and preservation; however, fish bone in general was recovered from the Long Point sites in relatively small quantities, especially when compared with shellfish, which has been attributed to the deliberate targeting of shellfish at this particular location (St George 2009). This is despite numerous ethnographic sources asserting that Ngarrindjeri diets traditionally consisted mainly of fish (Beveridge 1882; Hawdon 1952; Krefft 1865; Sturt 1982), a view reiterated today by community members (Ngarrindjeri Tendi 2007). As such, it is possible that these clusters of dates reflect times when there was a more focused effort on fishing at these sites, but without a larger sample size, the exact cause cannot be determined.

The provision of direct ages for the otoliths has implications for previous analyses conducted on these samples (Disspain 2009; Disspain et al. 2011). Fish otoliths were assigned dates either from radiocarbon dating of charcoal or shell from the same excavation unit or, if no dates were available, by using an age range from nearest available excavation units. Initially, otolith LP13 (*A. butcheri*) had been assigned an uncalibrated, inverted date of 190±40 (Disspain et al. 2011). After further dating was carried out, the age of the otolith was estimated to fall between 1822 cal. BP and a modern date (St George et al. 2013). This study has produced a direct date for otolith LP13 of 2067–1687 cal. BP. The scarcity of otoliths from *A. butcheri* at Long Point, combined with the samples' estimated recent ages (Table I), had previously been assumed to indicate that they did not preserve well within the site

(Disspain 2009). The new results indicate that otoliths of *A. butcheri* are in fact capable of surviving significantly long periods of time in archaeological deposits, and alternate causes for the scarcity of specimens may be preferential targeting of the larger species, *A. japonicus*, either through capture or sampling of midden material.

Changes in fish age and size through time were previously examined using only ages determined on associated materials (Disspain 2009). After reanalysing the trends over time using direct dates, we determine that, despite a number of direct dates being significantly different to the original associated dates, the overall patterns that were reported essentially remain the same. This indicates that associated dates are useful when examining broad-scale patterns in data, but when more precise information is required, direct dating is preferable.

Conclusion

Direct radiocarbon dating of fish otoliths from midden sites at Long Point may extend the period of human occupation of the area by 483–395 years from previous dating projects. The addition of otolith AMS radiocarbon dates to the archaeological information for the sites has refined previous research results that originally relied on associated dates of charcoal and shell with the same provenance. We recommend comprehensive direct dating, targeting multiple material types in order to investigate anomalies and site disturbance inherent within midden excavations. Further dating studies could establish the extent to which contamination exists through replication of radiocarbon dates for independent samples. Cross dating otoliths with other material types (shell or charcoal) is expected to provide important data, enabling regional ΔR values to be determined. In combination, the data provide us with a growing level of insight into broad patterns of human-environment relationships in the region.

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Chapter 7

General Discussion

Eating fish caught in a waterhole, cooked on a campfire, and cooled on eucalyptus leaves while doing fieldwork in the Pilbara, Western Australia.

General Discussion

Otolith analysis within archaeological and palaeoenvironmental research is becoming more frequently applied, with advances in modern fisheries research continually being incorporated into and/or adapted to the study of ancient samples. The unique properties of fish otoliths allow them to provide significant data with which to study past human populations, facilitating investigations of ancient subsistence strategies, fishing methods, cultural behaviours, and site occupation patterns. In addition, they contribute information concerning palaeoenvironmental conditions and baseline data for rehabilitating native fish species. Hence, archaeological otolith analysis has relevance in the broader research community, contributing vital, and otherwise difficult to obtain, information to ecological conservation efforts and environmental management/rehabilitation (e.g., Rowell et al. 2008), as well as to examining the 'shifting baselines syndrome' (Izzo et al. 2016).

Throughout this thesis, the reliability of data obtained from prehistoric fish otoliths was examined and their use and application within cross-disciplinary research areas was explored. Specifically, the development and future prospects of otolith studies within archaeology were overviewed and synthesised, the reliability of archaeological fish otoliths as proxies for environmental change was examined through the use of experimental archaeology, and numerous applications of archaeological otolith analyses were explored through the analysis of otoliths from a collection of archaeological sites. This thesis ultimately investigated what ancient otoliths can tell us about past environments, fish populations, and people. In this chapter, the main findings of this research are discussed, and future research directions are suggested.

Otoliths as Records of the Past

In Chapter 2, the use of otoliths in archaeological research was reviewed; applications and methods were outlined and limitations were discussed. The central finding of the chapter was that while ancient otoliths can reveal important anthropogenic, biological and environmental information, continuing technological and methodological advances and an increase in cross-disciplinary research programs would serve to increase the value of this resource. Since Chapter 2 was accepted for publication in the *Journal of Archaeological Science: Reports* in May 2015, further developments in the field of archaeological otolith science have been published. Synchrotron micro-X-ray fluorescence (µXRF) multi-elemental mapping is one such technique. Research into this method has recently yielded quantitative multi-elemental maps of archaeological otoliths with good lateral resolution that reveals the biogenic signal along the growth axis with an ability to identify possible diagenetic alterations (Cook et al. 2015). Further, a combination of µXRF and synchrotron micro-X-ray absorption spectroscopy (µXAS) was verified to be an effective method for examining biominerals and elucidation of incorporation mechanisms of trace elements (Cook et al. 2016). Laser-ablation inductively coupled plasma-mass spectrometry (LA-ICP-MS), which has only recently been applied to archaeological otoliths (Disspain et al. 2011, 2012), has now been explored further (Peacock et al. 2016). New developments in modern fisheries science have also been developed (e.g., Mapp et al. 2016; Weigele et al. 2016), suggesting the possibility of the future incorporation of new ideas, technologies and methods into the study of archaeological otoliths.

The Reliability of Archaeological Otoliths

As Chapter 2 confirms, the morphological and chemical properties of fish otoliths provide excellent environmental and anthropogenic proxies; however, they can be subjected to numerous taphonomic processes, both pre- and post-deposition, which may alter these properties, confounding interpretations. Taphonomic processes include human and non-human agents, with many archaeological remains likely to have been exposed to both effects. Of the human impacts, cooking and processing for consumption are the major agents of taphonomic transformations of faunal remains (Nicholson 1993,1995; Willis and Boehm 2014; Willis et al. 2008). Chapter 3 examined the effects of various cooking and processing methods on the morphology and chemistry of fish otoliths, and expanded the scope of the research to include fish vertebrae and scales. While results revealed disparities in the chemistry and morphology of otoliths and vertebrae processed in different ways, the impacts observed in the fish scales were less substantial. Ultimately, heat was identified as the primary agent affecting alteration throughout the investigation, with the use of heated archaeological samples in any trace element or isotopic analyses discouraged. While fish remains are valuable tools for examining palaeoenvironmental conditions, ancient fish populations, and past inhabitants of a site, identifying the influences of post-mortem processes is integral to accurate interpretations of data. Chapter 3 brings to light some limitations of archaeological otoliths, and reiterates the need to conduct palaeoenvironmental reconstructions with caution. It also leads the way for further investigations into the stability of otoliths that have been exposed to other taphonomic processes, such as weathering, inundation, diagenesis, or exposure to various trace elements post-depositionally – these areas of future research are further discussed below.

Applications of Archaeological Otolith Analyses

Despite the possibility of taphonomic alteration as discussed in Chapter 3, the unique properties of otoliths and the bountiful information able to be gleaned from them (as detailed in Chapter 2) ensure that they remain a valuable and well-utilised resource. Chapters 4, 5, and 6 provide examples of the array of knowledge that can be obtained through the systematic analysis of fish otoliths from archaeological assemblages. Chapter 4 demonstrates the type of information that can be deduced from basic morphological analyses of otoliths when an adequate sample size is used, and modern data are available for validation and comparison. It was determined that the assemblages from sites in the Atacama Desert, Chile, contained fish that were significantly larger than maximum recorded modern sizes of the same species from the region. The otoliths also provided information about site occupation and resource use, revealing similarities between Camarones Punta Norte and Caleta Vitor and other contemporaneous sites along this section of the Pacific coast.

Chapter 5 demonstrates the value of archaeological otolith analyses as a means of temporally expanding data relating to native fish species, especially those species that are commercially targeted. When combined with historical and modern data, broad-scale analyses of changes or stability within populations can be investigated and the phenomenon of shifting baselines can be addressed (Izzo et al. 2016; Pauly 1995). In recent years, the use of historical anecdotes and archives as records of past fish populations has increased (e.g., Galik et al. 2015; Thurstan et al. 2016; Thurstan et al. 2015), but the use of historically-based reference conditions has also come under scrutiny (Bouleau and Pont 2015; Haidvogl et al. 2015). Despite some difficulties inherent in using historical and/or archaeological data, both sources can provide information that would otherwise be impossible to obtain, making valuable contributions to understanding anthropogenic changes to ecosystems and fish populations over time.

A further application of otolith analysis is demonstrated in Chapter 6, which presents the results of radiocarbon dating of an otolith assemblage from a midden site in at the Coorong in South Australia. This chapter validates the use of otoliths in radiocarbon dating, and extends the known period of occupation of the site.

Future Directions

The research presented in this thesis is evidence of how cross-disciplinary research can enhance the scope of projects focused on fish otoliths. Modern fisheries research regularly tests and develops new or alternate ways to use and analyse otoliths. Increased collaboration between fisheries scientists and archaeologists would enable knowledge to be shared, and advances in fisheries research to be applied to ancient samples, thereby developing novel or improved ways of investigating palaeoenvironmental change, ancient Indigenous populations, and ancient fish species.

Specific future research suggestions are detailed as follows:

Further exploration into the effects of different pre- and post-deposition taphonomic processes on the chemistry and morphology of fish otoliths, such as weathering, burial in different sediment types, absorption of trace elements from the surrounding sediment (e.g., arsenic in the Atacama Desert (Swift et al. 2015)) would be highly beneficial. As revealed in Chapter 3, post-mortem influences can alter the results of analyses, and further experimental investigations into the mechanisms of such changes should be conducted to ensure the accuracy of future research. Research possibilities include investigating the extent of post-depositional absorption/dilution of trace elements and the taphonomic influences of different depositional contexts (e.g., shell midden, mound, and burials) including an investigation of how these contexts influence otolith preservation in comparison with fish bone.

Further analyses of the otolith assemblages from the Chilean archaeological sites (Caleta Vitor and Camarones Punta Norte) would enable more knowledge to be gained about the past inhabitants, fish species and environmental conditions of the region. It would be beneficial to conduct isotope analysis of a selection of the otoliths from the Chilean sites in order to investigate upwelling and palaeoenvironmental conditions. Age validation of modern *S. deliciosa* samples should be conducted to investigate the ability to accurately estimate the age of fish from archaeological samples, and thereby compare growth between the modern and ancient samples. An examination of the season of death of the fish using the edge increments of the otoliths could provide insight into whether the sites were used, or the fish were targeted, seasonally or continuously. It would be desirable to expand the sample size by collecting/excavating otoliths and other fish remains from other sites within the region. This would enable a broader investigation of fishing technologies and would widen the scope of the research to look for changes and continuities in the diet of coastal populations since the early Holocene (ca 10,000 BP) up to the 16th–17th century.

Additional analyses of the assemblage from the Greenfields mound site in South Australia would add to the knowledge gained from the research presented in Chapter 5. It would be valuable to conduct morphological (age/fish size/growth determination) analyses on the otoliths from other fish species that were recovered from the site. Large numbers of whiting (*Sillaginodes* spp.) were identified within the assemblage. This species is a suitable candidate for analyses as it is a commonly fished commercial species, for which modern fisheries data are readily available for comparison (Fowler et al. 2014) to investigate changes in the population over time. It would also be beneficial to investigate any evidence of seasonality in the archaeological whiting assemblage. The majority of mulloway were captured during warm season – were whiting caught at the same time, or did they provide a source of protein in the cooler months?

Conclusions

Archaeological fish otoliths are unique and valuable resources. They can provide anthropogenic, palaeoenvironmental, and biological data that would otherwise be impossible to obtain. The collection of such data from ancient otoliths needs to be conducted using tried and tested replicable methods to ensure accuracy, and interpretations must be accompanied by a clear understanding of possible confounding factors. When archaeological otolith analyses can be validated through the use of modern samples, analyses and interpretations can be further applied to broader research fields. Throughout this thesis, the objectives were achieved through literature searches, experimental archaeological research, and the analysis of three different otolith assemblages from archaeological sites in Australia and Chile. The information concluded from this research is summarised as follows:

Fish otolith analyses are increasingly being incorporated into archaeological and palaeoenvironemental research. They are valuable anthropogenic and environmental proxies, and are able to be analysed in a variety of ways. Continuing technological and methodological advances, and an increase in cross-disciplinary research programs, would serve to further increase the value of this resource.

Although otoliths contain valuable information, the morphological, chemical and isotopic properties of archaeological fish otoliths can be influenced by post-mortem factors such as cooking. As such, it is recommended that the incorporation of burnt or otherwise heated samples in analyses is avoided, and the interpretation of trace element and isotopic data is conducted with caution if using samples that may have been cooked.

Analyses of fish otoliths from archaeological sites in South Australia and in the Atacama Desert, Chile enabled knowledge about past inhabitants of the sites, their subsistence strategies and site occupation patterns to be gained. When compared or validated with modern otolith samples, investigations regarding the population structures of specific native fish species were conducted, facilitating examinations of changes in fish populations over time.

This research has provided a comprehensive review of the state of otolith analysis within archaeology, evaluated their reliability as anthropogenic and environmental proxies, and presented three case studies demonstrating different applications of otolith analyses to archaeological assemblages. Results show that the study of archaeological otoliths can reveal information about ancient human populations that is of relevance to current worldwide issues of fisheries management, conservation, and habitat rehabilitation. Their broadscale relevance to interdisciplinary research areas reaffirms archaeological fish otoliths as a valuable and unique resource.

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Appendix A: Supplementary Information for Chapter 3

Table S3.1: Trace element data for fish otoliths

Treatment	Otolith Edge (mmol/mol)								Otolith Nucleus (mmol/mol)							
	Li:Ca	Na:Ca	Mg:Ca	Mn:Ca	Zn:Ca	Sr:Ca	Ba:Ca	Pb:Ca	Li:Ca	Na:Ca	Mg:Ca	Mn:Ca	Zn:Ca	Sr:Ca	Ba:Ca	Pb:Ca
CL1	0.002605	10.880210	0.256781	0.001824	0.015197	1.760454	0.007153	5.98E-05	0.002084	10.516350	0.106273	0.005641	0.007946	1.581963	0.000869	4.34E-05
CL2	0.001935	9.335808	0.090976	0.003798	0.007551	2.109256	0.006115	3.64E-05	0.005656	14.047790	0.184842	0.013951	0.021232	1.747439	0.001850	5.98E-05
CL3	0.002456	11.181170	0.114729	0.002237	0.009257	1.496996	0.001422	5.73E-05	0.004034	13.077800	0.132194	0.017524	0.001201	1.560070	0.001911	3.79E-05
CL4	0.004034	10.379130	0.102746	0.000978	0.018104	1.824789	0.001504	4.24E-05	0.006460	14.502140	0.228779	0.012673	0.010158	2.352955	0.002610	2.94E-05
CL5	0.001503	9.239473	0.176046	0.000921	0.001216	1.634791	0.006206	3.69E-05	0.007308	13.872960	0.207660	0.030741	0.015150	1.809274	0.001399	3.14E-05
CL7	0.002292	10.465000	0.179870	0.001448	0.040836	1.731453	0.005965	5.58E-05	0.011015	15.547760	0.240379	0.018106	0.033664	1.833490	0.001542	5.78E-05
CL8	0.002828	10.487550	0.119701	0.001109	0.020647	1.365662	0.001091	3.99E-05	0.003855	12.756220	0.159431	0.011733	0.004234	1.527566	0.005401	5.63E-05
BC1	0.005656	13.395150	0.129644	0.001166	0.014518	1.694563	0.000718	4.29E-05	0.003751	13.290330	0.206895	0.016038	0.008420	1.808532	0.002114	6.28E-05
BC3	0.008335	11.676010	0.149955	0.001767	0.054564	1.735567	0.006461	6.63E-05	0.005284	8.589980	0.220280	0.011845	0.018767	1.629533	0.001745	3.99E-05
BC4	0.001890	11.035010	0.261158	0.003516	0.150138	1.803686	0.007447	4.44E-05	0.005954	6.231047	0.281427	0.023935	0.015355	1.658417	0.001835	3.74E-05
BC5	0.004763	10.493130	0.265152	0.001767	0.032416	1.375566	0.002761	6.73E-05	0.004465	11.789280	0.231328	0.008461	0.034217	1.338464	0.003152	0.000110
BC6	0.007740	7.162039	0.279302	0.014008	0.085527	1.432084	0.002573	9.32E-05	0.004317	4.562314	0.182080	0.002407	0.140849	1.935681	0.001723	5.63E-05
BC7	0.002635	11.294850	0.290733	0.004569	0.107596	1.548445	0.001377	5.98E-05	0.003289	13.723290	0.161683	0.011695	0.048814	1.508267	0.004716	7.03E-05
BF1	0.001741	10.775700	0.213439	0.004418	0.015387	2.521603	0.008583	4.24E-05	0.006490	15.304810	0.220535	0.022055	0.008436	1.795021	0.001632	3.69E-05
BF2	0.003557	10.319190	0.119913	0.001805	0.006366	1.692653	0.002430	3.24E-05	0.007576	14.020200	0.211697	0.006882	0.023870	2.329459	0.000886	3.04E-05
BF3	0.003438	12.480560	0.082563	0.001128	0.006824	2.005639	0.001632	4.54E-05	0.007442	13.144840	0.250195	0.019423	0.089144	1.820510	0.002114	4.29E-05
BF4	0.002783	9.193868	0.090041	0.001034	0.007867	1.408246	0.002475	3.94E-05	0.007621	13.709360	0.165975	0.012992	0.024375	1.912526	0.002415	3.54E-05
BF5	0.002024	9.774840	0.139800	0.001354	0.006856	1.320073	0.002159	5.53E-05	0.008380	15.621670	0.250917	0.009119	0.011516	2.281865	0.001572	6.03E-05
BF6	0.002471	10.457270	0.123058	0.000846	0.006003	1.432721	0.001474	3.84E-05	0.008916	14.494460	0.248113	0.009815	0.008594	2.226573	0.001068	4.04E-05
BF7	0.001474	9.099511	0.158539	0.000997	0.002749	1.565917	0.001565	4.29E-05	0.006639	13.887430	0.241866	0.015455	0.019257	1.964069	0.002430	4.54E-05
BS1	0.002024	11.512720	0.145919	0.003309	0.017472	1.518547	0.003370	3.59E-05	0.007368	14.430790	0.297489	0.010435	0.109902	1.634343	0.000897	3.39E-05
BS2	0.002739	10.932600	0.146599	0.000827	0.035465	2.007879	0.000989	3.14E-05	0.007174	13.701590	0.399385	0.011225	0.027393	1.804205	0.001813	3.04E-05
BS3	0.003498	9.623104	0.137675	0.001091	0.013933	1.762494	0.004408	4.39E-05	0.006043	14.759110	0.189601	0.014120	0.042605	1.482259	0.001753	4.74E-05
BS4	0.001503	10.193610	0.158964	0.000921	0.013933	1.861820	0.005220	3.79E-05	0.004823	14.365770	0.222787	0.013331	0.027487	1.534887	0.001700	4.79E-05
BS5	0.002188	10.231480	0.115707	0.001222	0.020473	1.446526	0.001023	5.38E-05	0.005879	13.645420	0.181612	0.022187	0.092715	1.793995	0.001873	8.08E-05
BS6	0.002456	9.790118	0.115027	0.000921	0.024818	1.594695	0.000963	3.99E-05	0.003587	14.332530	0.140480	0.012654	0.076933	1.907516	0.003663	4.24E-05
BS7	0.002709	10.726550	0.206725	0.001147	0.009131	1.934301	0.005506	4.94E-05	0.004659	11.862880	0.149148	0.008480	0.017898	1.484158	0.000918	4.94E-05
RF1	0.002292	10.107110	0.137505	0.001542	0.060899	1.554682	0.001692	4.99E-05	0.009228	15.756690	0.275010	0.011037	0.022148	2.710799	0.001076	6.13E-05
RF2	0.003915	9.991097	0.122718	0.000846	0.039683	2.136796	0.001407	2.74E-05	0.008038	14.658150	0.244161	0.012221	0.014265	2.178094	0.001768	3.09E-05
RF3	0.002724	10.806880	0.122590	0.001147	0.077865	1.769544	0.000760	4.09E-05	0.005358	14.420590	0.210719	0.014064	0.089508	1.637255	0.001918	5.68E-05
RF4	0.002382	9.196878	0.098242	0.001467	0.039873	1.946751	0.001106	4.99E-05	0.007740	14.474420	0.238339	0.019423	0.025671	1.690932	0.001279	4.34E-05
RF5	0.001340	11.343550	0.206598	0.000865	0.013633	1.473147	0.005687	3.19E-05	0.008187	14.603290	0.269869	0.020231	0.012148	1.841259	0.001550	3.44E-05
RF6	0.002754	11.387770	0.126160	0.000846	0.006603	1.501889	0.001249	3.04E-05	0.007740	15.562180	0.190748	0.007502	0.018325	2.330402	0.000985	2.79E-05
RF7	0.002262	12.343340	0.221215	0.001467	0.091672	1.180934	0.005762	7.73E-05	0.007442	17.506220	0.186329	0.017900	0.034928	1.656107	0.001738	6.43E-05
SD1	0.002471	9.836710	0.102619	0.001222	0.001659	1.713638	0.001003	3.89E-05	0.008038	25.124170	0.303863	0.008931	0.048277	2.675501	0.001926	4.24E-05
SD2	0.002337	11.877350	0.202476	0.001749	0.012764	1.739210	0.003377	4.69E-05	0.007591	20.021870	0.297021	0.018708	0.024281	2.022132	0.001602	3.49E-05

Treatment	Otolith Edge (mmol/mol)								Otolith Nucleus (mmol/mol)							
	Li:Ca	Na:Ca	Mg:Ca	Mn:Ca	Zn:Ca	Sr:Ca	Ba:Ca	Pb:Ca	Li:Ca	Na:Ca	Mg:Ca	Mn:Ca	Zn:Ca	Sr:Ca	Ba:Ca	Pb:Ca
SD3	0.00253	15.852170	0.130579	0.000940	0.002385	2.102795	0.001068	3.09E-05	0.004302	20.185290	0.211527	0.000921	0.013523	1.356702	0.000955	3.09E-05
SD4	0.001712	13.670540	0.196400	0.000997	0.016745	1.869931	0.004829	3.49E-05	0.006996	24.175430	0.268721	0.027019	0.040662	1.734836	0.001760	3.34E-05
SD5	0.002649	18.382070	0.244628	0.001166	0.002844	1.976719	0.001294	2.79E-05	0.008335	17.446180	0.271866	0.002463	0.020884	1.523157	0.000825	4.39E-05
SD6	0.002530	16.103390	0.121188	0.001222	0.009542	1.662107	0.001219	0.000628	0.005105	18.139930	0.190153	0.015361	0.008088	1.656354	0.001181	4.44E-05
SD7	0.003989	35.274430	3.430109	0.001335	0.089081	1.495204	0.007514	0.000643	0.005656	18.534980	0.141584	0.014365	0.003065	1.388557	0.001452	4.24E-05
WC1	0.003721	11.064620	0.109843	0.002012	0.014534	1.465578	0.001384	4.34E-05	0.006162	12.398110	0.189388	0.015455	0.027345	1.515848	0.002121	3.29E-05
WC2	0.003825	10.331230	0.135933	0.005265	0.005182	1.795929	0.004288	2.89E-05	0.006519	14.085440	0.181867	0.019235	0.006493	1.609774	0.001941	3.39E-05
WC3	0.007442	12.973330	0.230606	0.022074	0.023143	1.864979	0.001580	2.44E-05	0.001429	9.822693	0.155777	0.000884	0.013570	1.510767	0.003061	3.59E-05
WC4	0.001667	9.699803	0.284571	0.001598	0.080187	1.317750	0.003896	6.58E-05	0.007636	15.917730	0.240422	0.027094	0.012606	1.785047	0.001422	5.33E-05
WC5	0.003141	10.258760	0.168865	0.001166	0.021390	1.372689	0.002121	4.99E-05	0.007889	14.704020	0.223042	0.010360	0.016161	2.441729	0.001158	4.19E-05
WC6	0.001920	9.678371	0.120976	0.001260	0.006477	1.565776	0.001173	5.14E-05	0.006758	14.018410	0.197717	0.014045	0.009431	2.037529	0.002084	4.54E-05
WC7	0.002456	8.020736	0.086387	0.001373	0.024044	2.043106	0.001151	6.03E-05	0.005433	13.868150	0.154120	0.013481	0.016540	1.547609	0.001512	5.93E-05

Table S3.2: Trace element data for vertebrae and scales

Treatment	Vertebrae (mmol/mol)								Scales (mmol/mol)							
	Li:Ca	Na:Ca	Mg:Ca	Mn:Ca	Zn:Ca	Sr:Ca	Ba:Ca	Pb:Ca	Li:Ca	Na:Ca	Mg:Ca	Mn:Ca	Sr:Ca	Ba:Ca	Pb:Ca	Zn:Ca
CL1	0.005795	123.24360	41.18491	0.107213	0.160647	1.270821	0.008686	0.0000000	0.176834	1480.1210	369.1850	1.051890	8.495439	0.147016	0.003789	0.302963
CL2	0.006490	88.72138	30.97752	0.235684	0.170485	1.380000	0.008875	0.0001033	0.186837	1381.0220	334.4352	1.298259	9.634889	0.182959	0.007518	0.271400
CL3	0.014494	159.57470	26.31556	0.081565	0.127962	1.449715	0.005628	0.0001604	0.297390	879.3860	348.6297	0.992949	8.748422	0.185827	0.021581	0.198362
CL4	0.000000	110.52410	19.49546	0.054204	0.053474	1.229078	0.012604	0.0001596	0.507805	922.5417	368.5675	1.727773	10.065290	0.119363	0.000855	0.217177
CL5	0.018282	46.40349	23.92992	0.180536	0.168348	1.497802	0.007472	0	0.236514	838.4995	341.2204	1.144027	8.364760	0.098173	0.002931	0.217230
CL7	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
CL8	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
BC1	0.006555	56.71658	23.82312	0.087629	0.074429	1.335200	0.013633	9.62E-05	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
BC3	0.023946	107.92120	90.40943	2.194521	0.202267	1.485563	0.077406	0.0024374	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
BC4	0.017638	59.67150	27.83445	0.216389	0.129615	1.528562	0.019848	2.538E-05	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
BC5	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
BC6	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
BC7	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
BF1	0.022529	98.66606	25.47348	0.052965	0.157545	1.840691	0.003858	0.0001419	0.254434	785.7945	796.9715	7.296916	13.428250	0.283191	0.010248	0.268964
BF2	0.015837	175.48870	27.46584	0.048552	0.220148	1.257248	0.006591	0.0005960	0.249948	888.4170	568.3065	5.802899	10.922150	0.158657	0.001988	0.464483
BF3	0.027295	125.79410	37.68513	0.127	0.171801	1.465688	0.011782	0.0005124	0.610647	1034.8290	510.6366	10.206880	11.388300	0.208019	0.004308	0.233659
BF4	0.009158	62.82559	28.94641	0.063540	0.086042	1.556281	0.006035	0.0000000	0.338414	782.7306	579.7166	10.035590	10.852890	0.132292	0.004618	0.405577
BF5	0.013252	146.73900	39.25674	0.107511	0.268720	2.176071	0.025099	7.161E-05	0.293901	715.1085	534.8350	6.765678	9.964344	0.173274	0.002677	0.259188
BF6	0.016368	77.18153	25.93026	0.067831	0.143104	1.319023	0.006929	0.0000000	0.283396	603.0816	514.9778	6.390319	12.467340	0.168292	0.000810	0.182381
BF7	0.011806	88.52199	31.15503	0.096529	0.144170	1.472002	0.005776	0.0000000	0.335535	1188.2690	368.9384	5.991388	9.524621	0.119089	0.002031	0.364535
BS1	0.016245	77.04118	26.84345	0.043407	0.061714	1.477356	0.003837	0.0000000	0.321530	786.9280	606.9428	0.882940	12.652360	0.084998	0.011499	0.184960
BS2	0.007220	112.15340	27.25707	0.201580	0.131201	1.331549	0.012032	0.0000000	0.303013	1123.1270	607.0940	1.507968	12.356130	0.083519	0.001254	0.155740
BS3	0.011929	91.75082	43.46904	0.055530	0.120484	1.759546	0.005111	0.0000000	0.308017	560.7320	561.4473	1.745189	12.413750	0.113336	0.002912	0.129736
BS4	0.013081	95.24270	35.21475	0.080724	0.247617	1.401513	0.010443	0.0003375	0.204684	963.8666	606.1503	3.056957	13.443710	0.153875	0.011262	0.244324
BS5	0.023931	68.35185	26.46007	0.035320	0.075617	1.705637	0.003877	0.0000000	0.312580	1438.8840	559.5906	1.385049	12.433110	0.121575	0.001134	0.146646
BS6	0.011380	103.40070	34.25118	0.114872	0.107255	1.394326	0.012750	0.0000000	0.374015	1130.4220	568.9373	1.344952	11.469420	0.107656	0.002266	0.337022
BS7	0.005286	86.65257	25.64561	0.082064	0.154449	1.559838	0.013642	0.0003966	0.376271	1003.3910	757.4344	1.583220	16.224570	0.162361	0.004257	0.189177
RF1	0.008391	159.92940	37.79782	0.181663	0.235839	1.296550	0.019682	0.0001148	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
RF2	0.020840	74.85919	31.69891	0.090575	0.100936	1.356997	0.006194	9.819E-05	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
RF3	0.012504	74.92304	31.57618	0.028008	0.083736	1.377507	0.003480	0.0000000	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
RF4	0.014239	100.72000	27.18303	0.050452	0.077502	1.463430	0.005650	0.0000000	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
RF5	0.016863	108.52800	33.16886	0.092504	0.078355	1.919330	0.004287	0.0000000	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
RF6	0.016735	146.21000	35.88875	0.145553	0.201695	1.345642	0.018072	0.0001162	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
RF7	0.019257	70.65834	27.38244	0.051635	0.158817	1.901152	0.003866	0.0002580	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
SD1	0.004684	236.75900	28.79737	0.102432	0.495091	1.921215	0.015238	0.0006025	0.208162	2006.4020	516.9899	1.484188	9.430072	0.106040	0.000800	0.231987
SD2	0.009906	197.69510	40.31376	0.103461	0.101459	1.451864	0.007697	0.0000000	0.195380	2087.6590	781.7599	1.894293	14.827490	0.148706	0.003259	0.288474

Treatment	Vertebrae (mmol/mol)								Scales (mmol/mol)							
	Li:Ca	Na:Ca	Mg:Ca	Mn:Ca	Zn:Ca	Sr:Ca	Ba:Ca	Pb:Ca	Li:Ca	Na:Ca	Mg:Ca	Mn:Ca	Sr:Ca	Ba:Ca	Pb:Ca	Zn:Ca
SD3	0.000000	363.12080	156.06580	0.220396	0.327393	2.989549	0.008174	0.0004025	0.224041	4706.9900	555.0012	0.950203	14.262190	0.104097	0.002215	0.229694
SD4	0.005973	265.45300	107.38230	0.068598	0.095168	1.879574	0.014238	7.2E-05	0.196391	1448.8140	423.6559	1.350514	13.364680	0.173313	0.005014	0.299646
SD5	0.011224	259.26060	53.77111	0.100449	0.128941	1.538123	0.007204	2.538E-05	0.251519	2334.1310	463.9941	1.408025	9.890656	0.134002	0.013963	0.287198
SD6	0.006220	209.55600	56.70064	0.052662	0.109212	1.394011	0.005476	2.833E-05	0.167874	1803.0990	510.5647	0.930096	9.023541	0.106717	0.001798	0.219517
SD7	0.015400	183.23130	27.31040	0.059094	0.174627	1.625893	0.005877	0	0.242441	10250.6600	1654.8950	1.350971	15.321620	0.108132	0.004493	1.059867
WC1	0.017359	92.67484	32.89062	0.125568	0.112014	1.778597	0.012361	9.162E-05	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
WC2	0.015448	100.04430	24.45602	0.098326	0.110466	1.308473	0.005092	0	0.280661	1397.3050	478.1410	1.079601	9.940346	0.112307	0.000558	0.202384
WC3	0.020381	91.45898	36.24457	0.060198	0.082835	1.582811	0.004980	0	0.164675	986.0031	420.3014	1.981000	11.711770	0.189917	0.003158	0.256840
WC4	0.013480	70.45095	26.21079	0.221583	0.185513	1.438864	0.020149	3.505E-05	0.098431	928.0016	424.8464	1.073348	7.697596	0.166260	0.001340	0.235440
WC5	0.015010	74.90646	26.23117	0.064489	0.108647	1.425934	0.008960	3.549E-05	0.147210	1221.2440	396.0977	1.059691	8.525928	0.137441	0.000000	0.232236
WC6	0.018289	93.09659	46.55639	0.137662	0.271397	1.314338	0.012246	0.0001779	0.224662	803.7597	617.3620	1.405823	10.999620	0.089512	0.000399	0.217307
WC7	0.016441	132.23450	37.64222	0.104239	0.110840	1.432675	0.009440	0.0001757	0.368193	1574.4560	445.8960	1.171677	11.486610	0.147767	0.003358	0.201492

Table S3.3: Stable isotope data for fish otoliths, vertebrae, and scales

	Otolith				**Vertebrae**				**Scales**				
Fish Code	**d18O**	**±**	**d13C**	**±**	**d18O**	**±**	**d13C**	**±**	**d13C**	**d15N**	**%C**	**%N**	**C/N (atomic)**
CL1	1.12	0.02	-4.21	0.04	3.39	0.14	-7.07	0.06	-17.97	12.06	30.80	10.50	3.42
CL2	0.90	0.05	-6.30	0.02	3.71	0.07	-6.02	0.02	-18.21	12.14	25.99	8.86	3.42
CL3	1.64	0.07	-4.12	0.03	2.02	0.10	-6.81	0.05	-18.30	12.57	26.98	8.83	3.56
CL4	2.00	0.15	-2.64	0.03	1.82	0.11	-7.08	0.01	-17.99	12.10	26.85	9.12	3.43
CL5	1.55	0.04	-4.39	0.01	3.77	0.19	-7.87	0.02	-19.54	12.82	26.07	8.27	3.68
CL6	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
CL7	0.17	0.06	-5.69	0.04	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
CL8	1.99	0.01	-3.23	0.01	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
BC1	-7.83	0.04	-15.15	0.03	-13.16	0.25	-9.69	0.13	n/a	n/a	n/a	n/a	n/a
BC3	-1.08	0.08	-5.16	0.02	-29.37	0.78	-21.16	0.45	n/a	n/a	n/a	n/a	n/a
BC4	-2.31	0.03	-5.70	0.00	-9.21	0.20	-11.15	0.08	n/a	n/a	n/a	n/a	n/a
BC5	-1.63	0.03	-5.45	0.03	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
BC6	-7.62	0.07	-13.84	0.04	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
BC7	-2.93	0.04	-8.78	0.00	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
BC8	2.21	0.18	-2.96	0.08	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
BF1	-0.35	0.04	-6.12	0.04	0.54	0.09	-7.85	0.03	-18.68	12.14	19.07	5.05	4.40
BF2	0.16	0.07	-5.63	0.10	1.11	0.07	-7.64	0.03	-19.59	12.01	20.43	6.52	3.65
BF3	0.64	0.11	-4.62	0.08	1.31	0.11	-7.82	0.07	-18.97	12.13	21.24	6.26	3.96
BF4	0.53	0.01	-4.25	0.02	2.60	0.16	-6.49	0.01	-15.23	15.86	20.01	6.00	3.89
BF5	-0.41	0.02	-6.47	0.02	1.35	0.14	-7.58	0.03	-19.16	13.52	20.73	6.43	3.76
BF6	1.24	0.05	-5.83	0.03	-0.70	0.09	-6.24	0.05	-19.12	11.92	23.45	7.52	3.64
BF7	-0.05	0.16	-5.96	0.03	2.55	0.09	-7.79	0.01	-19.10	11.71	29.80	10.64	3.26
BS1	-1.72	0.07	-6.17	0.01	0.86	0.12	-7.86	0.01	-18.18	11.54	22.62	7.36	3.58
BS2	0.24	0.10	-4.83	0.09	1.16	0.11	-6.68	0.03	-17.76	12.24	16.20	5.27	3.59
BS3	0.23	0.08	-6.16	0.05	0.68	0.05	-6.62	0.02	n/a	n/a	n/a	n/a	n/a
BS4	0.51	0.05	-6.51	0.06	1.54	0.08	-7.35	0.03	-19.09	12.30	23.33	9.14	2.98
BS5	0.34	0.02	-5.35	0.17	1.97	0.06	-7.23	0.07	-18.82	12.13	16.76	6.01	3.25
BS6	1.48	0.07	-4.41	0.01	0.82	0.09	-7.07	0.01	-18.40	11.97	24.49	8.19	3.49
BS7	0.35	0.05	-6.13	0.06	-0.85	0.16	-7.19	0.14	-17.42	12.84	19.93	6.05	3.84
RF1	0.52	0.02	-4.91	0.02	0.19	0.08	-6.32	0.04	n/a	n/a	n/a	n/a	n/a
RF2	0.83	0.04	-4.59	0.02	2.19	0.49	-3.65	0.16	n/a	n/a	n/a	n/a	n/a
RF3	1.02	0.07	-4.45	0.06	-0.73	0.56	-5.75	0.09	n/a	n/a	n/a	n/a	n/a
RF4	-0.02	0.06	-6.11	0.04	3.49	0.13	-8.57	0.03	n/a	n/a	n/a	n/a	n/a
RF5	-1.79	0.02	-6.80	0.12	1.40	0.09	-7.18	0.02	n/a	n/a	n/a	n/a	n/a
RF6	-0.28	0.01	-5.43	0.03	-0.09	0.07	-7.39	0.02	n/a	n/a	n/a	n/a	n/a
RF7	-0.84	0.06	-7.31	0.09	2.95	0.09	-5.96	0.02	n/a	n/a	n/a	n/a	n/a
SD1	-0.67	0.07	-5.38	0.08	4.02	0.16	-5.64	0.04	-16.88	12.83	26.56	8.50	3.65
SD2	1.17	0.02	-4.71	0.05	1.77	0.09	-6.59	0.04	-17.47	13.11	26.96	9.01	3.49
SD3	0.75	0.18	-4.90	0.08	3.28	0.12	-6.90	0.02	-19.08	12.65	27.24	9.02	3.52
SD4	3.10	0.04	-4.27	0.04	5.39	0.20	-5.69	0.00	-17.70	13.13	27.77	9.50	3.41
SD5	0.79	0.03	-4.64	0.02	0.23	0.09	-4.92	0.04	-16.24	12.80	26.91	9.04	3.47
SD6	-0.04	0.05	-5.62	0.03	0.41	0.10	-7.25	0.14	-18.81	12.85	25.20	8.43	3.49
SD7	0.37	0.02	-5.51	0.03	1.02	0.02	-6.81	0.05	n/a	n/a	n/a	n/a	n/a
WC1	0.33	0.03	-5.46	0.07	-0.71	0.11	-8.14	0.02	-16.08	14.54	17.34	5.50	3.68
WC2	2.43	0.02	-4.04	0.02	-0.32	0.14	-5.57	0.04	-17.70	12.59	24.51	9.22	3.10
WC3	-1.10	0.10	-5.79	0.12	1.61	0.04	-6.02	0.05	-20.74	11.73	25.35	7.95	3.72
WC4	-1.81	0.15	-7.48	0.08	-3.88	0.04	-7.26	0.03	-18.18	12.02	24.21	9.38	3.01
WC5	0.39	0.10	-5.88	0.07	0.69	0.09	-7.52	0.03	-18.69	14.03	15.15	3.73	4.74
WC6	0.12	0.13	-5.22	0.08	-1.25	0.66	-5.93	0.18	-19.63	12.03	22.56	7.13	3.69
WC7	-1.29	0.09	-6.25	0.01	-0.04	0.08	-7.93	0.03	n/a	n/a	n/a	n/a	n/a

Appendix B: Supplementary Information for Chapter 5

Table S5.1: Greenfields archaeological otolith morphological data.

Otolith number	Unit	Square	Otolith length (mm)	Otolith width (mm)	Otolith thickness (mm)	Otolith weight (g)	Condition	Fish TL (mm)	Fish age at death (years)	Edge increment	Side
GF007	1C	B7	18.88	10.93	7.75	1.32	Complete	759	6	Narrow translucent	Right
GF020	1A	B9	16.30	8.99	6.85	0.92	Complete	620	9	Wide translucent	Left
GF028	1C	B10	21.16	11.42	7.63	1.50	Complete	815	6	Wide translucent	Right
GF044	1B	C7	18.44	10.80	7.44	1.24	Complete	733	6	Half width translucent	Right
GF080	1D	C8	18.01	9.36	7.74	1.12	Complete	692	7	Half width translucent	Right
GF101	1C	D8	21.93	12.06	9.47	2.20	Complete	1011	10	Wide translucent	Left
GF108	1A	D9	21.48	13.11	8.55	1.97	Complete	950	15	Wide translucent	Left
GF112	1C	D9	15.65	8.78	6.91	0.82	Broken tip	581	5	Wide translucent	Right
GF121	1C	D9	18.53	11.09	7.50	1.21	Complete	723	6	Wide translucent	Left
GF122	1D	D9	11.88	11.24	8.26	1.21	Broken tip	723	7	Half width translucent	Right
GF195	1B	H9	21.63	11.66	8.23	2.02	Complete	964	8	Wide translucent	Left
GF196	1B	H9	20.83	10.82	8.25	1.57	Complete	836	7	Wide translucent	Right
GF226	Not Recorded	Scrape 1	13.96	9.34	7.60	0.90	Broken tip	612	Unable to read	Unable to read	Left
GF231	Not Recorded	Scrape 1	11.28	10.67	5.20	0.53	Two broken pieces	455	Not sectioned	Not sectioned	n/a
GF233	Not Recorded	Scrape 2	16.65	9.26	7.22	0.99	Complete	646	Unable to read	Wide translucent	Left
GF240	Not Recorded	Scrape 3	18.88	10.58	8.22	1.40	Complete	784	8	Wide translucent	Left
GF247	Not Recorded	Scrape 3	14.28	8.03	6.19	0.63	Complete	501	4	Wide translucent	Right
GF268	Not Recorded	Scrape 3	21.06	11.90	7.84	1.73	Complete	883	10	Narrow translucent	Right
GF269	Not Recorded	Scrape 3	6.12	8.28	6.03	0.24	Less than half	292	Not sectioned	Not sectioned	n/a
GF286	F10	Scrape 3	17.61	9.56	7.71	1.19	Broken tip	716	6	Narrow translucent	Right
GF301	S9/E10	Scrape 3	21.25	11.09	8.33	1.74	Complete	886	8	Wide translucent	Left
GF302	S9/E10	Scrape 3	16.35	10.78	7.24	1.27	Broken tip	743	6	Half width translucent	Left
GF304	Not recorded	Scrape 5	16.69	8.94	6.90	0.90	Complete	612	6	Wide translucent	Left
GF306	A9	Scrape 5	16.18	9.22	6.98	0.94	Complete	627	7	Wide translucent	Left

Otolith number	Unit	Square	Otolith length (mm)	Otolith width (mm)	Otolith thickness (mm)	Otolith weight (g)	Condition	Fish TL (mm)	Fish age at death (years)	Edge increment	Side
GF312	Not recorded	Scrape 6	21.02	12.08	8.77	1.81	Complete	906	7	Narrow translucent	Left
GF323	Not Recorded	Scrape 7	18.31	10.48	7.29	1.24	Complete	733	6	Half width translucent	Right
GF324	Not Recorded	Scrape 7	10.77	11.43	4.67	0.57	Less than half	410	Not sectioned	Not sectioned	n/a
GF326	Not Recorded	Scrape 7	15.63	9.03	6.11	0.83	Broken tip	585	6	Narrow translucent	Left
GF327	Not Recorded	Scrape 7	6.38	7.12	4.92	0.24	Less than half	474	Not sectioned	Not sectioned	n/a
GF334	Not Recorded	Scrape 7	19.41	10.29	7.09	1.27	Complete	743	6	Wide translucent'	Right
GF339	Not Recorded	Scrape 7	18.08	9.46	7.71	1.10	Complete	685	5	Half width translucent	Right
GF342	Not Recorded	Scrape 7	17.51	9.53	6.61	1.00	Complete	649	5	Wide translucent	Left
GF344	Not Recorded	Scrape 7	18.57	9.84	7.07	1.13	Complete	696	6	Wide translucent	Right
GF351	Not Recorded	Side Garden	16.91	10.92	7.75	1.46	Broken tip	803	8	Wide translucent	Left
GF366	Not Recorded	Side Garden	21.35	11.33	8.48	1.72	Complete	880	9	Wide translucent	Left
GF367	Not Recorded	Side Garden	17.54	9.76	7.20	1.11	Complete	689	7	Wide translucent	Left
GF368	Not Recorded	Side Garden	14.86	8.19	6.77	0.74	Complete	548	6	Wide translucent	Right
GF370	Not Recorded	Side Garden	18.44	10.10	7.06	1.22	Complete	726	8	Half width translucent	Left
GF371	Not Recorded	Side Garden	14.36	9.22	7.21	0.83	Broken tip	585	Unable to read	Unable to read	Left
GF374	Not Recorded	Rubbish Pit	19.65	10.88	8.06	1.43	Complete	794	8	Wide translucent	Right
GF375	Not Recorded	Rubbish Pit	14.42	9.83	7.36	1.02	Broken tip	657	Unable to read	Unable to read	Left
GF377	Not Recorded	Office Garden	20.82	11.57	8.41	1.71	Complete	878	10	Half width translucent	Left
GF378	Not Recorded	Office Garden	21.37	11.02	8.45	1.67	Complete	866	7	Half width translucent	Left
GF379	Not Recorded	Office Garden	23.10	11.48	9.05	1.99	Complete	955	7	Wide translucent	Left
GF391	Not Recorded	Office Garden	23.98	13.07	9.19	2.23	Broken tip	1019	13	Wide translucent	Left
GF392	Not Recorded	Front garden	20.91	12.13	7.95	1.65	Complete	860	10	Half width translucent	Left
GF393	Not Recorded	Front Garden	16.40	9.62	7.03	1.04	Broken tip	664	10	Half width translucent	Right
GF396	Not Recorded	Front Garden	19.70	10.82	7.47	1.43	Complete	794	6	Wide translucent	Right
GF397	Not Recorded	Front Garden	15.64	10.30	8.06	1.19	Broken tip	716	7	Wide translucent	Left
GF411	Not Recorded	Front Garden	16.76	9.53	7.19	1.03	Broken tip	660	5	Wide translucent	Right

Otolith number	Unit	Square	Otolith length (mm)	Otolith width (mm)	Otolith thickness (mm)	Otolith weight (g)	Condition	Fish TL (mm)	Fish age at death (years)	Edge increment	Side
GF412	Not Recorded	Front Garden	15.92	9.10	6.35	0.85	Complete	593	5	Half width translucent	Right
GF416	Not Recorded	Front Garden	21.58	11.40	8.07	1.84	Complete	914	10	Half width translucent	Right
GF417	Not Recorded	Front Garden	19.35	10.86	7.50	1.38	Broken tip	778	10	Wide translucent	Right
GF419	Not Recorded	Front Garden	17.19	10.25	7.00	1.17	Broken tip	709	7	Just after end of opaque	Right
GF424	Not Recorded	Front Garden	14.18	11.12	7.91	1.23	Broken tip	729	9	Narrow translucent	Right
GF427	Not Recorded	Front Garden	23.62	12.42	8.75	2.10	Complete	985	Unable to read	Unable to read	Left
GF429	Not Recorded	Front Garden	21.18	11.31	8.39	1.60	Broken tip	845	9	Wide translucent	Right
GF430	Not Recorded	Front Garden	13.80	8.67	6.73	0.76	Broken tip	557	3	Half width translucent	Left
GF433	Not Recorded	Front Garden	21.18	11.58	8.46	1.84	Complete	914	13	Half width translucent	Left
GF437	Not Recorded	Front Garden	17.67	9.55	7.18	1.03	Complete	660	6	Wide translucent	Left
GF438	Not Recorded	Front Garden	17.34	10.08	7.31	1.01	Less than half	653	Not sectioned	Not sectioned	n/a
GF440	Not Recorded	Front Garden	16.96	9.14	6.49	0.89	Complete	608	8	Half width translucent	Left
GF442	Not Recorded	Front Garden	11.34	11.34	7.10	0.69	Less than half	388	Not sectioned	Not sectioned	n/a
GF443	Not Recorded	Front Garden	16.84	9.17	6.97	1.03	Complete	660	7	Half width translucent	Right
GF444	Not Recorded	Front Garden	16.76	9.13	6.95	0.98	Complete	642	6	Half width translucent	Left
GF446	Not Recorded	Front Garden	14.00	10.25	7.48	1.11	Broken tip	689	6	Wide translucent	Right
GF447	Not Recorded	Front Garden	17.00	9.15	6.85	1.01	Broken tip	653	6	Half width translucent	Right
GF450	Not Recorded	Front Garden	18.00	10.49	7.32	1.29	Complete	749	7	Wide translucent	Right
GF452	Not Recorded	Front Garden	17.00	9.26	6.48	0.90	Complete	612	8	Narrow translucent	Right
GF453	Not Recorded	Front Garden	21.00	11.56	8.43	1.64	Complete	857	10	Wide translucent	Left
GF454	Not Recorded	Front Garden	19.00	10.41	7.59	1.28	Complete	746	7	Half width translucent	Left
GF455	Not Recorded	Front Garden	18.00	9.95	7.08	1.20	Complete	719	8	Half width translucent	Left

Otolith number	Unit	Square	Otolith length (mm)	Otolith width (mm)	Otolith thickness (mm)	Otolith weight (g)	Condition	Fish TL (mm)	Fish age at death (years)	Edge increment	Side
GF456	Not Recorded	Front Garden	16.00	8.97	6.93	0.99	Complete	646	6	Half width translucent	Left
GF457	Not Recorded	Front Garden	11.00	10.53	7.12	0.89	Broken tip	608	6	Wide translucent	n/a
GF463	Not Recorded	Front Garden	25.00	13.38	9.77	2.79	Complete	1155	15	Wide translucent	Right
GF464	Not Recorded	Front Garden	11.00	9.73	4.15	0.44	Less than half	527	Not sectioned	Not sectioned	n/a
GF486	Not Recorded	Front Garden	17.00	9.95	6.86	1.00	Complete	649	4	Half width translucent	Right
GF497	Not Recorded	Front Garden	17.00	8.98	6.63	0.91	Complete	616	7	Wide translucent	Right
GF514	Not Recorded	Front Garden	18.00	9.66	7.50	1.11	Broken tip	689	7	Wide translucent	Left
GF524	Not Recorded	Front Garden	20.00	11.23	8.21	1.62	Complete	851	9	Wide translucent	Left
GF525	Not Recorded	Front Garden	6.00	9.99	7.21	0.40	Less than half	292	Not sectioned	Not sectioned	n/a

Table S5.2: Historical anecdotes from the National Library of Australia's database, Trove, dated from 1847–1999. Searches conducted using the keywords "mulloway OR butterfish", limited to South Australian newspaper records mentioning mulloway catches, including fish size (length or weight), and location of catch. Fish TL was estimated using the logarithmic relationship between fish length (TL) and fish weight (Fish length TL (cm) =21.303*ln(weight(kg))+47.41 (R^2 = 0.976, n=50) (Disspain unpublished data).

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1847	Oct	6	South Australian Register (Adelaide, SA 1839-1900)	Page 2 Local Intelligence	About a fortnight ago the fishermen of Port Adelaide had a grand catch of the finny tribe, principally of a kind called ' butterfish,' of which they took a hundred and ten at one haul. The extreme length of some of them was nearly four feet, and by many people they were esteemed a delicacy; but we understand that all are not agreed upon this particular point.	Port Adelaide	110	nearly 4 feet			121.92
1871	June	2	South Australian Register (Adelaide, SA 1839-1900)	Country Correspondence	The fishermen had extra luck the other day, having caught four large butterfish, each weighing 30 lbs. About 20 were in the net, but 16 escaped.	Port Wakefield	20 individuals	30lbs each	13.60	13.60	103.01
1871	Aug	4	Southern Argus (Port Elliot, SA: 1866-1954)	Country Intelligence	Last week, a fine mulloway fish was caught near the Murray mouth, by Mr. Bolger of Encounter Bay, it measured nearly 5 ft. in width, 2ft. 6in. in girth and weighed 62 lbs. after it was cleaned.	Port Elliot		5 ft., 62 lbs	28.20	28.20	118.55
1872	Nov	4	The South Australian Advertiser (Adelaide, SA 1858-1889)	Topics of the Day	*The Bunyip* speaks highly of the cured fish lately exhibited at the Town Hall, Gawler, by Messers, Neville and Adamson, and in another paragraph states that the same firm brought a splendid specimen of the butterfish to Gawler for sale, its length being 3 feet 7 inches, girth 24 inches, and the weight upwards of 27 lbs.	Gawler	1 individual	3 feet 7 inches, >27 lbs	12.30	12.30	100.87
1873	April	7	South Australian Register (Adelaide, SA 1839-1900)	Page 5	During the past week promenaders on the Semaphore Jetty were interested in watching the manoeuvres of a large fish which, was described by observers as being of varying lengths. Some broadly affirmed it was a twelve-foot shark of the tiger species, while in the distance it seemed to people of a fertile imagination to be a blue shark. On Saturday morning a persevering foreigner belonging to the press boat watched for a favourable opportunity, and by a skilful throw of the grains captured the finny monster which had caused some apprehension to bathers. It was found to be an enormous butterfish, measuring 5 feet 1 inch long, and in weight 67 lbs. The creature was as fine a fish as could be desired, and being in excellent condition it was when portioned out and served up at about a dozen different tables, pronounced a delicacy.	Semaphore Jetty	1 individual	5 feet 1 inch, 67 lbs	30.50	30.50	120.22

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1877	March	24	South Australian Register (Adelaide, SA 1839-1900)	Miscellaneous	...it was agreed to spend time calling at Spilsbury Island, a small isle of the Sir Joseph Banks group. There they found a cockatoo squatter named Sawyer in possession of the island, with his wife and children. They had about 800 sheep. The soil appeared very light, and was covered with low scrub. There was plenty of water, and the sea abounded with fish. Large butter-fish from 20 to 70 lbs. in weight could be speared close in shore, while there was a great number of small fry...	Spilsbury Island		20 - 70 lbs	9.1 - 31.8	31.80	121.11
1879	Dec	16	The Naracoorte Herald (SA 1875-1954)	Kingston	We have had several hauls of small fish, and tonight a splendid mulloway measuring over four feet and weighing between forty and fifty pounds was safely landed in a boat about a mile and a half from shore. He was not allowed to go far, as mine host of the Royal Mail Hotel eagerly seized the opportunity of purchasing, and will no doubt give his boarders a treat for tomorrow's dinner. Where he came from it is only but natural to suppose there is more.	Kingston	1 individual	>4 feet 40-50 lbs	18.2 - 22.7	22.70	113.93
1884	Nov	27	Southern Argus (Port Elliot, SA 1866-1954)	General News - The Protector at Port Victor	… a contingent of the party came back from the Coorong channel, where, fishing with a borrowed net, they had made a good haul of mulloway, bream, and mullet, a specimen, of the first-mentioned being a fine one, weighing over 40 lbs.	Coorong		>40 lbs	18.20	18.20	109.22
1886	Jan	15	South Australian Register (Adelaide, SA 1839-1900)	A Large Fish	The South-Eastern Star says : While a party of gentlemen were paying a visit to the Glenelg Punt the other day they came across a large mulloway in the shallow water near the sea beach, which they succeeded in capturing. The weight of the fish was 62 lb.	Glenelg	1 individual	62lb	28.20	28.20	118.55
1887	Aug	26	The South Australian Advertiser (Adelaide, SA 1858-1889)		Messrs. Edwin Board & Co. sold at the Central Market on Thursday evening a monster butterfish, weighing 60 lb, and measuring from head to tail 52 1/2 inches, and in girth 30 inches. It was caught at Goolwa. The purchaser, Mr. J. Lippman, of King William Street (S.A. Fishing Company), will exhibit it this morning.	Goolwa	1 individual	60 lb, 52 1/2 inches long, 30 inch girth	27.30	27.30	117.86
1888	April	13	The Mount Barker Courier and Onkaparinga and Gumeracha Advertiser (SA 1880-1954)	Port Victor	At the mouth of the Murray an edible fish called the mulloway or butterfish is caught. It is a fair approach to good English salmon, and in Lake Alexandrina is the Murray cod, but, though palatable, the flavour of the North Sea is not about him. The delectable schnapper aboundeth, but the butterfish is pre-eminent on the coast. He averages about 30 lbs in weight, and when mine host and his cook have dealt well with him—have just given him a flavour of eschalot and the sauce of the delicate anchovy is wisely added, he is a feast worthy of a square meal at Delmonico's or the Cafe Voisin in Paris.	Murray Mouth		30 lbs average size	13.60	13.60	103.01
1892	March	26	Border Watch (Mount Gambier SA 1861-1954)	Robe (From our own correspondent)	Mr. Lush landed a large butterfish on Wednesday evening. It weighed about 50 lbs, and was caught in a light mullet net at Boatswain Point.	Boatswain Point	1 individual	50lbs	22.68	22.68	113.91

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1892	May	4	The Advertiser (Adelaide SA 1889-1931)	The Fisheries Question No II. The Parliamentary Party. Mr Copley's Opinion	He thought that there were quite as many fish about now as three years ago, because though they might not have been caught they had been seen. For his own part he fished chiefly for butterfish and bream in the wide waters of the lake when the sea went up. When this was the case the cod went up stream, as they do not like salt water. The nets used were hung on poles in the stream, and visited twice a day for the purpose of taking fish out and preventing their being spoiled. If left too long fish were often taken out dead, as they at times "drowned" in a few hours. If fish were caught in "gill" nets they frequently died from being unable to work their gills in consequence of their entanglement. Butterfish, or mulloway, averaged 12 lb. each, though he had seen some weighing only 8 oz. His opinion was that the smallest sized mesh used for these should be 3 in., which would catch 6lb. fish. In his experience mulloway had no market value if under this weight, so that it was to the fishermen's interest to prevent small fish being taken.	Lake		12 lb	5.44	5.44	83.49
1892	May	4	South Australian Register (Adelaide, SA 1839-1900)	The Ministerial Party on the Murray	By a few persons a close season is recommended, more particularly in the waters of the Coorong, for about three months, from November 1 to the end of January. At this season the fish are said to have large roes in them. One fisherman declares his disbelief that the fish enter the Coorong or the reaches of the Murray to spawn. "We don't get many big fish then," he says, "the biggest fish are caught in June, July, and August; in December if we get a big fish it is usually a female. "What is the average weight of the fish? the Minister asked. "They vary considerably, sometimes we get butterfish from 8 to 10 lb., at other times we catch them from 15 to 30 lb. in weight.	Coorong		15-30 lb	6.8 - 13.61	13.61	103.03
1892	May	5	South Australian Register (Adelaide, SA 1839-1900)	The Murray Fisheries - No III	Butterfish weighing 85 lb. has been sold in Adelaide.	Adelaide	1 individual	85 lbs	38.56	38.56	125.21

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1892	June	15	South Australian Register (Adelaide, SA 1839-1900)	Fish and Game Industries Goolwa June 11	This has been a splendid week for hooking, the mulloway being very plentiful at the mouth, and their food, the congolli, scarce. The men have been able to catch a good supply. Some of the mulloway caught turned the scale at 48 lb. without the head. Most of the fish were opened on the wharf, and I saw no signs of roes in them. This is the wrong time for that. The roes are found in the mulloway in December and January, but very few then they seem to go out to be at sea and spawn. The mulloway is known to be a sea fish. The Coorong has been very salt, but very few go up there to spawn. All the nets are placed aside, and the men are all engaged in hooking, which will last about five weeks. The quantity sent away from here for the six days ending June 11 has been 11,505 lb., which will prove that they are as plentiful as ever. Nearly all has been sent to the Adelaide market, and the prices have been good considering the quantity.	Goolwa		48lb	21.77	21.77	113.03
1892	July	12	South Australian Register (Adelaide, SA 1839-1900)	The Fishing and Game Industries - Goolwa July 11	During the past week very few fish have been received here on account of the stormy weather, the men not being able to do any hooking. A few fish, mostly bream, have been caught up the Coorong. On Friday night last one man secured a nice lot of butterfish at the Mouth, seventeen in all, and the average weight of each was 23 lb. The prices during the week have been very good, butterfish selling at 4 1/2d. lb. to 5 1/2d. lb.; bream, 9d. to 1s. each; teralgie, 1s. to 1s. 3d. each. The quantity received here has been about 26 cwt.	Murray Mouth	17 individuals	23 lb average	10.43	10.43	97.36
1892	Aug	3	South Australian Register (Adelaide, SA 1839-1900)	The Fish and Game Industries - Goolwa August 2	The fish supply has been very scarce for the past week, and no fish have been hooked at the Murray mouth. All the fish we have received have been caught up the Coorong. A very nice lot of butterfish came down last Thursday. They were mostly all small fish, weighing from 6 lb. to 10 lb, and sold at from 4d. to 5d. per lb. in the Adelaide market. Teralgie and bream realize 9d. each. The total quantity of fish received for the week ending July 30 was 30 cwt.	Murray Mouth		6-10 lb	2.7 - 4.54	4.54	79.64
1892	Aug	9	South Australian Register (Adelaide, SA 1839-1900)	The Fish and Game Industry - Goolwa August 8	During the week ending August 6 some splendid lots of butterfish have been received here from the Coorong. The butterfish have mostly been small, weighing from 6 lb. to 12 lb., but a few turned the scale at 57 each. Very few bream and teralgie have been caught during the week. All the fish have been caught with the gillnets, and no hooking has been done at the Murray mouth. The fish at this time of the year go out to sea, and come in by each heavy blow for feed. The total quantity received here for the past week has been 4,282 lb. Most of this has been sent to the Adelaide market, and prices have been very good.	Coorong		6-12 lb	2.7 - 5.44	5.44	83.49

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1892	Oct	1	South Australian Register (Adelaide, SA 1839-1900)	The Fishing Industry - Goolwa September 30	Butterfish have been mostly landed here during the last fortnight, and very nice fish have been caught by the nets about the Murray mouth and above in the Coorong, some weighing over 50 lb. each. Very few bream are caught, and the small fish are mostly mullet and teralgie. The quantity exported for the fortnight ending September 24 is 2 tons 9 cwt.	Murray Mouth		over 50 lb each	22.68	22.68	113.91
1892	Dec	14	Border Watch (Mount Gambier SA 1861-1954)	Nelson	Last week Dr Bradford succeeded in landing a large mulloway 35 lbs in weight near the mouth of the Glenelg. The line used was a single cat-gut.	Mouth of the Glenelg	1 individual	35 lbs	15.88	15.88	106.31
1893	March	11	South Australian Chronical (Adelaide SA 1889-1895)	A good supply of fish - Goolwa March 7	A fine catch of butterfish was made at the Lakes and the Coorong today. A fisherman named Moore caught 15 cwt. of butterfish from 4 lb. upwards. All the fish were sent to the Adelaide market today. The total quantity weighed 30 cwt.	Lakes and Coorong	15 cwt	> 4lbs	1.81	1.81	60.05
1894	April	26	South Australian Register (Adelaide, SA 1839-1900)	A Holiday in the South-east - A Trip up the Glenelg	The Glenelg at this time of the year is salt and subject to tidal influence for ninety miles, but in the winter its numerous fresh-water tributaries overpower the saline element for many miles. Judging from the floodmarks in the forks of trees the river at times must be an immense stream. Wildfowl were seen occasionally, but other birds, except crows, were scarce. The water being salt for a great portion of the year no fish have been introduced into it. Nature, however, has provided for the disciples of Izaak Walton, and bream, perch, mullet, silver trout, and mulloway are at times very plentiful. I hauled up a mulloway about 5 lb. weight, and brought it home as a trophy of my holiday, my family pronouncing it to be first-class.	Glenelg River	1 individual	5lb	2.27	2.27	64.87
1894	Dec	29	South Australian Chronical (Adelaide SA 1889-1895)	The Week	On Monday morning Mr. Leachworthy, whilst fishing from the Largs Bay jetty, caught a large butterfish weighing 50 lb. This is the largest fish of its kind that has been caught at Largs Bay for some time.	Largs Bay	1 individual	50lb	22.68	22.68	113.91
1896	Jan	11	Adelaide Observer (SA 1843-1904)	Middleton - January 8	Amateur fishermen from our rocks have met with success, and recently an old hand hooked a fine mulloway which turned the scale at 35 lb.	Middleton	1 individual	35lb	15.88	15.88	106.31
1896	May	23	Chronicle (Adelaide SA 1895 - 1954)	Goolwa, May 15	Goolwa, May 15— A nice haul of butterfish was caught near Goolwa this morning. The fish averaged 12 lb. each, the total weight being 15 cwt. They were purchased by Mr. Dowland and forwarded to the Melbourne, Ballarat and Adelaide markets, some also being dispatched to the northern townships.	Goolwa	15cwt	12 lb each average	5.44	5.44	83.49

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1896	June	25	Southern Argus (Port Elliot, SA 1866-1954)	The Fishing Industry at Goolwa	One of the best hauls ever made at Goolwa was secured on Saturday last, when Mr Godfrey and his party netted about fifty mulloway of such unusually large size that a good many people went down to the wharf to inspect the splendid catch. Some of the fish measured over four feet long, and scaled close on 80 lbs, one going a good deal over that and none refusing to raise the beam under 40 lbs. The nets were set near the Murray Mouth and the whole lot taken in a very short time	Goolwa		4 ft. long 80 lbs average	36.29	36.29	123.92
1896	Oct	17	Chronicle (Adelaide SA 1895 - 1954)	Goolwa - October 12	A very nice haul of butterfish was made near Goolwa on Monday by Mr. George Henderson and others. The fish weighed from 6 lb. to 20 lb., and were alive when landed on the Goolwa wharf. The total weight of the lot was 1,277 lb. The fish was purchased by Mr. A. Dowland, and sent to the Adelaide, Melbourne, and Ballarat markets.	Goolwa	1277 lb	6 - 20 lb	2.72 - 9.07	9.07	94.38
1901	Nov	16	Chronicle (Adelaide SA 1895 - 1954)	Current Topics	A correspondent writes: A very fine mulloway, or butterfish, was caught off the Grange jetty on Monday afternoon by Mr. Charles Wise, a local resident. A number of these fine fish have been about for days, and the catch caused considerable excitement, as it is believed to be the largest fish caught from the jetty here. The fish measured 4 ft. 7 in. in length and 2 ft. 7 in circumference, and weighed 63 lb. 3 oz.	Grange Jetty	1 individual	4 ft. 7 inches 63lb 3 oz.	29.00	29.00	119.14
1901	Nov	22	The Advertiser (Adelaide SA 1889-1931)		Mr. J. Alexander, of Waymouth street, while fishing off the Largs Pier on Thursday afternoon, caught a mulloway, or butterfish, which weighed 46 lb. when cleaned.	Largs Pier	1 individual	46 lb	20.87	20.87	112.14
1901	Nov	26	The Advertiser (Adelaide SA 1889-1931)		Mr. Charles Wise, of the Grange, who recently caught a butterfish off the local jetty weighing over 63 lb., was again successful on Saturday afternoon, when he caught another of these fine fish. It weighed 51 lb., and measured 4 ft. 4 in. in length.	Grange Jetty	1 individual	51lb, 4ft 4inches	23.13	23.13	114.33
1903	April	4	Adelaide Observer (SA 1843-1904)	With the A.N.A - Our Garden in the South-East	At Tailem Bend they saw large mulloway - among them was a 70-pounder that, owing to the unprecedented soilness of the Murray waters, had invaded Lake Alexandrina, and been sent thence to the market. "We can catch salt water fish some distance up the river now," said a fisherman; "and such a thing was never known before.	Tailem Bend	1 individual	70lb	31.75	31.75	121.07
1904	April	23	Adelaide Observer (SA 1843-1904)	Port Germein April 14	Local fishermen are having a good time catching what are termed butterfish. These finny visitors have been coming and going around the jetty for some days, and good hauls have been made. As they weigh from 5 to 12 lb a piece the trade in butchers' meat has slackened considerably.	Port Germein		5 - 12 lb a piece	2.27 - 5.44	5.44	83.49
1905	Dec	30	Chronicle (Adelaide SA 1895 - 1954)	Mount Gambier December 18	During the last few days some good catches have been at the Glenelg River. Two mulloways, weighing over 10 lb. each, were hooked by local fishermen.	Glenelg River, Mount Gambier	2 individuals	>10lb each	4.53	4.53	79.59

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1906	Feb	3	The Advertiser (Adelaide SA 1889-1931)	Mount Gambier February 1	Mr. C. Barton, who has spent a month fishing on the Glenelg River, at Nelson, hooked no fewer than 400 fish. On Monday night he caught six fine mulloway. One turned the scales at 20 lb., measured 3 ft. 3 in. in length, and was 1 ft. 10 in. in girth. Another weighed 16 lb., one 10 lb., and the remainder were smaller. Fish are plentiful this year.	Glenelg River, Nelson	6 individuals	20lb weight, 3 ft. 3 inches length, 1ft. 10in. Girth (largest)	9.07	9.07	94.38
1906	March	7	Border Watch (Mount Gambier SA 1861-1954)	A Big Haul	Dr F. D. Jermyn, Mr. H. Engelbrecht, and a lad named Percy Matheson had an exciting evening's sport angling on the River Glenelg on Sunday last. The three went out trawling in a boat after tea, and within three hours landed seven large mulloway. They averaged in weight from 10 lbs to 25 lbs, and form what is perhaps the largest haul of mulloway ever made on the river. Two of them were landed by Matheson single-handed, the feat occupying about three-quarters of an hour for each fish. Dr Jermyn says the mulloway were biting very freely on the night in question, and that the party must have lost as many as they caught. Mr. P. C. Kook photographed the fish on Monday, and it is probable that a copy will be forwarded for insertion in one of the Melbourne weeklies.	Glenelg River, Mount Gambier	7 large individuals	25lbs (largest)	11.34	11.34	99.14
1906	March	10	The Advertiser (Adelaide SA 1889-1931)	Mount Gambier March 8	On Tuesday Mr H Youngman, from Coleraine, caught a mulloway which weighed 42 lb., and which was the largest caught at Nelson.	Nelson	1 individual	42 lbs	19.05	19.05	110.19
1906	March	14	Border Watch (Mount Gambier SA 1861-1954)	The Record Mulloway	We learn that Mr. G. Youngman's catch on Tuesday last, that weighed 42 lbs., was by no means the heaviest mulloway caught in the Glenelg River. The largest was one caught three years ago in the stream by Mr. A. B. Sinclair, which weighed 59 lbs.	Glenelg River, Nelson	1 individual	59lbs	26.76	26.76	117.43
1906	April	3	The Advertiser (Adelaide SA 1889-1931)	Kingston	Yesterday while Messrs B. Ling and A. Smith were engaged in hauling their net they found they had caught a large mulloway, weighing at least 50 lb. They continued dragging, expecting every minute to see the net rip and the monster escape, but the fish continued peaceful until too late to affect an escape. This mode of capture is most unusual.	Kingston	1 individual	>50lbs	22.68	22.68	113.91

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1906	May	5	Border Watch (Mount Gambier SA 1861-1954)	The Mulloway	Mr. D. MacDonald, in his last contribution to The Argus, says: "Two correspondents continue the discussion as to the identity of the mulloway or kingfish. As the subject excited so much comment, I have taken considerable trouble to unravel the confusion if possible, and fix the identity of the fish. The results are interesting. The mulloway, I find, has a different name in nearly every state. In South Australia and about the Murray Mouth it is either mulloway or butterfish, in Victoria kingfish, in New South Wales jewfish, and in Queensland dewfish. They are all absolutely the same species, *Sciaena Aquila*. On the other hand, the kingfish of New South Wales (*Seriola lalandii*) is the fish generally known in Melbourne as the yellowtail. The heaviest mulloway recorded for the Murray mouth fisheries weighed 84 lb. If it can be determined whether mulloway or mulloway is the correct aboriginal name, it might with advantage be generally adopted.	Murray Mouth	largest recorded	84lb	38.10	38.10	124.96
1907	Feb	26	The Advertiser (Adelaide SA 1889-1931)	Fine Haul of Fish	A party of young men, seven in number, from this neighbourhood, have just returned from an enjoyable holiday on the Coorong. Fish were very scarce, and the fishermen of Tarwidgery had decamped to Goolwa; leaving the fishing grounds free to the Hills' lads to try their skill. They claim to have made good use of their opportunities, for on Friday last they secured three large butterfish, weighing in the aggregate 140 lb. One alone, killed by Mr. F. West, weighed 60 lb., and measured 5 ft. in length. They were shot with guns, and were declared by the fishermen, to be the largest ever taken in the district. As the party returned next day the whole neighbourhood has been feasting on fish and ducks.	Coorong	3 individuals	60 lb weight 5ft length (largest)	27.22	27.22	117.79
1907	March	9	The Advertiser (Adelaide SA 1889-1931)	Goolwa March 6	The fishing industry has been somewhat slack of late, but the advent of the salt water has brought good shoals of mulloway (or butterfish), and several have been hooked at the Murray Mouth. One of the largest of this species, turning the scales at 70 lb., was brought up by Mr. George Estick this morning.	Murray Mouth	1 individual	70 lbs	31.75	31.75	121.07

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1908	Feb	15	The Advertiser (Adelaide SA 1889-1931)	Scenes in the Fish Market	"Mullet and butter fish. My word! You've never seen such butterfish. Fetch full price, it will! Get Mr. Daw to let me have some big baskets." The sacks were removed. A full half ton of plump and shimmering fish meet the eye. These have been caught by net in the neighbourhood of Port Noarlunga. I handled a few. They were in superb condition. Beneath the smaller mullet reposed the enormous butter fish, weighing up to 15 pounds. But all the butterfish had been decapitated. Why? I took the question to the hawker, who it transpired had in former times been a fisherman. Without relinquishing his task of keeping the post upright, he replied "It's only a fancy. The Noarlunga fishermen cut the heads off, but the Goolwa men leave them on. Stupid of them, too, I say, because the head counts in the weight of the fish." "They do look unsightly. But the customer prefers them with the heads off, I guess, eh?" was my remark. There was no answer to that, but a tremendous cloud of smoke burst from the lips of the patriarch, and presently he started on another subject – oysters.	Port Noarlunga	half tonne	up to 15lbs	6.80	6.80	88.25
1908	Feb	12	Border Watch (Mount Gambier SA 1861-1954)	The Fishing at the River	The Fishing at the River: Anglers have been having a good time on the Glenelg River during the last week or two, and some good hauls are reported. On Friday evening last Mr. Caulfield Barton hooked three large mulloway weighing, respectively, 10, 12, and 22 lbs., besides a number of perch and some bream. He has been fishing at the river since the commencement of the year, and during that time has caught 28 mulloway weighing 268 lbs. In his 1906 season at the Punt Mr. Barton hooked 16 mulloway, whose aggregate weight was 146 lbs., and the weight of the largest fish 20 lbs., and in 1907 18 mulloway total weight 175 lbs. and the weight of the largest fish 15 lbs. In addition to the mulloway caught this season he has also landed about 200 perch, weighing 260 lbs. Mr Barton intends to spend another week at the river.	Glenelg River, Mount Gambier	numerous	22 lbs (largest)	9.98	9.98	96.42
1908	Feb	1	The Advertiser (Adelaide SA 1889-1931)	Mount Gambier January 30	Anglers at the Glenelg River are having splendid sport of late, and some fine catches are reported. Mr. D. McCurne landed a mulloway weighing 35 lb. on Tuesday, and on the same evening Mr. C. Barton landed three mulloways of 18, 13, and 5 lb. respectively, while Mr. McEachern secured four weighing 12 lb. each.	Glenelg River, Mount Gambier	1 individual	35 lb	15.88	15.88	106.31

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1908	Feb	26	Border Watch (Mount Gambier SA 1861-1954)	Big Haul of Fish	A party of young men from Port MacDonnell, Messrs. H. Pascoe, J. Hitchcock, and E. Garrison took what, we believe, is a record haul of fish for one day at the River Glenelg on Sunday last. As the result of an hour or two's fishing on the stream after dark they brought back to land 5 large mulloway, whose aggregate weight was 131 1/4 lbs., and 9 dozen fair-sized bream. The two largest mulloway weighed, respectively, 43 1/2 lbs and 41 1/2 lbs. One of the fish caught was on view in Mr. E. Hosking's show window on Monday.	Glenelg River, Mount Gambier	5 individuals	131 1/4 lbs combined, largest weighed43 1/2 lb and 41 1/2 lbs	19.73 and 18.82	19.73	110.94
1909	Jan	7	Southern Argus (Port Elliot, SA 1866-1954)	Middleton Jan 5	This watering place has had a good share of the holiday-makers' patronage, over a hundred visitors staying here, all of whom have had a good time, the weather having been delightful right through the holidays. Fishing has been good, and some fine hauls have been made. Last week a mulloway weighing over 60 lbs was hooked close to the beach.	Middleton		60lbs (largest)	27.22	27.22	117.79
1909	Feb	5	The Advertiser (Adelaide SA 1889-1931)	Mount Gambier February 2	Good fishing is now possible at the Glenelg River. On Friday night two fine mulloway were landed, one by Mr. C. Barton (Port Pirie) weighing 33 1/2 lb., and the other by Mr. D. McCuspie weighing 34 lb.	Glenelg River, Mount Gambier	2 individuals	33 1/2 lb and 34 lb	15.42 and 15.20	15.42	105.69
1909	Feb	9	The Register (Adelaide, SA 1901-1929)	Goolwa February 6	The river here has fallen considerably lately, owing to the last rise having just about all run out through the Murray mouth. Consequently the salt water has again made its appearance, and so we are again reminded of the fact that an effective system of locks and storage basins should be carried into effect and some means also devised to keep the salt water back. The fishermen have been having good times lately. Something like three tons of fish a week for the last three weeks has been forwarded to the city market. A feature of the big hauls has been the hooking at the Murray mouth, as dozens of mulloway (butterfish) weighing from 40 to 50 lb., have been caught with hook and line.	Murray Mouth	dozens	40 - 50 lbs	18.14 - 22.68	22.68	113.91
1911	Jan	26	The Advertiser (Adelaide SA 1889-1931)	Fish and Fishermen	The subject of fishing has also been receiving the attention of pro-professionals at Goolwa, where a largely attended meeting, at which one of the officers of the Fisheries Department was present, was held on Saturday night to consider the advisableness of asking the Government to allow haulage nets to be used in the Murray mouth. Here a lot of mulloway, ranging up to 60 lb. in weight, have been caught lately with line and hook. After discussion it was agreed that it would be better to stand by the existing regulation, which proscribes the use of nets within one mile of the river month.	Murray Mouth		up to 60 lb each	27.22	27.22	117.79
1911	Feb	9	The Advertiser (Adelaide SA 1889-1931)	A Mammoth Butterfish - Hindmarsh Island February 7	Messrs. W. F. Newell and H. Hay caught a huge butterfish yesterday only a little less than 84 lb. in weight. Those who saw it were astonished at its immense size. The fish was forwarded to market. A good supply of smaller fish was also netted by our fishermen.	Hindmarsh Island		a little less than 84lb	38.10	38.10	124.96

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1911	Sept	29	The Advertiser (Adelaide SA 1889-1931)	Good Haul of Butterfish	William Wilkie, a Port Adelaide fisherman, made a fine haul of butterfish on the Gawler Flats on Thursday. He secured 32 of the fish by net. Their weight varied from 20 to 30 lb. Mr Wilkie did not leave the Port until 10am, and he was back again in the harbour by 4 in the afternoon. His catch was due to skilful manoeuvring. He noticed the butterfish swimming about in a school, and successfully encircled them with a strong net and secured them.	Gawler Flats	32 individuals	20-30lb	9.07 - 13.61	13.61	103.03
1912	Feb	14	Border Watch (Mount Gambier SA 1861-1954)	Port MacDonnell Feb 12	Good fishing was had in the bay last week, especially on Saturday. On Saturday all the available boats were out, and they brought in good hauls of whiting, salmon, trout, pike, and bream. Mr D. Carrison had the good fortune to net a splendid mulloway – one of the largest ever seen here. It was estimated to weigh about 50 lbs., and was readily sold when cut up at 6d. per lb. Several amateur photographers got snapshots of it before it was carted away for sale.	Port MacDonnell	1 individual	50lbs	22.68	22.68	113.91
1912	March	9	Border Watch (Mount Gambier SA 1861-1954)	Angling at Nelson	Mr. Percy Matheson, a Victorian Visitor to Nelson, is evidently having a good time among the mulloway. Writing to Mr R. Cummings, informing him that he was forwarding him a large mulloway which he caught on Tuesday night, he says before being cleaned it weighed 36 lbs. The landing of the fish gave him splendid sport. On the same night he hooked a smaller one weighing 9 lbs. Since Sunday Mr. Matheson has hooked six large fish, weighing 9 lbs., 36 lbs., 14 lbs., 22 lbs., 33 lbs., and 35 lbs. Good catches are also reported by other sportsmen.	Nelson	7 individuals	36lbs (largest)	16.33	16.33	106.91
1912	Nov	29	The Advertiser (Adelaide SA 1889-1931)	Mount Gambier November 27	The first mulloway of the season was caught on Saturday night. It weighed 35 lb.	Mount Gambier	1 individual	35lbs	15.88	15.88	106.31
1913	April	12	The Register (Adelaide, SA: 1901-1929)	Mount Gambier April 10	A splendid mulloway, weighing 55 lb. after being dressed, was caught in the River Glenelg yesterday by Mr. H. Glover. In past years, before the diversion of a freshwater creek from the river into the sea, such fish were frequently caught. Now they are rarely found in the stream.	Glenelg River, Mount Gambier	1 individual	55lb	24.95	24.95	115.94
1913	April	14	Daily Herald (Adelaide, SA 1910-1924)	Mount Gambier April 12	A large mulloway, caught in the Glenelg River, was exhibited in the town yesterday. The fish was nearly 5 ft. long and weighed 55 lb. It is many years since such a fine fish has been brought here from the Glenelg, and the catch excited much interest. The fact that such a large fish had been caught was used as an argument by a deputation to the Acting-Premier (Hon. R. Butler) last evening in favour of obtaining assistance for a scheme to improve fishing facilities at the river.	Glenelg River, Mount Gambier	1 individual	55lb nearly 5ft long	24.95	24.95	115.94

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1914	Jan	24	The Advertiser (Adelaide SA 1889-1931)	Fishing at Victor Harbour January 23	During the past week a heavy swell, due to rough weather outside, has been running. This has had the effect of making fish fairly plentiful. Easterly winds have brought in the freshwater and mulloway from the Murray. No fewer than one hundred of these fish, weighing from 20 lb., have been netted.	Murray Mouth	>100 individuals	>20lb	9.07	9.07	94.38
1914	Feb	4	Daily Herald (Adelaide, SA 1910-1924)	The Country- Aldinga	A splendid haul of mulloway way was obtained on Friday afternoon last. Messrs. How Bros, caught the largest school of butterfish that has ever been known to have been caught at Port Willunga. In one catch were about 700 fish, weighing from 2 lb. to 30 lb. Another school was caught on Saturday numbering about 600. On Sunday another school of about 200 was captured.	Port Willunga	700 fish, 600 fish, 200 fish	2lb-30lb	13.61	13.61	103.03
1914	July	9	Daily Herald (Adelaide, SA 1910-1924)	Enormous Butterfish	A shipment of 20 large butterfish, which were recently caught at Cowell, was brought to Port Adelaide by the steamer Wandana yesterday morning. 'They weighed over 1000 lb., the average weight being 50 lb. One of the fish turned the scale at 60 lb.'	Cowell	20 individuals , >1000lb	50lb average, 60lb max	22.68	22.68	113.91
1914	July	21	The Register (Adelaide, SA 1901-1929)	Huge Butterfish	Messrs. R. Fuss and E. Boothby (writes our Cowell correspondent) secured a phenomenal haul of huge butterfish on July 16. The catch comprised 52, and they ranged from 30 lb. to more than 80 lb. each. The total weight was considerably more than a ton. An idea of the size of the fish can be gained by the fact that only two of them could be put into a chaff bag at once.	Cowell	52 individuals	30 - 80lb	36.29	36.29	123.92
1915	Feb	16	The Naracoorte Herald (SA 1875-1954)	Mount Gambier- February 7	During the last week or ten days fish have been caught in larger quantities at Port MacDonnell, Beachport, and the River Glenelg, and Mount Gambler people have been benefited thereby. Fish is a much more palatable and healthful article of food in the very droughty summer weather we have been enduring than beef and mutton. On Wednesday a large consignment was received here from Beachport, where over two tons of fish is said to have been caught with the dragnet. The fish were schnapper and butterfish. At Port MacDonnell schnapper, butterfish, and pike were secured in large hauls. At the river the anglers have been having a great time with bream and mulloway. Some of the latter run over 30 lbs. in weight.	Port MacDonnell		>30lb	13.61	13.61	103.03

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1915	Sept	30	The Register (Adelaide, SA: 1901-1929)	The Fish Season	Quite recently, splendid hauls of young butterfish were made in Lake Alexandria, and they weighed from 3 to 6 lb. Before the rise of the river these were obtained so far up as Manoora, and are now working down towards the sea. In the early part of the year, during the breeding season, there were shoals, acres in extent, in the breakers, just outside the Murray mouth. The eggs of the butterfish are deposited in the open waters, and carried by the currents into the calmer areas of the river and the Coorong. After hatching, the young ones naturally seek protection in the shallower habitats, where they feed and mature prior to running down to the sea and setting out on the long journey of the coasts.	Lake Alexandrina		3 - 6lb	1.36 - 2.72	2.72	68.73

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1915	Dec	28	The Register (Adelaide, SA 1901-1929)	Fishermen's Christmas Box £250 Worth of Butterfish.	‘Visitors to Port Noarlunga witnessed a most remarkable and unique spectacle on the beach near the old jetty on Christmas morning', writes Mr. Lionel J. Jones, who is holidaymaking at this popular seaside resort. 'Some fishermen who had been watching a school of fish, which had gradually been making its way towards the beach, waited until it had got between the reef and the shore, and then laid their nets. Within a short period they began to draw the nets, and the result of their catch was speculated on by those who gathered around. By-and-by it was seen that the fishermen, neck deep in water, were labouring and pulling with all their might, with apparently little result. It was soon made plain that these strong, bronzed-neck men of the sea had secured a remarkable catch. Then, as the net got within a few yards of the beach, we beheld a sight, such as one only reads of or is told of in story. There were fish in hundreds, indeed thousands. They leapt up and fell again in the net, glistening like silver in the sunlight, in their endeavours to get away. By this time excitement ran high, until the men obtained two large boats, into which they transferred one by one the fish which they caught. The harvest proved to be of butterfish, and the specimens ranged in weight from 5 to 10 lb. each. The two boats having been completely filled, they were covered over and moored under the jetty. But still there were more and more fish to be gathered in, as net after net with its silver supply was hauled to shore. So numerous were they that a huge mound of living fish was thrown under the jetty, where another fisherman worked energetically with a sharp knife, gutting them as fast as his razor blade would go. I was informed that they would be all gutted–an all-day process–and then packed and taken to the freezers for the Adelaide market on Monday. It was calculated that the catch resulted in about 8,000 lb. weight of fish, worth about £250 — a grand Christmas box for the brave toilers of the sea. It is stated that they have not had such a haul down here for over two and a half years.	Port Noarlunga	Thousands of individuals 8000lb total weight	5-10lb	2.28 - 4.54	4.54	79.64
1916	Feb	9	The Register (Adelaide, SA 1901-1929)	A Fine Haul of Fish	Our Wallaroo correspondent writes: Fine catches of fish have recently been made here, and on Monday afternoon the record was broken. A school of mulloway appeared, and in a brief space of time scores of these fine fish were hauled on to the local jetty. The fish were a splendid variety, varying from about 18 in. to 2 ft.6 in. in length. Anglers had an exciting time, and the jetty was besieged by persons anxious to have a share in the haul.	Wallaroo	Scores	2ft 6 in	n/a	n/a	76.20

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1916	March	7	The Advertiser (Adelaide SA 1889-1931)	Mulloway at Brighton	Last week Mr. Peter Burdon, of Seacliff, Brighton, secured a fine haul of mulloway while netting from the beach. In all 189 fish were captured, varying in weight from two to ten pounds. Had a second fisherman not been near at hand to surround the already netted shoal with another net, many fish would have escaped, as their weight would have been too great for the first net. It is many years since such a fine haul was made on the beach.	Brighton Beach	189 fish	2 - 10 lb	4.54	4.54	79.64
1916	March	24	The Advertiser (Adelaide SA 1889-1931)	A Good Haul of Fish	Messrs. P. Marshall and Angus McDougall, of Adelaide, recently had a most successful week-end's fishing at the Glenelg River. They landed 32 fine mulloway, many of the fish weighing as much as 18 lb. each. According to the oldest residents this is a record haul with the rod for the Glenelg River.	Glenelg River	32 individuals	18lb	8.16	8.16	92.13
1917	Feb	3	Border Watch (Mount Gambier SA 1861-1954)	A Good Catch of Fish	A party consisting of Messrs. McEachern, Francis, Vause, and Shanasy had good sport on the Glenelg River on Thursday night. Between them they caught 20 mulloway and 30 bream. The mulloway scaled between 5 lbs. and 10 lbs., and the bream from 1/2 lb. to 3 lb.	Glenelg River	20 individuals	5-10lbs	4.54	4.54	79.64
1917	Feb	3	Border Watch (Mount Gambier SA 1861-1954)	Fishing in the Glenelg River	Several nice hauls of fish have been reported from the Glenelg River during the past few days. On Wednesday last Mrs. H. Vause landed four nice mulloway, which weighed from 7 lbs. to 12 lbs. Mr. Jack Vause also landed a fine 12 pounder.	Glenelg River		7 - 12 lbs	5.44	5.44	83.49
1917	Feb	7	Daily Herald (Adelaide, SA 1910-1924)	Mount Gambier News	Anglers continue to have excellent sport at the Glenelg River. On Wednesday, Mrs. H. Vause of the Nelson Hotel, landed four mulloway ranging from 7 lb. to 12 lb. and Mr J. Vause secured one weighing 12 lb. Their catch also included 20 bream. On the following evening Messrs. MacEachern, Francis, Yaw, and Shanasy, caught 20 mulloway and 30 bream, the former scaling up to 10 lb., and the latter to 3 lb.	Glenelg River		7-12 lbs	5.44	5.44	83.49
1917	March	14	Border Watch (Mount Gambier SA 1861-1954)	A Good Haul of Fish	Mr. L. G. Telford and two friends, who have been at Nelson, had the luck to get some fine mulloway, the biggest fish turning the scale at 18 lb., and three others were between the weights of 8 and 10 lbs. We are told that the 18 lb fish is the biggest caught this season.	Nelson		18 lb max	8.16	8.16	92.13
1917	Aug	29	Border Watch (Mount Gambier SA 1861-1954)		The Glenelg River has been very muddy for some time, and dozens of mulloway have been found choked. Messrs. W. Taylor and Albert Vause, of Nelson, found one 57 1/2 lbs. in weight, and several others up to 8 lbs. and 10 lbs.	Glenelg River		57 1/2 lbs max	26.08	26.08	116.88

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1918	Feb		Border Watch (Mount Gambier SA 1861-1954)	Good Fishing	A correspondent at Nelson informed us yesterday that some visiting parties of anglers have during the last few days done some marvellous fishing at the Glenelg River. He said, "We had a Hamilton party here last night, and they caught 44 mulloway, averaging 10 lb in weight. Captain and Mrs. Instone yesterday caught 41 bream, not one of which was under 2 1/2lb. in weight. They caught 22 bream on Saturday. Mr. Paterson caught 28 splendid bream for the week, and Mr. Poole 30 for the week, none of which were under 2 1/2 lb. in weight."	Glenelg River	44 fish	10 lb average	4.54	4.54	79.64
1918	Oct	22	The Advertiser (Adelaide SA 1889-1931)	Mulloway Fishing at Noarlunga	Three members of the South Australian Anglers' Association, Messrs. H. Bridgland, M. Johnson, and G. H. Williams have had the unusual experience in the past few days of catching mulloway, also known as butterfish, in the Onkaparinga River at Noarlunga. They were out for bream, and were fishing right in the township with light tackle calculated to land a fish weighting about two pounds. Messrs. Johnson and Bridgland, however, had rare sport with 5 lb. fish on the end of their lines, and the specimen landed by Mr. Williams weighed 6 1/2 lb.	Onkaparinga River, Noarlunga	3 fish	6 1/2 lb max	2.95	2.95	70.46
1920	Jan	6	Border Watch (Mount Gambier SA 1861-1954)	Good Haul at Nelson	Between Wednesday and Sunday last Messrs P. Bond, L. G. Telford, and party caught a large haul of fish at Mr. Tom Donovan's. It consisted of 42 bream, averaging 2 1/2 lbs, and 6 mulloway, the biggest turning the scales at 14 lbs, and the smallest at 6 lbs.	Nelson	6 fish	14 lb max 6 lbs min	6.35	6.35	86.79
1920	March	26	Border Watch (Mount Gambier SA 1861-1954)	A Big Mulloway	A big mulloway was landed on Thursday at Nelson by Captain Thornhill, of Melbourne, who is spending his first holiday at that favourite fishing resort. He was fishing from the landing near the hotel, when he hooked the fish. He immediately got into a boat, and played the fish for over an hour, going more than half a mile up stream. The fish, on being landed, was found to measure 57 1/2 in. long, with a girth of 28 inches, and weighed 54 1/2 lb. The length of the head was 15 inches. As well as the mulloway, the party landed 30 nice bream.	Nelson	1 individual	57.5 inches long, 28 inches girth, 54.5 lb weight, length of the head was 15 inches	24.72	24.72	115.74
1920	April	13	Recorder (Port Pirie, SA 1919-1954)	Steamer Kills Mulloway	One of the largest mulloway ever caught in Port Pirie was the reward of a few men who watched the departure of the steamer Dorset on Sunday. Apparently the fish was hit by a propeller blade, for it floated to the surface of the water just after the steamer started. It was recovered by the boatmen in attendance on the steamer, and a few men on the wharf, and was shared among them. The fish weighed 60 lb. The Dorset is alleged to have run down a fisherman's boat when coming into port; so apparently she has an aversion for fish and all connected with them.	Port Pirie	1 fish	60lb	27.22	27.22	117.79

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1921	March	11	Border Watch (Mount Gambier SA 1861-1954)	Fishing at Nelson	A correspondent writes: "Bream fishing at the Glenelg River is not up to the usual for this time of the year, but for all that some good catches are reported." Mr. H. E. Glover and Dr W. H. Jermyn caught 19 fine bream on Tuesday night, and a 12 lb. mulloway. Another party of two caught several bream and four mulloway, averaging about 8 lb. Mr. McCulloch is having mixed sport with bream and mulloway. A party of four from Hamilton; Messrs. Kelsall, Rountree, Brown, and Miller, had better luck, and during two weeks they landed over 40 fine mulloway, using live and ground bait. Mr. Poole, of Adelaide, landed during his stay about 300 bream. Mr. George Saunders, of Adelaide, and Mr. Johnston had good mulloway sport.	Glenelg River, Nelson	over 40 fish	12 lb	5.44	5.44	83.49
1921	March	1	Border Watch (Mount Gambier SA 1861-1954)	Beachport February 28	Fish is still very plentiful in and about the bay, and some good hauls have been registered. An enjoyable Easter vacation could be spent here with rod and line, especially as the duck shooting season is now open, and Mr. Reed, with his up-to-date 8 h.p. motor boat is making a speciality of catering for fishing parties. The well-known angler, Mr. L. J. Childs, recently landed a butterfish on a fairly light line weighing 18 lbs.	Beachport	1 fish	18lbs	8.16	8.16	92.13
1921	March	5	Observer (Adelaide, SA 1905-1931	Fishing - On the Murray and Coorong (photographs accompany text)	Recently a south-westerly blow sent the salt water up into the Murray and as a result, the fishermen reaped a rich harvest. Alf Probert, who had his nets set off Ram Island, caught a ton of mulloway (butter fish) in three days. The fish ranged from 5 to 25 lb. An Adelaide party watching Probert land 88 mulloway From left to right:—A. C. Cutten. T. J. Walter. Dr Allek Benson and John Sampson. 2. Probert showing some of his prizes. 3. Gutting the fish for market. 4. The well-known humpy on Ram Island, where Capt. Harry Butler recently spent his honeymoon. 5. Fishing for mullet in the Coorong Channels near the Murray Mouth. Seventy were caught in an hour.	Ram Island		5 - 25 lbs	11.34	11.34	99.14
1921	Sept	7	Recorder (Port Pirie, SA 1919-1954)	Big Butterfish Caught	A monster butterfish was on view at Mr F. Franco's Central Fish Saloon last night, which turned the scales at 40 lb. It was caught by Mr D. Degenaro, a Pirie fisherman.	Port Pirie	1 individual	40lb	18.14	18.14	109.15
1922	Feb	21	The Register (Adelaide, SA 1901-1929)	Butterfish Plentiful and Cheaper	Mr. J. M. Cooking, of Franklin Street, mentioned on Monday afternoon that the season for butterfish, which had been slack, had taken a turn for the better. About five tons of the fish had come to hand during the past day or two, principally from Port Willunga, where the fishermen had had an excellent haul. The sizes of the fish ranged from 3 lb. to 20lb. The result of the increased supply will be a reduction in the price, which should now range between 9d. and 1/ a lb.	Port Willunga	5 tons	3 lb - 20 lb	9.07	9.07	94.38

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1922	Feb	22	The Advertiser (Adelaide SA 1889-1931)	Butterfish Plentiful	Mr. J. M. Cocking of Franklin Street, states that the season for butterfish, which has been slack, has taken a turn for the better. About five tons of the fish have been received, principally from Port Willunga. The sizes of fish range from 3 lb. to 20 lb.	Port Willunga	5 tons	3 lb - 20 lb	9.07	9.07	94.38
1924	April	25	The Advertiser (Adelaide SA 1889-1931)	Mount Gambier	April 22—A huge mulloway was caught on a hand line from the Beachport jetty last week. It weighed about 50 lb., and was caught by Mr. H. Morgan.	Beachport Jetty	1 individual	50lb	22.68	22.68	113.91
1924	Nov	22	The Mail (Adelaide, SA 1912-1954)	Monster Fish (includes photograph)	Caught at Brighton. This huge butterfish was caught on Wednesday morning at Brighton by Mr. B. Clough. On Tuesday evening the fish was seen swimming alongside the jetty. Small boys tried to tempt it with relatively diminutive baits and hooks on tommyrough lines, but these the butterfish declined to notice. Next morning the fish was still there, and Mr. Clough angled for it with a strong schnapper line baited with squid. This bait was accepted, and the line held, but the fish was too strong to pull up and it had to be towed by boat on to the beach. Unfortunately the fish was not weighed until it had been cleaned. Then it turned the scale at 55 lb. It was nearly 5 ft. long. The fish was sold for £4 2/6.	Brighton		55lb, nearly 5ft long	24.95	24.95	115.94
1925	March	3	Border Watch (Mount Gambier SA 1861-1954)	Fishing at Nelson	Fishing at Nelson: Mr. J. T. Millerick, Nelson Hotel, informs us that Melbourne and Adelaide anglers, who have just returned, have had a successful fortnight's fishing on the River Glenelg. Mr. G. Lawley, of Adelaide, caught 101 bream, weighing from 1 lb to 3 1/2 lb., and Messrs. V. Lander, Smith, and Lemmon, of the Richmond Angling Club, caught 245 bream, averaging 1 3/4 lb, and one mulloway of 20 lb. Anglers state that the end of March will see fishing at its best, as at the present time, because of the absence of early winter floods, there is much green slime on the bed of the river.	Glenelg River, Nelson	1 individual	20lb	9.07	9.07	94.38
1925	Nov	28	The Mail (Adelaide, SA 1912-1954)	Big Fish (with photograph)	This is part of a big haul of butterfish made by fisherman W. Rumbelow at Victor Harbor last Monday. The fish ranged in weight from 40 to 60 lb. each.	Victor Harbour		40-60lb each	18.14 - 27.22	27.22	117.79
1925	Dec	12	The Mail (Adelaide, SA 1912-1954)	Photograph	Mulloway of 54 1/2 lbs caught with light rod and line at Glenelg River.	Glenelg River, Nelson	1 individual	54 1/2 lbs	24.72	24.72	115.74

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1926	Jan	30	The Mail (Adelaide, SA 1912-1954)	Mulloway at Middleton	Recently, a fisherman captured a couple of large mulloway at Middleton Beach, where the big fish are seen occasionally. The two weighed 62 pounds. To catch these fish at Middleton they use a stout line with a heavy sinker, with one or two large hooks on copper wire traces for preference, baiting with small mullet. Round the rocks on this coast the mulloway come close in to feed, and it is astounding that they are able to exist in such rough surge adjacent to the rocks. At times six or seven of them can be seen quite close in, rolling in the breakers. There is one place at Middleton where there is a fairly narrow channel, and at that spot the butterfish, as mulloway are often termed, can sometimes be seen in companies loafing round close-up to the rocks. Following the catching of the two big ones mentioned, an angler got a ten pounder here, but I'm informed there are not too many to be caught. At times the water becomes loaded with seaweed, and then of course fishing is out of the question, as the fish cannot see the bait.	Middleton Beach		62lbs	28.12	28.12	118.49
1926	May	22	The Mail (Adelaide, SA 1912-1954)	Strategy that Failed	A well-known city angler was fishing for mulloway out from Outer Harbor. He sighted a beauty. Promptly he attached the boat to a beacon (against the laws of the land), arranging it so that the rope would slide through and release the boat when he gave the word to his young assistant. The angler hooked the big butterfish. It must have weighed about 40 lb. He gave the word to let go, so that he could drift while playing the fish. However, there was a knot in the rope and the boat remained stationary. The big fish swam quickly round the boat and the beacon, and the angler was deprived of his fish, and most of his tackle. The principals themselves do not tell of these incidents. Their friends mention them.	Outer Harbour	1 individual	40lb	18.14	18.14	109.15
1926	Aug	14	The Mail (Adelaide, SA: 1912-1954)	Outer Harbour Butterfish	Fishing from the wharf at the Outer Harbor, Mr. W. Jewell, of Rundle Street has been securing some nice butterfish recently. Last week he took a 33 pounder and a 17 1/2 pounder from that part— the first of this class of fish reported as being hooked by anglers for some time. Mr. Jewell is a recognised trier, and will stop on the job all the night if he thinks the fish are about. He deserves success.	Outer Harbour		33lb and 17.5lb	14.97	14.97	105.06

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1926	Aug	27	The Register (Adelaide, SA 1901-1929)	A Big Mulloway	Lately we have been catching in our nets a few big mulloway (butterfish), which are returning from up the river to the sea,' proceeded the speaker. 'When they went up the big ones in this family were too strong for our nets, but a period in the fresher water seems to reduce their vitality, although their table qualities are not impaired. The other day I netted one which, after being gutted, weighed 84 lb. — the biggest one I have captured in those waters in a quarter of a century. I was told afterwards that this fine specimen was exhibited in Adelaide as weighing 104 lb. Probably the purchaser allowed too much for the wastage, as I think a 10 lb. margin would cover the removals.'	Murray Mouth		84lb	38.10	38.10	124.96
1927	Jan	8	The Mail (Adelaide, SA 1912-1954)	Victor Harbour	Fishing has been fairly good at Victor Harbor during the past week or two. When down there on Thursday of last week I was informed that the professionals had been successful. Rough weather had driven the butterfish in and they had been netting fair-sized catches, fish ranging up to 33 lb. One big haul averaged about 12 lb.	Victor Harbour		max 33lb, average 12lb	14.97	14.97	105.06

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1927	Feb	23	The Register (Adelaide, SA 1901-1929)	Wonderful Catch of Mulloway	The salt water had come in about a fortnight before our visit, and altogether about 3 tons of mulloway had been despatched from Goolwa to Adelaide, but Alf. Probert, who now looks after us on our annual visit, made the best single catch soon after our arrival. He had a dozen nets, each 50 yards long, set over in the direction of Point Sturt. He ran them twice a day. One morning after a big blow he caught one butterfish. This must have been the pilot of a big school which had come in from the sea and were doing a sort of grand tour before going out again at the mouth. The life history of the mulloway must be almost as interesting as that of the salmon. On the next morning Alf Probert was away to his nets soon after daylight, and a couple of hours afterwards, he returned to Ram Island with the flat-bottom boat nearly down to the gunwale in the water. 'Plenty fish' he called out, imitating the voice of an aborigine, and, making for the little sandy beach, we discovered the boat actually full of mulloway. There were 180 ranging from four to five pounders up to over 22 lb. Walter Probert, a brother, who was on his way to Goolwa from further upstream, was hailed, and the fish were all got ashore, and gutted, and returned to Walter Probert's motor boat. They were boxed at Goolwa, and left by the afternoon train for Adelaide. This catch of butterfish weighed 12 cwt. I took a photograph of the fish on the beach with a flock of gulls and some pelicans standing by waiting for the offal. One old pelican was so tame that he would take food almost from Probert's hand, but it was frightened of strange company. I also snapped Mr Arthur Cutten holding the biggest fish. These photographs will appear in The Observer this week.	Point Sturt	180 individuals , 12cwt	4lb - >22lb	9.98	9.98	96.42
1927	Feb	26	Border Watch (Mount Gambier SA 1861-1954)	Fishing at Nelson	On Thursday evening Messers Miller and Proudfoot, visitors staying at "The Cottage," Nelson, landed two large mulloway. They scaled 44 lb. and 66 lb. respectively.	Nelson	2 individuals	44 and 66lb	19.96 and 29.93	29.93	119.82
1927	March	19	The Mail (Adelaide, SA 1912-1954)	Port Noarlunga	A Port Noarlunga angler states that he was fishing from the jetties after tillies and accidentally hooked a 10 lb. butterfish, which he landed.	Port Noarlunga	1 individual	10lb	4.54	4.54	79.64
1927	May	7	The Mail (Adelaide, SA 1912-1954)	Sellicks Beach	Mulloway have provided some good hauls off Sellick's. Some time back one ton were brought in at one haul, some of the fish weighing up to 45 lb. Butterfish of 75 lb. weight have been caught off Sellick's, while further around the coast fish of 80 lb. weight have been brought in.	Sellicks Beach	1 ton	up to 45lb (75lb and 80lb also reported)	20.41	20.41	111.66
1927	July	9	The Register (Adelaide, SA 1901-1929)	Photograph	Mr John Gow and his biggest catch in the Glenelg River, a mulloway weighing 55 lb. Only two larger fish have been caught on rod and line in this stream.	Glenelg River, Nelson	1 individual	55lb	24.95	24.95	115.94

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1927	Oct	29	The Mail (Adelaide, SA 1912-1954)	Down the Gulf	Mulloway are still about The Shoe, Noarlunga, and last weekend Mr. Jack Edwards landed a nice specimen 10 lb. weight. Mr. H. J. Norris, who has been particularly fortunate recently, got a 4 1/2 pounder last Sunday and also a few bream.	The Shoe, Noarlunga	2 fish	10lb and 4.5lb	4.54	4.54	79.64
1927	Oct	15	The Mail (Adelaide, SA 1912-1954)	Noarlunga Bream	One of the greatest successes of the season was attained by Mr. E. Giles, of Toorak, at 'The Shoe' last Sunday. After a keen struggle, which tested his skill to the utmost with rod, light line, and hooks, he grassed a mulloway which weighed 10 lb. 4oz. This is claimed as a record fish from 'the Shoe,' but I shall be glad to hear of any bigger ones taken on rod and line from that part.	The Shoe, Noarlunga	1 individual	10lb 4oz	4.55	4.55	79.69
1927	Oct	27	The Register (Adelaide, SA 1901-1929)	A Trip to Poltalloch	We caught a couple of fine mulloway, a rainbow trout, and had one good haul of mullet. Walter Probert caught four big mulloway in his nets. They were 60 lb. fish.	Poltalloch	half dozen fish	60lb max	27.22	27.22	117.79
1927	Dec	17	The Mail (Adelaide, SA 1912-1954)	West Coast Sport	Though there was a slackening on the West Coast recently Mr. James Darling brought in 1 cwt. of large butterfish the other day. One weighed 17 lb. Good hauls of schnapper are being made off Port Neill, and at Carrow.	West Coast	1 cwt	max 17lb	7.71	7.71	90.92
1927	Dec	24	The Mail (Adelaide, SA 1912-1954)	Angling and Fishing: Murray River	Murray River Messrs. A. R Smith and C. Paech, who were in this vicinity recently, reported on taking 13 1/2 dozen salmon on cockles, also a few mullet. Many big mulloway up to 70 lb. have been taken there.	Murray River		up to 70lb	31.75	31.75	121.07
1928	Feb	24	The Naracoorte Herald (SA 1875-1954)	Mount Gambier	Good catches of fish have been reported from Nelson. Recently Messrs J. H. Rountree and Miller landed eleven nice mulloway, weighing up to 15 lb. On Wednesday some visiting anglers caught four mulloway, the largest turning the scales at 16 lbs.	Nelson	11 fish	up to 15lb	6.80	6.80	88.25
1928	Feb	18	Border Watch (Mount Gambier SA 1861-1954)	Fishing at Nelson	On Wednesday evening some visiting anglers got four nice mulloway, the largest turning the scale at 16 lbs.	Nelson	4 fish	max 16 lbs	7.26	7.26	89.64
1928	Feb	25	The Register (Adelaide, SA 1901-1929)	Caught on the Rod (with photograph)	A mulloway caught during January off the beach near to Middleton with a line by a local resident. It was 5 ft. long and weighed 53 lb.	Middleton	1 fish	5ft long, 53lb weight	24.04	24.04	115.15
1928	March	19	The Register (Adelaide, SA 1901-1929)	Milang - March 16th	On Thursday morning Sir Walter Woodrow had another large haul of mulloway, 13 fish, averaging over 50 lb. each.	Milang	13 fish	averaging over 50lb each	22.68	22.68	113.91
1928	March	17	The Register (Adelaide, SA 1901-1929)	Milang - March 14	Some large fish are being caught by the local fishermen. Mr Walter Woodrow recently netted some large mulloway, one weighing nearly 80 lb.	Milang		nearly 80lb	36.29	36.29	123.92

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1928	March	3	The Register (Adelaide, SA 1901-1929)	Big Harvest of Mulloway	It is an ill wind that blows nobody any good. The big storm brought the fish in, and some wonderful catches of mulloway were made. One man netted between 2 and 3 tons. Several tons were dispatched from Goolwa during the busy week. Jack Probert, who was fishing close to Ram Island, got a ton. Alf Probert, who was looking after us, set his nets, and he gathered in more than half a ton. One morning Alf Probert came home from his nets with three fish, but one was the biggest mulloway he had ever seen. It was 5 ft. 6 in. long, and 4 ft. round the girth. With its gut in Probert estimated that it weighed nearly 100 lb. I got Mr. Cutten and Probert to hoist it up while I photographed it. The fish was a dark bronze in colour. It had a large tookerie (bony bream) in its mouth and three large tookerie in various stages of digestion in its stomach. The life history of this mulloway would provide a delightfully interesting story. It would tell of its trips to sea and its cruises up and down the channels in the vicinity of the Murray Mouth.	Goolwa	2-3 tons, 1 ton (Ram Island), half a ton	max 5ft 6in long, 4ft girth, nearly 100lb	45.36	45.36	128.67
1928	May	5	The Mail (Adelaide, SA 1912-1954)	Angling and Fishing	It takes great patience and skill to catch butterfish at Outer Harbor, but there are triers who occasionally succeed after a night out with the lines. Spending the night in an open boat at this time of the year is not particularly attractive. Last Saturday night Mr. E. Just landed a mulloway, or butterfish as they are usually termed, at the harbor, and it weighed 30 lb.	Outer Harbour	1 fish	30lb	13.61	13.61	103.03
1928	May	5	The Mail (Adelaide, SA 1912-1954)	Angling and Fishing	Probably the best place in South Australian waters for mulloway is the Murray Mouth. Mr. John Gow, former president of the South Australian Fish Protection and Anglers' Association, has secured some large specimens from Glenelg River, Victoria. In that river light lines and rods are often used for the fish, but strong tackle is necessary at the Murray Mouth, where there is a strong pull of the tide. Fish weighing more than 40 lb. have been caught in this locality by Adelaide anglers. Squid is often the bait for mulloway, and golden carp is a favourite with some. Night time is usually the best time for catching these fish. Mr. Guy Saunders holds the record for Glenelg River with a 54 1/4 lb. fish. It was 4 ft. 10 1/2 in. long.	Murray Mouth		more than 40lb	18.14	18.14	109.15
1928	Aug	28	News (Adelaide, SA: 1923-1954)	Anglers Meet	Several anglers met at the residence of Mr. J. D. Nash, Marion Road, South Plympton, to congratulate him on his having landed an 11 lb. mulloway at Noarlunga.	Noarlunga	1 fish	11lb	4.99	4.99	81.65
1928	Aug	11	The Mail (Adelaide, SA 1912-1954)	Angling and Fishing - Glenelg River	An expert mulloway fisherman in Mr. Proudfoot, of Warrnambool, recently hooked a 32 lb. fish. It gave him a long fight.	Glenelg River, Nelson	1 fish	32lb	14.52	14.52	104.41

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1928	Aug	11	The Mail (Adelaide, SA 1912-1954)	Angling and Fishing	This week I was advised by a member of the association that a regular wharf angler at Outer Harbor last week landed butterfish, or mulloway, weighing 33 lb. The successful angler was on the job all night, and made his catch about 2 o'clock in the morning. It is rather unusual for these fish to lie about at the Harbor during this time of the year. Jumper have been biting at Siberia (Port River). One man secured nine nice ones this week. In the basin, Port River, a few mullet have been landed.	Outer Harbour Wharf	1 fish	33lb	14.97	14.97	105.06
1928	Sept	29	The Mail (Adelaide, SA 1912-1954)	Angling and Fishing	Mulloway, or Butterfish: Anglers are looking forward to mulloway fishing later on. For the big fish you want a fairly thick line with one or two large hooks, on a copper wire trace for preference, baited with a small mullet. Mulloway sometimes come into the surge near the rocks. At Middleton there is one place where there is a narrow channel, and the fish come quite close to the rocks. Mulloway weighing up to 30 lb. have been caught at Middleton beach. Occasionally the water becomes so loaded with seaweed that it is difficult to get them. Beneath the wharf at Outer Harbor is a favourite place of some mulloway fishermen. The mouth of the Murray is perhaps the greatest source of supply.	Middleton Beach		up to 30lb	13.61	13.61	103.03
1928	Nov	17	The Mail (Adelaide, SA 1912-1954)	Angling and Fishing	Twenty-one members of the South Australian Fish Protection and Anglers' Association held a successful competition in the Onkaparinga, Noarlunga, last Saturday afternoon. Almost all the competitors got sufficient bream for a meal. It is essential to have the proper gear for catching these fish, and it is desirable to get fitted out in a reliable tackle shop. Many fish of less than schedule size were caught, and returned to the water. Mr. Guy Saunders was the most successful, and he weighed in 12 lb. 4 oz., securing the trophy for the best catch of the day. Mr. R. J. Copeland was second with 9 lb. 14 oz. Others in the running included Mr. Fred Lavis, 9 lb. 9 oz.; Mr. E. Giles, 7 lb. 14 oz. In the catch of Mr. Copeland was a mulloway weighing 6 lb. 9 oz. He is now in the lead for the trophy presented to the angler who catches the, largest fish of the year on rod and line. Mr. F. Goldring, with a schnapper weighing 6 lb., had held top place for some time.	Onkaparinga River	1 fish	6lb 9oz	3.15	3.15	71.85
1928	Dec	28	The Register (Adelaide, SA 1901-1929)	News of the Day	Excitement was caused on Boxing Day Wednesday when Mr. Chant, while fishing with a line, secured a 70 lb. mulloway, which took half an hour to land. A record number of holiday visitors are staying, at Elliot, and a crowd quickly gathered to witness the fight with the fish. The foreshore is thickly dotted with camps.	Port Elliot	1 fish	70lb	31.75	31.75	121.07
1929	Jan	26	The Mail (Adelaide, SA 1912-1954)	Angling and Fishing	Fishing from the Middleton beach at night Mr. R. Rose, who is an expert at this class of angling, landed two 46 lb. mulloway and one weighing 36 lb.	Middleton Beach	3 fish	46lb (2fish) and 36lb	16.33	16.33	106.91

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1929	March	4	The Register News - Pictorial (Adelaide, SA 1929-1931)	Big Fish and a Tiny Church	Big Fish and a Tiny Church: Nelson possesses a tiny church, but this has been used of late mostly for the few public functions of the district. If Nelson does not take its church seriously, it does its fishing, and is proud of the 56 lb. mulloway which was landed after two and a half hours' fight on a rod and line more suited for bream. The skeleton of that and other monster mulloway are still displayed from the village windmill tower.	Nelson	1 fish	56lb	25.40	25.40	116.32
1929	April	13	The Mail (Adelaide, SA 1912-1954)	Angling and Fishing	Mr. A. Allison, who recently returned from a trip to Glenelg River, on the border between South Australia and Victoria, says mulloway were scarce while he was there. Mr. John Gow, former president of the South Australian Fish Protection and Anglers' Association, who for many years held the record for a mulloway taken from Glenelg River, is known as the 'Mulloway King' at Nelson. When there recently with Mr. G. Williams he secured seven mulloway, the largest of which weighed 38 lb. Mr. Allison mentioned that his party secured some fine perch from the river and an occasional bream. Taylor's Strait, about three miles up from Nelson, they found a good place. Bream fishing should be favourable from now on. Recently Victorian anglers have been successful with these fish.	Nelson		38lb	17.24	17.24	108.06
1929	May	11	The Mail (Adelaide, SA 1912-1954)	Angling and Fishing	Mr. Johnson and Mr. F. Choules of Rundle street, Adelaide, recently visited Middleton Beach to try out the mulloway. They fished from 7 o'clock to 11 at night without getting a touch, but the following morning Mr. Choules landed a 20 lb. mulloway.	Middleton Beach	1 fish	20lb	9.07	9.07	94.38
1929	June	1	The Mail (Adelaide, SA 1912-1954)	Angling and Fishing	Mr. Leo. Johnson landed 12 cod and callop at Mannum over the week-end. It was stated that a 36 lb. butterfish had been caught in that vicinity recently. Garfish have been biting fairly well for anglers at Victor Harbor, and barracouta are still taking the bait at the screw pile jetty.	Mannum	1 fish	36lb	16.33	16.33	106.91
1929	Aug	14	News (Adelaide, SA 1923-1954)	Weighed 93lb	This mulloway was caught at Goolwa off the jetty owned by Mr. Napier Birks. Mr. Arthur Sweetman was the lucky angler who landed the fish, which is believed to be the largest mulloway, save one, caught in South Australian waters (with Image).	Goolwa Jetty	1 fish	931b	42.18	42.18	127.13

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1930	Feb	20	The Register News - Pictorial (Adelaide, SA 1929-1931)	Huge Mulloway Trapped at Hindmarsh Island	Pitchforks and tomahawks were used to catch mulloway trapped inside the bar at Hindmarsh Island yesterday. The fish ranged in weight from 45 to 50 lb. Two Adelaide holidaymakers noticed that a large school of fish had apparently swum over the bar connecting Mundoo and Hindmarsh Island, and been trapped in the hollow with the falling of the tide. They slaughtered as many as they required with a tomahawk, after which a large party of residents and visitors joined in the sport with pitchforks. About 22 large fish were brought ashore by men wading in bathing costumes, armed with pitchforks, and it was estimated that about as many more were left in the pool. A resident of Hindmarsh Island said that when one of the party was dragging a fish away to be cleaned, carrying it over his shoulder, nothing could be seen of the man, and nine inches of the fish's tail was dragging on the ground.	Hindmarsh Island	22 fish	45-50lb	20.41 - 22.68	22.68	113.91
1930	March	1	Observer (Adelaide, SA 1905-1931	Mount Gambier	Visitors to the Glenelg River at Nelson are enjoying excellent sport, and some big catches have been reported. Mr. Harry Schmidt landed a mulloway weighing 35 lb., and many catches of up to 20 lb have been reported.	Glenelg River, Nelson		35lb	15.88	15.88	106.31
1930	July	26	The Register News - Pictorial (Adelaide, SA 1929-1931)	Big Catches	Big Catches: Besides many small fish we catch quite a number of large fish and sharks at Encounter Bay. Large edible fish are not very common. There are the mulloways or butterfish which measure from two to six feet long and weigh about sixty lb., and snook, long, thin fish, which weigh about three lb., and a few others.	Encounter Bay		about 60lb, 2-6 feet long	27.22	27.22	117.79

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1931	March	4	Advertiser and Register (Adelaide, SA: 1931)	Running the Nets	Alf Probert as usual, looked after the holiday party on Ram Island. He had his nets set off the island, but the harvest was only fair. Much of the mulloway which comes into the Adelaide market is hooked from Goolwa. Sometimes the fish are caught at the mouth on lines, one or two go in for trawling, but mostly his men who engage in the industry have fixed nets. These are attached to stakes driven into the mud, and sometimes one stretch of them will be a mile long. The harvest is generally best after a south-westerly blow. The men run the nets from their dinghies twice a day, and on occasions I have seen the boats literally loaded with fish. The largest I have seen was a hen fish, which weighed just on 100 lb. In the old days of the sailing boats, much fish was lost through men not being able to catch the train owing to an absence of wind. On occasions the men had pulled all the way from the Coorong, and then, missed the train. Now the motor boats can run almost to time table from the various fishing camps, where the men have tents and huts. Their homes and families are in Goolwa, although Walter Probert and his wife and children once lived at Shooting Creek up in the mud islands for six months, Jack Probert has his camp on Long Island, and Alf sticks to Ram Island. These men know the channels like we know King William street. It is a hard life in rough weather, but it is very healthy. The photograph shows Alf Probert running his nets, in which a mulloway is caught.	Ram Island		100lb	45.36	45.36	128.67
1932	Jan	11	The Advertiser (Adelaide SA 1889-1931)	It was a Butterfish	A 2 ft. 9 in. butterfish was seen yesterday in the Seacliff shark proof net enclosure which apparently explains the report of the presence of a shark in that area. At low tide Mr. K. Mathieson pointed out the presence or the butterfish, which Mr. J. B. Butterworth and he unsuccessfully endeavoured to harpoon with a tent peg. Mr. Bert Whitehead, a local fisherman, went all round the enclosure in a boat, but saw no sign of a shark.	Seacliff		2ft 9in			69.58
1932	Jan	21	Chronicle (Adelaide SA: 1895 - 1954)	Mount Gambier	Anglers have had record Christmas fishing on the Glenelg River at Nelson. The biggest haul was 54 perch and bream, and seven mulloway, one weighing 13 1/2 lb., made by Mr. W. A. Butt, of Ararat, and Mr. Casters, of Horsham. Old residents say they have not known better fishing at this time of the year for more than 40 years.	Glenelg River, Nelson	7 fish	max 13.5lb	6.12	6.12	86.00
1932	Jan	28	Chronicle (Adelaide SA: 1895 - 1954)	Mount Gambier	Big catches are reported by anglers at Nelson. Mr. J. Nash caught six mulloway which tipped the scales at 40 lb. when dressed. Messrs. J. Vause and A. Allison landed 80 perch, and Messrs. W. and J. Vause caught 90 perch and bream upstream. Ducks are also plentiful at the river.	Glenelg River, Nelson	6 fish	40 lb (combined or individual?)	18.14	18.14	109.15

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1933	Aug	18	The Advertiser (Adelaide SA 1931-1954)	Fish Becoming More plentiful	Recently a large butterfish was captured with their bare hands by Messrs. Gillett Bros., while it was feeding among the seaweed in shallow water near an old slag heap at Wallaroo. It weighed 13 lb. after it had been cleaned.	Wallaroo		13lb	5.90	5.90	85.22
1933	Nov	2	Chronicle (Adelaide SA: 1895 - 1954)	Image	Butterfish at Wallaroo. This fisherman had a busy day along the coast spearing the big fish. The largest specimen shown here weighed 100 lb. It was nearly 5 feet in length.	Wallaroo	1 fish	100lb, nearly 5ft long	45.35	45.35	128.67
1934	July	28	The Mail (Adelaide, SA: 1912-1954)	Image	Mr Angas MacDougall, of Victor Harbor, whose hobby is fishing. He caught four mulloway weighing in aggregate 104 lb. at the rocks at Middleton with a rod. The individual weight of the fish was 35, 31, 20, and 18 lb. Mr. MacDougall was formerly in a fish tackle business in Leigh Street. He has won more than 19 cups and trophies for angling.	Middleton	4 fish; 104lb	36, 31, 20 and 18lb	16.33	16.33	106.91
1935	Aug	1	Chronicle (Adelaide SA: 1895 - 1954)	Image	One that did not get away. This mulloway weighing 55 lb., was caught in the Glenelg River the other day by Mr. W. Fox, of Mt. Gambier. It is one of the largest fish the river has yielded for some years.	Glenelg River, Nelson	1 fish	55lb	24.95	24.95	115.94
1936	Feb	4	Border Watch (Mount Gambier SA 1861-1954)	Fishing in the Glenelg River	Good Hauls of Mulloway. During the last few days several fine catches of mulloway were made on the Glenelg River. In three nights Messrs. Bruce., Proudfoot and Son caught no less than 35 fine fish, eight of which weighed from 16 lbs. to 45 lbs. On Monday evening Mr. J. Bawden caught three weighing 7 1/2, 12, and 17 lbs, respectively. On Saturday night he caught two, one 6 lbs and the other 5 1/2 lbs. The fish came into the river about an hour after sundown, and an hour later anglers at Donovan's had good sport. Mr. Fowler caught two weighing 8 and 9 lbs each. Messrs Bird and T. Millard also had good sport but the fish they landed were smaller than those recorded.	Glenelg River, Nelson		5 - 45lbs	20.41	20.41	111.66
1936	Feb	24	The Advertiser (Adelaide SA 1931-1954)	Reports from Rural Centres	The Coorong is very low at present, and it is thought it entered the lakes at the Murray mouth with the flow of salt water. An occurrence of this kind is very rare. Fish are scarce, but some good specimens have been landed. Recently one fisherman landed four large mulloway, which together turned the scale at 250 lb.	Coorong	4 fish	62.5lb average	28.35	28.35	118.66
1936	March	16	The Advertiser (Adelaide SA 1931-1954)	Large Haul of Fish near Milang	A big school of mulloway was noticed in the vicinity of the Milang Jetty on Friday. Fisherman had never seen big fish so close to the shore before, and were at first sceptical; but quickly realised that something extraordinary was apparent, and nets were set. Large sprays could be seen from the shore and the sight attracted many townspeople. The fishermen worked at high pressure for four hours, and the catch was estimated at many tons. Some of the fish weighed from 60 to 70 lb. Fish of that size have never been caught in great numbers here before.	Milang	many tons	60-70lbs	27.21 - 31.75	31.75	121.07

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1936	March	17	News (Adelaide, SA: 1923-1954)	Big Mulloway Haul sold in Adelaide	Described as a fluke haul, the big catch of mulloway at Milang has been disposed of on the Adelaide market. The fish bought from 3d. to 4½d. a lb., compared with last week's prices of 5d. to 6½d. The market generally eases as a result of the glut. Milang fishermen estimated the haul at six to seven tons. The fish were first noticed by an angler on the jetty, and local fishermen worked at high pressure for four hours. Most of the fish were netted by the Woodrow brothers. It was stated today that many mulloway from the school were still in the lake, but had moved farther out from the shore. A large number of the fish forwarded to Adelaide weighed from 60 to 70 lb. each.	Milang	many tons	60-70lbs	27.21 - 31.75	31.75	121.07
1936	Sept	5	The Advertiser (Adelaide SA 1931-1954)	Port Victoria	A fine haul of mulloway was caught by Messrs. J. Waters and I. E. Rail. The largest weighed about 60 lb. and there were 34 in the haul.	Port Victoria	34 fish	max 60lb	27.22	27.22	117.79
1936	Dec	4	Victor harbour times	Middleton	Amateur anglers have begun the season excellently, having caught several mulloway weighing up to 60 lb.	Middleton	several	up to 60lb	27.22	27.22	117.79
1937	Feb	11	News (Adelaide, SA: 1923-1954	Duck Shooter Catches Mulloway	R. Godfrey told me of a feat of which he is proud. He said that while he was in a duck shooter's boat he caught a large mulloway. To get the fish on to the small surface of the boat without falling into the water was difficult, but he did it. The mulloway, he said, turned the scales at 62 lb. Here is another feat which was related by Mrs. E. H. Dodd, of Goolwa. She was standing on the deck on the boat in which her husband traded on the Murray when she noticed an eagle hawk swoop down and snatch a young duck. Her shot killed the hawk. The duck fell into the water and swam to its mother. Mr. Dick Lundstrom, who earns his living catching fish at the Murray Mouth, told me that crabs are doing much damage to nets. This crab, which is known as the mottled shore crab, he describes as the fisherman's permanent boarder. There is a shark down there also which is not improving the temper of the fisherman. It waits until a big mulloway has been hooked, then glides up and takes what it wants. It generally leaves the head. I inquired the weight of the largest mulloway ever caught at the Murray Mouth, and was told that it was 92 lb.	Goolwa	1 fish	62lb	28.12	28.12	118.49

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1938	Jan	25	News (Adelaide, SA: 1923-1954	Big Hauls of Mulloway	Pt. Noarlunga Catch: Visitors to Port Noarlunga today are being treated to the sight of two local fishermen, R. Price and A. Reyner, hauling in nets of large fish from adjacent grounds. A school was met early, and very soon more than 150 mulloway, weighing as much as 50 lb. each, were landed. These were promptly cleaned on the beach, where many sales were made among visitors. The remainder of the catch is being brought to Adelaide this afternoon. Jetty anglers have "been among 'em" too. Yellowtail, a fine fighting fish, have been landed with rod and line. Several of these have scaled up to 10 lb. Trevalli and large salmon also have helped make Port Noarlunga an angler's paradise. It is thought that the mulloway, commonly known as butterfish, have migrated from the River Murray. At Goolwa a seven-ton catch of mulloway has been reported.	Port Noarlunga	150 fish	max 50lb each	22.68	22.68	113.91
1938	Feb	23	News (Adelaide, SA : 1932-1954)	O.S in Butterfish	O.S. in Butterfish: The fish you see in this illustration alongside a fisherman in topless bathers is a butterfish, or mulloway, weighing 58 lbs captured near Goolwa. You will gather that it is an outsize when I tell you that, according to Mr. F. Moorhouse (Chief Inspector of Game and Fisheries) the weight of the average butterfish is from 15 to 20 lbs. Wholesale prices for butterfish fluctuate in response to supply and demand. At Christmas the quotation reached 1/3, and it is now in the neighbourhood of 6d. To catch a butterfish weighing 58 lbs. and selling at 1/3½ per lb. would be a good day's work.	Goolwa	1 fish	58lb	26.31	26.31	117.07
1938	Feb	16	The Advertiser (Adelaide, SA: 1931-1954	Big Hauls of Butterfish	Big Hauls Of Butterfish: Who said fish is getting scarce? A colleague of mine told me yesterday that, down at Goolwa the other day he saw six tons of butterfish landed at the wharf. These were caught in one haul in Coorong waters by Dick Lundstrom, and the weights averaged 20 lb. The biggest were 60 pounders. He had to call for Mrs. Lundstrom's aid. This catch was worth a lot of money. A fair number got away, and a boat following netted a ton and a half. Two days later Dick caught an additional two tons. He says he has never known a better season for fish.	Goolwa	6 tonnes	average 20lb, max 60lb	27.22	27.22	117.79

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1938	Nov	21	News (Adelaide, SA: 1923-1954)	Lucky Anglers	Goolwa has come into its own as a fishing centre. Tons of fish were hauled out of the waters round the barrages during the week-end, as boat loads of fishermen, attracted to the spot by reports of good sport, went into action. No boat came back to the wharves last night empty, one party of a dozen anglers getting 16 dozen without any trouble. But their bag was insignificant alongside the two-ton catch of butterfish by Mr. Jock Sauerbier, of Goolwa. The smallest was about 16 lb. They were netted in one haul at daylight yesterday, and they presented a remarkable sight when laid out on the wharf. Amateur anglers, in spite of their own big catches of salmon trout, mullet, and gar, bought this butterfish at 4d. a lb.!	Goolwa	2 ton	smallest 16lb	7.26	7.26	89.64
1939	Feb	7	The Naracoorte herald (SA: 1875-1954)	Shoals of Mulloway at Kingston	For the first time for years, mulloway in small shoals have been seen along the coast. Last week when Mr. P. Criddle and a party were at the long beach in a car they observed a school of porpoises driving two or three separate shoals of big fish, which, to escape, came into the shallow water at the edge. Mr. Dick Criddle, with the assistance of the car starting handle, succeeded in getting one about 30 lb. in weight. It is said there were 60 or more mulloway in the lot. At other places along the coast these fish are being caught. The presence again, after some years, of these fish, is welcome, and is probably due to changes taking place at the Goolwa barrage. If this is so they should again be seen in the Coorong at Salt Creek and Woods Well.	Kingston	1 fish	30 lb	13.61	13.61	103.03
1939	Feb	9	Chronicle (Adelaide SA: 1895 - 1954)	Haul of Mulloway	Portion of a large catch of mulloway netted at the Murray Mouth, and brought into Goolwa by fishermen last week. Some of the fish measured four feet in length.	Murray Mouth		4 feet			121.92
1939	Feb	16	News (Adelaide, SA : 1932-1954)	Night Fishing at Outer Harbour	Night fishing at Outer Harbor, Messrs. Burgess, H. Mufford, Vanderwall, and Muggleton had several runs, once contacting a 33 lb butterfish. Just at dawn they caught five big salmon.	Outer Harbour	1 fish	33 lb	14.97	14.97	105.06
1939	March	10	Australian Christian Commonwealth (SA 1901-1940)	Fish Story	Rev. J. C. Richmond, the well-known ministerial fisherman, recently caught four mulloway in the Glenelg River. The aggregate weight of the fish, after being cleaned, was 65 lb.	Glenelg River, Nelson	4 fish	total weigh 65lb	7.26	7.26	89.64
1939	March	31	Sport (Adelaide, SA: 1911-1948)	The Amateur Angler	The water is quite milky, but some nice cod and callop were caught off the lock at Berri during the week-end. A 17 lb. cod was part of a very nice haul at Waikerie last week, and two 16 lb. mulloway were caught on garden worms at Swanport.	Swanport	2 fish	16 lb	7.26	7.26	89.64

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1939	March	10	The Advertiser (Adelaide, SA 1931-1954	Angling Notes	Those attractive fish, mulloway (often known locally as butterfish) are plentiful at present. They are biting at Outer Harbor Wharf, and have been taken in nets at Victor Harbor. Mr. F. Robertson, of Murray Bridge, who was In the city this week, said that 32 mulloway were caught at Swanport. Just below Murray Bridge, the heaviest being 17 1/2 lb.	Swanport	32 fish	max 17.5lb	7.94	7.94	91.55
1939	March	17	The South Eastern Times (Millicent, SA 1906-1954)	Beachport	Good Fishing: Mr B. Russell, of Mount Gambier, fishing with Mr J. Lush, caught three and a half dozen sweep. Mr E. Johansen took a 35 lb. mulloway from his shark line on Tuesday. Mr P. Corigliano also caught a 35 pounder recently.	Mount Gambier	1 fish	35 lb	15.88	15.88	106.31
1939	June	22	News (Adelaide, SA 1923-1954)	Topics of Interest for Anglers	Some big mulloway have been caught at the Harbour this season. Mr Atkins showed me some photos of fish taken by him. The largest one was well over 35 lb., with several others round 30 lb.	Harbour	1 fish	35 lb	15.88	15.88	106.31
1939	July	3	The Advertiser (Adelaide, SA 1931-1954)	Mount Gambier	A mulloway weighing 35 lb. and measuring 3 ft. 8 in was caught with a hand-line by Mr Ashby of Mount Schank, while fishing off the beach near Cape Douglas.	Cape Douglas	1 fish	35 lb / 3ft 8 inches	15.88	15.88	106.31
1939	July	14	Sport (Adelaide, SA 1911-1948)	The Angler's Corner	Just had a chat to Frank Choulls who is always willing to help anyone fond of angling. He tells me the butterfish are still playing at the harbour. Size about 4 lb., but I believe one was landed — 44 lbs. Of course, you need live fish for bait.	Outer Harbour	1 fish	44 lb	19.96	19.96	111.19
1940	Feb	29	Chronicle (Adelaide SA 1895-1954)	Of Interest to Country Readers	The long-awaited mulloway season in the Glenelg River has opened, and scores of anglers have met with success, mostly below the bridge at Nelson. Odd fish have been landed upstream in the daytime. Catches total approximately 135 mulloway, ranging from 4 to 8 lb. The main catch of 35 was made by Messrs. C. Helmore and F. Manser of Mount Gambier. This is believed to be a record catch for two men in one night on the river.	Glenelg River, Nelson	135 fish	4 lb to 8 lb	3.63	3.63	74.87
1940	April	26	Sport (Adelaide, SA 1911-1948)	Angling Notes	Using rod and line an angler landed a 60 lb. mulloway and heaps of mullet and trout at Goolwa last weekend.	Goolwa	1 fish	60 lb	27.22	27.22	117.79
1940	May	30	News (Adelaide, SA 1923-1954)	Topics of Interest to Anglers	Small snapper are being taken in the Port River. Butterfish seem to be about, a recent catch including two 9 lb. and two 11 lb. fish.	Port River	4 fish	9 lb and 11 lb	4.99	4.99	81.65
1940	June	7	Sport (Adelaide, SA 1911-1948)	Angling Notes	Herb Charlesworth and "Chappie" have just returned from five days' holiday down Goolwa and the Coorong. Herb reports the jumper have all moved from the Goolwa and Mundoo Barrages, due to the barrages being opened to allow the fish to get away. From a fishing point of view they could have landed fish until they were tired, but they were satisfied with about 60 to 70 dozen, mostly medium trout, with a few large mullet. They also landed a mulloway of 7 lbs. and quite a few smaller ones.	Goolwa	1 fish	7 lbs	3.18	3.18	72.06

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1940	June	21	Sport (Adelaide, SA: 1911-1948)	Angling Notes	The Outer Harbor is flat as far as whiting go, a few small trout have been taken. Jumper have been around the wharf near the Yacht Squadron, but only odd fish have been hooked. A few mullet have been taken from the flats opposite. Also a nice butterfish or two have been hooked. One went 34 lb., but most of them are much smaller and only go to the angler who can stick.	Outer Harbour	1 fish	34 lb	15.42	15.42	105.69
1940	July	11	The Producer (Balaklava,, SA: 1940-1950)	Big Haul of Butterfish	One of the largest hauls of butterfish seen at Pt. Wakefield for some time was landed at the wharf last week by Mr J. Swayne. There were approximately 900 in the catch, with an average weight of about 4 lb. each.	Port Wakefield	approx. 900	average 4 lb	1.81	1.81	60.05
1940	July	26	The Advertiser (Adelaide, SA: 1931-1954	Mount Gambier	Fishing below the bridge at Nelson. Mr J. Proudfoot landed the largest mulloway caught in the Glenelg River for 21 years. It weighed 66 lb.	Glenelg River, Nelson	1 fish	66 lb	29.94	29.94	119.82
1940	Nov	29	News (Adelaide, SA: 1923-1954)	Angling	Mulloway were big and plentiful on the Coorong side of Pelican Point, where the blacks go out in the shallow water and spear the fish. Fourteen blacks brought in more than 30 fish, the largest weighing 38 lb.	Pelican Point, Coorong	30 fish	max 38 lb	17.24	17.24	108.06
1941	March	28	Sport (Adelaide, SA: 1911-1948)	Angling Notes	Outer Harbour: Quite a lot of anglers were on the job again last Sunday, but few met with any great deal of success. A chap that everyone refers to as Charlie was the only one to meet with any luck. He and his pal went to the north of the river and caught eleven nice butterfish, about six to eight pounds. They also had some fair sweep in the bag. The River: Butterfish have been showing up in the Port River and quite a few have been taken.	Outer Harbour	11 fish	6 - 8 lb	3.63	3.63	74.87
1941	April	9	News (Adelaide, SA: 1923-1954)	Angling Notes	Members of the Port Office staff were out with Mr. Cliff Atkins. They landed whiting, flathead, and small snapper. Alan Carr caught two nice butterfish at the harbour, 18 lb. and 20 lb.	Harbour	2 fish	18 and 20 lb	9.07	9.07	94.38
1941	June	12	News (Adelaide, SA: 1923-1954)	Notes on Angling	Alf Symonds and Bill Peterson, out with Alf Gowling in his boat, landed a couple of nice butterfish, weighing 8 lb. each. Butterfish are still being taken round Outer Harbor; every day anglers are getting their quota of these fish, which usually only feed during the night.	Outer Harbour	couple	8lb	3.63	3.63	74.87

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1941	June	5	News (Adelaide, SA: 1923-1954)	Anglers Get Good Catches	Mr W. Kimba, of Athelstone, has been to Fisherman's Bay with a party, and they had good sport. Whiting were good, and there were plenty of snapper from 2 to 3 lb. They were using tommy roughs for bait. There were plenty of big butterfish round the boat, but they would not take any bait. There are reports of good catches of Mulloway. Mr. Chapman landed 30 at the Harbor, the average weight being 8 lb. and the largest 12 lb. Bill Leonard landed a 60 lb. and 35 lb. fish the other day. Reg. Last has also been fishing among the mulloway. He told me of an amusing incident while with Robbie Osborne. Robbie was in the dinghy alongside the big boat when he contacted a mulloway. After a short but brisk fight he brought it alongside and, grasping it in the gills, tried to haul it into the boat. He slipped, and he and the fish landed full length in the bottom of the boat. A good wrestling match began and the fish took the count after a few minutes.	Harbour	numerous	60 lb max, 8 lb average	27.22	27.22	117.79
1941	Sept	4	Chronicle (Adelaide SA: 1895 - 1954)	News From Country Centres	Muddy water in the Glenelg River near Mount Gambier has caused considerable mortality among fish, particularly mulloway. One washed ashore at the mouth weighed 80 lb., which is the biggest known in the Glenelg. One 25 lb. mulloway was caught by hand in a weakened condition near Nelson. Mulloway will not return to the river until the water clears again.	Glenelg River, Nelson	2 fish	80 lb and 25 lb	36.29	36.29	123.92
1942	June	5	Whyalla News (SA)	Among the Fish	It was cold on Monday night but not too cold to stop Messrs. E. Palmer, Shiell and R. McDougall going out into the gulf to try their luck. They were rewarded for their enterprise. They returned with a bag of tommyruffs and a butterfish which they are prepared to say on oath weighed 24 lbs. Butterfish, or mulloway as they are also called, are plentiful at certain times of the year at the Murray mouth and are good eating.	Gulf (near Whyalla)	1 fish	25 lb	11.34	11.34	99.14
1945	March	21	The Advertiser (Adelaide SA 1931-1954)	Out Among the People	This is the sort of catch anglers like to hear about. Mr. Driscoll Cremer, fishing on the Coorong west of Campbell House last Thursday morning, caught a 10 lb mulloway (or butterfish)	Coorong	1 fish	10 lb	4.54	4.54	79.64

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1945	June	27	The Advertiser (Adelaide SA 1931-1954)	Out Among the People	We ran into Ted Mason, who told us he had been a licensed fisherman for 30 years, and showed us his snapshot (by James Morton) of a brown trout he had caught at Finniss Point last February. It was 3 ft., 3 in. long, and weighed 141 lb. Bob Harvey said it was the heaviest he had seen here. He got more than 1,000 young trout and perch from Ballarat, and liberated these in the Bremer and Rodwell. They stayed there for a couple of years, put in their resignation, and went to the Lake. However, he caught a lot of perch. Ted Mason told me his biggest cod was 40 lb., and mulloway 90 lb. Most fish caught in one haul was half a ton of salmon at Sellicks Beach. Biggest shark was 16 ft., at Port Vincent, where last February he caught 200 snapper, heaviest 9lb.	Lower Lakes	1 fish	90lb	40.82	40.82	126.43
1946	March	13	Recorder (Port Pirie, SA 1919-1954)	Port Germein Notes	Mr. A. Dixon, of Glenelg who is holidaying here, has enjoyed much success while fishing from the jetty. His catch included four large butterfish, the heaviest weighing more than 12 lbs. and the four together more than 40 lbs. Other fishermen have also been experiencing good catches recently.	Port Germein Jetty	4 fish	max 12 lb	5.44	5.44	83.49
1946	March	7	The Advertiser (Adelaide SA 1931-1954)	Robe	A butterfish or mulloway was caught off the jetty by Mr. Frank Birmingham. It weighed 51 lb.	Robe Jetty	1 fish	51lb	23.13	23.13	114.33
1947	March	20	Chronicle (Adelaide SA 1895 - 1954)	About Country People	Mr. N. H. Savage, while on a visit to his parents, Mr. and Mrs. A. W. Savage, at Robe, landed a seven foot carpet shark on a snapper hook. The next day he hooked a 43 lb. mulloway which was 4 ft. 6 in. long, also on a snapper hook, from the jetty.	Robe Jetty	1 fish	43 lb, 4ft 6in long	19.50	19.50	110.69
1947	July	21	The Advertiser (Adelaide SA 1931-1954)	SE Floods Trap Big Fish	Schools of mulloway have been trapped by the floods in the Glenelg River, and fish are being pulled out of the stream with boat hooks. One excited spectator jumped into the river, caught a 51 lb mulloway and staggered ashore with it clasped to his chest. With their gills clogged with mud from the swirling waters, the fish are being slowly suffocated.	Glenelg River	1 fish	51 lb	23.13	23.13	114.33
1949	March	5	Border Watch (Mount Gambier SA 1861-1954)	30 lb Mulloway Landed	Blackfellows Cave: A thirty pound mulloway, claimed to be the largest ever caught here, was landed last week. The successful fisherman was Mr. Allan Hammer, of Agnes Street, Mount Gambier. The fish was brought close in shore and Mr. Hammer leapt from his boat and fell on it to prevent the catch freeing itself from the line.	Blackfellow Caves	1 fish	30lb	13.61	13.61	103.03
1949	April	30	The Mail (Adelaide, SA 1912-1954)	Big Fish Caught	A 36 in. butterfish weighing 20 lb. was caught by Mr. F. LeLeu, of College avenue, Prospect, on rod and line from Ocean Wharf, Port Adelaide, today.	Ocean Wharf, Port Adelaide	1 fish	20 lb, 36 inches	9.07	9.07	94.38

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1949	June	18	Border Watch (Mount Gambier SA 1861-1954)	60 lb Mulloway Caught at River	A 60 lb mulloway and two others weighing 40 lbs each were caught at Nelson on Wednesday night. Mr. B. Proudfoot landed the 60 lb fish and Mr. W. Pell and Mr. C. Sutherland each caught fish weighing about 40 lbs. An amateur, Mr. E. A. Collins, of Nelson, landed one weighing about 37 lbs, and two amateurs from Winnap caught one of 24 lbs. Few were caught on Thursday night.	Nelson	numerous	60lb, 40lb, 37lb, 24lb	27.22	27.22	117.79
1950	July	29	Border Watch (Mount Gambier SA 1861-1954)	30 lb Mulloway Landed	Mr. Watkin Pell on Thursday night caught a Mulloway which weighed over 30 pounds. Three or four other fish were hooked and were the first catches here for some time.	Nelson	1 fish	30lb	13.61	13.61	103.03
1950	Oct	21	News (Adelaide, SA 1923-1954)	Big Fish on Small Line	This 50 lb butterfish is one that didn't get away. Fifteen-year-old Allen Phillips, of Esplanade, Henley Beach (pictured here with his catch), landed it at Outer Harbor wharf last night after a 30-minute struggle on a rod with a nylon line which had a breaking strain of 30 lb.	Outer Harbour	1 fish	50 lb	22.68	22.68	113.91
1950	Dec	2	The Mail (Adelaide, SA 1912-1954)	Mulloway at Noarlunga	With a trout rod and nylon line, Frank Messer did a neat spot of angling at 'The Shoe' Noarlunga. He landed two mulloway weighing 5 1/2 lb. each. The mulloway took him 100 yards down the mud bank before he subdued them.	The Shoe, Noarlunga	2 fish	5 1/2 lb each	2.49	2.49	66.84
1951	Jan	25	Border Watch (Mount Gambier SA 1861-1954)	River Fishing Improves	Fishing at the Glenelg River appears to be on the improve again, and good catches of mulloway and bream have been reported over the last few weeks. On Sunday, one Nelson fisherman landed eight mulloway, and another caught 11, all the fish being between eight and ten pounds.	Glenelg River	8 fish	8-10lb	4.54	4.54	79.64
1951	Feb	24	The Mail (Adelaide, SA 1912-1954)	With Rod and Line	A catch of 32 mulloway ranging between 4 lb. and 12 lb. from under the Jervois Bridge, at Port Adelaide will take some beating. Mr. Just landed the catch in the early hours of the morning. Worms were his main bait.	Port Adelaide	32 fish	4-12lb	5.44	5.44	83.49
1951	May	19	Border Watch (Mount Gambier SA 1861-1954)	Woman Lands 10 lb. Mulloway With Bream Gear	Nelson. Fishing with bream gear, and using a piece of rabbit as bait, Miss Mary Linn landed a 10 lb. mulloway near the bridge recently.	Nelson	1 fish	10lb	4.54	4.54	79.64
1951	June	2	The Mail (Adelaide, SA 1912-1954)	Rod and Line	Mulloway up to 20 lb have been landed at Port Adelaide and there are still plenty about.	Port Adelaide		up to 20lb	9.07	9.07	94.38
1951	July	26	Border Watch (Mount Gambier SA 1861-1954)	River Subsiding	Only one large fish has been reported washed up on the beach so far. This was a 54 lb. mulloway, discovered about five miles from Nelson by Mr. P. W. Brown. The fish was alive, although very sluggish, when discovered.	Nelson	1 fish	54lb	24.49	24.49	115.54

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1951	Aug	14	Border Watch (Mount Gambier SA 1861-1954)	Easy Way of Fishing	Between 90 and 100 big mulloway were washed up on Hollaway's Beach at Nelson by the high tide on Saturday. Mr. Frank Manner, of Donovan's, told "The Border Watch" that he recovered two. One weighed 54 lbs. and the other about the same. Most were just dead, and weighed between 7 and 9 lbs. They had been choked by the muddy water coming down the Glenelg River. Mud could be seen for miles in the sea off the mouth of the Glenelg. Hundreds of bream, 1 to 2 inches long, had been washed out of the river onto the beach. Mr. Manser said the mulloway had been feeding on the small bream. Mr. Max Holloway, a Nelson grazier, found one fish on the beach which measured 4 ft. 8 ins. in length, 26 ins round the girth, and weighed 56 lbs.	Nelson	90-100 fish	56 lb, 4ft 8in long, 26 inch girth max; average 7-9 lbs	25.40	25.40	116.32
1951	Oct	6	Border Watch (Mount Gambier SA 1861-1954)	Plenty of Bream	The Glenelg River has cleared and fishing at present is quite good. Some good sized bream have been taken and small mulloway (4 lbs)	Glenelg River		4lbs	1.81	1.81	60.05
1952	Jan	12	The Mail (Adelaide, SA 1912-1954)	10 Tons of Fish	Ten ton of mulloway were caught near the Murray Month last week. Professional fishermen made the haul with nets below the Goolwa barrage. The fish average 12lb. to 15 lb. If there are any left after this haul, anglers should try the channel on the Hindmarsh Island side of the river. They should use small live bait on a 4/0 to 6/0 hook. A seat is often used to keep the bait off the bottom away from the crabs.	Murray Mouth	10 tons	12 lb - 15lb average	6.81	6.81	88.28
1952	Jan	19	The Mail (Adelaide, SA 1912-1954)	With Rod and Line	Mulloway are the big news in fishing and some hefty fish have been landed by local enthusiasts. Round Osborne catches Include 10 lb., 15 lb., and 20 lb. Outer Harbor, Port Adelaide, and the Onkaparinga River at Port Noarlunga are also yielding their quota. About 30 ton of mulloway have been caught by Goolwa professional fishermen.	Outer Harbour	some	20lb	9.07	9.07	94.38
1952	Feb	19	Border Watch (Mount Gambier SA 1861-1954)	12 lb Mulloway Wins River	The Glenelg River Angling Club held a competition at the river at the weekend. The rod, donated by Mr H. Crafter, of Mount Gambier, was won by Mr. F Harris with a 12 lb. mulloway. Trophies were also won by Mr. M. Sims with the heaviest bag (4 mulloway, 20 lb. 6 oz.).	Glenelg River	1 fish	12 lb	5.44	5.44	83.49
1952	Feb	9	The Mail (Adelaide, SA 1912-1954)	With Rod and Line	Angling on local jetties is livening up with good catches of garfish and tommyruffs at night. At Grange Jetty the tommyruffs are a particularly large sample. Small garfish are biting freely at the northern end of the wharf at Outer Harbor. There are also some nice flathead about. Some 20 lb. mulloway have also been landed nearby. Les Backler took two 15 pounders on Saturday night.	Outer Harbour	2 fish	15 lb each	6.81	6.81	88.28

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1952	Feb	28	News (Adelaide, SA 1923-1954)	Giant Mulloway Caught	A giant mulloway, 5 ft. long and weighing 70 lb. about six times the size of a normal mulloway was caught near Goolwa yesterday. It has been presented to Adelaide Museum. The Museum's marine zoologist (Mr T. D. Scott) said today that as far as he knew it was the biggest yet caught in SA. A cast was being made of the fish. It would probably be on show at the Museum by the end of March. Mr Scott said the mulloway was netted by Mr P. Randall, of Meadows, about two miles from the Murray, mouth. Mr Randall, who was fishing with his wife, had difficulty in landing it. Mr Scott said mulloway normally weighed only about 10 or 12 lb., and were about 2 ft. long. He said Mr Randall had also caught a 12 lb. trout, probably a record for SA, in the same area on Tuesday. A cast was being made of it.	Goolwa	1 fish	70 lb, 5ft	31.75	31.75	121.07
1952	March	18	Border Watch (Mount Gambier SA 1861-1954)	Angling Notes	Another angling competition was held at the Glenelg River last weekend on Saturday and Sunday. Mr. Mel Sims won the trophy for heaviest bag and heaviest mulloway (7 1/2 lbs.) closely followed by Mr. V. Hulm with a mulloway 6 lbs 14 oz. The heaviest bream trophy went to Mr. P. Kilsby and Mr. Max Crouch claimed the trophy for heaviest perch. Thirty one members took part in very pleasant weather. Mr. Dave Mitchell landed a 4 lb. bream but unfortunately did not enter the competition. Mr. V. Hulm landed a 14 lb. mulloway after 6 pm and visitors from Warrnambool bagged 8 nice fish of the same species. Mr. Jack Peake, who is paying a visit to the district, landed a 7 lb. mulloway at Donovan's on Sunday afternoon. It is pleasing to know that Jack is much improved in health.	Glenelg River	1 fish	7 1/2 lbs	3.40	3.40	73.48
1952	March	8	The Mail (Adelaide, SA 1912-1954)	On the Murray	Below the barrage at Goolwa, large hauls of mulloway are being taken. The average weight would be five to 10 lb.	Goolwa		average 5-10lb	4.54	4.54	79.64
1952	March	15	The Mail (Adelaide, SA 1912-1954)	With Rod and Line	Below the barrage at Goolwa, large hauls of mulloway are being taken. The average weight would be five to 10 lb.	Goolwa		average 5-10lb	4.54	4.54	79.64
1952	March	29	The Mail (Adelaide, SA 1912-1954)	With Rod and Line	Members of the crew of an overseas ship at Outer Harbor made good use of their leisure by catching seven mulloway, ranging from 22 lb. to 29 lb.	Outer Harbour	7 fish	22-29lbs	13.15	13.15	102.30
1952	March	1	The Mail (Adelaide, SA 1912-1954)	With Rod and Line	Anglers at Outer Harbour wharf have been taking a variety of fish, including snapper, trevalli, flathead and leather jackets. League Footballer Brian Burke is keeping in trim for the coming season by landing large mulloway at Outer Harbor. A 45 pounder is his best effort.	Outer Harbour	1 fish	45 lb	20.41	20.41	111.66
1952	April	26	The Mail (Adelaide, SA 1912-1954)	With Rod and Line	Mulloway are again biting at Outer Harbor. Fish up to 20 lb. have been taken.	Outer Harbour		up to 20lb	9.07	9.07	94.38

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1952	May	20	Border Watch (Mount Gambier SA 1861-1954)	Angling Notes	The Glenelg River Angling Club held a competition at the weekend. The weather was on the wintry side, but 17 members took part. Mr B. had a 3 lb. bream and 1 lb. 14 oz. perch. Mr. Mel Sims had the heaviest mulloway (6 lbs).	Glenelg River	1 fish	6 lbs	2.72	2.72	68.73
1952	May	3	The Mail (Adelaide, SA 1912-1954)	With Rod and Line	Mulloway up to 20 lb have been taken at Outer Harbor, but the big fish are not biting freely.	Outer Harbour		up to 20lb	9.07	9.07	94.38
1952	June	21	The Mail (Adelaide, SA 1912-1954)	With Rod and Line	Mulloway up to 30 lb. were taken at Outer Harbor Wharf last week.	Outer Harbour		up to 30lbs	13.61	13.61	103.03
1952	July	19	The Mail (Adelaide, SA 1912-1954)	40 lb Mulloway	An Outer Harbor angler kept up his reputation by landing a 40 lb. mulloway last week. Several big ones were lost by other anglers. The high lift to the wharf loses many good fish.	Outer Harbour Wharf	1 fish	40lb	18.14	18.14	109.15
1952	Nov	15	The Mail (Adelaide, SA 1912-1954)	Harbour Mulloway	Night fishermen are catching mulloway between 8 lb. and 10 lb. at Outer Harbor.	Outer Harbour		8-10lb	4.54	4.54	79.64
1952	Dec	6	The Mail (Adelaide, SA 1912-1954)	Rod and Line	Night is the best time to fish for bream in the Onkaparinga. Good fish are biting at the rocks in the Shoe. Small mulloway round 4 lb. have also been giving good sport. Burley is the best bait. Worm may attract mulloway.	Onkaparinga River		4lb	1.81	1.81	60.05
1952	Dec	20	The Mail (Adelaide, SA 1912-1954)	Rod and Line	An angler, fishing from Outer Harbor wharf, landed 79 lb. mulloway after a tussle. The fish had to be hauled to the steps before it was landed. This is probably a record for a mulloway taken on a rod.	Outer Harbour Wharf		79lb	35.83	35.83	123.65
1953	Jan	24	Border Watch (Mount Gambier SA 1861-1954)	Angling Notes	Glenelg River Angling Club held an angling competition on the Glenelg River last weekend. Eighteen members entered in almost perfect conditions. Results were as follow: Heaviest mulloway (8 1/2 lbs), T. Papworth; Heaviest perch (1 lb. 7 oz.). S. Marks; Heaviest bag (12 lbs.). S. Marks; Heaviest bream (2 lb.3 oz.), H. Chaston. Mel Sims collected 5 sharks (Sweet William). It is interesting to note that the mulloway were caught on live muddy bait.	Glenelg River	1 fish	8 1/2 lb	3.86	3.86	76.18
1953	Feb	17	Border Watch (Mount Gambier SA 1861-1954)	Angling Notes	Mr. Syd Marks was easily the most successful competitor in the Glenelg River Angling Club's weekend competition. His 14 lb. bag was the heaviest, as was his 12 lb. perch. The heaviest mulloway, weighing 5 3/4 lbs. was taken by Mr. Tom. Papworth. A total of 16 men competed.	Glenelg River	1 fish	5 3/4 lb	2.61	2.61	67.85
1953	March	19	Border Watch (Mount Gambier SA 1861-1954)	Angling Notes	Seventeen members took part in the angling competition at the Glenelg River during the weekend. Conditions were perfect and fairly good fishing resulted. Results were: Heaviest mulloway-T. Papworth (7 lbs.).	Glenelg River	1 fish	7 lb	3.18	3.18	72.06

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1953	April	23	Border Watch (Mount Gambier SA 1861-1954)	Angling Notes	Winner of the trophy for the heaviest bag at the Glenelg River Angling Club's competition during the weekend was Mr L. Harris, whose total catch weighed 6 lbs. Harris also gained the trophy for the heaviest bag in the novice section. Weather conditions were not inviting on Saturday afternoon and evening, but the weather improved on Sunday. Ten members took part in the competition. It was pleasing to see Messrs. Tom Flark, L. Glover, J. Creasy and S. Day, of Portland. In spite of the conditions, these members had an enjoyable outing and caught a few fish; Mr. J. Creasy landed a small mulloway weighing 2 1/2 lbs, but large enough to secure the trophy in this section.	Glenelg River	1 fish	2 1/2 lb	1.13	1.13	50.01
1953	April	25	The Mail (Adelaide, SA 1912-1954)	With Rod and Line	Mulloway continue to attract night anglers to the Outer Harbor Wharf. Five fish up to 20 lb. were taken by one boatman out from the wharf.	Outer Harbour Wharf	5 fish	up to 20lb	9.07	9.07	94.38
1953	April	11	The Mail (Adelaide, SA 1912-1954)	With Rod and Line	Mulloway continue to respond at the Outer Harbor wharf. Several 30 pounders have been taken in one night's fishing.	Outer Harbour	several	30lb	13.61	13.61	103.03
1953	July	4	The Mail (Adelaide, SA 1912-1954)	With Rod and Line	Jumper and mulloway are the main attraction at Osborne Wharf. A 15 lb. mulloway has been the largest fish reported.	Osborne Wharf	1 fish	15lb	6.80	6.80	88.25
1953	Nov	28	The Mail (Adelaide, SA 1912-1954)	With Rod and Line	Mulloway are the main attraction at the Outer Harbor Wharf. Near the northern end 15 pounders are biting.	Outer Harbour Wharf		15lb	6.80	6.80	88.25
1954	Jan	23	The Mail (Adelaide, SA 1912-1954)	With Rod and Line	Mulloway are in the Port River, and fish up to 14 lb. were taken in the channel downstream from Osborne. Around the docks at Port Adelaide garfish, mullet, and occasional mulloway had anglers eagerly trying.	Port River		up to 14lb	6.35	6.35	86.79
1954	Feb	18	Border Watch (Mount Gambier SA 1861-1954)	Angling Notes	The Glenelg River Angling club held a very successful fishing competition last weekend. Conditions were ideal and very good fishing was enjoyed by the ten members who competed. The number of fish taken augurs well for the future, and proves conclusively that the fish, are in the River, particularly up-stream. G. Creasey, of Portland, had a bag of fish weighing 52 lbs. His catch consisted of 16 bream (heaviest 2 1/2 lbs.) and six mulloway (heaviest - 9 1/2 lbs). He will collect the trophies for heaviest mulloway and heaviest bag.	Glenelg River	1 fish	9 1/2 lb	4.31	4.31	78.53
1954	Feb	20	The Mail (Adelaide, SA 1912-1954)	With Rod and Line	A city angler in a few hours hooked 12 mulloway and landed three, the largest 15 lb. at the Outer Harbor wharf this week.	Outer Harbour Wharf	3 fish	15 lb max	6.80	6.80	88.25
1954	Feb	16	Border Watch (Mount Gambier SA 1861-1954)	Mulloway Come in	Last week fishermen at the Glenelg River struck a big school of mulloway and over 100 were caught. Biggest catch was 53 fish and the heaviest about 80 lbs.	Glenelg River	over 100	80lb max	36.29	36.29	123.92

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1954	March	9	Border Watch (Mount Gambier SA 1861-1954)	Personal	Messrs. T. Papworth and S. Butler have just returned from a very enjoyable fortnight's holiday at Nelson, as the guests of Mr. and Mrs. Proudfoot. They enjoyed some good fishing, landing mulloway ranging in weight from six to 15 lbs.	Nelson		6-15lb	6.80	6.80	88.25
1954	April	3	The Mail (Adelaide, SA 1912-1954)	With Rod and Line	Further confirmation has been received of mulloway taken at the back of Torrens Island. One catch consisted of eight mulloway of seven to 15 pounds. The location was between the old cattle station jetty and the red post at the cutting. Best results came from baiting with very small trumpeters as they live a long time on the hook. It's necessary to be early to get a good position at the Copper Co. Wharf at Port Adelaide, where the mullet are biting freely. One regular arrived at 5 am to find 50 enthusiasts waiting for the fish to come on the bite. Early morning is also the best time to fish the Outer Harbour Wharf, where tommies, mullet, and salmon move in on the early tide. Mulloway still keep the night triers out in the cold along the wharf channel.	Back of Torrens Island	8 fish	7-15lb	6.80	6.80	88.25
1954	April	8	Border Watch (Mount Gambier SA 1861-1954)	16 lb Mulloway Landed	Mulloway have provided good sport for anglers on the Glenelg River this season. Although the season is getting late, there still seems to be a number waiting to be caught. Fishing downstream near Donogan's on Saturday night, Mr. Chaston of Mount Gambier, had a three quarters of an hour fight before landing a 16 lb. mulloway. Mr. Chaston was using light gear and his success was a tribute to his patience and ability to handle this tackle.	Glenelg River	1 fish	16lb	7.26	7.26	89.64
1954	May	8	The Mail (Adelaide, SA 1912-1954)	With Rod and Line	Fishing below No. 3 basin among the mangrove snags in the Port River, two young anglers had a big thrill, landing a 15 lb. mulloway. Both hauling on the stout line, they gave the fish no quarter until it was beached.	Port River	1 fish	15 lb	6.80	6.80	88.25
1954	Oct	7	Border Watch (Mount Gambier SA 1861-1954)	Mulloway Biting	For many months fishermen at the Glenelg River have been complaining about the scarcity of fish, but there were no complaints at all on Tuesday night. Messrs F. and J. Livingston fishing at the mouth landed six 20 lb. mulloway in half an hour. Everyone was catching them that night. This is heartening news for river fishermen.	Glenelg River	6 fish	20lb	9.07	9.07	94.38
1954	Nov	6	The Mail (Adelaide, SA 1912-1954)	20 lb Mulloway	Fishers had sport with mulloway at Middleton Beach, landing 20 pounders. Straight out from the road at Basham Beach is worth a try for mulloway and schnapper. Cast from the beach well out near the break in the reef. Try, too, from the rock at the point nearest Goolwa.	Middleton Beach		20lb	9.07	9.07	94.38
1954	Dec	16	Border Watch (Mount Gambier SA 1861-1954)	Angling Notes	The Glenelg River Angling Club held an angling competition on the Glenelg River recently. Good bags of mulloway and bream were obtained. The heaviest mulloway, 8 lbs. 1 1/2 oz.	Glenelg River	1 fish	8lb 1 1/2 oz.	3.63	3.63	74.87

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1954	Dec	31`	The Advertiser (Adelaide, SA 1931-1954	Grey Nurse Shark Caught in SE	Bathers were cautious at Beachport yesterday afternoon after Mr. P. Corigliano caught an 8 ft. grey nurse shark near the jetty. The shark was inspected by many visitors, and was later cut up for baiting crayfish pots. Three mulloway, weighing up to 15 lb., were caught by Mr. R. Turner.	Beachport	3 fish	up to 15lb each	6.80	6.80	88.25
1954	Dec	4	The Mail (Adelaide, SA 1912-1954)	With Rod and Line	Big mulloway: From the Dolphin to the customs shed big mulloway were caught by night. Goolwa reports tons of mulloway taken by professionals netting the Coorong and mouth of the river. They ranged from 5 lb. to 40 lb.	Goolwa	tons	5 - 40lb	18.14	18.14	109.15
1957	Aug	2	Victor Harbour Times	Speared 60 lb Fish	While scoop fishing for garfish by torch light last Friday night, Messrs. Perc Tugwell and Allan Pearsons saw the scales of a large fish gleaming in the beam of their light. The fish was hand speared by Tugwell and hauled with difficulty into the boat. When weighed the mulloway touched the scales at 60 lbs, which is not much less than that of the fisherman.	Victor Harbour	1 fish	60lb	27.22	27.22	117.79
1958	Feb	14	Victor Harbour Times	65 lb Butterfish Speared	Two local spear fishermen, Messrs. Peter Wearne and Roger Tugwell, returning from a reef a mile off shore at dusk recently, saw a butterfish in about 2ft of water. A spear gun was fired from their boat, and the fish was struck in the head and killed instantly. Afterwards when weighed the butterfish tipped the scales at 65 lbs, and measured 5ft in length by 32 in. around the girth.	Victor Harbour	1 fish	65lb, 5ft length, 32 inch girth	29.48	29.48	119.49
1964	Dec	24	Victor Harbour Times	Good Fishing at Weekend	Sixteen members of the Victor Harbour Angling Club competed at an outing last Sunday at Waitpinga and Parsons' Beach. The weather was perfect for the two beaches and with a fresh northerly wind and a smooth sea everyone was keen to get among the big ones. Things began in line style with Ted Dean landing a 3 lb. butterfish in real professional style by showing he was the master.	Waitpinga and Parson's Beach	1 fish	3 lb	1.36	1.36	53.96
1965	March	12	Victor Harbour Times	Fishing News for Anglers	The Victor Harbour Angling Club held an all-night fishing contest at Hindmarsh Island last weekend. The weather was favourable, with a slight breeze to keep the mosquitoes and flies away. Twenty members made the trip, and all enjoyed the outing. Several cars became bogged and one competitor severely gashed his foot. Although the injury bled freely, the victim retained his sense of humour and related how a large butter fish jumped over his line to take the bait of the competitor beside him. He claimed half the fish. Bill Williams won the competition with a mulloway which tipped the scales at 5 lb 9 oz. Second was Bill Elliot with 4 lb. 4 oz. (another mulloway), then Joe Sirtton with a mixed bag of bream and mullet weighing 3 lb. 15oz.	Hindmarsh Island	1 fish	5lb 9oz	2.27	2.27	64.87

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1966	March	18	Victor Harbour Times	Fishing News for Anglers	Last weekend was the Victor Harbour Angling Club's surf meeting. It was an overnight competition held between the Hindmarsh River mouth and Surfers. The weather was rather unpleasant early Saturday evening, but conditions were ideal for Sunday. However, fish were again scarce, although the total weight of 23 lbs was considerably greater than the previous meeting. Fish caught were rock cod, sweep, mulloway and snapper. The competition was won by Barry Sweeney with two mulloway weighing 11 lb. 1 oz.	Hindmarsh Island	2 fish	11lb 1oz	4.99	4.99	81.65
1967	Jan	6	Victor Harbour Times	For the Anglers	Members of the Victor Harbour Angling Club are reminded that the next competition will be held at Gold Coast, Normanville, on Sunday 8th January. Competitors to meet at Toop's used car lot at 6 am. If necessary, an alternative location will be elected before departure. The next general meeting will be held at the oval clubrooms at 8 p.m. on 13th January 1967. Persons interested in joining the club are invited to attend meetings and outings at any time. Junior member, Don Williams' largest fish for the season (a 9 lb. 6 oz. salmon) has been bettered by his father Mr Bill Williams. Bill hooked and landed a 15 lb. 11 oz. mulloway at the Murray Mouth over the Christmas week-end. This catch puts Bill in the running for the Ellis Trophy for the biggest catch in or out of competition. Mulloway are plentiful around the coast this year and several good fish have been landed.	Murray Mouth	1 fish	15lb 11oz	7.26	7.26	89.64
1967	May	19	Victor Harbour Times	For the Anglers	In the Coorong area odd mulloway up to about 8 lb. are being boated, also a few nice bream.	Coorong		up to 8lb	3.63	3.63	74.87
1967	Oct	27	Victor Harbour Times	For the Anglers	A Victor Harbour club member, Allan Tonkin, landed a 9 lb. 15 oz. mulloway last week at Basham's Beach. This is the largest fish taken in or out of the club competition this season.	Basham's Beach	1 fish	9lb 15oz	4.53	4.53	79.59
1968	June	28	Victor Harbour Times	Angling Club Notes	The last outing of the Victor Harbour Angling Club's 1967-68 season was held in the Waitpinga area under ideal weather conditions on June 16. R R Ellis trophy, B Sweeney, 27 lb. 4 oz. (mulloway).	Waitpinga	1 fish	27lb 4 oz.	12.25	12.25	100.79
1969	Nov	21	Victor Harbour Times	Angling Club Notes	Last weekend the Victor Harbour Angling Club held its monthly outing. The contest was fished in two stages from 4 pm Saturday until 10 pm, followed by a rest period until 5 am, the area fished was four miles of coastline on the far end of the South Coast. At the 10 pm weigh-in Bob Dibbons showed members that not all the big ones got away when he returned with a 17 1/2 lb. mulloway.	Victor Harbour	1 fish	17 1/2lb	7.71	7.71	90.92
1976	Aug	11	Victor Harbour Times	You Should Have Seen the One That Got Away	Alister Wood, professional fisherman of Victor Harbor pictured with his 60 lb. mulloway which he caught last week at the Murray Mouth. Mr Wood said it was one of the largest mulloway he had caught in recent months.	Murray Mouth	1 fish	60lb	27.22	27.22	117.79

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1978	Jan	5	Victor Harbour Times	Caught from Breakwater	This 60 lb. mulloway was caught from the break water at Granite Island last Monday night by David Hogg, 30, of Adelaide. The 5 ft. long and 24 in. girth fish was caught on a 40 lb. line and it took almost a half hour to land. Pictured are David Hogg (right) and a friend, Stephen Jam's, 21, also of Adelaide.	Granite Island	1 fish	60lb, 5ft	27.22	27.22	117.79
1980	Oct	29	Victor Harbour Times	Huge Mulloway landed at Jetty	Keen angler Mr. Phillip Broadbent, of Victor Harbor, landed a huge mulloway at the Screwpile Jetty on Granite Island last week. Mr. Broadbent caught the fish, weighing more than 22 kg, with rod and line at about 1 am on Friday. 'It fought pretty well for about 15 minutes' said Mr. Broadbent, adding that the mulloway had to be gaffed to get it up onto the jetty. He said that the huge fish had taken squid bait. The fish, destined for the table, later had to be carried all the way over the causeway.	Granite Island	1 fish	>22kg	22.00	22.00	113.26
1983	Feb	9	Victor Harbour Times	One That Didn't Get Away	Port Elliot: A huge mulloway weighing about 55 lbs has been caught off the Port Elliot Jetty by a young Adelaide fisherman. Michael Boas, 14, of Fulham Gardens, caught the five-foot-long fish, his biggest ever, on a rod with a 45 lb line, using mullet bait. Michael and Michael Stanko, 15, of Henley Beach, were after sharks and stingrays when the mulloway was caught at 2 am on Tuesday. On Sunday night, the pair, who were fishing at Port Elliot for the first time, landed two gummy sharks two feet and three feet long, a 10 pound eagle ray, and 2 lb mulloway between them. The huge fish was destined for the tea tables of the boys' families. Michael Stanko (left) and Michael Boas with the huge mulloway caught at Port Elliot.	Port Elliot Jetty	1 fish	55lb	24.95	24.95	115.94
1984	March	14	Victor Harbour Times	One That Didn't Get Away	There's no fishy story to be told about this huge mulloway–and Sandy Lambert has the evidence that it's one big one that didn't get away. Sandy, a Victor Harbor bar attendant, landed the 45-pounder off Chiton Rocks on 20 lb line early on Wednesday morning. She was fishing with Ashley Cranfield, Bob Hughes, and Karen Orr when the big fish was hooked. And it took her 45 minutes to bring it to shore. 'It was exciting–I was rapt,' said Sandy, whose only other successful fishing catch had been a small bream. 'I never expected the mulloway to be so big,' she added. 'At first I thought it might be 10 lb or so, but when it took so long to bring the fish in I realised it was much bigger. 'And after the success on her first mulloway outing, Sandy Lambert reckons she'll be going out again after more big mulloway.	Chiton Rocks	1 fish	45lb	20.41	20.41	111.66

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1985	Jan	30	Victor Harbour Times	Anglers Head for Victor	Rod St Clair, of Blue Water Sport fishing Club, with the trophy for the highest points scoring fish, at the Victor Harbor sport fishing convention on Monday. Victor Harbor: About 100 competitors from Whyalla, Port Lincoln, Adelaide, and Melton in Melbourne took part in a sport fishing convention at Victor Harbor over the weekend. The Blue Water Sport fishing Club held the Victor Harbor convention for the Australian National Sport fishing Association, South Australian branch. A spokesman said there were some good catches of salmon and some large snook and good mackerel were recorded. Although not competing, a Victor Harbor Angling Club junior weighed in with an 8 kg mulloway. Melton emerged champion club for the second year in a row.	Victor Harbour	1 fish	8kg	8.00	8.00	91.71
1988	March	11	Times (Victor Harbour, SA 1987-1999)	Fishing	The latest outing was from Rapid Bay to Hindmarsh Island on February 27 and 28. Fishing conditions were again windy, with most anglers fishing on Granite Island. Results were quite pleasing with a good mixture of fish consisting of garfish, King George whiting, tommies, mulloway, silver drummer and flat head. Jeff Homer got among the fish. The one-that-got-away award went to Ben (seagull) Shannon for his feathered catch. Results were: Men's heaviest bag: Brenton Dibben. Junior Heaviest bag: Stephen Dibben. Ladies Heaviest bag: Dawn Dibben. Sprats Heaviest bag: Mark Foster. Heaviest fish: Stephen Dibben 3.725 kg Mulloway.	Hindmarsh Island	1 fish	3.725kg	3.73	3.73	75.42
1989	March	8	Times (Victor Harbour, SA 1987-1999)	Anglers Compete	The recent Fleurieu Anglers competition held at the Murray Mouth and Mundoo Channel was attended by 23 members who were ferried from Sugars Beach, Hindmarsh Island to the Murray Mouth by Brian Foster. The heaviest bag for men was won by Gary Harvey who also caught the heaviest fish of the competition–a 10.5 kg mulloway. Enid Haywood won the heaviest bag for ladies and Robert Gamble won the heaviest bag for juniors. Twenty-nine fish with a total weight of 137 kg were caught, only three of which were mulloway and the rest mullet. Catch of the match went to Trevor Thomson. Seeing another angler on the beach lose his rod in the surf after hooking an unstoppable mulloway, he cast in, hooked and landed the rod and reel, minus the mulloway, and was able to return it to the delighted owner. The competition ended with the weigh in and barbecue at Victor Harbor.	Murray Mouth	1 fish	10.5kg	10.50	10.50	97.50

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1992	Dec	11	Times (Victor Harbour, SA 1987-1999)	The Big One That Didn't Get Away	When it comes to telling fish tales, Port Elliot man Lawrie Harvey has one that will take some beating. He'll talk about the one that didn't get away — a 42 pound (18.80 kilogram) mulloway hooked and landed with a six pound garfish line. Lawrie was fishing for gar off the Screwpile Jetty on Granite Island on Monday morning when he hooked on to the big fish. "At first I didn't have any idea of what it was," he said. "I thought there was no way that I could have hooked the ground from where I was. I always had visions of walking back across the causeway with a fish over my shoulder but I never thought it would happen quite like this. Then it moved and jerked a little and I knew I had a big one." Lawrie worked the fish for about 45 minutes up and down the jetty before finally getting it close enough to land, with some help from a couple of other fishermen. He then had the arduous task of carrying the fish back across the causeway to his car. Using gents as bait, Lawrie said he had been hooking little tommies and believed the mulloway had taken hold of one of these. A regular fisherman off Granite Island, he said Monday's catch was the highlight of his fishing career. "I always had visions of walking back across the causeway with a fish over my shoulder but I never thought it would happen quite like this," he said. "It would have to be the biggest fish I've ever caught—and I've been fishing for 55 years." Left: Lawrie Harvey with the big mulloway caught at the Screwpile Jetty on Monday—a big one that didn't get away!	Granite Island	1 fish	42 lb	19.00	19.00	110.14
1994	March	4	Times (Victor Harbour, SA 1987-1999)	Hooked at Victor	Landing this huge mulloway while fishing on the Screwpile Jetty recently was a dream come true for local amateur fisherman Adam Cooper. Adam, 17 who fishes regularly from the jetty, hooked this 52 lb mulloway on his custom built, 30 lb, short stroker rod matched with a 4/0 wide spool and a 30 lb line. Three of his friends, Daniel and Thomas Hird and Nick Hough helped him land the monster with a rope gaff. Adam's previous best catch was 11 gummy sharks in one night. Adam Cooper of Victor Harbor with the huge mulloway he hooked off the Screwpile Jetty	Granite Island	1 fish	52lb	23.59	23.59	114.75
1997	Feb	21	Times (Victor Harbour, SA 1987-1999)	Fish Contest Winner	Victor Harbour: Great Southern FM's fishing program has announced the winner of its recent mulloway fishing competition. Ben Hurrell caught the largest mulloway during December and January. It weighed 25 kilograms. Ben receives Daiwa fishing gear for his efforts.	Victor Harbour	1 fish	25kg	25.00	25.00	115.98

Year	Month	Date	Source	Title	Anecdote	Location	Quantity	Individual size (lb/ft.)	Individual size (kg)	Maximum size (kg)	Fish TL (cm)
1997	Feb	28	Times (Victor Harbour, SA 1987-1999)	Police Warn Beachgoers	Victor Harbor police have warned beachgoers there are some large sharks cruising South Coast waters. Sergeant Frank Cresp, himself a keen fisherman, said he had heard numerous stories of "bite-offs" of large fish from the area's professional fisherman. Professional fisherman Rod Ness said he had lost a number of large mulloway, up to 60 lbs, which had been bitten off at their heads from his long lines. "There are some big sharks out there," he said.	Victor Harbour		up to 60lb	27.22	27.22	117.79
1997	Aug	7	Times (Victor Harbour, SA 1987-1999)	The Happy Angler	Basham's Beach. An eight kilo mulloway was landed during the week. Another was lost when the line fouled on the reef	Basham's Beach	1 fish	8kg	8.00	8.00	91.71
1997	Dec	4	Times (Victor Harbour, SA 1987-1999)	The Happy Angler	Basham’s Beach: School mulloway are being landed on whole pilchard baits. One lucky angler landed an 18 lb beauty on very light tackle. Several fish could not be landed after strong runs as they were fouled on the adjoining reef.	Basham's Beach	1 fish	18lb	8.16	8.16	92.13
1998	Oct	22	Times (Victor Harbour, SA 1987-1999)	Fishing Lines	A local angler, fishing the beach between Goolwa and Middleton on the Tuesday after the long weekend, on his second cast, hooked and landed a gigantic mulloway weighing 46.2 kilograms.	Goolwa	1 fish	46.2kg	46.20	46.20	129.06
1998	Dec	10	Times (Victor Harbour, SA 1987-1999)	Fishing Lines	Screwpile Jetty: Early morning this week a mulloway in the 20 lb bracket was landed. Salmon trout catches have been good in the evenings.	Granite Island	1 fish	20lb	9.07	9.07	94.38
1999	Feb	18	Times (Victor Harbour, SA 1987-1999)	Fishing Lines	Horseshoe Bay Jetty: Rumour is rife that during last week a monster 30 kg mulloway was landed from the jetty and another large one was lost on the gaffing.	Horseshoe Bay Jetty	1 fish	30kg	30.00	30.00	119.87
1999	April	15	Times (Victor Harbour, SA 1987-1999)	Fishing Lines	Screw Pile Jetty: A rumour is abounding of a monster size 34 kilo mulloway (75 lb) being caught from here on a recent weekend, by an Adelaide angler.	Granite Island	1 fish	75lb	34.02	34.02	122.54
1999	Oct	14	Times (Victor Harbour, SA 1987-1999)	Fishing Lines	32kg mulloway: Local angler Brad Wallace, fishing from the beach near the Victor Harbor Tennis Courts, hooked and landed a 32 kg mulloway recently using only a 6 kg breaking strain line on his reel.	Victor Harbour	1 fish	32kg	32.00	32.00	121.24
1999	Dec	9	Times (Victor Harbour, SA 1987-1999)	Surfer Grabbed Mulloway	Local surfer Bruce Keelan must get the prize for having the fish story of the century. Bruce was surfing last weekend 500 yards from Surfers Beach near Middleton, when he saw a fin appear next to his surf board. First ensuring it wasn't a shark, he grabbed the marine creature by the tail and managed to hold on. Imagine his surprise to be holding the tail of a large mulloway. He put his hand in the gills to paddle back to shore with fish in tow. The mulloway was in pristine condition and weighed 45 lb. Who needs a rod and reel when you can catch fish like this?	Middleton Beach	1 fish	45lb	20.41	20.41	111.66

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