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Developing baseline data to understand environmental change: a geochemical study of archaeological otoliths from the Coorong, South Australia

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ABSTRACT

Otoliths are calcium carbonate structures found in the inner ear of teleost fish. While they are routinely studied by marine scientists, analyses of otoliths recovered from archaeological sites in Australia and the Pacific have generally been restricted to identification of species and sometimes the fish age. Otoliths can also provide information on the season of catch, and, through trace element analysis, allow the reconstruction of environmental conditions experienced by fish. In this study, we use otoliths from mid- to late Holocene aged archaeological shell middens at the Coorong (South Australia) to examine species present, season of catch, age of fish and environmental conditions experienced by fish. Results demonstrate that the majority of the fish (identified as *Argyrosomus japonicus* and *Acanthopagrus butcheri*) were caught in freshwater environments during the warm season, and had grown to an age and size indicative of their having reached sexual maturity. This study provides data indicating fluctuating levels of salinity in the estuary, which are significantly lower than the hypersaline conditions experienced today. Ultimately, this project highlights the usefulness of conducting more detailed investigations of otoliths, including geochemical analyses, to address a wide range of research questions in archaeology and palaeoenvironmental research.

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1. Introduction

Otoliths are small structures involved in fish auditory processes found in the head of all teleost fishes. Of the three pairs, sagittal otoliths are routinely analysed, as their shape is characteristic of individual species, they possess daily and annual growth increments allowing accurate estimates of the age and growth of a fish, and they are not resorbed through time (Campana and Thorrold, 2001; Furlani et al., 2007). More recently, the isotopic and trace element information within otoliths has been used to address a number of ecological and fisheries questions (Elsdon and Gillanders, 2005; Elsdon et al., 2008). Microsampling and beam-based probes allow elemental assays to be coupled with annual growth increments, thus providing a detailed record of ecological patterns and palaeoenvironmental conditions at extremely fine resolution (Elsdon et al., 2008). Otoliths recovered from archaeological contexts provide opportunities to collect data about fishing practices and environmental conditions for periods prior to the keeping of written records. As such, they enable evaluations of the long-term environmental effects of anthropogenic alterations to natural waterways. These sorts of assessments are often otherwise impossible because many rivers and lakes were modified long before modern ecological monitoring began (Kennish, 2002), and thus baseline data on past conditions and species life histories are hard to obtain (Dayton et al., 1998; Jackson et al., 2001). Archaeological samples provide a means by which researchers can, at least partially, circumvent this issue.

The inorganic nature of otoliths means they generally have a high potential for archaeological preservation. Although chemical otolith analyses have been widely undertaken in marine sciences (e.g., Elsdon and Gillanders, 2002; Gemperline et al., 2002; Gillanders, 2002; Gillanders and Kingsford, 2003), and there have been several international archaeological studies incorporating such analyses, they are not yet commonly employed by archaeologists working in the Australian or Pacific regions, where the focus is usually restricted to identifying the species and sometimes the age of the fish through morphological comparisons with modern reference samples, and by counting the annuli. In one such Tasmanian study, Colley and Jones (1987) used otoliths (amongst other skeletal fish remains), to identify individual fish

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species from two sites at Rocky Cape dating to approximately 8000 BP. The samples were dominated by rocky reef fish, including wrasse, conger eel, porcupine fish and leather jacket, but also included species from bays and estuaries, such as freshwater eel, barracouta, whiting and mullet. Based on local Indigenous knowledge about fishing technologies and the environments in which specific species lived, inferences were then able to be made about the method of capture for the archaeological specimens. For example, it was suggested that the rocky reef fish were most likely caught using a baited box trap, while the fish from the bays and estuaries were most likely harvested using a tidal trap. In a similar study from middens along the lower Darling River in mainland southeastern Australia, Balme (1983) studied golden perch otoliths, suggesting that their differing length-frequency distributions might reflect exploitation of local fish stocks, the use of various fishing techniques or differing environmental conditions at the time of capture. She inferred from the spatial distribution and uniform size of >500 otoliths that nets were the most likely fishing technique used at one site, whereas at another the fish were gathered from small pools or traps. Balme (1995) inferred also that people must have made string from vegetable fibre, have had a social structure that allowed them sufficient time to make and maintain nets, and that they were aware of the conditions under which netting was effective. She also discussed the cooperative nature of net fishing, requiring two or more people, and that the fish meal thus provided was an end product of a corporate investment of labour (Balme, 1995:17). Ultimately, the labour involved was costly, but the food resulting from the use of the net was equally considerable. Hence, information about otolith size allowed deductions beyond merely fish size, enabling inferences to be made concerning fish population dynamics, Indigenous subsistence strategies and social structures.

Internationally, otolith analyses within archaeology and palaeontology have increasingly included trace element and isotopic studies. Using carbon, oxygen and strontium isotope ratios in four otoliths from the Late Cretaceous (67–65 mya), Carpenter et al. (2003) reconstructed the ontogenetic history and palaeoenvironmental conditions of *Vorhisis vulpes*. The death of each fish occurred without precipitation of a final spring–summer growth increment, from which it was concluded that their return to estuarine waters to spawn occurred in the autumn. In another study, Wurster and Patterson (2001) evaluated Holocene climate change for the eastern interior United Sates via stable oxygen isotope analysis of freshwater drum sagittal otoliths ($n = 14$) recovered from the Eastman archaeological rockshelter site in northeast Tennessee. The δ^{18}O values from the otoliths supported a general decline in maximum summer temperatures from approximately 5.5 to 1.0–0.3 ka, punctuated by warmer climates at 2.9, 1.7–1.6 and 1.2–1.0 ka (Wurster and Patterson, 2001:97). Rowell et al. (2008) documented the impact of diverting Colorado River flow from the Gulf of California on the life history of a now-endangered marine fish, *Totoaba macdonaldi*. They determined that growth increments in 1000–5000 year old otoliths ($n = 5$) documented that pre-dam juveniles grew twice as fast and matured 1–5 years earlier than post-dam fish ($n = 5$). Oxygen isotope analysis linked these changes to the elimination of estuarine habitat, providing evidence that river diversion can have a dramatic effect on life history of marine fishes by slowing growth during the juvenile stage, thus delaying maturation (Rowell et al., 2008).

This paper presents a study of archaeological otoliths from late Holocene aged middens in the Coorong estuary in South Australia. The study set out to broadly contribute to our understanding of human behaviour and palaeoenvironmental conditions through the mid- to late Holocene. Within this framework, the project had several specific aims, including, to identify the species of captured fish, to assess their age and size at death in order to examine issues of traditional Indigenous fisheries management, and to determine the changing ambient water conditions throughout the lives of the fish. The study was designed to contribute to a better understanding of Ngarrindjeri subsistence strategies and occupation in the region of the Coorong and Lower Murray, as well as to serve as a pilot study demonstrating archaeological otoliths could provide data against which to compare the current health of the Coorong and Lower Murray River, thus contributing to reconstructing a more continuous and comprehensive history of the waterways.

2. Background to the Coorong study area

The Coorong is a shallow saline lagoon stretching >100 km in length separated from the Southern Ocean by a narrow strip of sand-dunes at the terminus of the largest river in Australia, the Murray River (Fig. 1). At its northern extremity lie Lakes Alexandrina and Albert which, together with the Coorong, were listed as a Wetland of International Importance under the Ramsar Convention in 1975. While the region is naturally dynamic, human activities (specifically barrage construction and agricultural irrigation) have led to reductions in water flows to an estimated 20% of natural levels, causing severe degradation of the hydrological system (Eccleston, 2008; Fluin et al., 2007; Ngarrindjeri Tendi et al., 2007; Shuttleworth et al., 2005; Walker, 2006). In its natural state, the Coorong estuary would have comprised fresh, brackish and saline environments strongly influenced by saline marine inflows and freshwater from river flow; however, river regulation has resulted in significantly increased salinity ranges, and hypersaline conditions are now present (Jones et al., 2002; Scheltinga et al., 2006). The current salinity gradient runs from low in the north (around seawater levels of 40 g/L) to extremely hypersaline in the south (156.7 g/L), with Lake Alexandrina containing brackish water (5.8 g/L) (Gillanders and Munro, 2009). Though it currently exhibits extremely low biodiversity owing to European clearance through the twentieth century, the surrounding vegetation was, pre-clearance, a predominantly dense heath formation intermixed with a mallee stratum (Barritt and Mowling, 1979:6; Ganf, 2002; MDBMC, 2002). Together, the Coorong and Lower Lakes support 78 species of fish, including mulloway (*Argyrosomus japonicus*), black bream (*Acanthopagrus butcheri*), yellow-eye mullet (*Aldrichetta forsteri*) and golden perch (*Macquaria ambigua*).

For thousands of years this area has comprised (and continues to comprise) the traditional *ruwe* (country) of the Ngarrindjeri people (Ngarrindjeri Tendi et al., 2007). At the time of European arrival, post-1836, it was amongst the most densely populated areas in Australia owing to the richness of natural resources it afforded (Jenkin, 1979; Taplin, 1879). Archaeological surveys have recorded hundreds of midden sites comprising millions of discarded shells interspersed with the bones of terrestrial animals and marine fauna resulting from the meals of the myriad of people who have lived here (e.g., Luebbers, 1978, 1981, 1982; St George, 2009). Radiocarbon dating demonstrates the middens generally range in age from ca 7000 years ago (the approximate time of sea level stabilization) to the present, though the majority are less than 2000 years of age. In 2009 four middens in the Long Point area of the northern Coorong were subject to excavation: LP4, LP9, LP11 and LP16 (Fig. 2) (see St George, 2009 for details). Additional material was collected from the surface of an exposed cultural lens in a dune blowout (LP9). All four middens were excavated to culturally sterile sediment using arbitrary 5 cm spits. 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 were available for analysis from the aforementioned five sites; Table 1 indicates the site,

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