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The effects of temperature and salinity on otolith chemistry of King George whiting

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ABSTRACT

Otolith chemistry is used widely to reconstruct the environmental histories of fish. Examining the relationships between environmental conditions and otolith chemistry is an essential first step towards accurately reconstructing environmental histories, with lack of information potentially resulting in the erroneous interpretation of fish movement and the environments they have inhabited. We evaluated the influence of seawater temperature and salinity on the otolith chemistry of juvenile King George whiting (*Sillaginodes punctatus*) (Cuvier 1829), a commercially and recreationally important fish species in southern Australia. Juveniles were reared under controlled laboratory conditions at four temperatures (16, 19, 22 and 25 °C) and two levels of salinity (30 and 40) for 90 days. Otoliths were analysed for barium (^{138}Ba), strontium (^{88}Sr), magnesium (^{24}Mg) and manganese (^{55}Mn) using laser ablation inductively coupled plasma-mass spectrometry (LA ICP-MS), and ratioed to calcium (^{43}Ca). Otolith chemistry data were analysed using generalized linear mixed models (GLMM). Analyses showed that Mg:Ca and Mn:Ca in the otolith of the fish increased with increasing salinity, whereas Sr:Ca and Ba:Ca decreased with increasing salinity. Temperature only had a minor influence on elemental concentration. The influence of salinity on otolith chemistry suggests that otolith chemistry could be used as a potential tool for reconstructing the salinity and movement history of King George whiting from estuaries to open coast regions.

1. Introduction

The life history and movement patterns of fish have been reconstructed using otolith elemental chemistry (Campana, 1999; Reis-Santos et al., 2013). Elemental concentrations in otoliths vary with environmental factors (e.g. temperature, salinity, water chemistry) (Elsdon and Gillanders, 2003), but may also be influenced by physiology (e.g. metabolic rate) (Gaetani and Cohen, 2006). Understanding how otolith chemistry is related to environmental variability is a necessary prerequisite for reconstructing the environmental conditions that a fish has experienced (Elsdon et al., 2008).

Otoliths are composed of calcium carbonate usually in the form of aragonite (Campana, 1999; Thorrold et al., 1997). Trace elements (e.g. Sr, Ba, Mg and Mn) are incorporated into the calcium carbonate matrix of the otolith often in relation to the ambient water chemistry or the environmental conditions surrounding the organism (Bath et al., 2000; Thorrold et al., 1997). Thus, if water conditions vary among areas then the trace elements within the otolith can be used as a natural tag. The advantage of using trace elements as a natural tag is that their composition represents a permanent record of the entire life of the fish and that variation across the otolith can be related to the age of the fish (Beck et al., 1992; Campana and Thorrold, 2001).

Otoliths are not in direct contact with the physical environment (i.e. water) and barriers, such as the gills and the ear membrane (endolymphatic fluid), regulate the uptake of trace elements (Campana and Thorrold, 2001). Hence, environmental and biological parameters have the potential to alter the chemical composition of the otolith, such that there may not be a direct relationship between water chemistry and otolith chemistry (Elsdon et al., 2008). Temperature and salinity are two major environmental factors that affect the rate at which elements replace calcium in the aragonite matrix (Elsdon and Gillanders, 2003; Fowler et al., 1995; Wei et al., 2000). Temperature also affects the pH of the blood plasma and endolymph fluid thereby affecting the crystallisation process and consequently the otolith chemical composition (Gauldie et al., 1995; Romanek and Gauldie, 1996). Salinity can also affect the otolith elemental composition by mediating the elemental uptakes into the blood, endolymph and otolith (McCormick, 2001). For the fish species that moves across salinity gradients osmoregulation

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Table 1
Summary of rearing conditions for each treatment tank for juvenile King George whiting (data are displayed as mean ± standard error, n = 3; TL = total length and BW = body weight, n = 64).

Treatment Temperature/salinity	Tank	Temperature (°C)	Salinity	TL (mm)	BW (g)
16 °C, 30	1	16.01 ± 0.07	30.22 ± 0.07	46 ± 0.10	0.47 ± 0.04
	2	16.13 ± 0.06	29.83 ± 0.09	45 ± 0.20	0.45 ± 0.06
19 °C, 30	1	19.26 ± 0.04	30.35 ± 0.04	48 ± 0.23	0.42 ± 0.02
	2	19.34 ± 0.04	30.21 ± 0.05	47 ± 0.47	0.42 ± 0.04
22 °C, 30	1	21.77 ± 0.09	29.89 ± 0.03	46 ± 0.23	0.42 ± 0.03
	2	21.64 ± 0.04	30.45 ± 0.08	42 ± 0.14	0.37 ± 0.02
25 °C, 30	1	24.66 ± 0.10	30.11 ± 0.05	45 ± 0.30	0.37 ± 0.04
	2	24.49 ± 0.13	29.84 ± 0.09	49 ± 0.19	0.38 ± 0.22
16 °C, 40	1	16.34 ± 0.04	40.22 ± 0.04	53 ± 0.44	0.62 ± 0.11
	2	16.22 ± 0.03	40.20 ± 0.03	43 ± 0.23	0.35 ± 0.05
19 °C, 40	1	19.27 ± 0.03	39.93 ± 0.06	45 ± 0.25	0.35 ± 0.02
	2	19.31 ± 0.00	39.89 ± 0.08	43 ± 0.23	0.40 ± 0.04
22 °C, 40	1	21.90 ± 0.03	40.34 ± 0.09	43 ± 0.32	0.38 ± 0.03
	2	21.95 ± 0.05	39.99 ± 0.05	47 ± 0.32	0.40 ± 0.04
25 °C, 40	1	25.05 ± 0.04	40.27 ± 0.02	42 ± 0.014	0.37 ± 0.03
	2	24.82 ± 0.10	40.30 ± 0.09	45 ± 0.20	0.40 ± 0.04

demands on movement can alter the ion transport rate across their gill membrane (Martin and Wuenschel, 2006; Miller, 2011).

Previous studies have investigated the relationship between temperature and/or salinity and otolith elemental concentration and have indicated varying results including positive, negative and in some cases no significant relationship for different species (Dorval et al., 2005; Elsdon and Gillanders, 2005; Kraus and Secor, 2004; Payan et al., 1997). Several elements have been used as a marker of movement between habitats with salinity gradients (e.g. Sr and Ba) (Milton and Chenery, 2005). These elements are used for reconstructing anadromous migrations (Kalish, 1990; Secor et al., 2001; Trudel et al., 2010). For example, a positive Sr:Ca correlation with salinity, where otolith Sr:Ca is low in freshwater and increases in marine waters, is commonly reported (Kraus and Secor, 2004). In contrast, a negative correlation between Ba:Ca and salinity has been reported (Dorval et al., 2005; Elsdon and Gillanders, 2005; Stanley et al., 2015).

Some studies have indicated that Sr:Ca in otoliths is temperature dependent (Radtke and Shafer, 1992; Townsend et al., 1992). Temperature significantly affected the elemental concentration of Mg, Mn, Sr and Ba in otoliths of juvenile Atlantic cod (*Gadus morhua*), but salinity had no significant effect on Mg:Ca (Stanley et al., 2015). The influence of temperature and salinity on otolith Mn:Ca and Mg:Ca also varies among species from positive (Dorval et al., 2007) to negative (Miller, 2009) and no influence (DiMaria et al., 2010; Martin and Thorrold, 2005). The varying results from different species indicate that the relationship between the element:Ca ratio and salinity and temperature is species specific.

For species that live in dynamic environments, such as estuaries and shallow nursery areas, otoliths may be used to reconstruct environmental histories provided the relationship between the environmental parameters and otolith chemistry is known. Given that the effects of environmental variables on otolith chemistry are species specific (Gillanders and Kingsford, 2003), evaluating how local environmental conditions affect otolith chemistry for different fish species is essential for accurate environmental reconstruction. Herein, we designed a controlled laboratory experiment to examine the individual and interactive effects of temperature and salinity on the otolith chemistry of juvenile King George whiting (*Sillaginodes punctatus*).

2. Methodology

2.1. Study species

King George whiting (*Sillaginodes punctatus*) is endemic to temperate southern Australia (Hyndes et al., 1998; Kailola et al., 1993). King George whiting fishery status in South Australia is extensive and includes all coastal waters of Gulf St Vincent through Denial Bay. The South Australia catch makes the highest contribution to the national catch of King George whiting (Fowler et al., 2014) and is twice the harvested biomass of this species in Victoria and Western Australia (Fowler et al., 2014). The population of whiting is under pressure from long-term high exploitation as well as changing environmental conditions due to climate change (Fowler et al., 2014). Further, this species has been categorized as high risk to the effects of climate change (Pecl et al., 2014). Understanding the effects of environmental changes on biology of temperate fish species can help in predicting their responses to a changing environment.

The south Australian population of King George whiting (adults) generally spawn in coastal areas in early spring and the post larvae are transported by ocean currents to shallow seagrass beds (juvenile habitats) (Jenkins and May, 1994; Jenkins and Wheatley, 1998). The range of salinities in the wild nursery areas for juveniles is between 30 and 50 (Meakin and Qin, 2011). Juveniles in shallow nursery areas are exposed to fluctuations in temperature and salinity and are thus good candidates to study the influence of environmental factors on otolith elemental composition.

2.2. Experimental procedure

Juvenile King George whiting, 40–60 mm in total length, were collected in December 2014 from Port Vincent, Gulf St Vincent, South Australia (34.77°S, 137.85°E). Samples were collected by beach seine (6 m spread, 2 mm mesh) and placed into containers equipped with aeration for transfer to The University of Adelaide. Upon arrival, fish were held in a 100 L tank for 10 days to acclimate to laboratory conditions. The holding tank contained natural seawater and temperature and salinity conditions were matched to the collection site (20 °C and 40). On completion of acclimation, fish were randomly assigned to 40 L tanks at a density of 4 fish per tank. Each tank was covered with a clear Plexiglas lid to minimize evaporation. Treatments consisted of four different temperatures (16, 19, 22 and 25 °C) and two salinities (30 and 40) with two replicate tanks per treatment (Table 1). For the fish acclimated to lower salinities (30), half of the de-chlorinated seawater was diluted with freshwater at the beginning of the trial and salinity was monitored over the course of the trial.

Estimates of monthly sea surface temperature (SST) from the Gulf St Vincent over 5 years (2010–2014) were downloaded and processed from the Integrated Marine Observing System (IMOS) data portal (http://www.imos.org.au). Temperatures selected were based on temperatures that the species experience in nature (Fig. 1). The selected salinities were based on marine and estuarine conditions.

All experimental tanks were placed in water baths that were