Available online at www.sciencedirect.com
SCIENCE @ DIRECT®
Estuarine, Coastal and Shelf Science 68 (2006) 686–702
ESTUARINE COASTAL AND SHELF SCIENCE
www.elsevier.com/locate/ecss

Barium variation in *Pagrus auratus* (Sparidae) otoliths: A potential indicator of migration between an embayment and ocean waters in south-eastern Australia

Paul A. Hamer [a,b,*], Gregory P. Jenkins [a,b], Patrick Coutin [a]

[a] *Department of Primary Industries Research Victoria, Marine and Freshwater Systems, P.O. Box 114, 2A Bellarine Highway, Queenscliff, Vic. 3225, Australia*
[b] *Department of Zoology, University of Melbourne, Parkville, Vic 3052, Australia*

Received 6 December 2005; accepted 22 March 2006
Available online 22 May 2006

Abstract

Chronological variation in otolith chemistry can be used to reconstruct migration histories of fish. The use of otolith chemistry to study migration, however, requires knowledge of relationships between the chemical properties of the water and elemental incorporation into otoliths, and how water chemistry varies in space and time. We explored the potential for otolith chemistry of snapper, *Pagrus auratus*, to provide information on movement history between a large semi-enclosed bay, Port Phillip, and coastal waters in south-eastern Australia. Comparisons of water chemistry across two years demonstrated that ambient barium (Ba) levels in Port Phillip Bay were approximately double those in coastal waters (11 μg L^{-1} versus 6 μg L^{-1}). Ba levels in otolith margins of wild juvenile snapper were highly positively correlated with ambient levels across 17 sampling locations, and levels in otolith margins of adult snapper collected from Port Phillip Bay were approximately double those of snapper collected in coastal waters. Mean partition coefficients for Ba (D_{Ba}) were similar for juvenile (0.43) and adult (0.46) otoliths, suggesting that otolith Ba incorporation relative to ambient levels was similar across life-stages. Low Ba variation across otoliths from adult snapper maintained in tanks for three years indicated that annual temperature and/or growth cycles did not strongly influence otolith Ba variation. We concluded that chronological Ba variation in snapper otoliths would be a reliable proxy for life-history exposure to variable ambient Ba. We used water chemistry data and Ba levels across otoliths of ocean resident snapper to estimate otolith Ba levels indicative of residence in Port Phillip Bay (>10 μg g^{-1}) or coastal waters (<6 μg g^{-1}). Peaks in Ba exceeding 10 μg g^{-1} were common across otoliths of snapper collected in Port Phillip Bay and a nearby coastal region. The location of strong Ba peaks within otoliths was consistent with residence in Port Phillip Bay during the spring/summer when snapper move into the Bay from coastal waters to spawn. Our results for snapper support the use of otolith Ba as a proxy for ambient levels throughout the life-history, however, confident interpretation of migration history from otolith Ba chronologies will most likely require matching time series of ambient Ba in the water bodies of interest.

Keywords: otolith chemistry; barium; migration; sparidae; laser ablation; ICP-MS

1. Introduction

Understanding the migration behaviour of fish is necessary for determining spatial population structure, local population dynamics, and habitat use. Knowledge of migration behaviour has, however, been limited by the lack of methods for studying movement of fish over their entire lives. Recent work has demonstrated that fish otoliths, calcified structures found in the inner ear, have the potential to store information on both the environmental and movement histories of fish (Campana, 1999; Campana and Thorrold, 2001). This is possible because the incorporation of certain chemical elements into otoliths can be influenced by variation in environmental factors such

* Corresponding author. Department of Primary Industries Research Victoria, Marine and Freshwater Systems, P.O. Box 114, 2A Bellarine Highway, Queenscliff, Vic. 3225, Australia.
E-mail address: paul.hamer@dpi.vic.gov.au (P.A. Hamer).

0272-7714/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ecss.2006.03.017

as temperature (Townsend et al., 1992; Elsdon and Gillanders, 2002), salinity (Secor et al., 1995; Secor and Rooker, 2000), and the concentration of elements in the water (Gallahar and Kingsford, 1996; Bath et al., 2000; Elsdon and Gillanders, 2004). Further, because otoliths grow throughout life and are metabolically inert, they can permanently record environmental variations experienced over the entire lifespan (Campana, 1999). Otoliths also exhibit microstructure features such as daily and annual growth increments (Pannella, 1971; Campana and Thorrold, 2001) that allow chemical variations within otoliths to be placed into a chronological context. Individual migration histories can therefore be reconstructed from otoliths by coupling chronologies of otolith chemistry with knowledge of spatial variation in the environmental parameters known to influence otolith chemistry.

Previous studies of diadromous fish have used chronologies of otolith strontium:calcium (Sr:Ca) ratios, and the Sr isotope ratio ($^{87}Sr/^{86}Sr$), to indicate movement patterns of fish between marine, brackish and freshwater environments (Secor, 1992; Secor et al., 1995; Kennedy et al., 1997; Tzeng et al., 1997; Milton and Chenery, 2003). However, the use of otolith Sr to indicate migration history can be ambiguous, particularly where movement is across smaller salinity gradients (Kraus and Secor, 2004), and the $^{87}Sr/^{86}Sr$ ratio is generally constant in marine waters (Hodell et al., 1989). The use of otolith chemistry to infer movement histories of fish among marine dominated water bodies (i.e. constant salinity) may therefore depend on interpreting variations of other trace elements in otoliths. Trace elements found in otoliths, such as manganese (Mn), and barium (Ba), have nutrient type profiles in marine waters and potential to be enriched (above oceanic waters) in inshore coastal waters and marine dominated bays and estuaries (Bruland, 1983; Thorrold et al., 1997). For Ba in particular, there is also growing evidence that incorporation into otoliths is driven primarily by ambient concentration (Bath et al., 2000; Elsdon and Gillanders, 2004).

Assessing the potential for trace elements in otoliths to be used as indicators of migration between water bodies will initially require knowledge of variation in ambient chemistry between the water bodies of interest and over time (i.e. bay/estuary versus ocean). If consistent spatial differences in ambient water chemistry are demonstrated, it will then be necessary to validate relationships between levels of specific elements in the water and incorporation into otoliths of the species of interest. Furthermore, it will also be important to demonstrate that variations in elemental incorporation into otoliths are not significantly influenced by factors such as ontogeny, stress, and seasonal variations in temperature and/or growth (Kalish, 1991, 1992; Sadovy and Severin, 1992, 1994). Significant influences of these factors on incorporation rates could result in confounding of interpretations of migration history from otolith chemistry.

Snapper, *Pagrus auratus* (Sparidae), support major commercial and recreational fisheries in Australia, New Zealand and Japan (Kailola et al., 1993; Fujita et al., 1996). In southeastern Australia the major fisheries for this species are localised in the large bays and gulfs (Coutin et al., 2003; Fowler et al., 2003), with one of the most important fisheries occurring within Port Phillip, a large sheltered bay in western Victoria (Fig. 1). During the spring/summer (October–February) adult snapper migrate into Port Phillip from ocean waters to spawn, and are thought to return to the ocean in autumn (March–May), although longer term residency in both coastal and bay waters is also suspected (Coutin et al., 2003). The fishery is concentrated on migratory adults within Port Phillip Bay over the summer months (Coutin et al., 2003). Consequently, understanding the dynamics of these migrations is critical to understanding yearly fluctuations in the fishery. Water temperature and salinity differences are negligible (i.e. <2 °C and 2) between Port Phillip Bay and Victorian coastal waters. Port Phillip Bay, however, receives inputs from a catchment that includes approximately 4,000,000 people, considerable industrial development, one major and several minor rivers, and a sewerage treatment facility (Longmore et al., 1999; Murray and Parslow, 1999) (Fig. 1). These inputs coupled with Port Phillip Bay's narrow entrance and long flushing time (approximately 300 days) (Walker, 1999) offer strong potential for enrichment of its waters, above ocean levels, with trace elements that could be incorporated into otoliths.

We were interested in investigating whether otolith chemistry could provide information on movement of snapper between Port Phillip Bay and coastal waters. We initially compared ambient water chemistry (magnesium – Mg, calcium – Ca, Mn, Ba, Sr) among Port Phillip Bay, two other bays where adult snapper occur, and Victorian coastal waters. Based on these comparisons, we identified Ba as a potential migration indicator. To determine if otolith Ba could provide a reliable proxy for ambient Ba, we investigated relationships between ambient Ba levels and levels in otolith margins of wild caught juvenile and adult snapper. We also used otoliths from adult snapper maintained in tanks for three years to investigate whether seasonal temperature and/or growth cycles might influence variation in otolith Ba. To further assess longer-term stability of coastal water Ba levels we used Ba levels across otoliths from ocean resident and tag/recaptured snapper as a proxy for ambient levels. Based on these preliminary investigations we attempted to interpret chronological Ba variation in adult snapper otoliths in terms of residence periods in Port Phillip Bay.

2. Methods

2.1. Water chemistry

Initially we investigated spatial variation in water chemistry (Mg, Ca, Mn, Sr, Ba) across Victoria's three major bay/estuaries (all marine dominated) where adult snapper can occur; Port Phillip, Western Port, Corner Inlet, and inshore coastal waters (Fig. 1, Table 1). This spatial comparison was conducted during summer (February/March) 2001. Secondly, we investigated temporal variation in ambient water chemistry. This involved comparing ambient levels of elements in water samples collected in Port Phillip Bay during summer (February/March) and winter (July/August) of 2001 and 2002, and