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Age-related otolith chemistry profiles help resolve demographics and meta-population structure of a widely-dispersed, coastal fishery species

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ABSTRACT

Snapper, *Chrysophrys auratus*, is a highly important fishery resource of southern Australia. Through the late 2000s, the State of South Australia (SA) produced record commercial catches of this species, making the dominant contribution to the national catch. This was associated with dramatic changes in contributions from SA's regional fisheries. The demographic processes responsible for these unprecedented changes were not understood, reflecting poor understanding of large-scale movement of snapper and its influence on regional population dynamics and stock structure. This study used otolith chemistry to investigate the movement behaviour and stock structure of snapper in the eastern part of southern Australia. Transverse sections of otoliths from four year classes and six geographic regions distributed over 1500 km of coastline were sampled by continuous life-history profiles across the chronological structure using laser ablation inductively coupled plasma mass spectrometry. Element:calcium ratios were integrated with annual increment measurements to produce profiles of age-related, annual averages for Ba:Ca, Sr:Ca, Mn:Ca and Mg:Ca. Significant regional differences for each annual zone were used to infer differences in fish origins and inter-regional movement. Variation in Ba:Ca was most informative and indicated that an episodic fishery along the south east coastal region of SA is linked to periods of stock range expansion, involving movement over 600 km, from a major nursery area, Port Phillip Bay (PPB), in the adjacent state of Victoria. Periods of stock range expansion coincided with exceptionally strong year-classes originating from spawning in PPB. Inferences from the element:calcium profiles and other information suggested that the populations in the northern parts of the two gulfs of SA appear to be separate, self-recruiting and independent of inter-regional movement. Each, however, is an important nursery area and source of emigration that replenishes regional populations in adjacent coastal waters. The results support SA's snapper fishery being divided into three stocks, each dependent on a primary nursery area. The source for the intermittent fishery in the south east region of SA is within a separate management jurisdiction (Victoria), necessitating consideration of multi-jurisdictional assessment and management. We hypothesise that density-related processes are responsible for range expansion of this multi-jurisdictional stock, with strong year classes producing more extensive emigration and range expansion into SA waters. The study provides an example of the value of life-history otolith chemistry profiles for resolving stock structure at regional scales with implications for fisheries assessment and management.

1. Introduction

The dispersion of individuals of a fish species usually conforms to an ensemble of local populations that constitutes a meta-population (Bailey, 1997). Such local populations may be linked through the movement of individual fish either by the transport of eggs and larvae through oceanographic processes or the movement of juveniles and adults. The level of such connectivity determines

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the extent to which the demographic processes that drive the population dynamics of adjacent local populations are inter-related or independent of each other. This determines the 'stock structure' of the meta-population. It is important to correctly identify the stock structure as it determines the appropriate spatial scale at which fishery assessment and management should be directed (Hilborn and Walters 1992; Begg and Waldman 1999). Failures to achieve this in the past have led to notable failures in the single-species approach to fishery management (Stephenson 1999; Hutchinson 2008). Nevertheless, determining stock structure is extremely challenging as it requires understanding the demographic consequences of fish movement over potentially large spatial scales across complex oceanographic and inshore environments. Such determination is often based on inferences about connectivity that are drawn from comparing phenotypic characteristics amongst populations. Such comparisons are challenging and benefit from an holistic or 'multiple technique' approach (Begg et al., 1999; Begg and Waldman, 1999; Abaunza et al., 2008; Baldwin et al., 2012).

One significant phenotypic approach for investigating stock structure that has developed over the past 20 years is the analysis of otolith chemistry (Campana, 1999; Elsdon et al., 2008; Sturrock et al., 2012). As a fish's otoliths grow on a daily basis they incorporate ions from some elements as impurities in minor and trace quantities from the aquatic environment at rates that are influenced by the physico-chemical environment that the fish is living in at that time (Campana, 1999). Such ions are not simply deposited in otoliths in proportion to their ambient concentrations but at rates that are mediated through complex physiological processes (Campana 1999), which are not yet fully understood (Sturrock et al., 2012, 2014). As the otoliths grow throughout a fish's life and because they are metabolically inert, they ultimately manifest an 'elemental fingerprint' that relates to the aquatic environments that the fish experienced throughout its life (Campana, 1999, 2005; Campana and Thorrold, 2001; Sturrock et al., 2012; Kerr and Campana, 2014). Such 'elemental fingerprints' are natural tags that can be used to infer long-distance movement, and temporal/spatial separation of fish, that can in-turn indicate patterns of stock structure (Gillanders, 2002; Fowler et al., 2005; Hamer et al., 2006; Elsdon et al., 2008; Steer et al., 2009, 2010; Kerr and Campana, 2014; Gillanders et al., 2015; Hughes et al., 2015).

Snapper (*Chrysophrys auratus*) is a large, long-lived demersal finfish species of the family Sparidae (Perciformes: Percoidei). It is broadly distributed throughout the Indo-Pacific region including Australia, where its broad distribution includes the coastal waters of the southern two thirds of the continental mainland as well as northern Tasmania (Kailola et al., 1993) (Fig. 1). Throughout this distribution, snapper occupy a diversity of habitats from shallow bays and estuaries to the edge of the continental shelf across a depth range down to at least 200 m. As each mainland State supports important commercial and recreational fisheries for snapper (Fowler et al., 2014), it is one of Australia's most significant and iconic fishery resources.

The State of South Australia (SA) encompasses a geographically complex part of the southern coastline of the continent that supports a number of contiguous regional snapper fisheries. From 2007 to 2012, the combined catches from across these regions were at record levels that established SA as the highest State-based contributor to the total national commercial catch (Fowler et al., 2013). Nevertheless, through this period of record productivity some fishery management concerns emerged. The primary concern was that the record catches were associated with a significant change in the spatial structure of the fishery. Prior to 2003, the relatively small region of Northern Spencer Gulf (NSG) had generally contributed >50% of the State's catch, and was the focus of much of the snapper fishing effort (Figs. 1 and 2). For a few years until 2009, Southern Spencer Gulf (SSG) dominated the catches. However, from then on, the annual catches and effort for both NSG and SSG declined annually, dropping and remaining at a low level from 2013 onwards (Fig. 2). In contrast, over the same period there were dramatic increases in catches and effort in both Northern Gulf St. Vincent (NGSV) and the south eastern coastal region of the State (SE). These dramatic changes in distribution of catch and fishing effort were clearly related to changes in the regional availability and biomass of snapper (Fig. 2).

The demographic processes responsible for the significant and contrasting changes between regions and the extent to which they were inter-related were not understood. This reflected the limited understanding of movement behaviour of snapper and its demographic consequences. In general, the spatial changes may have reflected demographic and fishery processes that operated in Spencer Gulf (SG) independent from those in NGSV and the SE region. Alternatively, there may have been significant movement of large numbers of fish out of SG, with some eventually moving into one or both of NGSV and the SE region. At the same time, however, the fishery in central and western Victoria (the state jurisdiction immediately east of SA), particularly in Port Phillip Bay (PPB) (Fig. 1), had increased dramatically to historically high catch rates due to several strong year classes (2001 and 2004) that originated from the main spawning and nursery area of PPB (Hamer and Conron, 2016; Hamer et al., 2011). This provided an alternative hypothesis that the SE regional fishery may have been derived from emigrants that had originated in PPB.

The aim of this study was to enhance our understanding of the demographic processes that drive the population dynamics of snapper at the regional scale in SA, and the extent to which these are related across regions. The purpose ultimately was to account for the significant changes in spatial structure that occurred throughout the 2000 s (Fig. 2). The study was based on the regional comparison of profiles of age-related concentrations of minor and trace elements in otoliths. Otolith chemistry studies have already made significant contributions to understanding movement and stock structure for snapper in this geographic region (Fowler et al., 2005; Hamer et al., 2005, 2006, 2011). They have identified three significant nursery areas in the eastern part of southern Australia, i.e. NSG, NGSV and PPB (Fig. 1) that are the primary sources of fish that ultimately move over distances of up to several hundred kilometres to replenish populations in adjacent regions. Nevertheless, this model of connectivity amongst source and sink populations is not yet sufficiently comprehensive and refined to account for the recent changes in regional fishery production. As such, this study increased the temporal scale of the earlier studies by considering otoliths from four different year classes, i.e. fish that were born in particular years and were sampled later as adults at ages that related to different periods in the South Australian and Victorian snapper fisheries. Furthermore, the study also increased the spatial scale, by considering otoliths from places that were up to 1500 km apart representing different regions across both jurisdictions of SA and Victoria. The main objective was to identify common nursery origins for different fishery regions and to identify when during the life-history that any inter-regional movement took place. Since this relates to connectivity amongst regional populations, the results were also interpreted in terms of the stock structure of snapper throughout the eastern part of southern Australia.

2. Materials and methods

2.1. Study region

The geographic region of interest in this study was the eastern part of Australia's southern coastline, the latter being the world's longest zonal, mid-latitude continental shelf (Middleton