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Factors influencing growth of *Acanthopagrus butcheri* (Sparidae) in a eutrophic estuary have changed over time

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A B S T R A C T

The overall growth of *Acanthopagrus butcheri* in the eutrophic Swan River Estuary has previously been shown to decline between 1993–95 and 2007–11. This was attributed to the effects of an increase in hypoxia on *A. butcheri* in deeper water, brought about by reductions in freshwater flushing, and to density-dependent effects as this species became concentrated in the better-oxygenated, nearshore shallow waters. In the present study, a year-effect model was developed that provided a good fit to the lengths at age and could thus be used to explore the following: 1) The extent to which somatic growth of *A. butcheri* differed between years in the above two periods and within the later period, which was extended to include data for 2012 to 2014, and 2) whether annual growth in 2007–14 was related to temperature and/or freshwater discharge. Annual length increments for females and males during the second year of life, predicted from the model and when using a common initial length, were almost invariably less in each year in 2007–14 than in 1993–95. In 2007–14, these predicted increments varied by ~2 times for both females and males and were positively correlated with average temperature during the main growth phase of *A. butcheri*. They were not significantly correlated, however, with freshwater discharge in the preceding cool wet 'winter' months, when the vast majority of rainfall occurs. The demonstration that the growth of *A. butcheri* was positively correlated with temperature for years in the latter period is consistent with the metabolic theory of ecology and contrasts with growth declining between 1993–95 and 2007–14 when temperatures were increasing. Thus, any influence of temperature on growth between those periods was overridden by the effects of other factors, *i.e.* hypoxia and related changes in density. As *A. butcheri* completes its life cycle within its natal estuary and has plastic biological characteristics, it is an ideal candidate for use as an indicator of the health of an estuary and for hypothesising on the effects of climate change on fish species.

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1. Introduction

An understanding of the growth of individuals in a fish stock is crucial for determining the status of that stock and thus for assessing its resilience to fishing pressure (Beverton and Holt, 1957; Quinn and Deriso, 1999; Haddon, 2011). The growth of fish in a population is typically described by fitting a von Bertalanffy growth model to the lengths at age of individuals in that population, using pooled data for several years (Ricker, 1979; Quinn and Deriso, 1999; Jennings et al., 2009). This enables the expected lengths at age of

fish overall to be estimated for the period for which lengths and ages were recorded, irrespective of the extent to which growth varied among years.

The overall von Bertalanffy growth curves of the females and males of the Black Bream *Acanthopagrus butcheri* in the Swan River Estuary in south-western Australia in 1993–95 were compared with those in 2007–11 (Cottingham et al., 2014). This showed that, overall, the growth of this estuarine species was less in the latter period, when environmental conditions had declined through detrimental effects caused by reductions in freshwater discharge, brought about by declining rainfall. These detrimental effects included a pronounced increase in the extent of hypoxia in deeper water, which, on the basis of other studies, would presumably have

inhibited the growth of those fish that remained within those waters (Pichavant et al., 2000, 2001; Eby et al., 2005). The increases in hypoxia also led, however, to larger *A. butcheri* tending to move from deeper waters into the shallow and better oxygenated waters, where, as a consequence, densities increased markedly, but subsequently remained relatively constant through 2007–11. It was thus proposed that density-dependent effects contributed to the reduction in the growth of *A. butcheri* that occurred in the intervening years between 1993–95 and 2007–11. As this reduction occurred when temperatures were increasing (Australian Bureau of Meteorology (2015)), and growth would thus have been expected to increase (Brown et al., 2004), any positive influence of temperature was overridden by those other effects.

Relatively few studies have explored the extent to which the growth of individuals of an estuarine species, *i.e.* whose life cycle is completed within the estuary (Potter et al., 2015), varies either between or within periods in a given system and is related to certain environmental variables. The results of those few studies in temperate estuaries, which typically used a mixed-modelling approach to relate annual growth increments in otoliths to selected environmental variables, varied with region and between species. While such growth in *A. butcheri* was thus found to be negatively correlated with temperature in a suite of estuaries in Tasmania, it was positively correlated with that environmental variable in an estuary in South Australia, where climatic conditions are very different (Doubleday et al., 2015). As with *A. butcheri* in South Australia, otolith growth of the Estuary Perch *Percalates colonorum* in Victoria, further east in southern Australia, was positively correlated with temperature and, in this case, to a greater extent than any other variable examined (Morrongiello et al., 2014). The growth of the otoliths of *A. butcheri* in South Australia were positively correlated with rainfall but, surprisingly, not with freshwater discharge (Doubleday et al., 2015), whereas the growth of the otoliths of *P. colonorum* in Victoria was correlated with freshwater discharge, but not as strongly as with temperature (Morrongiello et al., 2014). Analyses of annual increments in otoliths and back-calculations of length at age demonstrated that the growth of the Spotted Seatrout *Cynoscion nebulosus* in San Carlos Bay, Florida, was positively correlated with salinity and thus negatively with freshwater discharge (Bortone et al., 2006).

Each of the above studies assumed a proportionality between annual increments in body length and otolith size, either explicitly, *e.g.* Bortone et al. (2006), or when drawing inferences regarding growth in length at age from otolith growth (Morrongiello et al., 2014; Doubleday et al., 2015). The results of several studies suggest, however, that, at least in some species, direct coupling does not occur, with, for example, otoliths continuing to grow after growth in body size has largely or entirely ceased and sometimes respond to environmental factors in different ways than body size (*e.g.* Fey, 2006; Wilson et al., 2009; Réveillac et al., 2015).

No study has used an appropriate model, fitted to length-at-age data, to explore the extents to which, in terms of body size, the growth of an estuarine fish species varies among years. In the case of the lacustrine species *Coregonus hoyi*, Szalai et al. (2003) described the lengths at age, using a von Bertalanffy growth curve with time-varying L_∞ and assuming a linear relationship with k, to predict the length increments of each age class in successive years and thereby account for inter-annual variations in growth. He and Bence (2007) later extended that model, for another lacustrine species, to allow each year-specific von Bertalanffy growth parameter to vary over time.

The first aim of this study was to develop a model that would enable the extent to which the somatic growth of *A. butcheri* in the Swan River Estuary varies among years to be estimated. A year-effect model, based on but less complex than that of He and Bence (2007), was thus developed to accommodate the characteristics of the data obtained for *A. butcheri* (see Materials and Methods). The results were used to determine how annual increments in body length of *A. butcheri* in the Swan River Estuary varied among years in 1993–95 and 2007–14, the latter period encompassing the years in 2007–11 for which the average, but not annual, growth had previously been determined (Cottingham et al., 2014). The model thus enabled the following hypotheses regarding *A. butcheri* in the Swan River Estuary to be explored. 1) Annual somatic growth was consistently less in each year in 2007–14 than in each year in 1993–95. 2) Since the densities in 2007–14 had stabilised in shallow waters, where the majority of *A. butcheri* then resided, annual somatic growth of their younger individuals is positively related to temperature, as is typical of fish species within their normal temperature range (Angilletta et al., 2010; Neuheimer et al., 2011) and of the otoliths of *A. butcheri* and *P. colonorum* further east on mainland Australia (Morrongiello et al., 2014; Doubleday et al., 2015). 3) The question of whether somatic growth in 2007–14 was related to freshwater discharge, which occurs predominantly in the non-growth period of mid-winter to early spring, was examined. Finally, the observed lengths at age for the years in 1993–95 and 2007–14 periods, and those for more fragmentary data for some intermediate years, were used to elucidate how the pattern of growth of *A. butcheri* in the Swan River Estuary changed over more than two decades, during which this system was subjected to severe anthropogenic perturbations.

2. Materials and methods

2.1. Sampling regime

Acanthopagrus butcheri was sampled at nine sites in the upper Swan River Estuary (Fig. 1). Nearshore, shallow waters were sampled using 21.5 and 41.5 m long seine nets in each season between spring 2007 and winter 2011. Offshore waters were sampled by gill netting in waters adjacent to each seine net site. Gill netting was undertaken at the same time (season) as seine netting between spring 2007 and winter 2009, after which it was discontinued as it was catching few fish. *Acanthopagrus butcheri* was also caught at intervals between the spring and following winter in 2011–2014 using seine and gill nets in the same region of the upper Swan River Estuary as the above nine sampling sites.

The 21.5 m seine net, which consisted of a 1.5 m wide bunt of 3 mm mesh and two 10 m long wings (each comprising 4 m of 3 mm mesh and 6 m of 9 mm mesh), swept an area of 116 m², while the 41.5 m seine net, which contained a 1.5 m wide bunt made of 9 mm mesh and two 20 m long wings comprising 25 mm mesh, swept an area of 274 m². The 21.5 m seine net was laid parallel to the bank and then hauled onto the shore, whereas the 41.5 m seine was deployed in a semi-circle from the bank using a small boat and then likewise hauled on to the shore. The gill net, which comprised eight 20 m long panels, each with a different stretched mesh size, *i.e.* 38, 51, 63, 76, 89, 102, 115 and 127 mm, was set, just after sunset, parallel to the shore in water depths of 2–6 m and retrieved 3 h later.

Acanthopagrus butcheri had previously been caught in the upper Swan River Estuary between spring 1993 and winter 1995 by using the 41.5 m long seine net at six of the above nine sites in nearshore, shallow waters, and by employing a gill net (comprising panels of the same dimensions and mesh sizes as described above) at all nine sites in offshore waters (Sarre and Potter, 2000).

Throughout the subsequent text, each of the 12 months between the spring of one year and the winter of the next year (which thus commences when *A. butcheri* spawns) is subsequently referred to as a 'year', *e.g.* spring 2008 to winter 2009 is referred to as 2008/