



Decadal changes in the ichthyofauna of a eutrophic estuary following a remedial engineering modification and subsequent environmental shifts



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ABSTRACT

This study has determined how the characteristics of the ichthyofauna of a large eutrophic microtidal estuary changed, initially in response to major structural remedial modifications, and then, during later years, as the environment became further modified, due mainly to effects of climate change. Data on the ichthyofauna of the Peel-Harvey Estuary, in south-western Australia, were derived firstly by seining seasonally in five regions over two consecutive twelve months (two years) in 2008–10. These data were then collated with those recorded previously using the same sampling regime throughout 1980 and 1981, when massive macroalgal growths were present, and throughout 1996 and 1997, soon after the opening, in 1994, of an artificial, deep and second entrance channel. The latter resulted in greater tidal flushing, consistently high salinities and reduced macroalgal biomass. Ichthyofaunal composition changed significantly overall and in four of the five regions across the three periods. Although increased tidal exchange did not lead to a rise in the number either of those marine species that typically use estuaries as nursery areas (marine estuarine-opportunists) or of those that complete their life cycle within the estuary (estuarine residents), the contributions made by the abundances of the representatives of those two groups to the total catch of fish varied markedly between periods. Those differences were largely responsible for the inter-period changes in species composition. In contrast to the situation with marine estuarine-opportunists, increased tidal exchange and higher salinities resulted in a greater number of marine straggler species entering the system, albeit in low numbers. The ichthyofauna during 1980–81 contained relatively large numbers of species that are typically associated with macrophytes, including marine estuarine-opportunists, e.g. *Pelates octolineatus*, and estuarine residents e.g. *Ostorhynchus rueppellii* and *Hyporhamphus regularis*. Following the opening of the artificial entrance channel, the relative abundances of these three macrophyte-associated species declined, whereas those of species, e.g. the marine estuarine-opportunist *Torquigener pleurogramma* and estuarine resident *Favonigobius lateralis*, which typically occur over unvegetated areas and in elevated salinities, increased. By 2008–10, such species had become more abundant, following declines in freshwater discharge and a longer persistence of high salinities, with macrophyte-associated species, e.g. the marine estuarine-opportunists *P. octolineatus*, *Gymnapistes marmoratus* and *Haletta semifasciata* and estuarine resident *O. rueppellii*, becoming more numerous as macroalgal and seagrass areas became better developed. This study demonstrates the great value of long-term data sets for detecting and predicting the effects of major structural changes and climate change on the faunas of estuaries.

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1. Introduction

Estuaries are among the most productive of all aquatic ecosystems (Schelske and Odum, 1961; Heip et al., 1995; Costanza et al., 2007), with their high primary and secondary productivity providing a rich food source (Elliott and Hemingway, 2002; França

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et al., 2011; Potter et al., 2015a). This energy source is used by the wide range of marine fish species that enter estuaries in appreciable numbers, particularly during early life. Thus, in comparison with their natal environment, the juveniles of these species grow more rapidly and, through the presence of fewer large piscivores, are less susceptible to predation (Blaber, 1980; Le Pape et al., 2003; Yamashita et al., 2003; Veale et al., 2016). Estuaries have therefore often been considered as important nursery areas for fish (Blaber and Blaber, 1980; Beck et al., 2001; Able and Fahay, 2010; Sheaves et al., 2014). They also comprise the sole environment for the entire life of some species and act as an essential route for diadromous species during their migration from their main feeding areas in freshwater to their spawning regions in the marine environment or vice versa (Potter et al., 2015a,b).

Marine species dominate the ichthyofaunas of macrotidal estuaries in temperate regions, both in terms of number of species and overall abundance (Haedrich, 1983; Claridge et al., 1986; Dadswell and Rulifson, 1994; Thiel and Potter, 2001; Maes et al., 2005). Although marine fish species are also numerous in microtidal estuaries, such as those of south-western Australia and southern Africa, these estuaries contain a greater number of species that complete their life cycles and are abundant in these systems (Potter et al., 1990; Potter and Hyndes, 1999; Whitfield, 1999; Tweedley et al., 2016a). The success of these species in south-western Australian estuaries has been attributed to the conditions for spawning being particularly favorable in late spring to early summer, when breeding typically occurs in this Mediterranean climate (Potter et al., 2015a; Tweedley et al., 2016b). At this time, a combination of limited freshwater discharge and tidal action means that there is little water movement up and down the estuary and thus a far less turbulent and turbid environment than that produced by the strong tidal action in macrotidal estuaries. Furthermore, salinities in the main body of microtidal estuaries remain elevated during that period and are thus at or near those of the marine environment in which these species presumably evolved (Potter and Hyndes, 1999).

As estuaries perform such an important ecological function for fishes and a range of other faunas, there has been widespread concern that, in temperate regions, they are regarded as the most degraded of all aquatic ecosystems (Jackson et al., 2001). In this context, eutrophication from increased nutrient input has become a major problem in many parts of the world, with, for example, 67% of the combined surface area of estuaries in the United States exhibiting moderate to high degrees of eutrophication, a trend also found elsewhere (Duarte, 2009; Rabalais et al., 2009; Paerl et al., 2014). The organic material, derived from eutrophication and other sources, tends to be retained in microtidal estuaries due to their long residence times (Patchineelam et al., 1999; Tweedley et al., 2012), thus leading to hypoxic conditions in deeper waters, but not necessarily in the shallows where substantial wind-induced mixing occurs (Eby and Crowder, 2002; Kurup and Hamilton, 2002; Tweedley et al., 2014).

The microtidal Peel-Harvey Estuary, which is by far the largest estuary in south-western Australia, covers an area of ~136 km² and comprises two large, shallow basins (Peel Inlet and Harvey Estuary), a narrow, natural entrance channel at Mandurah and three main tributaries (Fig. 1). Between the 1960s and 1980s, this estuary became increasingly eutrophic, through the input of large amounts of nutrients leached from the surrounding sandy soils following clearing for agriculture, and by entry from point sources such as piggeries (McComb and Humphries, 1992; McComb and Lukatelich, 1995). This eutrophication was reflected in the replacement of seagrasses by massive growths of macroalgae, belonging in particular to the genera *Cladophora*, *Chaetomorpha* and *Ulva* (McComb et al., 1981; Lukatelich and McComb, 1986).

As the large Peel-Harvey Estuary contains commercial and recreational fisheries and is widely used by residents and tourists for boating and other activities (Potter et al., 1983; Steckis et al., 1995; Lepesteur et al., 2008), it was decided to construct a deep second entrance channel to increase markedly the flushing of nutrients and organic material from this microtidal system and thereby reduce the extent of eutrophication (Gilles et al., 2004; Brearley, 2005; Elliott et al., 2016). The opening of this so-called Dawesville Channel in 1994 led to a tripling in tidal water exchange with the ocean, a marked increase in salinity, a 2–4 fold decrease in total phosphorous and nitrogen concentrations and a flushing of 10% of the estuary volume each day (Brearley, 2005; Ruibal-Conti, 2014; Elliott et al., 2016). This resulted in a reduction in macroalgal growths (Wilson et al., 1997, 1999).

The presence of massive macroalgal growths in the Peel-Harvey Estuary in the 1980s was reflected in the domination of the fish fauna by two macrophyte-associated species, the Western Striped Grunter *Pelates octolineatus* (previously erroneously referred to as *Pelates sexlineatus*) and the Western Gobbleguts *Ostorhinchus rueppellii* (Potter et al., 1983; Loneragan et al., 1986). The reductions in macroalgal biomass in the late 1990s, following the opening of the Dawesville Channel (Wilson et al., 1997, 1999), were accompanied by a decline in the density of the above two species and changes in ichthyofaunal composition (Young and Potter, 2003b). However, marked reductions in freshwater discharge over recent years, due to declining rainfall, have reduced the effectiveness of freshwater flushing of the waters close to the mouths of tributaries, thereby leading to the development of macroalgal beds in those areas (Zammit et al., 2006; Pedretti et al., 2011). In contrast, regular strong tidal flushing in areas closer to the Dawesville Channel has increased water clarity and resulted in salinities remaining at or approaching that of the surrounding ocean, thus facilitating the development of seagrass beds (Pedretti et al., 2011). Substantial areas of unvegetated substrata still remain, however, in the Peel-Harvey Estuary.

This unique study explores how the characteristics of the fish fauna in the large, microtidal Peel-Harvey Estuary changed over ~30 years, during which (in 1994) this system underwent a major structural change (i.e. construction of Dawesville Channel). For this purpose, data on the fish fauna were collected seasonally for two consecutive twelve months (two years) in 2008–10 and compared with those recorded seasonally throughout 1980 and 1981 (Loneragan et al., 1986; Potter et al. unpublished data) and throughout 1996 and 1997 (Young and Potter, 2003a,b). Emphasis has been placed on determining how the structure and species composition of the ichthyofaunal community, throughout and within regions of the estuary, changed between the first two periods, in response to a reduction in eutrophication and increase in salinity as a result of greater tidal exchange, and subsequently, through declining rainfall, to the maintenance of high salinities for longer during the year and the development of greater areas of seagrass and macroalgae. It is hypothesised that these changes would be accompanied by increases in the number of marine stragglers and that macrophyte-associated species, such as *P. octolineatus* and *O. rueppellii*, would be more numerous in 1980–81 and 2008–10 than in 1996–97, whereas species, such as *Torquigener pleurogramma*, which are typically found over unvegetated substrata and in high salinities, would be most abundant in the two most recent periods.

2. Materials and methods

2.1. Sampling regime

During the present study, 102.5 and 21.5 m long seines were

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