Peel-Harvey Estuary condition assessment based on fish communities -2020/21

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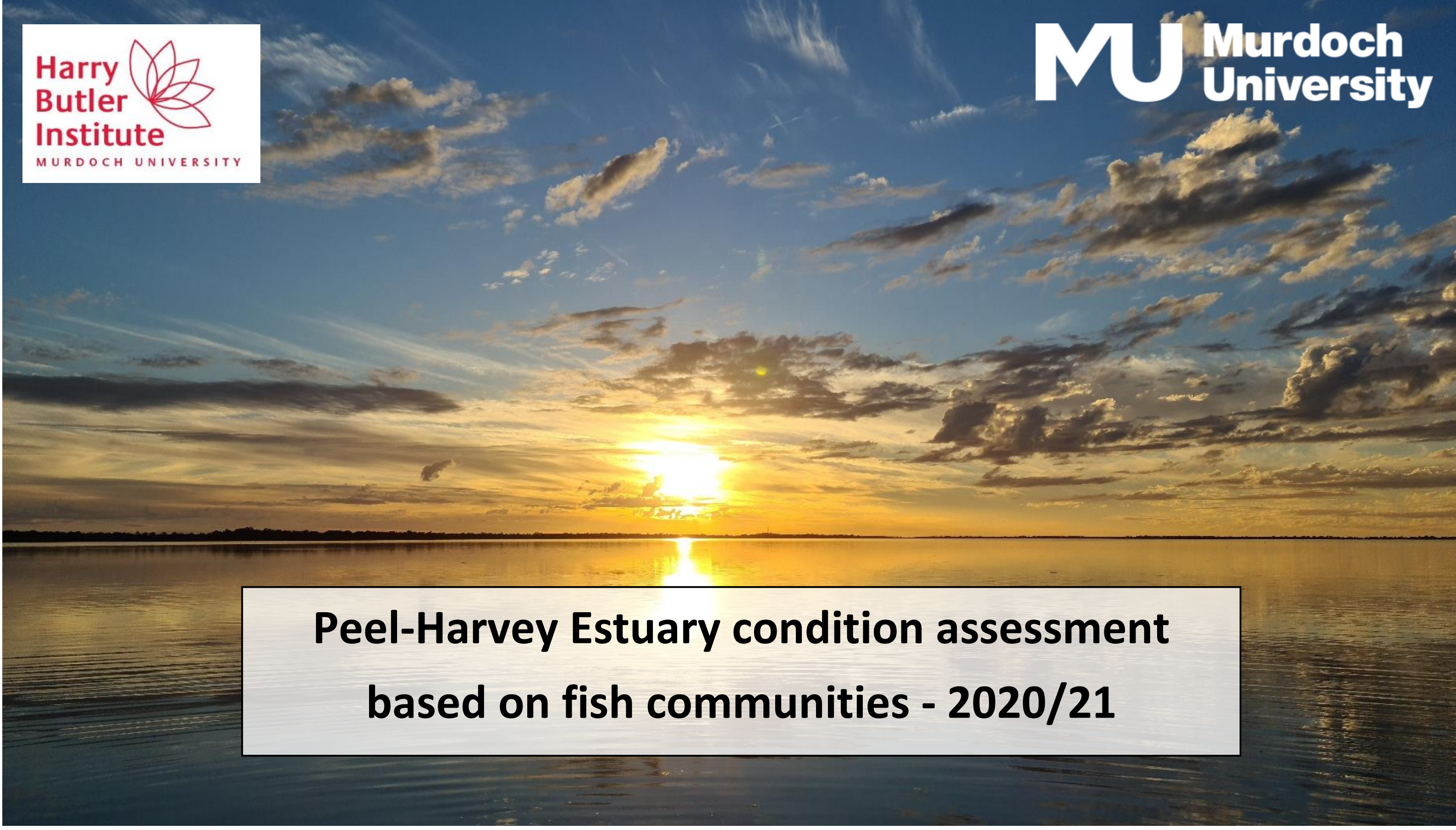

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Final Report

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Executive summary

This report describes the monitoring and evaluation of fish communities in the Peel-Harvey Estuary during summer and autumn of 2020/21 and applies the Fish Community Index (FCI) that was developed as a measure of the ecological condition. This index, which was specially designed to work in south-western Australian estuaries, has versions developed for both the shallow, nearshore waters of the estuary ($\leq$ 1 m deep) and also for its deeper, offshore waters (> 1 m deep) using an extensive fish data set from the 1970s to 2018. The index integrates information on various biological variables (metrics). Each of these metrics quantifies an aspect of the structure and/or function of estuarine fish communities, and together they respond to a range of stressors affecting the ecosystem.

Fish communities were sampled using different nets at six nearshore and three offshore sites in eight and seven regions of the Peel-Harvey Estuary, respectively (MC, Mandurah Channel (nearshore only); EP, Eastern Peel; WP, Western Peel; NH, Northern Harvey; SH, Southern Harvey; SP, Serpentine River; LM, Lower Murray River and UM, Upper Murray River) during summer and autumn of 2020/21. As many fish as possible were returned to the water alive after they had been identified and counted. The resulting data on the abundances of each fish species from each sample were used to calculate a Fish Community Index score (0 – 100). These index scores were then compared to established scoring thresholds to determine ecological condition grades A (very good) to E (very poor) for each zone and for the estuary as a whole, based on the composition of the fish community. This method has been adopted annually for over a decade in the Swan-Canning Estuary and has been shown to be a sensitive and robust tool for quantifying ecological health responses to local-scale environmental perturbations and tracking the subsequent recovery.

Nearshore Fish Communities

In the nearshore waters of all regions of the Peel-Harvey Estuary, small-bodied, schooling species of Whitebait, hardyheads (Atherinidae) and gobies (Gobiidae) dominated catches, representing 85 % of all fish recorded and constituting the four of the five most abundant nearshore species overall. In particular, Whitebait was the most abundant species overall (47 %) and reached a remarkable 90 % of all fish recorded in the Mandurah Channel. Presbyter's hardyhead and the Gobbleguts were abundant in the basins, reflecting their preference for saline conditions. In contrast, the riverine regions, and particularly the Upper Murray, contained high densities of Wallace’s hardyhead which prefer more brackish waters.

The nearshore waters of the estuary as a whole were in poor/fair (D/C) condition during the summer but improved to fair condition (C) in autumn. These scores are consistent with the relatively stable trends in condition reported between 2016 and 2018 and represent an improvement over those recorded in the 1970s and 1980s due to the absence of toxic blue-green algae. The average nearshore FCI scores the Mandurah Channel were lower than those in any of the other regions, due to their poor diversity and particularly for benthic (bottom-dwelling species). Scores for most regions increased by autumn especially in the Serpentine River and Lower Murray.

Offshore fish communities

Perth Herring was among the most dominant species in offshore waters and occurred mainly in the riverine areas as did the Sea Mullet. In contrast Australian Herring and Tailor were abundant in the basins.

Overall, the offshore waters of the estuary were also in good (B) condition in summer and fair (C) during autumn, which was a slight improvement for the grades for these seasons between 2016 and 2018. However, the Upper Murray region was rated as very poor in autumn 2021. This result was likely caused by the high levels of organic matter and stratification of the water column which lead to persistent very low levels of oxygen (hypoxia). As a response, fish moved away from these areas either vertically, into the shallows or horizontally upstream/downstream, which helps explain why no fish were recorded in two of the three samples from this region in autumn. The Murray River seems to be more susceptible to low oxygen levels than the Serpentine River due to its deeper holes which facilitate stratification. While these poor scores for the Upper Murray are similar to those recorded previously, predictions suggest than hypoxic conditions will become more prevalent in the future due to declining freshwater flows.

Future directions

In summary, and across the estuary as a whole, the ecological condition of both the nearshore and offshore waters in 2020/21 were assessed as in fair (C) condition based on their fish communities. However, several regions, *i.e.* the shallow waters of the Mandurah Channel and deeper waters of the Murray River scored very poor and/or poor in one of the seasons. Similar trends have been detected previously in these regions and indicate that their ecological health is under significant threat. Considering this and the broader spatial and temporal trends in condition, it is clear that the ecological health of the Peel-Harvey is under considerable stress and it is imperative that a consistent and regular fish monitoring program is continued to better assess its ongoing health into the future. Such a program would have the ability to detect short and longer-term changes to help understand the effect of climate change and assess the effectiveness of any remediation and management actions in the catchment and estuary.

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Contents

Acknowledgements 2

Executive summary 3

Contents 5

1. Introduction 6

  Background 6

  Rationale 7

  Study objectives 8

2. Methods 9

3. Results and discussion 13

  3.1 Context: water quality and environmental conditions 13

  3.2 Fish community 16

    Nearshore waters 16

    Offshore waters 23

  3.3 Ecological condition 28

    Nearshore waters 28

    Offshore waters 30

    Longer term trends in ecological condition 34

4. Summary 36

5. Recommendations 37

6. References 38

7. Appendices 43

1. Introduction

Background

Estuaries are a focal point for humans as they provide food, both directly from their waters (fisheries) and indirectly through agriculture on surrounding fertile land, sheltered harbours for ships and key transport route for the import and export of goods. Estuaries also provide a range of services including tourism, recreation, coastal protection, erosion control, water purification and act as nursey areas for a range of fish and crustacean species (Beck et al., 2001; Sheaves et al., 2014; Tweedley et al., 2016b). However, anthropogenic (human-induced) influences, such as land clearing, dredging, canal cutting and land reclamation, can result in the loss or modification of habitats in the estuary through eutrophication (excess primary production) and hypoxia (low oxygen), due to excessive nutrients from surrounding agricultural land, urban development and sewage (Kennish, 2002; Bricker et al., 2008; Rabalais et al., 2010; Cowley et al., 2022). As a result of these influences temperate estuaries are regarded as the most degraded of all marine ecosystems (Jackson et al., 2001). Warwick et al. (2018) argue that microtidal estuaries (*i.e.* those with a limited tidal range; < 2 m) in Mediterranean and arid climates, like those in south-western Australia, are naturally less resilient than well-flushed macrotidal estuaries. This means that any increase in anthropogenic perturbations will further decrease the health of a system in which the biota already experiences 'natural' stress (Elliott and Quintino, 2007).

One such example of a highly-modified estuary with huge social, cultural, biological and economic value is the Peel-Harvey on which the City of Mandurah is situated. The city is home to ~88,000 people and is one of the fastest growing cities in Australia (+1.85 % per year), with the population estimated to increase by 44 % between 2016 and 2036 (City of Mandurah, 2022). The Peel-Harvey Estuary covers an area of ~136 km^2 making it the largest system in south-western Australia (Valesini et al., 2019). It has two entrance channels, the natural Mandurah Channel and artificial Dawesville Channel, which was constructed in 1994 to increase tidal exchange with the Indian Ocean (Elliott et al., 2016) and is fed by three rivers, *i.e.* the Harvey, Murray and Serpentine. The extensive Peel Inlet and Harvey Estuary basins are shallow < 2 m deep and, like the entrance channels, comprise coarse–fine sands with silt in the deeper waters and silt and soft mud in the upper reaches and rivers (Valesini et al., 2014). Some seagrasses are present (*i.e. Halophila ovalis*, *Heterozostera* sp. and *Ruppia megacarpa*) in the basins together with accumulations of macroalgae, particularly opportunistic chlorophytes (green algae) such as *Chaetomorpha* and *Ulva* (Valesini et al., 2014; Potter et al., 2021).

The Mediterranean climate results in large seasonal fluctuations in rainfall, freshwater inflow and temperature, which can induce periodic hypersalinity, salt wedge formation, stratification and hypoxia in parts of the system (Tweedley et al., 2019; Valesini et al., 2019). The Peel-Harvey Estuary has been classified as extensively modified (Commonwealth of Australia, 2002; Tweedley et al., 2017b) and has a history of hyper-eutrophication from agricultural nutrients that leached from the sandy catchment into the estuary (McComb et al., 1981; Valesini et al., 2019). These nutrients have had marked effect on the flora (Lavery et al., 1991; Potter et al., 2021), zooplankton (Rose et al., 2019, 2020), benthic invertebrates (Wildsmith et al., 2009; Tweedley et al., 2012; 2014) and fish faunas of the estuary (Valesini et al., 2009; Potter et al., 2016).

Biotic indicators are being used to measure the ecological health of estuaries around the world (Whitfield and Elliott, 2002; Hallett et al., 2012; Tweedley et al., 2015). Among the various fauna used, fish are excellent indicators as a healthy and diverse community requires good water quality, the provision of habitat and connectivity between the estuary and surrounding marine and freshwater environments. Fish species also vary widely in their (i) diets, *e.g.* from low-level consumers, such as detritivores, to apex-predators, such as piscivores, (ii) habitat affinity, *e.g.* vegetated and unvegetated and from fresh to hypersaline waters, (iii) estuary usage, from occasional visitors to obligate users (*e.g.* complete their life cycle in these systems) and their life spans from < 1 year to decades. Thus, the presence of different species and their traits can provide important 'signals' of estuary health. Taking a community-wide view of the composition of the fish fauna can thus reveal many clues about the cumulative and complex impacts of the estuarine environment on higher ecological health.

The Fish Community Index (FCI) was developed by Murdoch University, through a collaborative project between the Department of Biodiversity, Conservations & Attractions, Department of Primary Industries & Regional Development and Department of Water & Environmental Regulation (Hallett, 2010; Hallett and Valesini, 2012; Hallett et al., 2012), for assessing the ecological condition of the Swan-Canning Estuary. The FCI has been subjected to extensive testing and validation over a period of several years in that system, and has been shown to be a sensitive and robust tool for quantifying ecological health responses to local-scale environmental perturbations and the subsequent recovery of the system following their removal (Hallett et al., 2016). The development and rationale of the FCI, along with its implementation and outcomes to date, are summarized in Hallett et al. (2019b) and were recently validated for use in the Peel-Harvey after three years of testing and evaluation (Hallett et al., 2019a).

Rationale

Separate versions of the FCI were developed for the shallow, nearshore waters (< 1 m deep) and deeper, offshore waters (> 1 m deep) of the Peel-Harvey Estuary, as the composition of the fish communities living in these different environments tends to differ, as do the methods used to sample them (Chuwen et al., 2009; Hoeksema et al., 2009; Tweedley et al., 2018). These indices integrate information on various biological variables ('metrics'; Table 1), each of which quantifies an aspect of the structure and/or function of estuarine fish communities. Together, the metrics respond to a wide array of stressors affecting the ecosystem. The FCI therefore provides a means to assess an important component of the ecology of the system and how it responds to, and thus reflects, changes in estuarine condition (Hallett et al., 2019b; Tweedley et al., 2021).

The responses of estuarine fish communities to increasing ecosystem stress and degradation (*i.e.* declining ecosystem health or condition) is summarised in a conceptual model (Figure 1). In response to increasing degradation of estuarine ecosystems, fish species with specific habitat, feeding or other environmental requirements will tend to become less abundant and diverse, whilst a few species with more general requirements become more abundant. This leads ultimately to an overall reduction in the number and diversity of fish species (Whitfield and Elliott, 2002; Fonseca et al., 2013; Krispyn et al., 2021). So, in a degraded estuary with poor water, sediment and habitat quality, the abundance and diversity of specialist feeders (*e.g.* Garfish and Tailor), bottom-living ('benthic-associated') species (*e.g.* Cobbler and Flathead) and estuarine spawning species (*e.g.* Black Bream, Perth Herring and Yellow-tail Trumpeter) will tend to decrease, as will the overall number and diversity of species. In contrast, generalist feeders (*e.g.* Banded Toadfish or Blowfish) and detritivores (*e.g.* Sea Mullet), which eat particles of decomposing organic material, will become more abundant and dominant (see left side of Figure 1). The reverse will be observed in a relatively unspoiled system that is subjected to fewer human stressors (see right side of Figure 1; noting that this conceptual diagram represents either end of a continuum of ecological condition from very poor to very good).

Each of the metrics that make up the FCI are scored from 0 – 10 according to the numbers and proportions of the various fish species present in samples collected from the estuary using either seine or gill nets. These metric scores are summed to generate an FCI score for the sample, which ranges from 0 – 100. Grades (A – E) describing the condition of the estuary, and/or of particular regions, are then awarded based on the FCI scores (see Section 2 for more details).

Table 1. Summary of the fish metrics comprising the nearshore and offshore Fish Community Indices developed for the Peel-Harvey Estuary (Hallett et al., 2019a).

Metric	**Predicted response to degradation**	***Nearshore Index***	***Offshore Index***
Number of species (No.species)	Decrease	✓	✓
Shannon-Wiener diversity (Sh-div) [a]	Decrease		✓
Proportion of trophic specialists (Prop.trop.spec.) [b]	Decrease	✓	
Number of trophic specialist species (No.trop.spec.) [b]	Decrease	✓	✓
Number of trophic generalist species (No.trop.gen.) [c]	Increase	✓	✓
Proportion of detritivores (Prop.detr.) [d]	Increase	✓	✓
Proportion of benthic-associated individuals (Prop.benthic) [e]	Decrease	✓	✓
Number of benthic-associated species (No.benthic) [e]	Decrease	✓	
Proportion of estuarine-spawning individuals (Prop.est.spawn) [f]	Decrease	✓	✓
Number of estuarine-spawning species (No.est.spawn)	Decrease	✓	
Proportion of *Pseudogobius olorum* (Prop. *P. olorum*) [g]	Increase	✓	
Total number of *Pseudogobius olorum* (Tot no. *P. olorum*) [g]	Increase	✓	

[a] A measure of biodiversity

[b] Species with specialist feeding requirements (*i.e.* zooplanktivore, zoobenthivores, herbivore and piscivore)

[c] Species that are omnivorous or opportunistic feeders

[d] Species that eat detritus (decomposing organic material)

[e] Species that live on, or are closely associated with, the sea/river bed

[f] Species that spawn in estuaries (*i.e.* estuarine species and semi-anadromous)

[g] The Blue-spot or Swan River goby, a tolerant, omnivorous species that often inhabits silty habitats

Study objectives

This report describes the monitoring and evaluation of fish communities in the Peel-Harvey Estuary during summer 2020 and autumn 2021 for the purposes of applying the FCI as a measure of ecological condition. The objectives of this study were to:

1. Undertake monitoring of fish communities in mid-summer and mid-autumn periods, following an established approach as detailed in Hallett et al. (2019a) using six nearshore and three offshore sites in each of eight and seven regions of the estuary, respectively.
2. Analyse the information collected so that the FCI is calculated for nearshore and offshore waters in each region and grouped together for the basins and rivers and for the estuary overall. Present the results as quantitative FCI scores (0 – 100), qualitative condition grades (A – E) and descriptions of the fish communities. Use radar plots to demonstrate the patterns of fish metric scores for each region.

3. Provide a report that summarises the approach and results of the monitoring and compares the condition to those in previous years.

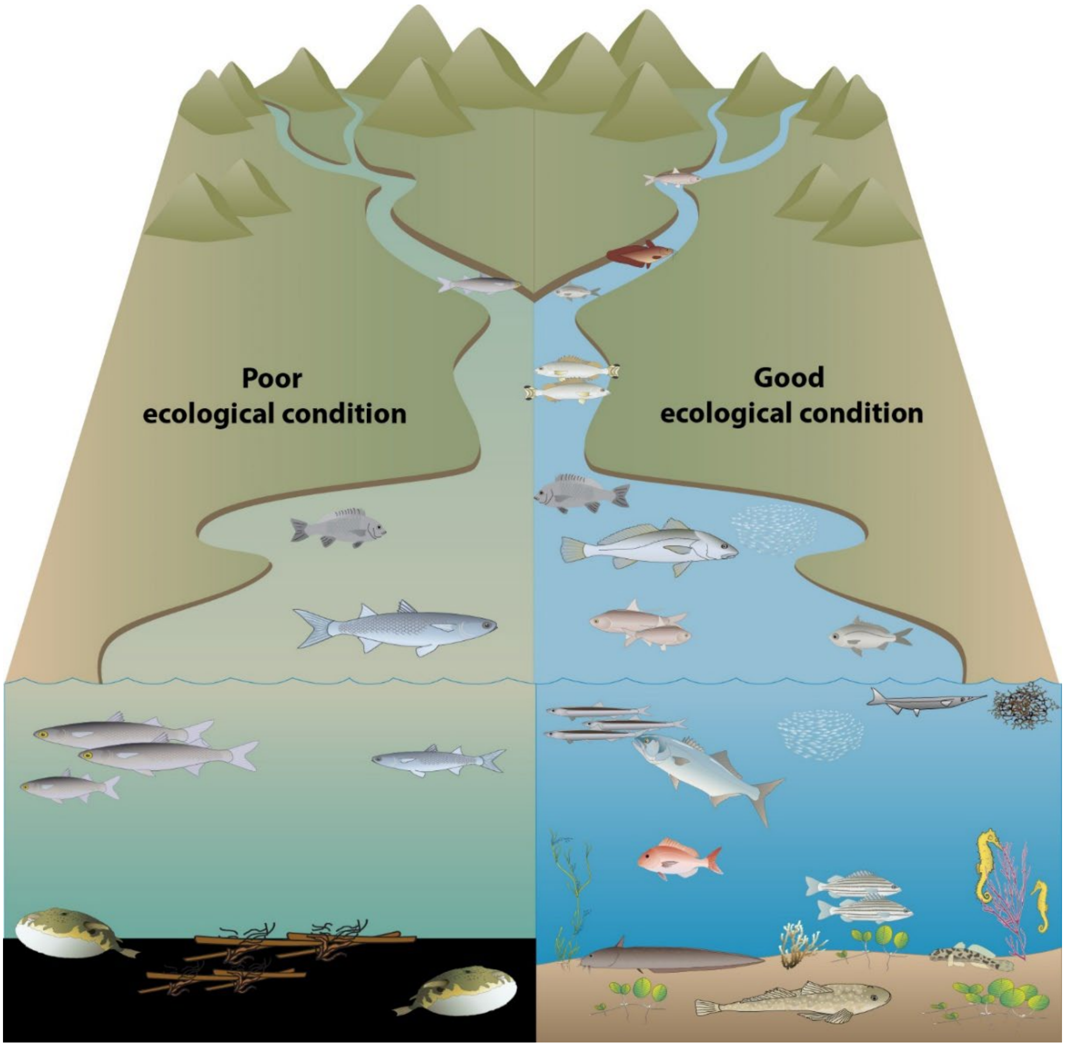


Figure 1. Conceptual diagram illustrating the predicted responses of the estuarine fish community to situations of poor and good ecological condition (Images courtesy of the Integration and Application Network [ian.umces.edu/symbols/]).

2. Methods

Fish communities were sampled at six nearshore and three offshore sites in eight and seven regions of the Peel-Harvey Estuary, respectively (MC, Mandurah Channel (nearshore only); EP, Eastern Peel; WP, Western Peel; NH, Northern Harvey; SH, Southern Harvey; SP, Serpentine River; LM, Lower Murray River and UM, Upper Murray River; Figure 2). In total, 69 sites were sampled with 48 in nearshore waters and 21 in offshore waters. Sampling was conducted during summer (16 – 30 December 2020) and autumn (16 March – 4 April 2021). All sampling was conducted under permits approved by Murdoch University's Animal Ethics Committee (permit number RW3286/20) and the Department of Primary Industries and Regional Development, Fisheries Division (exemption number 3585).

Nearshore waters were sampled using a 21.5 m seine net that was walked out from the beach to a maximum depth of approximately 1.5 m and deployed parallel to the shore, and then rapidly dragged towards and onto the shore (Figure 3). Offshore waters were sampled using 160 m-long, sunken, multimesh gill nets, each consisting of eight 20 m-long panels with stretched mesh sizes of 35, 51, 63, 76, 89, 102, 115 and 127 mm (Figure 3). These were deployed (*i.e.* laid parallel to the bank and sunk at a depth of 1.5 to 3 m, depending on the depth of water at each site) from a boat just after sunset and retrieved after one hour. These methods and sites follow those used by Hallett et al. (2019a).

Once a sample had been collected, any fish that could be identified immediately to species (*e.g.* larger species that are caught in relatively lower numbers) were identified, counted and returned to the water alive. All other fish caught in the nets were euthanised in ice slurry. In the cases when large catches (*e.g.* thousands) of small fish were caught, an appropriate sub-sample (*e.g.* one-half to one-eighth of the catch, depending on the total size of the catch) was retained and the remaining fish returned alive to the water. All retained fish were then frozen until their identification in the laboratory by experienced fish biologists, using available keys and identification guides where required. See appendices (i and ii) for full details of the sampling locations and methods employed.

Water temperature (°C), salinity (ppt) and dissolved oxygen concentration (mg/L) were measured in the middle of the water column at each nearshore site and at the top and bottom of the water column at each offshore site when a fish sample was collected using a Yellow Spring Instrument 556 Handheld Multiparameter Instrument. Due to the presence of pronounced stratification in some regions the subsequent results utilise data from only offshore sites.

To provide background on the fish communities of the Peel-Harvey Estuary the density of each fish species (100 m^{-2}) in nearshore waters and catch rate (h^{-1}) in offshore waters were subjected to multivariate analyses using PRIMER v7 (Clarke and Gorley, 2015). The data for the fish species in nearshore waters were dispersion-weighted and square-root transformed. These pre-treated data for each season were used to construct separate Bray-Curtis resemblance matrices, shown visually as a non-metric Multidimensional Scaling (nMDS) ordination plot and subjected to one-way Analysis of Similarities (ANOSIM) to determine if the fish communities in the various regions were different ($P < 0.05$). The magnitude of any differences were assessed using the R-statistic, which ranges from ~0 to 1 (Lek et al., 2011). To determine the species whose abundances were different between regions, the data for each region were averaged and used to provide a shade plot. This is a is a simple visualisation of the abundance data where a white space for a species demonstrates that it was never collected in that region, while the depth of shading from grey to black is linearly proportional to its abundance (Clarke et al., 2014). This process was repeated for the data from offshore waters.

The abundances of each fish species in each sample were used to derive values for each of the relevant metrics comprising the nearshore and offshore indices (Hallett and Valesini, 2012; Hallett et al., 2012). Metric scores were then calculated from these metric values, and the metric scores in turn combined to form the FCI scores. The method for calculating these scores is detailed in Hallett and Valesini (2012), but can be summarised simply as follows:

1. Allocate each fish species in a particular sample to its appropriate Habitat guild, Estuarine Use guild and Feeding Mode guild (Appendix iii), then calculate the values for each fish metric from the abundances of fishes in the sample.
2. Convert metric values to metric scores (0–10) based on their deviation away from established benchmark values or '*reference conditions*'. These reference conditions were defined for each

region of the estuary and season using historical data collected between 1979 and 2017 to account spatial and temporal variations in metric values.

3. Combine scores for the component metrics into a scaled FCI score (0–100) for each sample.
4. Compare the FCI score to the thresholds used to determine the condition grade for each sample ranging from A, very good, to E, very poor (Table 2). Intermediate grades *e.g.* B/C (good-fair) or C/B (fair-good) are awarded if the index score lies within one point either side of a grade threshold.

The FCI scores and condition grades for nearshore and offshore samples collected during summer and autumn 2020/21 were then examined to assess the condition of the basins and rivers separately and the Peel-Harvey Estuary as a whole during this period, using data averaged across the relevant regions. These were compared to previous summer and autumn seasons in 2016-2018 (Hallett et al., 2019a) through a qualitative examination of the patterns and trends in scores.

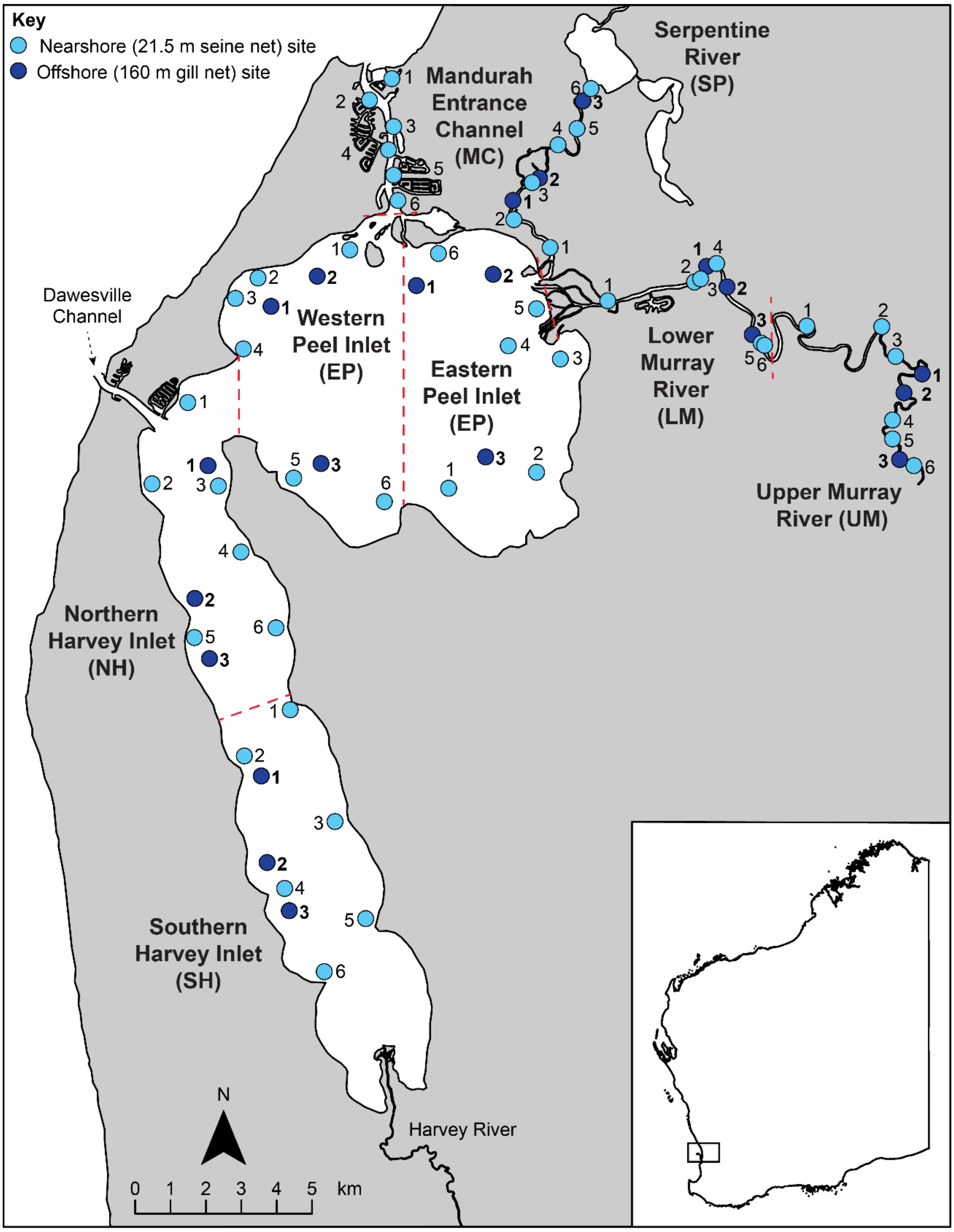


Figure 2. Locations of nearshore (light blue circles) and offshore (dark blue circles) sampling sites for the Fish Community Index of estuarine condition in the Peel-Harvey Estuary.

Table 2. Fish Community Index (FCI) scores comprising each of the five condition grades for both nearshore and offshore waters in the Peel-Harvey Estuary.

Condition grade	Nearshore FCI scores	Offshore FCI scores
A (very good)	> 77.67	> 71.00
B (good)	66.33 - 77.67	54.00 – 71.00
C (fair)	58.59 - 66.33	41.00 – 54.00
D (poor)	46.50 - 58.59	10.40 – 41.00
E (very poor)	< 46.50	< 10.40

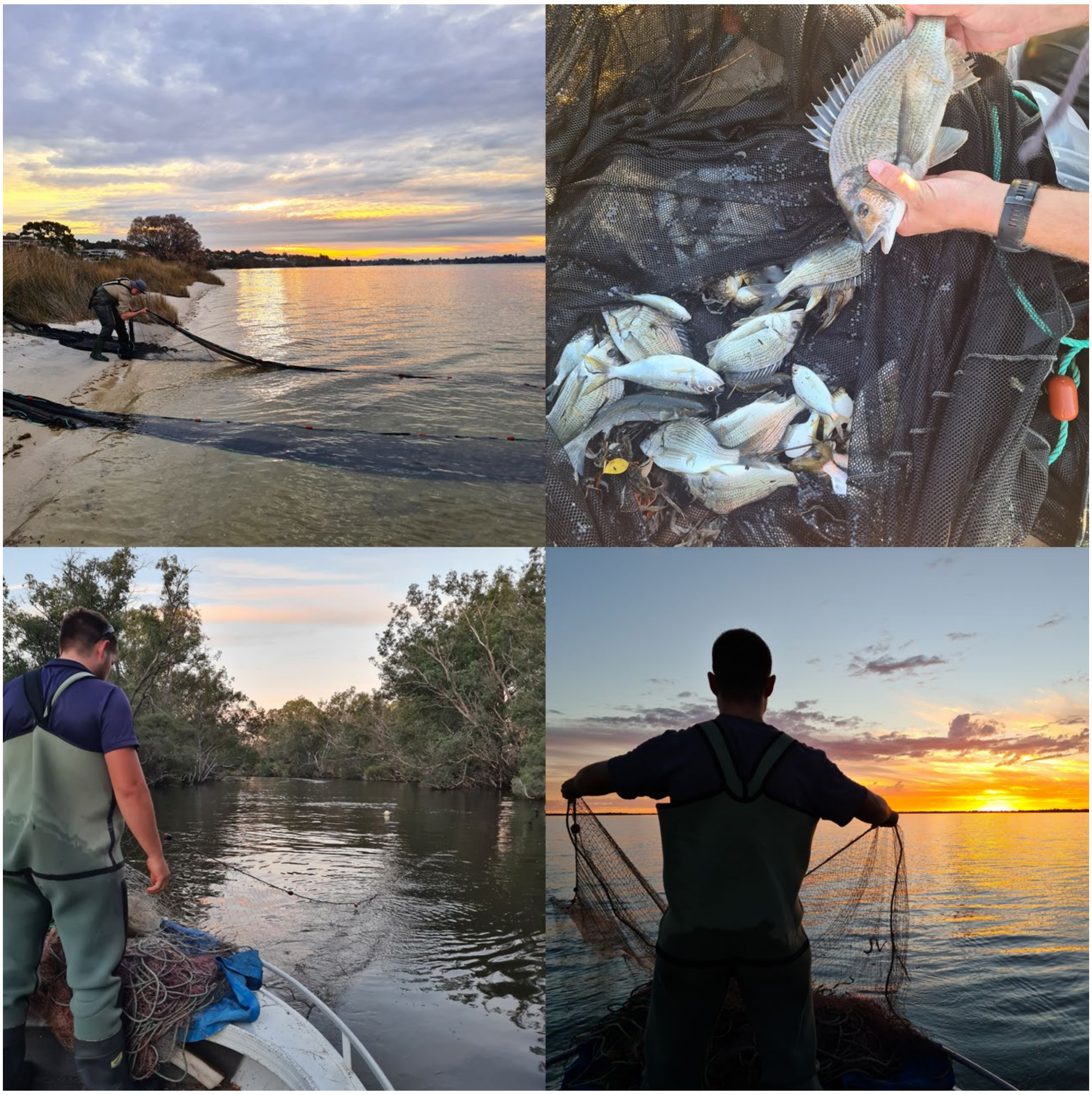


Figure 3. Images of the beach seine netting (upper row) used to sample the fish community in shallower, nearshore waters and the multimesh gill netting (lower row) used to sample fish communities in deeper, offshore waters. Images courtesy of Kurt Krispyn, Murdoch University.

3. Results and discussion

3.1 Context: water quality and environmental conditions

During summer 2020 surface water temperatures in the basin regions (Mandurah Channel, Eastern and Western Peel and Northern and Southern Harvey) were fairly similar ranging between 22.6 and 25.6 °C, but were far warmer in the Lower and Upper Murray with values of 27.5 and 29.0 °C, respectively (Figure 4). Temperature in the bottom waters were fairly similar, but noticeable warmer compared to the surface temperatures in the Upper Murray (*i.e.* 29 vs 32°C).

Salinities of 39 ppt were recorded throughout Peel Inlet (EP and WP) and the Harvey Estuary (NH and SH) but were slightly greater in the Serpentine River (41 ppt) and considerably lower in the

Lower and Upper Murray, *i.e.* 26 and 15, respectively (Figure 4). Stratification, where saltier water lies below fresher water, was recorded in the Murray River, with the salinity being 8 ppt greater in bottom waters of the Lower Murray than the surface and 12 ppt greater in the Upper Murray. In the other regions, salinities in the surface and bottom waters were similar.

The surface waters of all regions were relatively well-oxygenated during summer, with values ranging from 5.5 to 6.4 mg/L (Figure 4). Similar values were recorded for the bottom waters of all regions in the basin and the Serpentine River (5.5 to 6.3 mg/ L). However, oxygen levels were low, *i.e.* 3.95 (mg/L) and hypoxic (< 2 mg/L; Tweedley et al., 2016a), *i.e.* 1.12 mg/L, in the bottom waters of the Lower and Upper Murray, respectively.

During autumn 2021, surface and bottom water temperatures in each region were cooler than in summer, particularly in the Southern Harvey. Among all regions, they were highest in the Upper Murray (Figure 4). Salinities in the basin regions (except the Southern Harvey) and the Serpentine River were similar in both seasons, but surface salinities decreased and those in the bottom waters increased in the Murray River. For example, in the Upper Murray, surface salinity halved from 15.0 to 7.6 ppt from summer to autumn but values in the deeper water increased from 26-27 to 32-38 ppt (Figure 4). Oxygen concentrations were relatively high throughout autumn except in the Lower and Upper Murray where they were 2.15 and 1.22 mg/l, respectively, in the bottom waters.

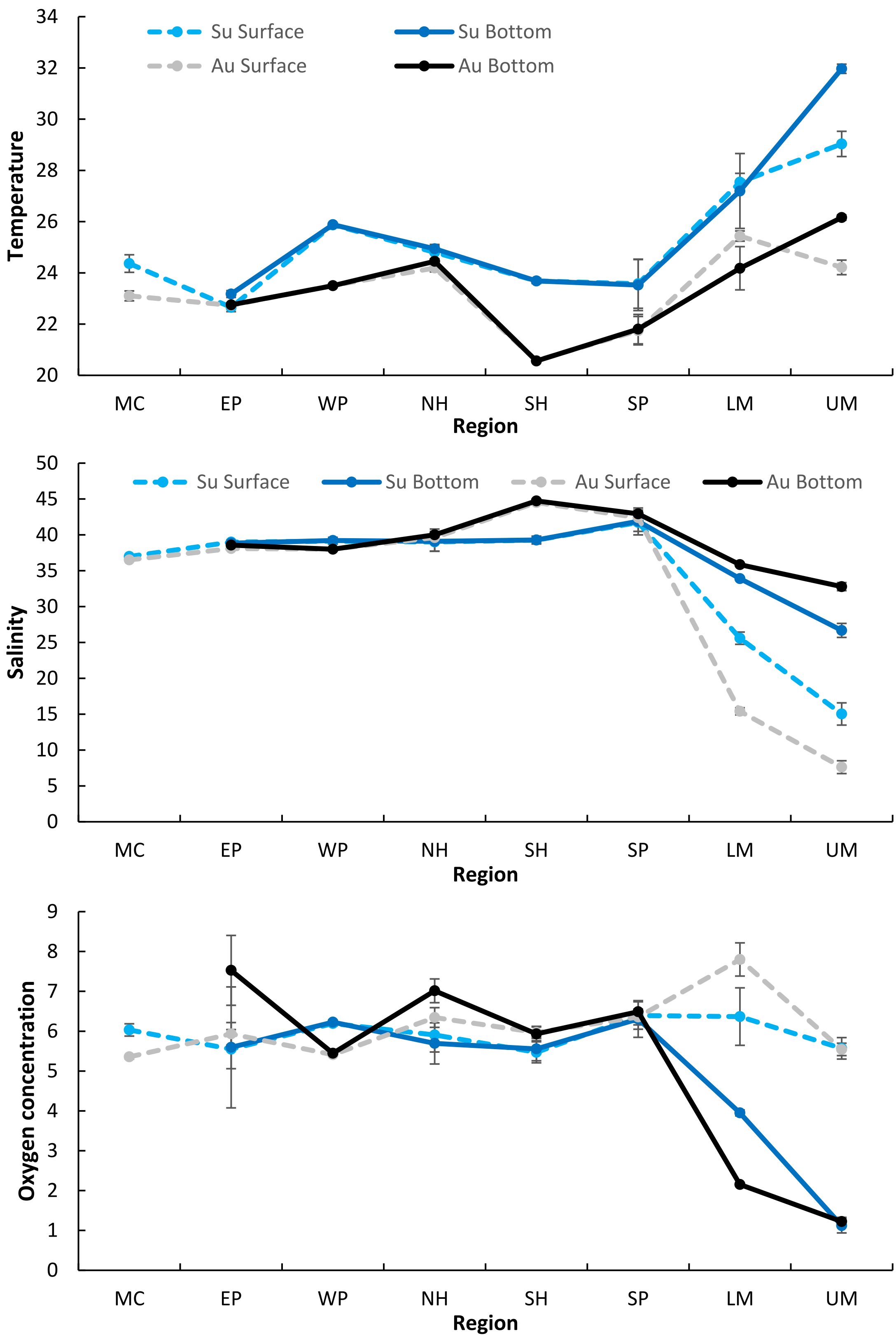


Figure 4. Mean values (±SE) for water temperature (°C), salinity (ppt) and dissolved oxygen concentration (mg/L) at the surface and bottom of the water column in each region of the Peel-Harvey estuary in summer (Su) 2020 and autumn (Au) 2021. Note only the nearshore waters of the Mandurah Channel were sampled and thus water quality measurements from the bottom of the water column were not recorded.

3.2 Fish community

Nearshore waters

A total of 47 species were recorded in the 96 seine net samples collected from the shallow, nearshore waters of the Peel-Harvey Estuary in summer 2020 and autumn 2021 combined (Table 3). These species represented 25 families, the most species-rich of which were the gobies (Gobiidae) and hardyheads (Atherinidae) with eight and five species, respectively. Together, hardyheads and herrings (Clupeidae) comprised 83 % of all fish caught with Whitebait (47 %), Presbyter's Hardyhead (14 %), the Elongate Hardyhead (14 %) and Wallace's Hardyhead (6 %) being the most abundant. Among the habitat guilds, 17 of the species were demersal, but represented only 1.7 % of the number of individuals, whereas the eight small pelagic and nine bentho-pelagic species contributed 83 and 10 % to the total number of fish, respectively. A total of 21 of the 47 species were marine estuarine-opportunist, *i.e.* species that spawn in marine waters, but whose juveniles use estuaries as nursery areas (Table 3). These fish represented 68 % of the total number of individuals, with the other abundant estuarine usage guild being estuarine species, comprising 13 species and accounting for 30 % of individuals. Most species and individuals were tropic specialists, *i.e.* the 25 zoobenthivores (28 % of individuals) and seven zooplanktivores (67 %), with omnivores (seven species) and opportunists (three species) making up 4.5 % of all fish recorded.

The number of species was greatest in the regions closet to the Indian Ocean, *i.e.* Northern Harvey and Mandurah Channel (30 and 28 species, respectively) and lowest in the Upper Murray (15 species; Table 4). The highest densities of fish were found in the Mandurah Channel and Southern Harvey with densities of < 10 % of those recorded in the Eastern Peel and Lower Murray. Whitebait was the most abundant species overall and represented almost 90 % of all fish caught in the Mandurah Channel, largely due to ~17,000 individuals of this highly-schooling species being recorded in a single sample (Table 4). This species which was amongst the most abundant recorded in this estuary in the 1990s and 2000s (Potter et al., 2016) was found in all eight regions, but made notable contributions in the Serpentine and Murray Rivers and particularly the upper region of the latter river. Regions in Peel Inlet and the Harvey Estuary were dominated by Presbyter's Hardyhead, the Gobbleguts and the Elongate Hardyhead, with the latter species, Wallace's Hardyhead and the Yellow-eye Mullet (*Aldrichetta forsteri*) being abundant in the riverine regions (Table 4). The non-native Mosquito Fish (*Gambusia holbrooki*) was recorded in the Upper Murray, where it was the fourth most abundant species. This fish has been found in freshwater environments throughout Western Australia (Morgan et al., 2004) and is known to occur in the Swan-Canning and Vasse-Wonnerup estuaries to the north and south, respectively (Tweedley et al., 2017a; 2021). Mosquito Fish were not caught in previous studies in the Peel-Harvey (*i.e.* Valesini et al., 2009; Potter et al., 2016) as sampling was restricted to the basins and lowest reaches of the rivers. Moreover, despite extensive sampling in earlier studies, three other species were new records for the Peel-Harvey Estuary (c.f. Hallett et al., 2019a), namely Dusky Frillgoby (*Bathygobius fuscus*), Castelnau's Wrasse (*Dotalabrus aurantiacus*) and the Tasselled Leatherjacket (*Chaetodermis penicilligerus*). These new records highlight the benefit of an annual monitoring program in summer and autumn each year in helping to detect the presence of new and/or non-native species in this highly urbanised estuary.

One-way ANOSIM detected significant difference in fish communities between the various regions in summer 2020 (P = 0.001), with the extent of the difference being relatively large (Global R = 0.669). At a pairwise level each region supported a distinct fauna except the Western Peel, which was similar to the other three basin regions (Eastern Peel and the Northern and Southern Harvey; Table

5). The differences between regions are clearly shown on the nMDS plot, where the samples from the basins are located on the left, with those from the Mandurah Channel in a narrow strip in the centre and those form the Serpentine and Murray rivers on the right (Figure 5a). The Mandurah Channel was characterised by Whitebait and the Long-finned Goby, which were more abundant in this region than any others (Figure 5b). Fish species that were abundant in the Western Peel, *e.g.* Gobbleguts, Devilfish, Western Striped Grunter, Blowfish and Tarwine, were also found in appreciable densities in one or more of the other basin regions and not in the rivers. Yellow-eye Mullet and Wallace's Hardyhead were particularly abundant in the Upper Murray and to a lesser extent in the Serpentine River (Figure 5b).

The fish community remained different among the regions in autumn 2021 (P = 0.001; Global R = 0.612) with a similar pattern to summer observed except the fish community Mandurah Channel was not significantly different to that in the Eastern Peel (Table 6; Figure 6a). Regions in the basin were dominated by Gobbleguts, Presbyter's Hardyhead, Devilfish and Blowfish, while species such as Roach, the Southwestern Goby and Wallace's Hardyhead were far more abundant in the rivers (Figure 6b).

Table 3. Fish species caught in the nearshore waters of the Peel-Harvey (total number [Tot] and percentage contribution [%]) during summer 2020 and autumn 2021 combined. The habitat (Ha), Estuarine usage (EU) and feeding (Feed) guild of each species is provided. Species shaded in grey represented > 5 % to the total number of fish. D, Demersal; P, Pelagic; BP, Bentho-pelagic; SP, Small pelagic; SB, Small benthic; MS, Marine straggler; MEO, Marine estuarine-opportunist; SA, Semi-anadromous; ES, Estuarine species; F, Freshwater; ZB, Zoobenthivore; PV, Piscivore; ZP, Zooplanktivore; DV, Detritivore; OV, Omnivore; Op, Opportunist; HV, Herbivore. * denotes non-native species.

						Entire estuary	
Species	**Common name**	**Family**	**Ha**	**EU**	**Feed**	**Tot**	**%**
Hyperlophus vittatus	Whitebait / Sandy Sprat	Clupeidae	SP	MEO	ZP	25,038	47.36
Leptatherina presbyteroides	Presbyter's Hardyhead	Atherinidae	SP	MEO	ZP	7,221	13.66
Atherinosoma elongata	Elongate Hardyhead	Atherinidae	SP	ES	ZB	7,141	13.51
Ostorhinchus rueppellii	Gobbleguts	Apogonidae	BP	ES	ZB	3,741	7.08
Leptatherina wallacei	Wallace's Hardyhead	Atherinidae	SP	ES	ZP	3,146	5.95
Aldrichetta forsteri	Yellow-eye Mullet	Mugilidae	P	MEO	OV	1,141	2.16
Craterocephalus mugiloides	Mugil's Hardyhead	Atherinidae	SP	ES	ZB	827	1.56
Gymnapistes marmoratus	Devilfish	Tetrarogidae	D	MS	ZB	607	1.15
Favonigobius lateralis	Long-finned Goby	Gobiidae	SB	MEO	ZB	546	1.03
Gerres subfasciatus	Roach	Gerreidae	BP	MEO	ZB	504	0.95
Pseudogobius olorum	Blue-spot / Swan River Goby	Gobiidae	SB	ES	OV	427	0.81
Pelates octolineatus	Western Striped Grunter	Terapontidae	BP	MEO	OV	361	0.68
Afurcagobius suppositus	Southwestern Goby	Gobiidae	SB	ES	ZB	321	0.61
Torquigener pleurogramma	Blowfish / Banded Toadfish	Tetraodontidae	BP	MEO	OP	316	0.60
Atherinomorus vaigiensis	Ogilby's Hardyhead	Atherinidae	SP	MEO	ZB	308	0.58
Spratelloides robustus	Blue Sprat	Clupeidae	SP	MEO	ZP	219	0.41
Rhabdosargus sarba	Tarwhine	Sparidae	BP	MEO	ZB	202	0.38
*Gambusia holbrooki**	Mosquito Fish	Poeciliidae	SP	F	ZB	181	0.34
Sillago burrus	Western Trumpeter Whiting	Sillaginidae	D	MM	ZB	149	0.28
Amniataba caudavittata	Yellow-tail Trumpeter	Terapontidae	BP	ES	OP	124	0.23
Favonigobius punctatus	Red-spot Goby	Gobiidae	SB	ES	ZB	120	0.23
Mugil cephalus	Sea Mullet	Mugilidae	P	MEO	DV	66	0.12
Sillaginodes punctatus	King George Whiting	Sillaginidae	D	MEO	ZB	51	0.10
Sillago schomburgkii	Yellow-finned Whiting	Sillaginidae	D	MEO	ZB	15	0.03
Ammotretis elongatus	Elongate Flounder	Pleuronectidae	D	MEO	ZB	14	0.03
Bathygobius fuscus	Dusky Frillgoby	Gobiidae	SB	MEO	ZB	11	0.02
Hyporhamphus regularis	Western River Garfish	Hemiramphidae	P	ES	HV	10	0.02
Haletta semifasciata	Blue Weed Whiting	Odacidae	D	MS	OV	9	0.02
Pseudorhombus jenynsii	Small-toothed Flounder	Paralichthyidae	D	MEO	ZB	8	0.02
Enoplosus armatus	Old Wife	Enoplosidae	D	MS	ZB	7	0.01
Pomatomus saltatrix	Tailor	Pomatomidae	P	MEO	PV	4	0.01
Stigmatopora argus	Spotted Pipefish	Syngnathidae	D	MS	ZP	3	0.01
Hyporhamphus melanochir	Southern Sea Garfish	Hemiramphidae	P	ES	HV	2	< 0.01
Pugnaso curtirostris	Pugnose Pipefish	Syngnathidae	D	MS	ZP	2	< 0.01
Nannoperca vittata	Western Pygmy Perch	Percichthyidae	BP	F	ZB	2	< 0.01
Acanthopagrus butcheri	Black Bream	Sparidae	BP	ES	OP	2	< 0.01
Callogobius mucosus	Sculptured Goby	Gobiidae	SB	MS	ZB	2	< 0.01
Arenigobius bifrenatus	Bridled Goby	Gobiidae	SB	ES	ZB	2	< 0.01
Callogobius depressus	Flathead Goby	Gobiidae	SB	MS	ZB	2	< 0.01
Meuschenia freycineti	Sixspine Leatherjacket	Monacanthidae	D	MEO	OV	2	< 0.01
Acanthaluteres spilomelanurus	Bridled Leatherjacket	Monacanthidae	D	MEO	OV	2	< 0.01
Cnidoglanis macrocephalus	Estuarine Cobbler	Plotosidae	D	MEO	ZB	1	< 0.01
Urocampus carinirostris	Hairy Pipefish	Syngnathidae	D	ES	ZP	1	< 0.01
Platycephalus laevigatus	Rock Flathead	Platycephalidae	D	MS	PV	1	< 0.01
Pentapodus vitta	Western Butterfish	Nemipteridae	BP	MS	ZB	1	< 0.01
Dotalabrus aurantiacus	Castelnau's Wrasse	Labridae	D	MS	ZB	1	< 0.01
Chaetodermis penicilligerus	Tasselled Leatherjacket	Monacanthidae	D	MS	OV	1	< 0.01
					Number of samples	96	
					Number of species	47	
					Average density (100 m^2)	474.69	
					Total number of fish	52,862	

Table 4. Compositions of the fish communities (# = average density fish 100 m^{-2} and % = percentage composition) observed across the six nearshore sites sampled in each region of the Peel-Harvey Estuary during summer 2020 and autumn 2021 combined. Species ordered by overall abundance and those shaded in grey represented > 5% to the total number of fish in any region. MC, Mandurah Channel; EP, Eastern Peel; WP, Western Peel; NH, Northern Harvey; SH, Southern Harvey; SP, Serpentine River; LM, Lower Murray River and UM, Upper Murray River. * denotes non-native species.

	MC		**EP**		**WP**		**NH**		**SH**		**SP**		**LM**		**UM**	
Species	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**
Whitebait / Sandy Sprat	1,362.00	89.59	3.74	4.49	9.63	6.28	3.30	1.69	64.01	7.38	43.10	21.20	13.58	13.34	299.35	44.49
Presbyter's Hardyhead	18.46	1.21	30.68	36.87	28.66	18.71	117.96	60.21	319.68	36.87	2.59	1.27	0.72	0.71		
Elongate Hardyhead	18.75	1.23	16.95	20.38	45.98	30.00	17.10	8.73	240.59	27.75	55.24	27.17	13.22	12.99	105.17	15.63
Gobbleguts	1.44	0.09	13.22	15.89	36.14	23.58	9.99	5.10	203.09	23.43	0.14	0.07	4.74	4.66		
Wallace's Hardyhead			0.14	0.17					0.22	0.02	10.63	5.23	4.60	4.52	210.42	31.27
Yellow-eye Mullet	32.33	2.13	0.14	0.17	0.79	0.52	0.43	0.22	1.01	0.12	25.29	12.44	12.43	12.21	9.55	1.42
Mugil's Hardyhead	5.68	0.37	0.72	0.86	4.02	2.63	0.29	0.15	6.32	0.73	38.43	18.90	3.66	3.60	0.29	0.04
Devilfish	1.72	0.11	2.37	2.85	6.68	4.36	23.28	11.88	9.55	1.10						
Long-finned Goby	31.54	2.07	1.15	1.38	1.44	0.94	3.30	1.69			1.80	0.88				
Roach	6.90	0.45	0.14	0.17					0.14	0.02	3.30	1.63	18.10	17.78	7.61	1.13
Blue-spot / Swan River Goby	0.72	0.05	1.72	2.07	1.65	1.08	0.14	0.07	15.52	1.79	6.82	3.36	0.22	0.21	3.88	0.58
Western Striped Grunter	6.97	0.46	1.94	2.33	6.97	4.55	8.84	4.51	0.43	0.05			0.65	0.64	0.14	0.02
Southwestern Goby											6.39	3.14	0.72	0.71	15.95	2.37
Blowfish / Banded Toadfish	10.85	0.71	2.80	3.37	3.59	2.34	2.37	1.21	1.22	0.14	0.07	0.04	1.80	1.76		
Ogilby's Hardyhead	7.33	0.48	5.60	6.74			3.74	1.91	2.23	0.26	0.79	0.39	2.44	2.40		
Blue Sprat	1.80	0.12					0.50	0.26					13.43	13.20		
Tarwhine	1.15	0.08	1.08	1.30	6.39	4.17	1.44	0.73	1.01	0.12	0.29	0.14	2.87	2.82	0.29	0.04
Mosquito Fish*															13.00	1.93
Western Trumpeter Whiting	8.84	0.58	0.07	0.09			0.07	0.04	0.07	0.01	1.29	0.64	0.36	0.35		
Yellow-tail Trumpeter	1.15	0.08									3.09	1.52	3.45	3.39	1.22	0.18
Red-spot Goby							0.86	0.44	0.57	0.07	0.72	0.35	1.36	1.34	5.10	0.76
Sea Mullet											1.58	0.78	2.44	2.40	0.72	0.11
King George Whiting	0.93	0.06			0.14	0.09	0.79	0.40	0.57	0.07	1.22	0.60				
Yellow-finned Whiting					0.07	0.05	0.14	0.07	0.07	0.01	0.43	0.21	0.36	0.35		
Elongate Flounder	0.07	< 0.01	0.14	0.17	0.29	0.19	0.14	0.07	0.29	0.03	0.07	0.04				
Krefft's Frillgoby	0.36	0.02			0.14	0.09	0.29	0.15								
Western River Garfish			0.22	0.26					0.07	0.01			0.43	0.42		
Blue Weed Whiting	0.22	0.01			0.29	0.19	0.14	0.07								
Small-toothed Flounder	0.22	0.01	0.22	0.26			0.07	0.04	0.07	0.01						
Old Wife	0.43	0.03					0.07	0.04								
Tailor	0.14	0.01							0.07	0.01			0.07	0.07		
Spotted Pipefish	0.07	< 0.01	0.07	0.09	0.07	0.05										
Southern Sea Garfish							0.14	0.07								
Pugnose Pipefish					0.07	0.05	0.07	0.04								
Western Pygmy Perch															0.14	0.02
Black Bream													0.14	0.14		
Sculptured Goby							0.14	0.07								
Bridled Goby	0.14	0.01														
Flathead Goby			0.07	0.09					0.07	0.01						

Table 4. continued.

Sixspine Leatherjacket					0.07	0.05	0.07	0.04								
Bridled Leatherjacket	0.07	< 0.01			0.07	0.05										
Estuarine Cobbler							0.07	0.04								
Hairy Pipefish									0.07	0.01						
Rock Flathead							0.07	0.04								
Western Butterfish					0.07	0.05										
Castelnau's Wrasse	0.07	< 0.01														
Tasselled Leatherjacket							0.07	0.04								
Number of samples	12		12		12		12		12		12		12		12	
Number of species	28		21		22		30		24		21		23		15	
Average density (100 m^2)	1,520.33		83.19		153.23		195.91		866.95		203.30		101.80		672.84	
Total number of fish	21,163		1,158		2,133		2,727		12,068		2,830		1,417		9,366	

Table 5. Pairwise *R*-statistic values derived from a one-way ANOSIM test on the composition of the nearshore fish fauna among regions in summer 2020. Pairwise comparisons that are not significantly different shade in grey. Full region names given in Figure 2 and Table 4.

	MC	EP	WP	NH	SH	SP	LM
EP	0.428						
WP	0.374	0.148					
NH	0.480	0.391	-0.015				
SH	0.587	0.352	0.200	0.293			
SP	0.581	0.933	1.000	0.952	0.915		
LM	0.685	0.856	0.894	0.820	0.840	0.470	
UM	0.939	0.998	1.000	0.983	0.944	0.463	0.617

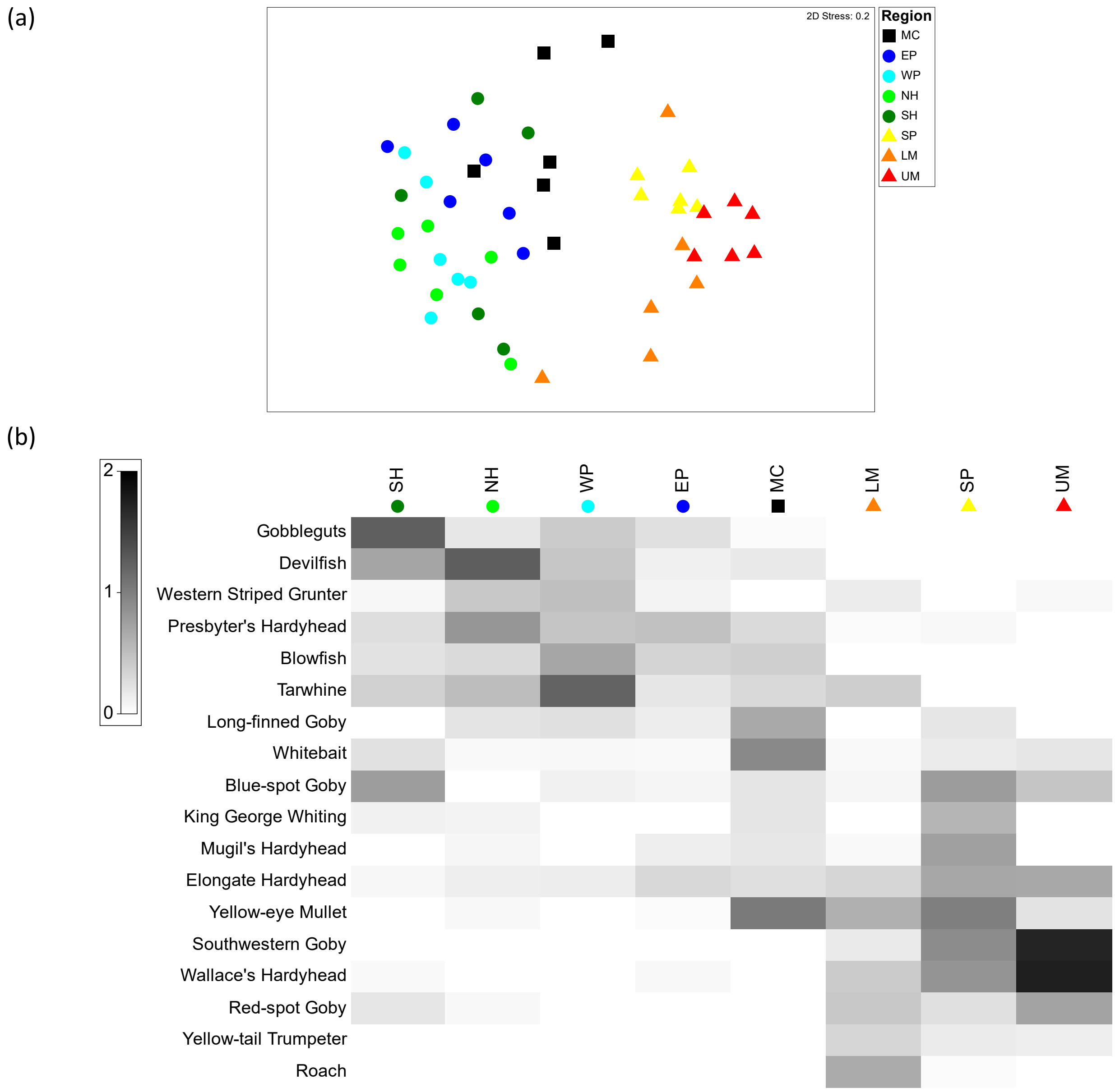


Figure 5. (a) nMDs plot of the nearshore fish community at each site in the Peel-Harvey estuary in summer 2020. (b) Shade plot of the transformed density of each species in each region. Full region names given in Figure 2 and Table 4.

Table 6. Pairwise *R*-statistic values derived from a one-way ANOSIM test on the composition of the nearshore fish fauna among regions in autumn 2021. Pairwise comparisons that are not significantly different shade in grey. Full region names given in Figure 2 and Table 4.

	MC	EP	WP	NH	SH	SP	LM
EP	0.115						
WP	0.356	0.102					
NH	0.392	0.150	0.016				
SH	0.617	0.411	0.093	0.469			
SP	0.815	0.859	0.607	0.849	0.730		
LM	0.711	0.702	0.594	0.729	0.743	0.231	
UM	0.983	0.985	0.807	0.935	0.943	0.850	0.852

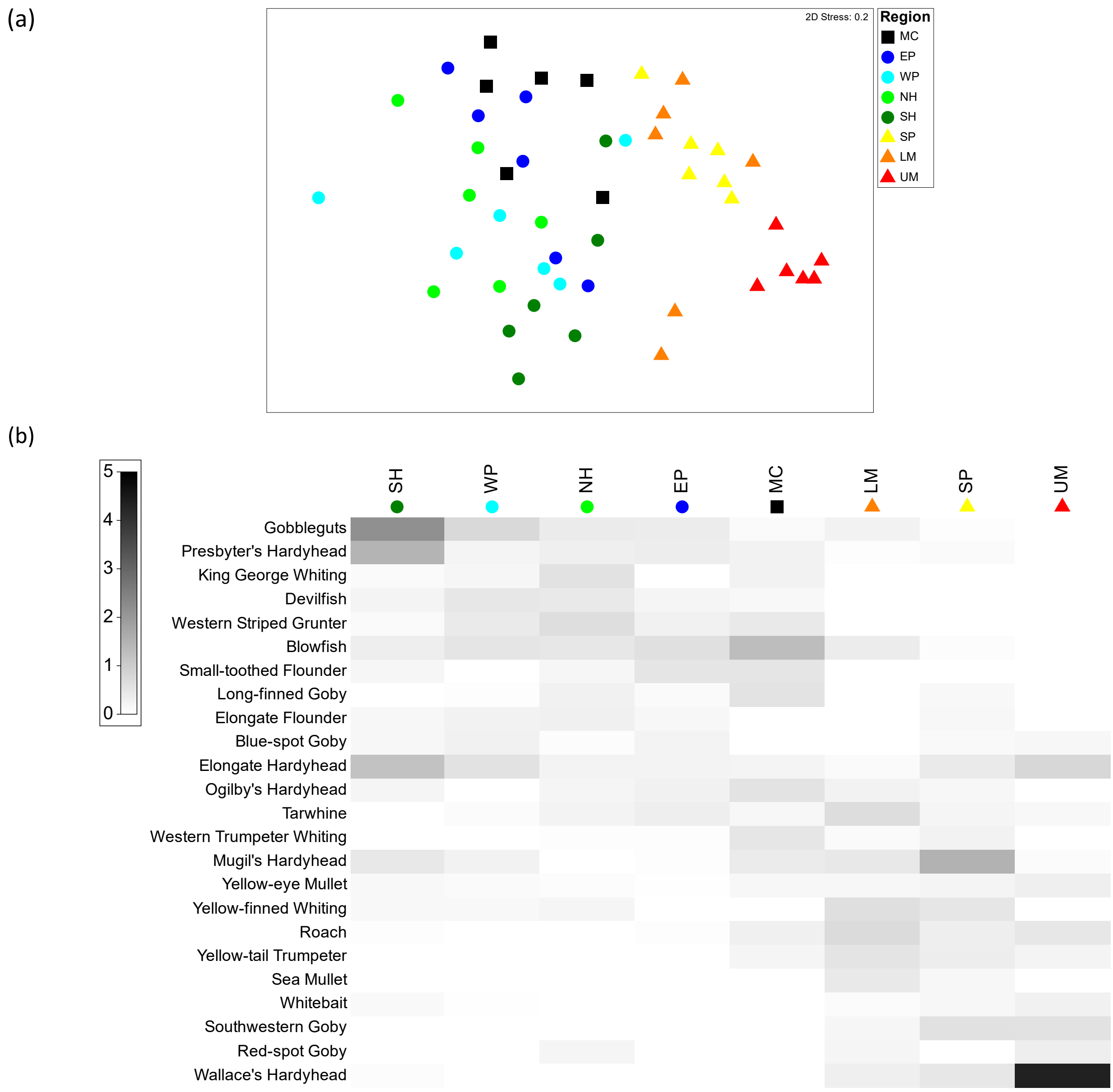


Figure 6. (a) nMDs plot of the fish community at each site in the Peel-Harvey estuary in autumn 2021. (b) Shade plot of the transformed density of each species in each region. Full region names given in Figure 2 and Table 4.

Offshore waters

A total of 21 species were recorded in the 42 gill net samples collected from the deeper, offshore waters of the Peel-Harvey Estuary in summer 2020 and autumn 2021 combined (Table 7). These species represented 15 families, of which most contain a single species except for the whitings (Sillaginidae), sea bream (Sparidae), grunters (Terapontidae) and mullets (Mugilildae). Together, the four most abundance species comprised > 70 % of all fish caught, *i.e.* Perth Herring (27 %), Australian Herring (16 %), Sea Mullet (15 %) and Tailor (13 %). The fish present in these waters represented three habitat guilds, with most species being either bentho-pelagic (9) or demersal (5) and most individuals belonging to the former guild or being pelagic (each 45 %; Table 7). The majority of species, *i.e.* 15 of the 21, were marine-estuarine opportunists (60 % of all individuals), with four species, representing 34% of the total number of fish, able to spawn in the estuary (estuarine and semi-anadromous). Zoobenthivores were represented by the highest number of species (11), with most other guilds containing one to three species. As in the nearshore waters most individuals were trophic specialists, with detritivores (41 %) and piscivores (29 %) being well represented, and only 16 % of species representing trophic generalist guilds (Table 7).

The number of species was greatest in the basin regions (11-14) and lower in the Serpentine River (9), Lower Murray (7) and Upper Murray (5; Table 8). However, catch rates were by far the greatest in the Upper Murray and lowest in the Southern Harvey and Serpentine River. Perth Herring was the most abundant species overall and comprised ~27 % of all fish recorded, followed by Australian Herring (16 %), Sea Mullet (15 %) and Tailor (13 %). Similarly, Perth Herring was also the most abundant fish species in the offshore sampling for the Swan-Canning Estuary FCI in both 2020 and 2021 (Tweedley et al., 2021; 2022). Some species showed marked spatial patterns of distribution, for example while Perth Herring were recorded in each region of the Peel-Harvey Estuary they represented 2-7 % of fish in each basin region, but contributed 30, 62 and 73 % in the Upper Murray, Serpentine River and Lower Murray, respectively. In contrast, Australian Herring and Southern Eagle Rays were abundant in the basin regions, but not caught in any of the riverine regions. In recent years, Eagle Rays has been amongst the most abundant fish in the deeper, offshore waters of the Lower Swan-Canning Estuary, reflecting the large sand flat areas and consistently high (marine-like) salinities (Tweedley et al., 2021). Other species that made a notable contribution in one of more regions were the Western Striped Trumpeter in the Northern Harvey and Yellow Tail Trumpeter in the Upper Murray (Table 8). The former species is closely associated with seagrass beds and feeds on the plant material and small invertebrates living on the leaves (Veale et al., 2015; Poh et al., 2018). It is thus relevant that the seagrass *Ruppia* is most prevalent in the Northern Harvey. The Yellow Tail Trumpeter prefers less saline waters of the upper estuary (Wise et al., 1994), explaining their presence only in the Upper Murray which always had the lowest salinity.

One-way ANOSIM detected significant difference in fish communities between the various regions in summer 2020 (P = 0.001), with the extent of the difference being large (Global R = 0.758). At a pairwise level each region supported a distinct fauna except the Northern Harvey, which was similar to the other three basin regions (Eastern Peel and Northern and Southern Harvey; Table 9). The differences between regions during summer are clearly shown on the nMDS plot, where the samples from the basins are located away from the Serpentine and Lower and Upper Murray rivers on the right (Figure 7a). While there was intermingling of points for the basin regions, each of the points for the three riverine regions formed a distinct group. The basin sites during summer were characterised by Tailor and Australian Herring and, to a lesser extent, Blowfish, Yelloweye Mullet and Yellow-finned Whiting.

Table 7. Fish species caught in the offshore waters of the Peel-Harvey (total number [Tot] and percentage contribution [%]) during summer 2020 and autumn 2021 combined. The habitat (Ha), Estuarine usage (EU) and feeding (Feed) guild of each species is provided. Species shaded in grey represented > 5 % to the total number of fish. D, Demersal; P, Pelagic; BP, Bentho-pelagic; SP, Small pelagic; SB, Small benthic; MS, Marine straggler; MEO, Marine estuarine-opportunist; SA, Semi-anadromous; ES, Estuarine species; F, Freshwater; ZB, Zoobenthivore; PV, Piscivore; ZP, Zooplanktivore; DV, Detritivore; OV, Omnivore; Op, Opportunist; HV, Herbivore.

						All	
Species	**Common name**	**Family**	**Ha**	**EU**	**Feed**	**Tot**	**%**
Nematalosa vlaminghi	Perth Herring	Clupeidae	BP	SA	DV	290	26.65
Arripis georgianus	Australian Herring	Arripidae	P	MEO	PV	178	16.36
Mugil cephalus	Sea Mullet	Mugilidae	P	MEO	DV	162	14.89
Pomatomus saltatrix	Tailor	Pomatomidae	P	MEO	PV	139	12.78
Myliobatis tenuicaudatus	Southern Eagle Ray	Myliobatidae	D	MS	ZB	61	5.61
Pelates octolineatus	Western Striped Grunter	Terapontidae	BP	MEO	OV	57	5.24
Amniataba caudavittata	Yellow-tail Trumpeter	Terapontidae	BP	ES	OP	50	4.60
Torquigener pleurogramma	Blowfish	Tetraodontidae	BP	MEO	OP	32	2.94
Acanthopagrus butcheri	Black Bream	Sparidae	BP	ES	OP	24	2.21
Sillago schomburgkii	Yellow-finned Whiting	Sillaginidae	D	MEO	ZB	22	2.02
Rhabdosargus sarba	Tarwhine	Sparidae	BP	MEO	ZB	21	1.93
Gerres subfasciatus	Roach	Gerreidae	BP	MEO	ZB	17	1.56
Aldrichetta forsteri	Yellow-eye Mullet	Mugilidae	P	MEO	OV	9	0.83
Cnidoglanis macrocephalus	Estuarine Cobbler	Plotosidae	D	MEO	ZB	7	0.64
Sillaginodes punctatus	King George Whiting	Sillaginidae	D	MEO	ZB	7	0.64
Pseudocaranx wrightii	Sand Trevally	Carangidae	BP	MEO	ZB	3	0.28
Bathytoshia brevicaudata	Smooth Stingray	Dasyatidae	D	MS	ZB	2	0.18
Hyporhamphus melanochir	Southern Sea Garfish	Hemiramphidae	P	ES	HV	2	0.18
Sillago burrus	Western Trumpeter Whiting	Sillaginidae	D	MEO	ZB	2	0.18
Chrysophrys auratus	Snapper	Sparidae	BP	MEO	ZB	2	0.18
Pseudorhombus jenynsii	Small-toothed Flounder	Paralichthyidae	D	MEO	ZB	1	0.09
					Number of samples	42	
					Number of species	21	
					Average catch rate (h^{-1})	25.90	
					Total number of fish	1,088	

Table 8. Compositions of the fish communities (# = average catch rate fish/h[1] and % = percentage composition) observed across the three offshore sites sampled in each region of the Peel-Harvey Estuary summer 2020 and autumn 2021 combined. Species ordered by overall abundance and those shaded in grey represented > 5% to the total number of fish in any region. MC, Mandurah Channel; EP, Eastern Peel; WP, Western Peel; NH, Northern Harvey; SH, Southern Harvey; SP, Serpentine River; LM, Lower Murray River and UM, Upper Murray River.

	EP		WP		NH		SH		SP		LM		UM	
Species	#	%	#	%	#	%	#	%	#	%	#	%	#	%
Perth Herring	0.50	2.38	2.67	7.80	0.33	1.32	0.33	4.76	7.00	62.69	21.17	72.99	16.33	30.43
Australian Herring	6.67	31.75	13.00	38.05	9.33	36.84	0.67	9.52						
Sea Mullet									0.17	1.49	0.50	1.72	26.33	49.07
Tailor	5.33	25.40	6.50	19.02	4.50	17.76	2.50	35.71	1.17	10.45	3.17	10.92		
Southern Eagle Ray	0.50	2.38	7.67	22.44	1.17	4.61	0.83	11.90						
Western Striped Grunter	1.00	4.76	0.33	0.98	7.00	27.63			0.33	2.99	0.67	2.30	0.17	0.31
Yellow-tail Trumpeter													8.33	15.53
Blowfish	1.67	7.94	1.67	4.88	0.33	1.32	1.67	23.81						
Black Bream									0.17	1.49	1.33	4.60	2.50	4.66
Yellow-finned Whiting	2.67	12.70			0.17	0.66	0.17	2.38	0.67	5.97				
Tarwhine	0.33	1.59	0.50	1.46	0.50	1.97	0.17	2.38	0.67	5.97	1.33	4.60		
Roach	0.67	3.17	0.17	0.49	0.17	0.66	0.17	2.38	0.83	7.46	0.83	2.87		
Yellow-eye Mullet	0.67	3.17	0.17	0.49	0.50	1.97			0.17	1.49				
Estuarine Cobbler	0.67	3.17	0.33	0.98			0.17	2.38						
King George Whiting			0.50	1.46	0.67	2.63								
Sand Trevally			0.33	0.98	0.17	0.66								
Smooth Stingray					0.17	0.66	0.17	2.38						
Southern Sea Garfish			0.33	0.98										
Western Trumpeter Whiting	0.17	0.79					0.17	2.38						
Snapper					0.33	1.32								
Small-toothed Flounder	0.17	0.79												
Number of samples	6		6		6		6		6		6		6	
Number of species	13		13		14		11		9		7		5	
Average catch rate (h^{-1})	3.50		5.69		4.22		1.17		1.86		4.83		8.94	
Total number of fish	126		205		152		42		67		174		322	

The fish community remained different among the regions in autumn 2021 (P = 0.001; Global R = 0.317; Table 10; Figure 8a) although the extent of the differences were far less than in summer . Generally speaking, during autumn the regions formed three groups i) basin sites which were characterised by Australian Herring and Tailor, ii) the Serpentine River and Lower Murray River, dominated by Perth Herring and iii) the Upper Murray that contained only Sea Mullet.

Table 9. Pairwise *R*-statistic values derived from a one-way ANOSIM test on the composition of the offshore fish fauna among regions in summer 2020. Pairwise comparisons that are not significantly different shaded in grey. Full region names given in Figure 2 and Table 8.

	EP	WP	NH	SH	SP	LM
WP	0.815					
NH	0.259	-0.037				
SH	0.852	0.185	0.333			
SP	0.889	1.000	0.778	0.778		
LM	1.000	1.000	1.000	0.556	1.000	
UM	1.000	1.000	1.000	1.000	0.963	0.778

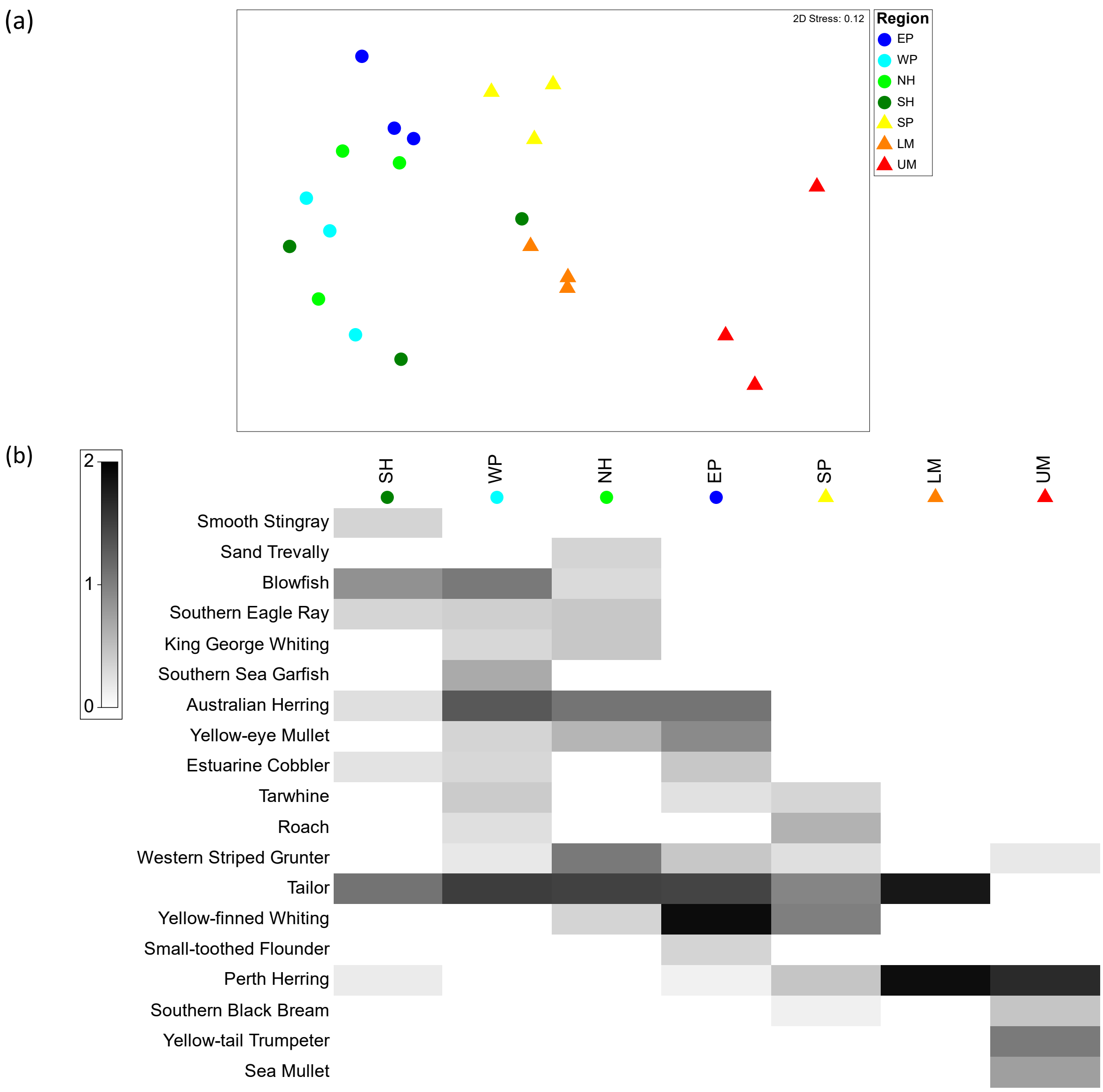


Figure 7. (a) nMDs plot of the offshore fish community at each site in the Peel-Harvey estuary in summer 2020. (b) Shade plot of the transformed catch rate of each species in each region.

Table 10. Pairwise *R*-statistic values derived from a one-way ANOSIM test on the composition of the offshore fish fauna among regions in autumn 2021. Pairwise comparisons that are not significantly different shade in grey. Full region names given in Figure 2 and Table 4.

	EP	WP	NH	SH	SP	LM
WP	0.000					
NH	0.185	0.444				
SH	0.000	0.593	0.444			
SP	0.222	0.444	0.370	0.111		
LM	0.407	0.667	0.500	0.444	-0.204	
UM	0.556	0.556	0.556	0.600	-0.086	0.156

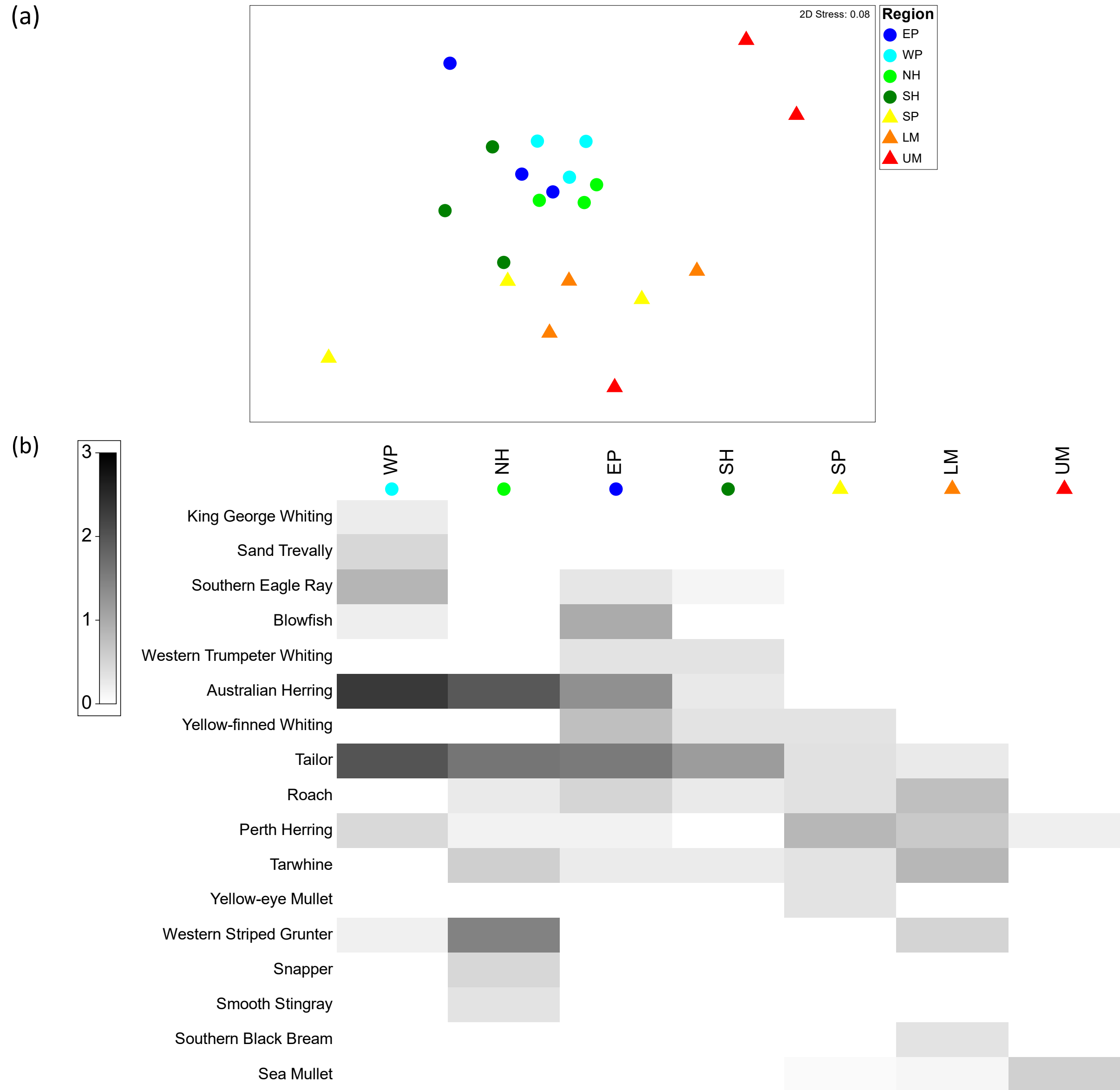


Figure 8. (a) nMDs plot of the offshore fish community at each site in the Peel-Harvey estuary in autumn 2021. (b) Shade plot of the transformed catch rate of each species in each region. Full region names given in Figure 2 and Table 8.

3.3 Ecological condition

Nearshore waters

The ecological condition, based on fish communities, of the nearshore waters of the Peel-Harvey Estuary was poor/fair (D/C) in summer and improved to fair (C) in autumn (Figure 9a). The condition of each zone varied substantially during summer (mean FCI scores 46–75), being lowest in the Mandurah Channel (E/D; very poor/poor), slightly better in Eastern and Western Peel, the Serpentine River and Lower Murray (all D; poor), increasing to fair (C) in the Northern and Southern Harvey and best in the Upper Murray (B; good). In autumn grades in each nearshore region generally either remained the same or improved with the exception of the Upper Murray, which declined to fair condition from good (Figure 9).

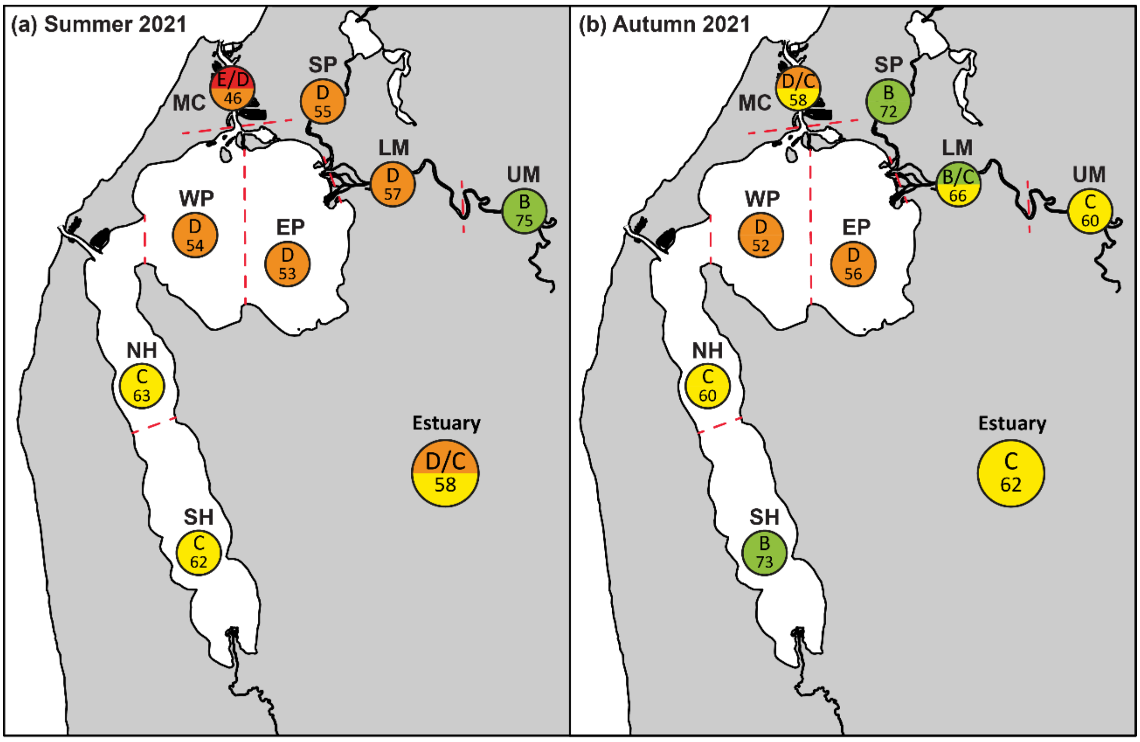
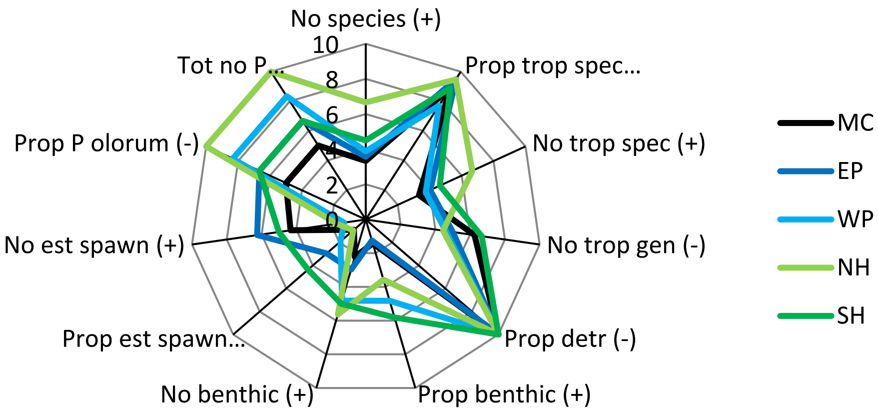


Figure 9. Average nearshore Fish Community Index scores and resulting condition grades (A, very good; B, good; C, fair; D, poor; E, very poor) for each zone of the Peel-Harvey Estuary, and for the estuary as a whole, in summer and autumn of 2021. Full region names given in Figure 2 and Table 4.

Radar plots of the nearshore metric scores for each zone in each season (Figure 10) revealed that the Mandurah Channel, which had the lowest grade (E/D; very poor/poor), scored badly in the several positive metrics, *i.e. Number of species*, *Number of trophic specialist species*, *Number of benthic-associated species*, *Number of estuarine-spawning species,* the *Proportion of estuarine-spawning individuals* and the *Proportion of benthic associated individuals.* The Mandurah Channel scored highly in the *Proportion of detritivores* (a negative metric) and the *Proportion of trophic specialists*, which was due to very large catches of Whitebait, a species that is adapted to feed on zooplankton and so lowering the proportion of generalist feeders, such as the Blowfish (Potter et al., 1988; Goh, 1992). Both the Eastern and Western Peel received a similar score (D; poor), due to low *Number of species, Number of trophic specialist species* and *Proportion of estuarine-spawning individuals,* suggesting that environment in summer was not suitable for estuarine species. Low *Total numbers* and *Proportion* of the Blue Spot Goby (*P. olorum*) and, in turn a low *Proportion of detritivores* and high *Proportion of trophic specialists* caused the two regions in the Harvey Estuary to be classified as in fair condition. The good condition in the nearshore waters of the Upper Murray, was due to high scores in all metrics except *Proportion of estuarine-spawning individuals* and *Proportion of benthic associated individuals,* which reflects the low abundance of the Blue Spot Goby (whose counts contribute to several negative metrics) and the high abundances of the marine-spawning trophic specialist Whitebait (Table 4).

(a) Basin regions summer 2021



(b) Riverine regions summer 2021

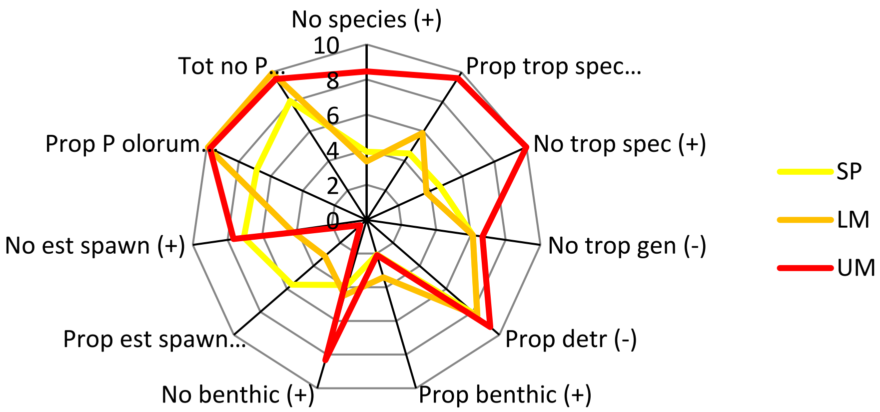
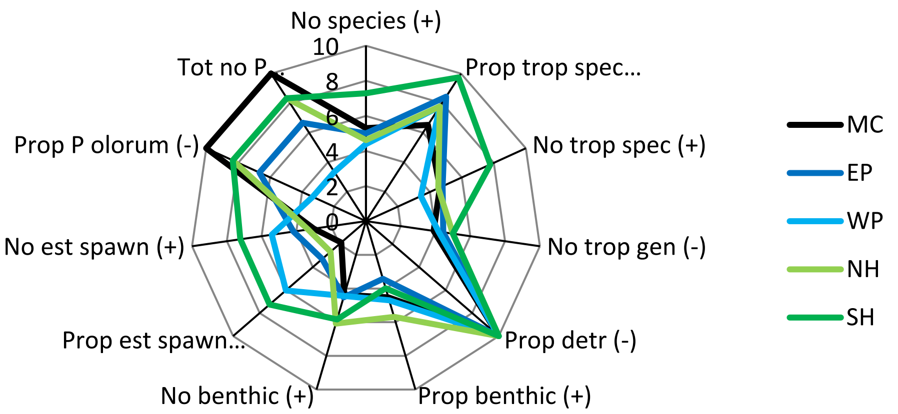


Figure 10. Average scores (0–10) for each component metric of the nearshore Fish Community Index, calculated from samples collected throughout each zone in the (a) basins and (b) rivers in summer 2020. Note that an increase in the score for positive metrics (+) reflects an increase in the underlying variable, whereas an increase in the score for negative metrics (-) reflects a decrease in the underlying variable. Therefore, the larger the area covered by the radar plot the better the condition in that zone. Full metric names and explanations are given in Table 1. Full region names given in Figure 2 and Table 4.

The higher scores in the basin regions in nearshore waters in autumn were due to increases in the *Number of species, Number of benthic-associated species* and *Number and Proportion of estuarine-spawners* (Figure 11). Increases in the *Number and Proportion of trophic specialists*, which would also raise the *Number of species* were driven by greater abundances of small pelagic zoobenthic and zooplanktivorous species such as Hardyheads, Whitebait and Blue Sprat, leading to far higher scores in the Serpentine and Lower Murray in autumn rather than summer. The decline in score for the nearshore waters of the Upper Murray was, in part, due to reductions in the *Number of species,* particularly *benthic-associated species* and greater *Numbers and Proportion of P. olorum* (negative metric)*,* which as a detritivore (Gill and Potter, 1993), decreased the *Proportion of trophic specialists.* This species, which occurs in the upper reaches of estuaries (Hogan-West et al., 2019) is known to be tolerant of the low oxygen levels, which typify the deeper waters of this region (Gee and Gee, 1991).

(a) Basin regions autumn 2021



(b) Riverine regions autumn 2021

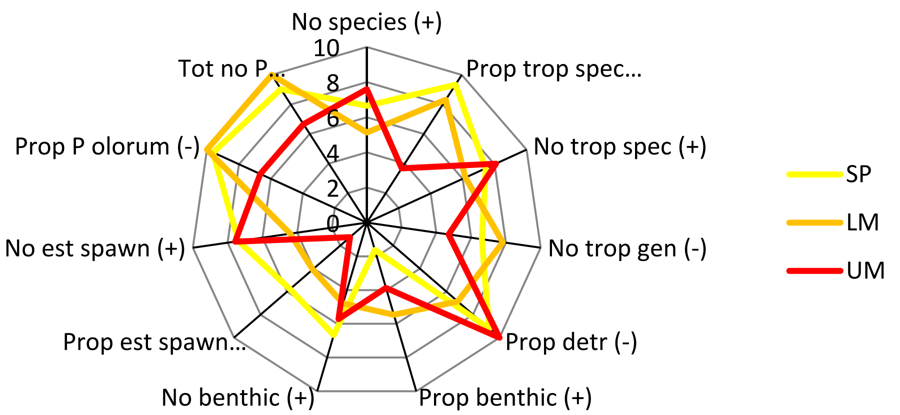


Figure 11. Average scores (0–10) for each component metric of the nearshore Fish Community Index, calculated from samples collected throughout each zone in the (a) basins and (b) rivers in autumn 2021. Note that an increase in the score for positive metrics (+) reflects an increase in the underlying variable, whereas an increase in the score for negative metrics (-) reflects a decrease in the underlying variable. Therefore, the larger the area covered by the radar plot the better the condition in that zone. Full metric names and explanations are given in Table 1. Full region names given in Figure 2 and Table 4.

Offshore waters

The ecological condition of the offshore waters of the Peel-Harvey Estuary was good (B) during summer 2020, but declined to fair (C) in autumn (Figure 12), the opposite trend to the nearshore waters. In summer, all regions were in good (B) condition except the Eastern Peel, Southern Harvey and Upper Murray, which were fair (C) or fair/poor (C/D). During autumn, the condition of the Southern Harvey improved to very good/good (A/B) and the Western Peel remained good (B), but all other regions declined most notably the Serpentine (B to C/D) and Upper Murray (C/D to E).

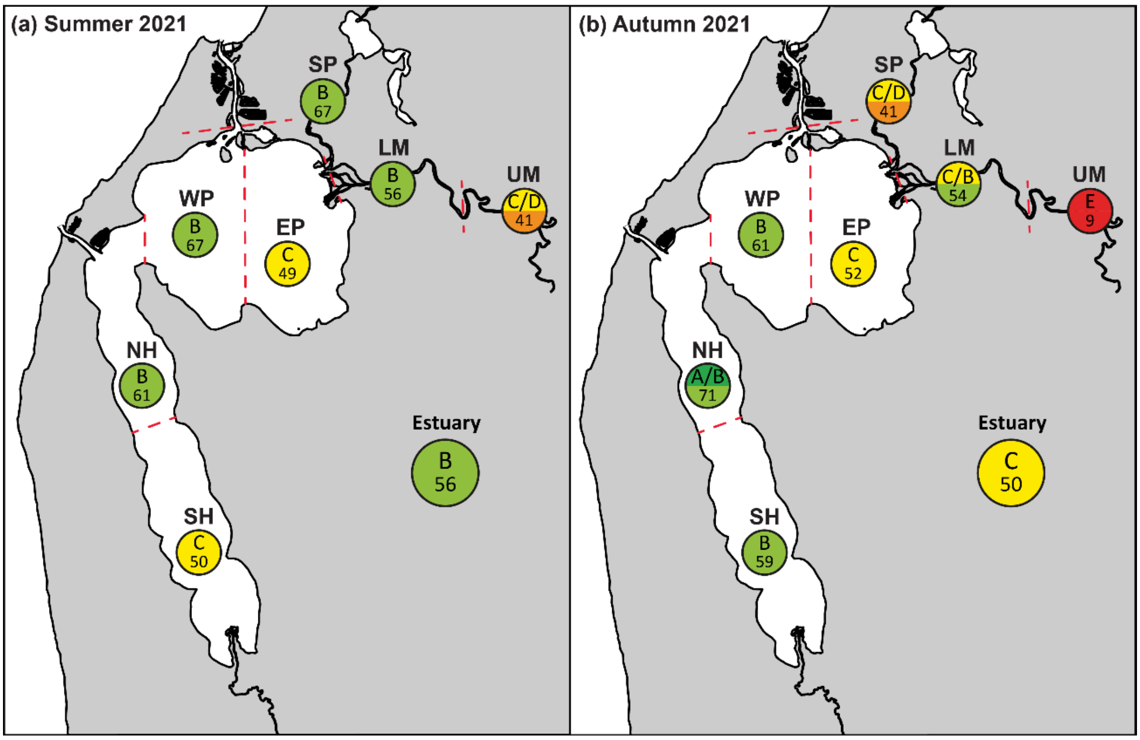
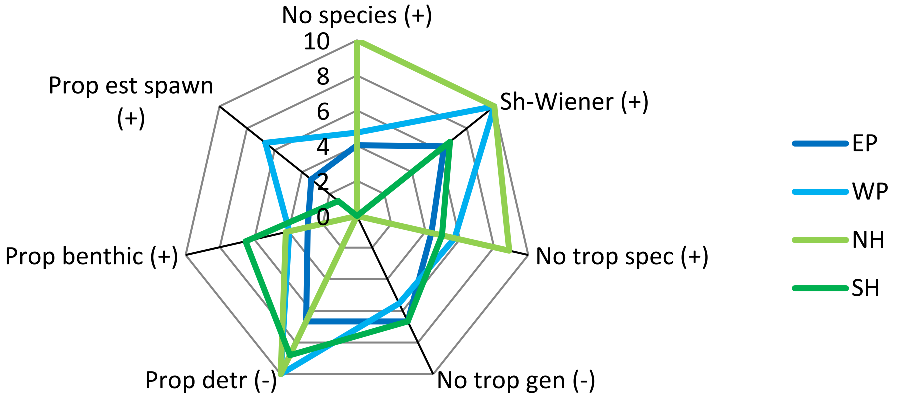


Figure 12. Average offshore Fish Community Index scores and resulting condition grades (A, very good; B, good; C, fair; D, poor; E, very poor) for each zone of the Peel-Harvey Estuary, and for the estuary as a whole, in summer and autumn of 2020/21. Full region names given in Figure 2 and Table 8.

Radar plots of offshore metric scores for the regions in the basin (Figure 13a) showed that the good offshore FCI scores in summer were due to a relatively high *Number of species*, *Shannon-Wiener diversity*, and the *Number of trophic specialist species* (all positive metrics) and the *Proportion of detritivores* (negative metric). The scores would be higher if not for the fact that many of these species, particularly those in the Northern and Southern Harvey had marine origins and so could not spawn in estuaries (Potter et al., 2015a) *e.g.* Australian Herring and Tailor, hence the low score for *Proportion of estuarine-spawning individuals.* The lower condition of the Eastern Peel (C) compared to the other basin regions was due to lower scores for the *Number of species* and *Shannon-Wiener diversity*. This region has often scored slightly lower than the Western Peel and Northern Harvey due to its position further away from the entrance channels and so lower richness of marine taxa (Hallett et al., 2019a).

Among the riverine regions, the *Proportion of estuarine spawning* and *Benthic-associated individuals* was high and *Number of trophic generalists* (negative metric) low (Figure 13b) resulting in a good (B) score for the Lower Murray. Although the *Number of species* was fairly low in the Serpentine River, *Shannon-Wiener diversity* was very high and together with a large *Proportion of benthic-associated individuals* and low *Proportion of detritivores* resulted in a good score. Values for all metrics, and especially the *Number of trophic specialist species* were typically lowest in the Upper Murray. Catches in this region were species-poor and comprised mainly Sea Mullet, a detritivore, and Black Bream and Yellow-tail Trumpeter, which are opportunist feeders and thus trophic generalists.

(a) Basin regions summer 2021



(b) Riverine regions summer 2021

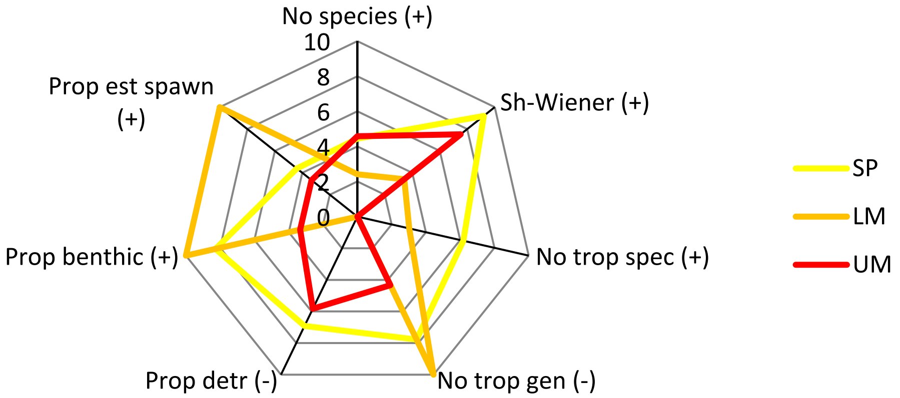
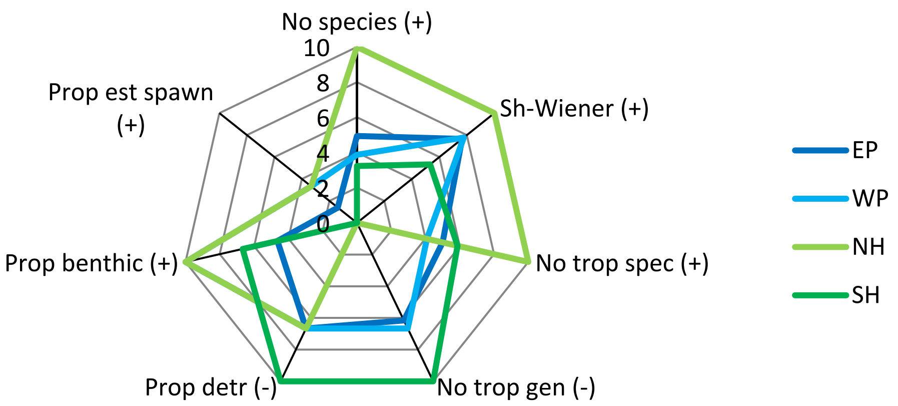


Figure 13. Average scores (0–10) for each component metric of the offshore Fish Community Index, calculated from samples collected throughout each zone in the (a) basins and (b) rivers in summer 2020. Note that an increase in the score for positive metrics (+) reflects an increase in the underlying variable, whereas an increase in the score for negative metrics (-) reflects a decrease in the underlying variable. Therefore, the larger the area covered by the radar plot the better the condition in that zone. Full metric names and explanations are given in Table 1. Full region names given in Figure 2 and Table 4. Full region names given in Figure 2 and Table 8.

Patterns among metrics were fairly similar for the offshore waters of the basin regions in autumn, although the improvement in scores for the *Number of trophic generalist species* (negative metric) led to the Northern Harvey receiving a grade of very good/ good (A/B). The biggest shift in the offshore waters in autumn was in the Upper Murray, which scored very poorly in every metric (Figure 14b). This was undoubtably the result of two of the three gill net samples containing no fish and the remaining net only yielding Sea Mullet and Perth Herring, both of which are detritivores. This region at the time of sampling was heavily stratified with the bottom waters having a salinity of 25 ppt greater than at the surface. Under conditions like this, high levels of organic matter in this region increase the biological consumption of oxygen from the bottom waters which cannot be replenished due to the stratification causing the hypoxic conditions. Hypoxia is known to cause fish kills in south-western Australian estuaries (Beatty et al., 2018; Warwick et al., 2018), including in the Upper Murray after a major flow event in summer 2017 (Hallett et al., 2019a). During development and testing of the Peel-Harvey Fish Community Index by Hallett et al. (2019a) the condition of this region was rated as poor (D) in six of the eight seasons and never scored better than fair (C). Thus, this area is considered to suffer from chronic stress and its ecological health to be under ongoing threat.

(a) Basin regions autumn 2021



(b) Riverine regions autumn 2021

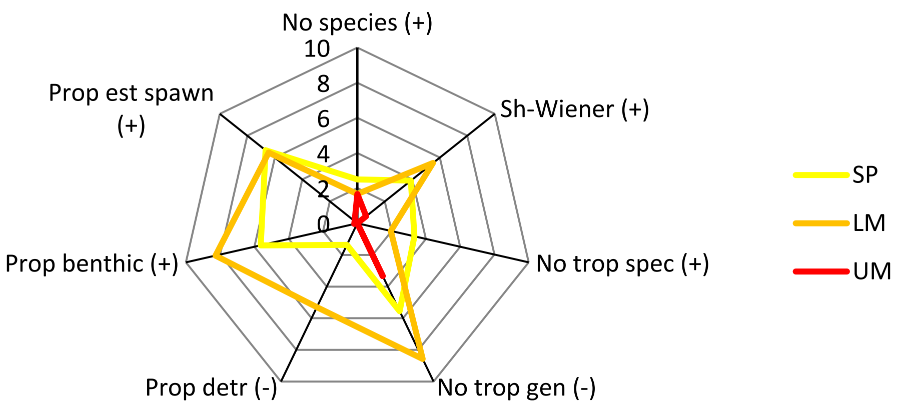


Figure 14. Average scores (0–10) for each component metric of the offshore Fish Community Index, calculated from samples collected throughout each zone in the (a) basins and (b) rivers in autumn 2021. Note that an increase in the score for positive metrics (+) reflects an increase in the underlying variable, whereas an increase in the score for negative metrics (-) reflects a decrease in the underlying variable. Therefore, the larger the area covered by the radar plot the better the condition in that zone. Full metric names and explanations are given in Table 1. Full region names given in Figure 2 and Table 4. Full region names given in Figure 2 and Table 8.

Scores in the other two riverine regions also declined. In the Lower Murray this was due to lower *Proportions of estuarine-spawning individuals* and *Benthic-associated individuals* and the *Number of trophic specialist species,* caused, in part, from the dominance of Perth Herring and lack of benthic species which could be caused by the low (but not hypoxic) oxygen levels present in this region (*i.e.* ~ 4 mg/L). The lower scores in the Serpentine River are likely to have been influenced by the 'zerocatch' in one of the three samples. Typically, such catches reflect hypoxic conditions as fish move to more oxygenated areas, however, on this occasion no hypoxia was detected.

Longer term trends in ecological condition

Results indicate that the nearshore waters of the Peel-Harvey Estuary as a whole were in fair (C) condition during 2020/21, consistent with the overall trend in summer and autumn since 2016 (Figure 15) and consistent with the gradual improvement since the 1970s (Hallett et al., 2019a). The mean score for the riverine regions (*i.e.* Serpentine, Lower Murray and Upper Murray) were graded higher than that for the basin regions (*i.e.* Mandurah Channel, Eastern Peel, Western Peel, Northern Harvey and Southern Harvey) in both seasons in 2020/21 and the scores in autumn were greater than in summer. Scores (and grades) were more consistent in 2020/21 than in previous years, although those in the riverine regions were lower than in autumn 2017 and summer 2018. This consistency could be related to the more stable water quality conditions due to the reductions on freshwater flow due to climate change (Hallett et al., 2018; Huang et al., 2020) and the absence of blooms of the toxic blue-green alga *Nodularia spumigena,* which upon their death led to deoxygenation of the water column and fish kills (Potter et al., 1983; Potter et al., 2015b).

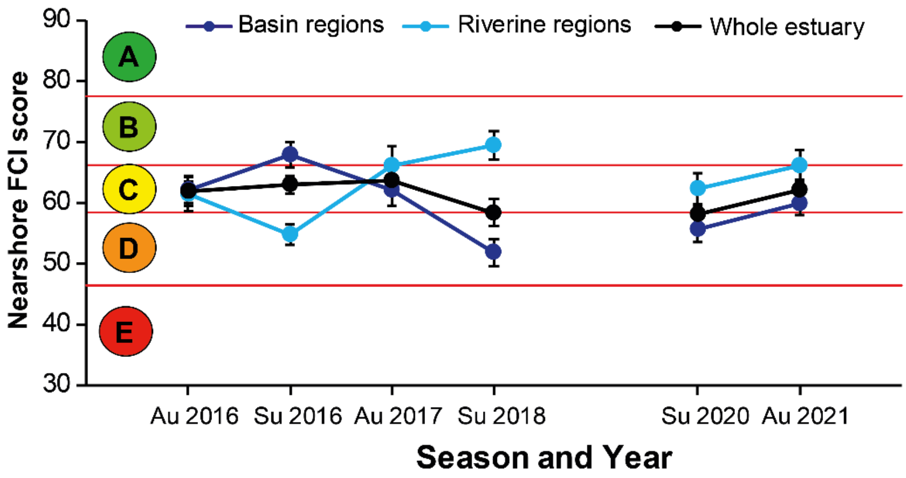


Figure 15. Trend plot of mean (±SE) nearshore Fish Community Index (FCI) scores and resulting condition grades (A, very good; B, good; C, fair; D, poor; E, very poor) for basin and riverine regions and the Peel-Harvey Estuary as a whole, in summer and autumn seasons in recent years. Red lines denote boundaries between condition grades. Data from 2016-2018 taken from Hallett et al. (2019a).

The mean offshore FCI score for the estuary during 2020/21as a whole was fair (C), with the scores in summer 2020 being higher than in the summer and autumn seasons sampled in 2016-18 (Figure 16). Among broad areas, the scores in the basin regions in 2020/21 were amongst the highest recorded recently (2016-18), as where the riverine regions in summer, however, scores declined markedly from good/fair (B/C) to poor (D) in autumn. This reflects the low oxygen conditions present throughout the Murray river in autumn and the likely movement of many species away from these deeper waters to more oxygen-rich areas. The values from 2020/21 are, however, lower than scores from the 1970s and 1980s, caused by the decline in the number and proportion of benthic-dwelling species and/or those than spawn in estuaries (Hallett et al., 2019a).

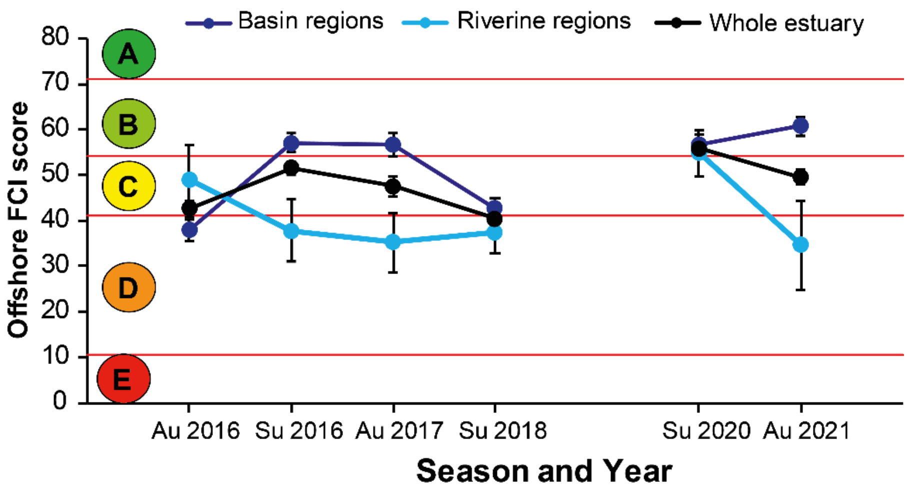


Figure 16. Trend plot of mean (±SE) offshore Fish Community Index (FCI) scores and resulting condition grades (A, very good; B, good; C, fair; D, poor; E, very poor) for the basin and riverine regions and the Peel-Harvey Estuary as a whole, in summer and autumn seasons in recent years. Red lines denote boundaries between condition grades. Data from 2016-2018 taken from Hallett et al. (2019a).

4. Summary

Using a range of historical fish data (1970s onwards) from sites throughout the Peel-Harvey Estuary, the Fish Community Index (FCI) considers the fish community as a whole and provides a means to assess how the structure and function of these communities in shallow, nearshore (< 1 m deep) and deeper, offshore waters (> 1 m deep) respond to a wide array of stressors affecting the ecosystem and how these change over time. Note that the FCI does not provide information on the population dynamics or health of particular species (in comparison to *e.g.* Cottingham et al., 2014; Crisp et al., 2018), nor does it provide information on the size or status of the fish stocks in the estuary (*e.g.* Smith and Lenanton, 2021).

Across the estuary as a whole, the ecological condition of both nearshore and offshore waters in 2020/21 was assessed as fair (C), based on their fish communities (Table 11). In the case of the nearshore waters these are consistent with the relatively stable trends in condition reported between 2016 and 2018 and represent an increase over those recorded in the 1970s and 1980s due to the absence of the blue-green alga *Nodularia spumigena* since the construction of the Dawesville Cut. Due to its high salinities, proximity to the ocean and well-flushed natures, the Mandurah Channel region could be expected to be in good condition, however, it was rated as very poor/poor (E/D) in summer and poor-fair in autumn, which is consistent with the earlier work (2016-18) by Hallett et al. (2019a). It seems that the Mandurah Channel currently supports a far less diverse group of species and not those that are benthic and/or breed in estuaries. We recommend that this area, in particular, should be monitored in the future.

Overall, the offshore waters were in slightly better condition in 2020/21 than between 2016 and 2018, however, the Upper Murray region was rated as very poor in autumn, mirroring results in recent years. High levels of organic matter and stratification are likely major drivers leading to low oxygen conditions in bottom water and consistently poor FCI scores. This region seems to be more susceptible than the Serpentine to those conditions due to its deeper holes. Furthermore, predictions in the future suggest that hypoxic conditions will become more prevalent in the future due to declining freshwater flow (Huang et al., 2019; 2020). Thus, this region appears to be chronically-stressed and its ecological health is under significant threat and should be monitored regularly.

Table 11. Fish Community Index (FCI) scores and corresponding ecological condition grades for each zone of the estuary, and the estuary as a whole, during the 2020/21 monitoring period (mean of all summer and autumn of 2020).

	Nearshore		**Offshore**	
	Mean FCI score	*Condition*	*Mean FCI score*	*Condition*
Mandurah Channel	52.18	D		
Eastern Peel	54.66	D	50.51	C
Western Peel	52.91	D	63.57	B
Northern Harvey	61.56	C	66.46	B
Southern Harvey	67.71	B	54.41	B/C
Serpentine River	63.79	C	54.40	B/C
Lower Murray River	61.68	C	54.71	B/C
Upper Murray River	67.18	B/C	24.96	D
Estuary	**60.21**	**C**	**52.72**	**C**

5. Recommendations

From the evidence presented in this report and the earlier work by Hallett et al. (2019a) it is clear that the ecological health of the Peel-Harvey is under considerable stress and it is imperative that a consistent and regular fish monitoring program (*e.g.* the Fish Community Index) is continued to assess its health into the future. The regions of particular concern and should be a priority are the nearshore waters of the Mandurah Channel and deeper offshore waters of the Lower and Upper Murray. If implemented, such a monitoring program, like that which has been running on the Swan-Canning Estuary since 2012 (Department of Biodiversity Conservation and Attractions, 2022), would have the ability to detect short term changes, due to, for example, unseasonal heavy rainfall (such as in summer 2017), and longer-term effects from implementation of management actions in the catchment and estuary, such as those initiatives to reduce nutrient input, decrease the extent and magnitude of stratification and hypoxia and restock key fish species *e.g.* Black Bream.

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7. Appendices

<u>Appendix (i).</u> Descriptions of (a) nearshore and (b) offshore Fish Community Index monitoring sites. MC, Mandurah Entrance Channel; WP Western Peel Inlet; EP, Eastern Peel Inlet; SP, Serpentine River; NH, Northern Harvey Inlet; SH, Southern Harvey Inlet; LM, Lower Murray River; UM, Upper Murray River.

Zone	Site Code	Lat-Long (S, E)	Description
(a) - *Nearshore*			
MC	MC1	32°31'28.2"S 115°43'10.2"E	Keith Holmes Reserve inside Mandurah Marine
	MC2	32°31'48.1"S 115°42'47.3"E	Henry Sutton Grove
	MC3	32°32'19.6"S 115°43'10.2"E	Inside Samphire Point
	MC4	32°32'37.5"S 115°43'02.9"E	500m down from bridge on Samphire Cove Reserve
	MC5	32°32'50.3"S 115°43'08.9"E	Northern side of Mandurah Estuary Bridge (Waterside Drive)
	MC6	32°33'22.9"S 115°43'12.3"E	Inside channel on Creery Wetland nature reserve
WP	WP1	32°34'01.6"S 115°42'17.0"E	On sand bar at Sticks Channel
	WP2	32°34'25.6"S 115°40'53.0"E	200m out off Novara Foreshore Reserve
	WP3	32°34'30.9"S 115°40'26.5"E	200m out off Novara Beach Reserve
	WP4	32°35'37.9"S 115°40'26.6"E	Ward point
	WP5	32°37'31.4"S 115°41'11.8"E	Point Grey NW end
	WP6	32°37'37.2"S 115°43'02.5"E	In between Point Grey and Nirimba Cay
EP	EP1	32°37'20.3"S 115°43'59.4"E	West end of Austin Bay
	EP2	32°37'26.8"S 115°45'22.9"E	East end of Austin Bay
	EP3	32°35'59.7"S 115°46'04.6"E	North Austin Bay Nature Reserve
	EP4	32°35'34.0"S 115°45'02.6"E	Boodalan Island
	EP5	32°35'01.5"S 115°45'49.1"E	300m out off Worallgarook
	EP6	32°34'05.8"S 115°43'57.1"E	Creery Island
SP	SP1	32°33'57.8"S 115°45'54.7"E	Furnissdale Rd and Riversode Dr
	SP2	32°33'40.1"S 115°45'20.1"E	Beach near salt flat off Macquarie Dr
	SP3	32°33'08.4"S 115°45'38.9"E	Beach on river bank in Furnissdale
	SP4	32°32'29.5"S 115°46'10.0"E	Beach on river bend on Joseph and Dulcie Nannup Trail
	SP5	32°32'18.9"S 115°46'27.5"E	River bank across from mud flat off Redcliffe Rd and Carnegie Pl
	SP6	32°31'41.0"S 115°46'44.0"E	Bank before Goegrup Lake
NH	NH1	32°36'19.8"S 115°39'17.5"E	Liptons -Windurfing
	NH2	32°37'34.7"S 115°38'30.4"E	Dawesville Boatramp
	NH3	32°37'38.7"S 115°40'04.6"E	Otherside of Estuary from Dawesville Boat Ramp
	NH4	32°38'45.7"S 115°40'27.8"E	West side of Point Grey and South 1km
	NH5	32°39'54.2"S 115°39'17.7"E	Park Ridge Boat Ramp
	NH6	32°39'54.8"S 115°41'05.0"E	Otherside of estuary from Park Ridge Boat Ramp
SH	SH1	32°41'07.0"S 115°41'01.3"E	Mealup Point Nature Reserve
	SH2	32°41'49.8"S 115°40'09.2"E	Crescent Dr
	SH3	32°42'42.8"S 115°41'56.4"E	Lake Mclarty Nature Reserve
	SH4	32°43'51.8"S 115°40'54.8"E	Wattsies Place
	SH5	32°44'27.2"S 115°42'33.7"E	Herron Point
	SH6	32°45'04.1"S 115°41'38.5"E	Island Point Reserve
LM	LM1	32°34'56.3"S 115°46'58.2"E	Down river from Pelicans on the Murray Café
	LM2	32°34'37.5"S 115°48'33.4"E	Other side of river from Jettys Bar and Grill
	LM3	32°34'40.3"S 115°48'36.2"E	Jettys Bar and Grill
	LM4	32°34'21.1"S 115°48'56.6"E	Forrest Highway Bridge
	LM5	32°35'41.1"S 115°49'50.3"E	Murray Bend by the House boat moorings
	LM6	32°35'41.1"S 115°49'50.3"E	Murray Bend by the House boat moorings (same as LM5 but on different day due to lack of suitable alternative sites in this part of the region.)
UM	UM1	32°35'39.9"S 115°51'09.0"E	from Western Greenery Nursery and Landscapes
	UM2	32°35'25.6"S 115°51'59.3"E	Creek from Lake Maelup
	UM3	32°35'48.1"S 115°52'06.8"E	River bank 400m up river from UM3
	UM4	32°36'48.4"S 115°52'07.0"E	Up river from Redcliffe on The Murray
	UM5	32°37'10.1"S 115°52'12.3"E	Wilson Rd
	UM6	32°37'28.9"S 115°52'28.8"E	Pinjarra (Henry Street) Boatramp

Zone	Site Code	Lat-Long (S, E)	Description
(b) - *Offshore*			
WP	WPG1	32°34'35.2"S 115°40'23.9"E	Novara Beach Reserve
	WPG2	32°34'31.0"S 115°41'03.4"E	Novara Foreshore Reserve
	WPG3	32°37'24.7"S 115°41'18.0"E	Robert Bay / Point Grey
EP	EPG1	32°34'49.6"S 115°43'28.6"E	West side of Creery Island
	EPG2	32°34'38.1"S 115°44'23.8"E	Coodanup
	EPG3	32°37'07.9"S 115°44'04.4"E	Austin Bay
SP	SPG1	32°33'23.2"S 115°45'19.4"E	Riverview Foreshore Boat ramp
	SPG2	32°33'03.5"S 115°45'45.5"E	Furnissdale
	SPG3	32°31'44.8"S 115°46'38.3"E	Just before Geogrup Lake
NH	NHG1	32°37'38.5"S 115°39'55.3"E	West side of Point Grey
	NHG2	32°38'30.8"S 115°39'00.2"E	Warrungup Spring Reserve
	NHG3	32°39'49.6"S 115°39'23.1"E	Point Morfitt
SH	SHG1	32°41'54.2"S 115°40'19.4"E	Crescent Dr
	SHG2	32°43'01.3"S 115°40'27.5"E	Estuary Hideaway Holiday Park
	SHG3	32°43'49.4"S 115°41'03.0"E	Wattsies Place
LM	LMG1	32°34'31.5"S 115°48'43.6"E	Up River from Jettys Bar and Grill
	LMG2	32°34'47.6"S 115°49'08.8"E	Pericho Cl
	LMG3	32°35'42.5"S 115°49'50.3"E	Murray Bend
UM	UMG1	32°36'04.6"S 115°52'35.2"E	Paterson Rd
	UMG2	32°36'17.9"S 115°52'18.3"E	Upriver from Redcliffe on The Murray
	UMG3	32°37'26.4"S 115°52'18.6"E	Down river from Pinjarra (Henry Street) Boat ramp

Appendix (ii). Descriptions of sampling and processing procedures.

Nearshore sampling methods

- On each sampling occasion, one replicate sample of the nearshore fish community is collected from each of the fixed, nearshore sampling sites.
- Sampling is not conducted during or within 3-5 days following any significant flow event.
- Nearshore fish samples are collected using a beach seine net that is 21.5 m long, comprises two 10 m-long wings (6 m of 9 mm mesh and 4 m of 3 mm mesh) and a 1.5 m-long bunt (3 mm mesh) and fishes to a depth of 1.5 m.
- This net is walked out from the beach to a maximum depth of approximately 1.5 m and deployed parallel to the shore, and is then rapidly dragged towards and onto the shore, so that it sweeps a roughly semicircular area of approximately 116 m^2.
- If a seine net deployment returns a catch of fewer than five fish, an additional sample is performed at the site (separated from the first sample by either 15 minutes or by 10-20 m distance). In the event that more than five fish are caught in the second sample, this second replicate is then used as the sample for that site and those fish from the first sample returned to the water alive. If, however, 0-5 fish are again caught, the original sample can be assumed to have been representative of the fish community present and be used as the sample for that site. The fish from the latter sample are then returned alive to the water. The above procedure thus helps to identify whether a collected sample is representative of the fish community present and enables instances of false negative catches to be identified and eliminated.
- Once an appropriate sample has been collected, any fish that may be readily identified to species (*e.g.* those larger species which are caught in relatively lower numbers) are counted and returned to the water alive.
- All other fish caught in the nets are placed into zip-lock polythene bags, euthanised in an ice slurry and preserved on ice in eskies in the field, except in cases where large catches (*e.g.* thousands) of small fish are obtained. In such cases, an appropriate sub-sample (*e.g.* one half to one eighth of the entire catch) is retained and the remaining fish are returned alive to the water. All retained fish are then bagged and frozen until their identification in the laboratory.

Offshore sampling methods

- On each sampling occasion, one replicate sample of the offshore fish community is collected from each of the fixed, offshore sampling sites.
- Sampling is not conducted within 3-5 days following any significant flow event.
- Offshore fish samples are collected using a sunken, multimesh gill net that consists of eight 20 m-long panels with stretched mesh sizes of 35, 51, 63, 76, 89, 102, 115 and 127 mm. These nets are deployed (*i.e.* laid parallel to the bank) from a boat immediately before sunset and retrieved after one hour.
- Given the time and labour associated with offshore sampling and the need to monitor the set nets for safety purposes, a maximum of three replicate net deployments is performed within a single zone in any one night. The three nets are deployed sequentially, and retrieved in the same order. Note sampling of the offshore waters of the Mandurah Channel region is excluded due to it considered unsafe given the extent and movements of boat traffic.
- During net retrieval (and, typically, when catch rates are sufficiently low to allow fish to be removed rapidly in the course of retrieval), any fishes that may be removed easily from the net are carefully

removed, identified, counted, recorded and returned to the water alive as the net is pulled into the boat.

- All other fish caught in the nets are removed once the net has been retrieved. Retained fish are placed into zip-lock polythene bags in an ice slurry, preserved on ice in eskies in the field, and subsequently frozen until their identification in the laboratory.

Following their identification to the lowest possible taxon in the field or laboratory by fish specialists trained in fish taxonomy, all assigned scientific and common names are checked and standardised by referencing the Checklist of Australian Aquatic Biota (CAAB) database (Rees *et al.* on-line version), and the appropriate CAAB species code is allocated to each species. The abundance data for each species in each sample is entered into a database for record and subsequent computation of the biotic indices.

Rees, A.J.J., Yearsley, G.K., Gowlett-Holmes, K. and Pogonoski, J. Codes for Australian Aquatic Biota (on-line version). CSIRO Marine and Atmospheric Research, World Wide Web electronic publication, 1999 onwards. Available at: http://www.cmar.csiro.au/caab/. Last accessed 24 April 2021.

Appendix (iii). List of species caught from the Peel-Harvey Estuary, and their functional guilds: D, Demersal; P, Pelagic; BP, Bentho-pelagic; SP, Small pelagic; SB, Small benthic; MS, Marine straggler; MEO, Marine estuarine-opportunist; SA, Semi-anadromous; ES, Estuarine species; F, Freshwater; ZB, Zoobenthivore; PV, Piscivore; ZP, Zooplanktivore; DV, Detritivore; OV, Omnivore; OP, Opportunist; HV, Herbivore. See Potter et al. (2015a); Whitfield et al. (2022) for descriptions of the guilds.

Species name	Common name	Family	Habitat Guild	Estuarine Use Guild	Feeding Guild
Bathytoshia brevicaudata	Smooth Stingray	Dasyatidae	D	MS	ZB
Myliobatis tenuicaudatus	Southern eagle ray	Myliobatidae	D	MS	ZB
Elops machnata	Giant herring	Elopidae	P	MS	PV
Sardinops sagax	Australian pilchard	Clupeidae	P	MS	ZP
Spratelloides robustus	Blue sprat	Clupeidae	SP	MEO	ZP
Hyperlophus vittatus	Whitebait / Sandy sprat	Clupeidae	SP	MEO	ZP
Nematalosa vlaminghi	Perth herring	Clupeidae	BP	SA	DV
Engraulis australis	Southern anchovy	Engraulidae	SP	ES	ZP
Galaxias maculatus	Common jollytail	Galaxiidae	BP	F	OV
Galaxias occidentalis	Western minnow	Galaxiidae	SB	F	ZB
Cnidoglanis macrocephalus	Estuarine cobbler	Plotosidae	D	MEO	ZB
Hyporhamphus melanochir	Southern sea garfish	Hemiramphidae	P	ES	HV
Hyporhamphus regularis	Western river garfish	Hemiramphidae	P	ES	HV
Gambusia holbrooki	Mosquito fish	Poeciliidae	SP	F	ZB
Leptatherina presbyteroides	Presbyter's hardyhead	Atherinidae	SP	MEO	ZP
Atherinomorus vaigiensis	Ogilby's hardyhead	Atherinidae	SP	MEO	ZB
Atherinosoma elongata	Elongate hardyhead	Atherinidae	SP	ES	ZB
Leptatherina wallacei	Wallace's hardyhead	Atherinidae	SP	ES	ZP
Craterocephalus mugiloides	Mugil's hardyhead	Atherinidae	SP	ES	ZB
Hippocampus angustus	Western spiny seahorse	Syngnathidae	D	MS	ZP
Urocampus carinirostris	Hairy pipefish	Syngnathidae	D	ES	ZP
Stigmatopora argus	Spotted pipefish	Syngnathidae	D	MS	ZP
Stigmatopora nigra	Wide-bodied pipefish	Syngnathidae	D	MS	ZB
Pugnaso curtirostris	Pugnose pipefish	Syngnathidae	D	MS	ZP
Filicampus tigris	Tiger pipefish	Syngnathidae	D	MS	ZP
Gymnapistes marmoratus	Devilfish	Tetrarogidae	D	MS	ZB
Leviprora inops	Long-head flathead	Platycephalidae	D	MS	PV
Platycephalus laevigatus	Rock flathead	Platycephalidae	D	MS	PV
Platycephalus westraliae	Yellowtail flathead	Platycephalidae	D	ES	PV
Platycephalus speculator	Southern blue-spotted flathead	Platycephalidae	D	ES	PV
Nannoperca vittata	Western pygmy perch	Percichthyidae	BP	F	ZB
Amniataba caudavittata	Yellow-tail trumpeter	Terapontidae	BP	ES	OP
Pelates octolineatus	Western striped grunter	Terapontidae	BP	MEO	OV
Siphamia cephalotes	Woods siphonfish	Apogonidae	BP	MS	ZB
Ostorhinchus rueppellii	Gobbleguts	Apogonidae	BP	ES	ZB
Perca fluviatilis	Redfin perch	Percidae	BP	F	PV
Sillaginodes punctatus	King George whiting	Sillaginidae	D	MEO	ZB
Sillago bassensis	Southern school whiting	Sillaginidae	D	MS	ZB
Sillago burrus	Western trumpeter whiting	Sillaginidae	D	MEO	ZB
Sillago schomburgkii	Yellow-finned whiting	Sillaginidae	D	MEO	ZB
Sillago vittata	Western school whiting	Sillaginidae	D	MEO	ZB
Pomatomus saltatrix	Tailor	Pomatomidae	P	MEO	PV
Trachurus novaezelandiae	Yellowtail scad	Carangidae	P	MS	ZB
Pseudocaranx georgianus	Silver trevally	Carangidae	BP	MEO	ZB
Pseudocaranx wrighti	Sand trevally	Carangidae	BP	MEO	ZB
Arripis georgianus	Australian herring / Tommy rough	Arripidae	P	MEO	PV
Arripis truttaceus	Southern Australian salmon	Arripidae	P	MS	PV
Gerres subfasciatus	Roach	Gerreidae	BP	MEO	ZB
Chrysophrys auratus	Snapper	Sparidae	BP	MEO	ZB
Acanthopagrus butcheri	Black bream	Sparidae	BP	ES	OP
Rhabdosargus sarba	Tarwhine	Sparidae	BP	MEO	ZB
Argyrosomus japonicus	Mulloway	Sciaenidae	BP	MEO	PV

Species name	Common name	Family	Habitat	Estuarine Use	Feeding Mode
Upeneus tragula	Bartail goatfish	Mullidae	D	MS	ZB
Parupeneus spilurus	Black-saddled goatfish	Mullidae	D	MS	ZB
Upeneichthys vlamingii	Bluespotted goatfish	Mullidae	D	MS	ZB
Kyphosus sydneyanus	Silver drummer	Kyphosidae	BP	MEO	HV
Microcanthus strigatus	Stripey	Scorpididae	BP	MS	ZB
Girella tricuspidata	Luderick	Kyphosidae	BP	MS	ZP
Enoplosus armatus	Old wife	Enoplosidae	D	MS	ZB
Aldrichetta forsteri	Yellow-eye mullet	Mugilidae	P	MEO	OV
Mugil cephalus	Sea mullet	Mugilidae	P	MEO	DV
Sphyraena obtusata	Striped barracuda	Sphyraenidae	P	MS	PV
Dotalabrus aurantiacus	Castelnau's Wrasse	Labridae	D	MS	ZB
Notolabrus parilus	Brownspotted wrasse	Labridae	D	MS	ZB
Halichoeres brownfieldi	Brownfield's wrasse	Labridae	D	MS	ZB
Neoodax balteatus	Little weed whiting	Odacidae	D	MS	OV
Siphonognathus radiatus	Long-rayed weed whiting	Odacidae	D	MS	OV
Haletta semifasciata	Blue weed whiting	Odacidae	D	MS	OV
Parapercis haackei	Wavy grubfish	Pinguipedidae	D	MS	ZB
Lesueurina platycephala	Flathead sandfish	Leptoscopidae	D	MS	ZB
Omobranchus germaini	Germain's blenny	Blenniidae	SB	MS	ZB
Parablennius intermedius	Horned blenny	Blenniidae	D	MS	ZB
Petroscirtes breviceps	Short-head sabre blenny	Blenniidae	SB	MS	OV
Trinorfolkia incisa	Notched threefin	Tripterygiidae	SB	MS	ZB
Cristiceps australis	Southern crested weedfish	Clinidae	D	MS	ZB
Callogobius mucosus	Sculptured goby	Gobiidae	SB	MS	ZB
Favonigobius lateralis	Long-finned goby	Gobiidae	SB	MEO	ZB
Arenigobius bifrenatus	Bridled goby	Gobiidae	SB	ES	ZB
Pseudogobius olorum	Blue-spot / Swan River goby	Gobiidae	SB	ES	OV
Bathygobius fuscus	Dusky Frillgoby	Gobiidae	SB	MEO	ZB
Callogobius depressus	Flathead goby	Gobiidae	SB	MS	ZB
Favonigobius punctatus	Yellow-spotted sandgoby	Gobiidae	SB	ES	ZB
Afurcagobius suppositus	Southwestern goby	Gobiidae	SB	ES	ZB
Pseudorhombus jenynsii	Small-toothed flounder	Paralichthyidae	D	MEO	ZB
Ammotretis rostratus	Longsnout flounder	Pleuronectidae	D	MEO	ZB
Ammotretis elongatus	Elongate flounder	Pleuronectidae	D	MEO	ZB
Acanthaluteres brownii	Spiny-tailed leatherjacket	Monacanthidae	D	MS	OV
Acanthaluteres vittiger	Toothbrush leatherjacket	Monacanthidae	D	MS	OV
Scobinichthys granulatus	Rough leatherjacket	Monacanthidae	D	MS	OV
Monacanthus chinensis	Fanbellied leatherjacket	Monacanthidae	D	MEO	OV
Chaetodermis penicilligerus	Tasselled Leatherjacket	Monacanthidae	D	MS	OV
Brachaluteres jacksonianus	Southern pygmy leatherjacket	Monacanthidae	D	MS	OV
Meuschenia freycineti	Sixspine leatherjacket	Monacanthidae	D	MEO	OV
Acanthaluteres spilomelanurus	Bridled leatherjacket	Monacanthidae	D	MEO	OV
Torquigener pleurogramma	Weeping toadfish / Blowfish	Tetraodontidae	BP	MEO	OP
Contusus brevicaudus	Prickly toadfish	Tetraodontidae	BP	MS	OP