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

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Graphical Abstract

Graphical abstract
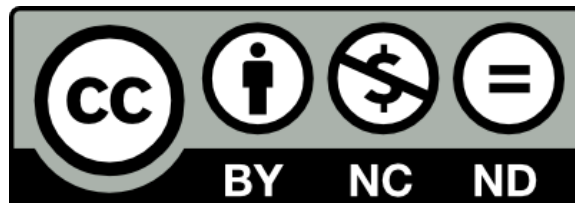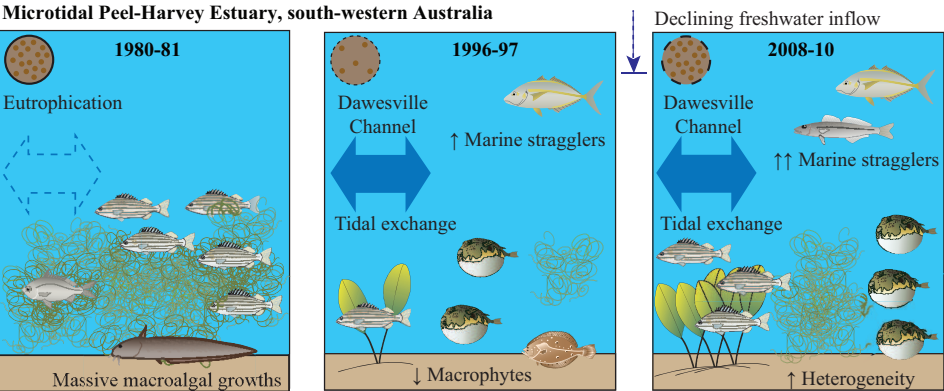
Highlights

- Ichthyofauna of a eutrophic microtidal estuary following engineering intervention
- Species composition changed after opening of an artificial subsidiary entrance channel
- Increased tidal exchange and persistent high salinities influenced species composition
- Species composition also reflects extent of macrophyte abundance
- Great value of long-term data for predicting changes in estuarine ichthyofaunas

1   **Decadal changes in the ichthyofauna of a eutrophic estuary following a**

2   **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 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. *Ostorhinchus 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 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.

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 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

88 period and are thus at or near those of the marine environment in which these species

89 presumably evolved (Potter and Hyndes, 1999).

90   As estuaries perform such an important ecological function for fishes and a range of

91 other faunas, there has been widespread concern that, in temperate regions, they are regarded

92 as the most degraded of all aquatic ecosystems (Jackson et al., 2001). In this context,

93 eutrophication from increased nutrient input has become a major problem in many parts of

94 the world, with, for example, 67% of the combined surface area of estuaries in the United

95 States exhibiting moderate to high degrees of eutrophication, a trend also found elsewhere

96 (Duarte, 2009; Rabalais et al., 2009; Paerl et al., 2014). The organic material, derived from

97 eutrophication and other sources, tends to be retained in microtidal estuaries due to their long

98 residence times (Patchineelam et al., 1999; Tweedley et al., 2012), thus leading to hypoxic

99 conditions in deeper waters, but not necessarily in the shallows where substantial wind-

100 induced mixing occurs (Eby and Crowder, 2002; Kurup and Hamilton, 2002; Tweedley et al.,

101 2014)

102   The microtidal Peel-Harvey Estuary, which is by far the largest estuary in south-

103 western Australia, covers an area of ~136 km^2 and comprises two large, shallow basins (Peel

104 Inlet and Harvey Estuary), a narrow, natural entrance channel at Mandurah and three main

105 tributaries (Fig. 1). During the 1960s to 1980s, this estuary became increasingly eutrophic,

106 through the input of large amounts of nutrients leached from the surrounding sandy soils

107 following clearing for agriculture, and by entry from point sources such as piggeries

108 (McComb and Humphries, 1992; McComb and Lukatelich, 1995). This eutrophication was

109 reflected in the replacement of seagrasses by massive growths of macroalgae, belonging in

110 particular to the genera *Cladophora, Chaetomorpha* and *Ulva* (McComb et al., 1981;

111 Lukatelich and McComb, 1986).

112   As the large Peel-Harvey Estuary contains commercial and recreational fisheries and

113 is widely used by residents and tourists for boating and other activities (Potter et al., 1983;

114 Steckis et al., 1995; Lepesteur et al., 2008), it was decided to construct a deep second

115 entrance channel to increase markedly the flushing of nutrients and organic material from this

116 microtidal system and thereby reduce the extent of eutrophication (Gilles et al., 2004;

117 Brearley, 2005; Elliott et al., 2016). The opening of this so-called Dawesville Channel in

118 1994 led to a tripling in tidal water exchange with the ocean, a marked increase in salinity, a

119 2-4 fold decrease in total phosphorous and nitrogen concentrations and a flushing of 10% of

120 the estuary volume each day (Brearley, 2005; Ruibal-Conti, 2014; Elliott et al., 2016). This

121 resulted in a reduction in macroalgal growths (Wilson et al., 1997; 1999).

122   The presence of massive macroalgal growths in the Peel-Harvey Estuary in the 1980s

123 was reflected in the domination of the fish fauna by two macrophyte-associated species, the

124 Western Striped Grunter *Pelates octolineatus* (previously erroneously referred to as *Pelates*

125 *sexlineatus*) and the Western Gobbleguts *Ostorhinchus rueppellii* (Potter et al., 1983;

126 Loneragan et al., 1986). The reductions in macroalgal biomass in the late 1990s, following

127 the opening of the Dawesville Channel (Wilson et al., 1997; 1999), were accompanied by a

128 decline in the density of the above two species and changes in ichthyofaunal composition

129 (Young and Potter, 2003b). However, marked reductions in freshwater discharge over recent

130 years, due to declining rainfall, have reduced the effectiveness of freshwater flushing of the

131 waters close to the mouths of tributaries, thereby leading to the development of macroalgal

132 beds in those areas (Zammit et al., 2006; Pedretti et al., 2011). In contrast, regular strong tidal

133 flushing in areas closer to the Dawesville Channel have increased water clarity and resulted

134 in salinities remaining at or approaching that of the surrounding ocean, thus facilitating the

135 development of seagrass beds (Pedretti et al., 2011). Substantial areas of unvegetated

136 substrata still remain, however, in the Peel-Harvey Estuary.

137   This unique study explores how the characteristics of the fish fauna changed in the

138 large, microtidal Peel-Harvey Estuary over ~30 years, during which (in 1994) this system

139 underwent a major structural change (i.e. construction of Dawesville Channel). For this

140 purpose, data on the fish fauna were collected seasonally for two consecutive twelve months

141 (two years) in 2008-10 and compared with those recorded seasonally throughout 1980 and

142 1981 (Loneragan et al., 1986; Potter et al. unpublished data) and throughout 1996 and 1997

143 (Young and Potter, 2003a,b). Emphasis has been placed on determining how the structure and

144 species composition of the ichthyofaunal community, throughout and within regions of the

145 estuary, changed between the first two periods, in response to a reduction in eutrophication

146 and increase in salinity as a result of greater tidal exchange, and subsequently, through

147 declining rainfall, to the maintenance of high salinities for longer during the year and the

148 development of greater areas of seagrass and macroalgae. It is hypothesised that these

149 changes would be accompanied by increases in the number of marine stragglers and that

150 macrophyte-associated species, such as *P. octolineatus* and *O. rueppellii*, would be more

151 numerous in 1980-81 and 2008-10 than in 1996-97, whereas species, such as *Torquigener*

152 *pleurogramma,* which are typically found over unvegetated substrata and in high salinities,

153 would be most abundant in the two most recent periods.

154

155

156 **Materials and Methods**

157 *Sampling regime*

158 During the present study, 102.5 and 21.5 m long seines were used to sample fishes at

159 four sites, spread throughout nearshore, shallow waters in each of the five regions of the Peel-

160 Harvey Estuary (Fig. 1), viz. Mandurah (Entrance) Channel (MC), Eastern Peel (EP),

161 Western Peel (WP), Northern Harvey (NH) and Southern Harvey (SH). Each site was

162 sampled using both seines in each season between winter (July) 2008 and autumn (April)

163 2010. Previously, one or two sites in each region were sampled using the 102.5 m seine twice

164 in each season between summer 1980 and spring 1981 (Loneragan et al., 1986; Potter et al.,

165 unpublished data) and three sites in each region using both the 102.5 and 21.5 m seines

166 between summer 1996 and spring 1997 (Young and Potter, 2003a,b). Samples were thus

167 collected using the 102.5 m seine in eight consecutive seasons (i.e. over two years) in three

168 decadal periods, i.e. 1980-81, 1996-97 and 2008-10, and with the 21.5 m seine during the last

169 two of those periods.

170 The 102.5 m seine consisted of two wings, each comprising a 44.5 m (25.4 mm mesh)

171 and 5.5 m panel (15.9 mm mesh), and a bunt measuring 2.5 m in width at the mouth (15.9

172 mm mesh), tapering to 0.4 m (9.5 mm mesh) over a distance of 2.5 m. This seine fished to a

173 maximum depth of 1.8 m and swept an area of 1,600 m^2. The 21.5 m seine, which comprised

174   two 10 m long wings (6 m of 9 mm mesh and 4 m of 3 mm mesh) and a 1.5 m bunt (3 mm

175   mesh), fished to a maximum depth of 1.5 m and swept an area of 116 m^2.

176   Salinity and water temperature in the middle of the water column were recorded at

177   each site on each sampling occasion in 2008-10 using a Yellow Springs International Model

178   556 water quality meter (www.ysi.com). Comparable data were recorded in 1980-81

179   (Loneragan et al., 1986; Potter et al. unpublished data) and 1996-97 (Young and Potter,

180   2003a,b).

181   After their capture, the fish were immediately euthanised in an ice slurry and

182   transported to the laboratory, where each was identified to species. The total number of

183   individuals of each species in each sample was recorded and converted to a density (number

184   100 m^{-2}).

185   Each species was assigned to a life cycle guild, based on the results of numerous

186   studies of the biology of fish species in south-western Australian estuaries (Potter and

187   Hyndes, 1999). The ways in which fish use estuaries are considered to comprise four

188   categories, i.e. marine, estuarine, diadromous and freshwater, with each containing multiple

189   guilds (Potter et al., 2015a,b). The first three categories are represented in the Peel-Harvey

190   Estuary by between one and three guilds. The two guilds in the marine category are marine

191   straggler (MS) and marine estuarine-opportunist (MEO). Marine stragglers are species that

192   spawn at sea and typically enter estuaries sporadically and in low numbers and are most

193   common in the lower reaches, where, for most of the year, salinities typically do not decline

194   much below ~35. Marine estuarine-opportunists species are those that spawn at sea and

195   regularly enter estuaries in substantial numbers, particularly as juveniles, but also use, to

196   varying degrees, coastal marine waters as alternative nursery areas. The three guilds in the

197   estuarine category are solely estuarine (E), estuarine & marine (E&M) and estuarine &

198   freshwater (E&F). Solely estuarine species are typically found only in estuaries. In contrast,

199   the estuarine & marine species and the estuarine & freshwater species are represented not

200   only by populations whose individuals complete their life cycle in estuaries, but also by

201   populations in coastal marine waters and fresh water, respectively. In south-western

202   Australian estuaries, the anadromous category is represented by the semi-anadromous guild

7

203 (SA), which comprises species whose growth occurs mainly at sea, followed by a migration

204 into the upper reaches of estuaries for spawning.

205

206 *Statistical analyses*

207   Multivariate statistical testing of the abundance data for the ichthyofaunal

208 assemblages used a four-factor design (Period/Year/Season/Region), with three decadal

209 periods for the 102.5 m seine samples (1980-81, 1996-97, 2008-10) and two decadal periods

210 for the 21.5 m seine samples (1996-97, 2008-10) and, for each period, two consecutive years,

211 five regions (MC, EP, WP, NH, SH) and all four seasons in each year. All factors were

212 considered fixed and crossed, except for Year, which was nested in Period. The design was

213 not balanced in terms of spatio-temporal replication, with, for example, 62, 120 and 155

214 replicate samples collected with the 102.5 m seine in the 1980-81, 1996-97, 2008-10 periods,

215 respectively, noting however, that all but one of the 120 Year $\times$ Region $\times$ Season

216 combinations had at least one replicate. All statistical analyses employed here are able to

217 handle this degree of imbalance in replication without bias.

218   The accumulating number of different species, recorded as the number of samples

219 increased, when using the 102.5m seine in 1980-81, 1996-97 and 2008-10 and the 21.5 m

220 seine in the latter two periods, were plotted as species accumulation curves (Ugland et al.,

221 2003; Clarke and Gorley, 2015). For this purpose, within each period and each size of seine,

222 the full set of samples were randomly ordered and the curve of cumulative numbers of

223 different species calculated. This computation was repeated for a further 999 random

224 orderings of the samples, and the resulting curves averaged and plotted. The same procedure

225 was then repeated having excluded marine stragglers, and finally for marine stragglers on

226 their own.

227   Variability in the numbers of individual species in the replicate seine samples was

228 used to carry out dispersion weighting for each species (Clarke et al., 2006). This

229 downweights the densities of heavily-schooling species such as *Torquigener pleurogramma*

230 and *Pelates octolineatus*, i.e. those whose numbers are erratic over replicates, relative to

231 those which return more consistent values, as would be expected from individuals arriving in

232 the seine independently of one another. Dividing counts for each species by its mean index of

233 dispersion (average of the variance to mean ratio in replicate seines) then ensures all species

234 have equivalent variability structure, and prevents the analyses becoming dominated by

235 strong outliers. In this case, it is then optimal to further transform the dispersion-weighted

236 data, by a milder square-root transformation, as demonstrated by Clarke et al. (2014a) for fish

237 communities, and particularly those in estuaries and nearshore coastal waters where the

238 prevalence of juvenile and small schooling species are high.

239   Bray-Curtis similarity was then calculated on the dispersion-weighted, transformed

240 data and input to permutational ANOVA, using the PERMANOVA routine in the PRIMER

241 v7 package (Anderson, 2001; Anderson et al., 2008; Clarke and Gorley, 2015). Since the

242 primary focus of this study was to compare fish communities across the three decadal

243 periods, the appropriate 'replicate' variation for those period tests is obtained from the year-

244 to-year variability within each decade (the Year factor is nested in the Period factor).

245 PERMANOVA tested for the main effects of Period, Year, Season and Region, two-way

246 interactions between each pair of these main effects, and also three-way interactions, all of

247 which may be relevant to understanding the subtlety of changes between the three decadal

248 periods.

249   Separate three-way crossed Analysis of Similarities (ANOSIM; Clarke and Green,

250 1988; Clarke et al., 2014b) were used to interpret the relative size of the overall Period, Year,

251 Season and Region effects on the fish compositions derived from the 102.5 and 21.5 m seine

252 samples, using the same resemblances as for the PERMANOVA tests. All pairs of these four

253 factors are crossed with each other (i.e. the same Regions are examined in the same Seasons

254 in the same Years and Periods), with the one exception that Year is nested within Period

255 (each period contains different years, naturally). This is conventionally denoted as the design

256 Season $\times$ Region $\times$ Year(Period). It is handled here in two stages, first testing the

257 crossed/nested three-factor ANOSIM design (B$\times$C(A); see Table 6.4 in Clarke et al., 2014b),

258 in which Year C (nested in Period A) is crossed with the "flattened" factor B, consisting of all

259 20 combinations of Season and Region, to obtain ANOSIM $\bar{R}$ values for Period and Year.

260 Then a three-factor fully crossed design (A$\times$B$\times$C; see Table 6.4 in Clarke et al., 2014b) of

261 Season $\times$ Region $\times$ Time computes Region and Season $\bar{R}$ values for comparing with those for

262 Year and Period. Here the "Time" factor consists of the 6 levels of all years in all periods,

263 and thus combines both differences between years within each period and changes over

264 periods.

265   The ANOSIM R-statistics provide a robust and universally scaled measure of effect

266 sizes, ranging from ~0, when the average similarities among and within groups do not differ,

267 up to 1, when the compositions of all samples within each group are more similar to each

268 other than to those of any sample from other groups (Clarke and Warwick, 2001). The same

269 combination of ANOSIM designs was utilised for analysing the data derived from the 21.5 m

270 seine samples as for the 102.5 m seine, recognizing however, that, as the 21.5 m seine was

271 not used in 1980-81, comparisons are restricted to 1996-97 vs 2008-10.

272   As four-way PERMANOVA detected strong Period $\times$ Region interactions (and no

273 significant Period $\times$ Season interaction) with the data for either seine (see Results), separate

274 Bray-Curtis similarity matrices were extracted for each region from the resemblance matrix.

275 When assessing the relative size of effects within a single region, both globally for Period and

276 Season factors and between specific pairs of periods or seasons, it is more efficient and

277 meaningful to work with averages (in some form) over the lowest level of variability in the

278 design, i.e. over spatio-temporal samples taken within a specific region in a particular season

279 and year. This is possible since there is no necessity in this case to remove a year effect (a

280 consistent and strong year difference over seasons is not present, see Results), so simpler 2-

281 way crossed ANOSIMs are performed, in which the two years in each period become the

282 replicate level for tests of Period and Season within each Region, and for Region and Season

283 within each Period.

284   Non-metric Multidimensional Scaling (nMDS) ordination then used data at this same

285 level of averaging over samples for each Region, Season and Year(Period) combination, to

286 visualise the extents to which ichthyofaunal composition differed across seasons and periods

287 for the separate regions. Further nMDS ordinations were then constructed at a higher level,

288 averaging now over both the years and seasons in order to display, on a single plot for each

289 seine, the scale of (significant) Period $\times$ Region interactions in the context of Period and

290   Region main effects. All of these plots were constructed by calculating the distances between

291   each pair of group centroids, *i.e.* the relevant average in the 'Bray-Curtis space' of all

292   samples (Anderson et al., 2008; Lek et al., 2011). This is preferable here to calculating

293   averages in the (transformed) 'species space' of the original data matrix because of the

294   imbalance in numbers of replicates among groups.

295   Segmented bubbles of proportional sizes, representing the dispersion-weighted and

296   square-root transformed abundances of six selected species, those pre-treated abundances for

297   each species having been averaged over all seasons and years in each period, were overlaid

298   on the corresponding centroid nMDS plot for the 102.5 m seine samples. This illustrates the

299   abundance trends exhibited by some of the species, which varied conspicuously between

300   period and/or regions, and thus how they contribute to the structure of this nMDS plot. For

301   visual clarity, however, the data are restricted to those for the Mandurah Channel, Eastern

302   Peel and Southern Harvey.

303   Data for a suite of species recorded in at least five samples, obtained using the

304   102.5 m seine across 1980-81, 1996-97 and 2008-10, and for the 21.5 m seine across the last

305   two periods, were used to produce separate shade plots (sensu Clarke et al., 2014a), with

306   species clustered using the Index of Association (Whittaker, 1952; Somerfield and Clarke,

307   2013) and placed in optimum serial order, constrained by the cluster dendrogram (Clarke et

308   al., 2014b). These plots illustrate the trends exhibited by the abundance of each of those

309   species with respect to Period, Region and Season. For this purpose, the number of

310   individuals of each species in each sample were dispersion weighted and square-root

311   transformed, and those for each Period, Region and Season combination then averaged. The

312   shade plot is then a simple visualization of this averaged data matrix, where a white space for

313   a species demonstrates that the species was not collected, while the depth and colour of

314   shading, ranging from blue shades through the spectrum to black, represents increasing

315   values for the (dispersion-weighted and transformed) abundance of that species (Clarke et al.,

316   2014a; Valesini et al., 2014). The averaged samples (on the *x* axis of the plot) are ordered

317   according to season in each region in each period.

318

320 **Results**

321 *Salinity and water temperature*

322   The mean seasonal salinity in the Peel-Harvey Estuary underwent similar seasonal

323 changes in 1980-81, 1996-97 and 2008-10, peaking in summer and autumn and declining in

324 winter and spring (Fig. 2a-c). The extent to which salinity declined in winter varied, however,

325 more among regions in both years of 1980-81, than in those of either 1996-97 or 2008-10.

326 Thus, in the winter of both years in 1980-81, mean salinities in the Southern Harvey and

327 Eastern Peel fell to less than 5-10, compared with only 18 to 25 in the Mandurah Channel and

328 Western Peel. The particularly low salinities in the first two regions in the winter and spring

329 of 1980-81 are due to the major tributaries discharging directly into those regions (Fig. 1) and

330 for such flow to be greatest during those seasons, as a consequence of highly seasonal

331 rainfall. The presence of more pronounced variations in salinity among regions in all seasons

332 in 1980-81 than in 1996-97 and 2008-10 (Fig. 2) is also related to tidal water exchange

333 occurring only through the natural entrance channel in the first period, whereas it was

334 augmented by that through the Dawesville Channel in the last two periods, which led to far

335 greater mixing within the estuary. Minimum salinities (i.e. in winter) were far lower in 1996

336 than in 1997, 2008/9 and 2009/10, due to far greater discharges of freshwater into the estuary

337 as a result of much higher rainfall in that year (Veale, 2013). Note, however, that salinities

338 remained low for a shorter time in 1996, than in the two pre-Dawesville Channel years of

339 1980-81, because, following the opening of that channel, tidal influence increased far more

340 rapidly as fresh water discharge declined.

341   Mean water temperature exhibited similar pronounced seasonal changes at all sites

342 and in each year, declining from maxima of ~25 ºC in summer to minima of ~14 ºC in winter

343 and then rising in spring (Veale et al., 2016).

344

345 *Ranking and contributions of fish species*

346   On the basis of the 102.5 m seine samples, the mean overall density of fish in the

347 Peel-Harvey Estuary over two consecutive years in both 1980-81 and 2008-10 was the same,

348   i.e. 44 fish 100 m^{-2}, which was far greater than the 13 fish 100 m^{-2} recorded in 1996-97

349   (Table 1). Although the total number of species recorded increased progressively with period,

350   it should be recognised that the number of samples also increased with period (Table 1). The

351   mean density of fish, derived from the 21.5 m seine samples, was also greater in 2008-10,

352   i.e. 283 fish 100 m^{-2}, than in 1996-97, i.e. 224 fish 100 m^{-2} (Table 2). Although the number of

353   samples was less in 2008-10 than in 1996-97, the total number of species recorded rose

354   slightly from 43 to 46 between those periods.

355   Although eight of the ten most abundant species caught using the 102.5 m seine in

356   2008-10 also ranked among the ten most abundant in both 1980-81 and 1996-97, the ranking

357   by abundance and relative contribution of some species to the total catch differed markedly

358   between periods (Table 1). For example, *T. pleurogramma* ranked first in both 2008-10 and

359   previously 1996-97, when its contribution to total fish numbers was as high as 31 and 42%,

360   respectively, compared with sixth and only 6% in 1980-81. The overall density of this marine

361   estuarine-opportunist was also greater in the two most recent periods. *Ostorhinchus rueppellii*

362   ranked second in both 1980-81 and 2008-10, with respective contributions of 14 and 25%,

363   whereas this estuarine & marine species was the sixth most abundant species and constituted

364   only 3% of the total catch in 1996-97, trends that reflect those of density. The marine

365   estuarine-opportunist *P. octolineatus*, which was the most abundant species in 1980-81, when

366   it contributed as much as 37% to the total catch, was the seventh most numerous species in

367   2008-10 with a contribution of 2.5%, which, in turn, exceeded the tenth ranking and

368   contribution of only 1.0 % in 1996-97 (Table 1). These trends again parallel those of density.

369   The marine estuarine-opportunist *Hyperlophus vittatus* ranked among the four most abundant

370   species in each period, with contributions ranging from 7 to 17 %. The atherinids

371   *Atherinosoma elongata* and *Leptatherina presbyteroides* both ranked among the five most

372   abundant species in 1996-97 and 2008-10, but only tenth and eleventh in 1980-81, when their

373   densities were also lower. The tropical atherinid *Craterocephalus mugiloides* ranked ninth

374   and contributed 1.9% in 2008-10, the latter being far greater than in 1980-81 (0.3%) and

375   1996-97 (<0.1%).

376   The trends exhibited by the ranking of the most abundant species caught using the

377   21.5 m seine in 1996-97 and 2008-10 were similar to those recorded with the 102.5 m seine

378   during the same two periods (Table 2). Thus, the macrophyte-associated species *O. rueppellii*

379   likewise ranked higher and made a greater contribution in the more recent of those two

380   periods, i.e. 5 and 7.0% vs 7 and 1.7%, and the same was true for *C. mugiloides,* i.e. 4 and

381   11.3% vs 22 and < 0.1%. Although the contributions made by *T. pleurogramma* to the

382   catches obtained using the 21.5 m seine in 1996-97 and 2008-10 were both less than those

383   with the 102.5 m seine in those years (in which this marine estuarine-opportunist was the

384   most abundant species), this tetraodontid still ranked fourth and sixth in the samples taken

385   with the smaller seine in 1996-97 and 2008-10 (Table 2). *A. elongata*, *H. vittatus* and

386   *L. presbyteroides* were very abundant and ranked in the top three species in the 21.5 m seine

387   samples in both 1996-7 and 2008-10 (Table 2). While these three species were also abundant

388   in the 102.5 m seine samples in 1996-97 and 2008-10, ranking in the top five species in both

389   periods, their collective contribution to the total number of fish caught by the 21.5 m seine

390   was far greater in both of those two periods. This trend is attributable to these species being

391   relatively small and most abundant in shallow waters along the shore line and thus more

392   susceptible to capture by the 21.5 m seine as this seine has smaller meshes and sampled just

393   the waters close to the shore line.

394

395   *Contributions of life cycle categories and guilds*

396   In terms of life cycle guild, the number of marine straggler species taken by the

397   102.5 m seine in 1980-81, 1996-97 and 2008-10 increased sequentially from 6 to 13 to 23

398   (Table 3). In contrast, the number of marine estuarine-opportunist species was similar in each

399   of those three periods, i.e. 17 or 18, as also were the numbers of estuarine & marine species,

400   i.e. 8 or 9, and solely estuarine species, i.e. 4. The number of species representing the marine

401   estuarine-opportunist, estuarine & marine and solely estuarine life cycle guilds in the 21.5 m

402   seine samples from 1996-97 and 2008-10 were each the same or very similar to those of the

403   corresponding guilds in the 102.5 m seine samples (Table 3). Although fewer species of

404 marine straggler were caught in the smaller than larger seine, their number likewise increased
405 between 1996-97 and 2008-10.

406 In terms of number of individuals, the 102.5 m seine samples were dominated by
407 marine estuarine-opportunists and estuarine & marine species collectively, with their
408 combined contributions ranging from 84% in 1996-97 to 93% in 1980-81 (Table 3). The
409 contributions of marine estuarine-opportunists in 1980-81 and 1996-97 were 68-70% and still
410 as high as 56% in 2008-10, while those for the estuarine & marine guild in those three
411 periods ranged from 23-32%. The densities of both life cycle guilds were least in the
412 intervening period. The contributions by the solely estuarine guild ranged from 3.2 to 8.2%
413 (Table 3).

414 In the 21.5 m seine samples, the contributions of marine estuarine-opportunists ranged
415 widely from 37% in 2008-10 to 70% in 1996-97, reflecting, in particular, exceptionally large
416 numbers of a single species, i.e. *H. vittatus*, in the earlier period (Table 2). Conversely, but
417 not to the same extreme degree, the estuarine & marine species made greater contributions in
418 2008-10 than in 1996-97. In comparison with the 102.5 m seine, the relative abundance of
419 solely estuarine species in the 21.5 m seine catches were greater in both 1996-97 and
420 particularly 2008-10, when they contributed as much as 38% to the total catch, which was
421 due almost entirely to large numbers of the atherinids *A. elongata* and *C. mugiloides* (Table
422 2).

423 Although relatively small, the contributions by marine stragglers to the 102.5 m seine
424 catches in the three periods, 2.6-3.0%, far exceeded the 0.3% by those in the 21.5 m seine
425 (Table 3). The estuarine & freshwater species, and single semi-anadromous species, made
426 only small contributions to the catches by either seine in any period.

427 The species-accumulation curve, derived from the 102.5 m samples, displayed a less
428 pronounced asymptote in 1996-97 and 2008-10 than in 1980-81 (Fig. 3a). Furthermore, in
429 comparison with 1980-81, the total number of species in 62 samples (the maximum number
430 of samples recorded in 1980-81) was slightly greater in 1996-97 and, to an even more marked
431 extent, in 2008-10. The curves constructed from the same samples, but excluding marine
432 stragglers, were very similar in 1996-97 and 2008-10 (Fig. 3b). While the curve for the

433   corresponding samples in 1980-81 rose more rapidly to an asymptote, the number of species

434   at 62 samples in that period was very similar to those in 1996-97 and 2008-10. Conversely,

435   when the curves were restricted to data solely for marine stragglers, the curve for 1980-81 lay

436   well below that for 1996-97, and even more particularly that for 2008-10 (Fig. 3c).

437   The relationship between the trends in the species-accumulation curves constructed

438   for the 21.5 m seine samples in 1996-97 and 2008-10, using firstly all species (Fig. 3d), then

439   all species except marine stragglers (Fig. 3e) and finally just marine stragglers (Fig. 3f)

440   closely parallel those exhibited using the 102.5 m seine in those two periods (Fig. 3a-c).

441   Thus, the curve for all species and for just marine stragglers in 2008-10 lay above the

442   corresponding curves for 1996-97, whereas the curves for all species except marine stragglers

443   were very similar in those periods.

444

445   *Variations in ichthyofaunal composition with period, region and season*

446   On the basis of PERMANOVA, the ichthyofaunal compositions in the Peel-Harvey

447   Estuary, derived from the 102.5 m seine samples in 1980-81, 1996-97 and 2008-10 and for

448   the 21.5 m seine samples in the last two periods, differed significantly for Period, Season,

449   Region and Year(Period) (Table 4a,b). The interactions for Period $\times$ Region and Year(Period)

450     $\times$ Season were also significant for the samples obtained with both seines. Although, in the

451   case of the 21.5 m seine samples, the pseudo-F (*pF*) value for Period was the second greatest,

452   this main effect was not significant ($P = 0.339$) because the number of possible permutations

453   (45) was small for a test based on (1, 2) degrees of freedom. However, Monte Carlo testing,

454   using the asymptotic permutation distribution (Anderson et al., 2008), suggested a high level

455   of significance, i.e. $P = 0.003$ (Table 4b). There was a smaller Period $\times$ Region interaction,

456   though more strongly significant since it was based on (4, 8) degrees of freedom, and with

457   many possible permutations.

458   Separate three-way crossed ANOSIM tests for the 102.5 and 21.5 m seine catches

459   yielded respective $\bar{R}$ values of 0.585 and 0.375 for Period, 0.235 and 0.249 for Region, 0.241

460   and 0.251 for Season and 0.147 and 0.132 for Year. This confirms the relatively large size of

461   the Period effect and that Year was far less influential than Region and Season.

462   On the nMDS ordination plots, derived from the distance among centroids matrices

463   for the 102.5 m seine samples, the points for the samples for each period in 1980-81, 1996-97

464   and 2008-10 progressed sequentially from left to right and then upwards (Fig. 4a).

465   Furthermore, in each period, the point for the Mandurah Channel typically lay above those

466   for the other four regions and that for the Southern Harvey lay below those for all other

467   regions. On the corresponding ordination plot, derived from data using the 21.5 m seine, the

468   point for the sample from each region in 2008-10 lay to the right of that for the corresponding

469   region in 1996-97 (Fig. 4b).

470   Two-way crossed ANOSIM tests demonstrated that the composition of the fish fauna

471   was significantly related to Region in 1980-81 and 2008-10, but not in 1996-97, and was

472   significantly related to Season only in 2008-10 (Table 5). The composition of the fish fauna

473   in the 21.5m seine samples was influenced significantly by Region and Season in both 1996-

474   97 and 2008-10.

475   Two-way crossed Period × Season ANOSIM tests demonstrated that the compositions

476   of the fish faunas in the Mandurah Channel, Eastern Peel, Northern Harvey and Southern

477   Harvey differed significantly between periods, with the $\bar{R}$ statistics for those regions ranging

478   upwards from 0.508 in the Southern Harvey and 0.583 in the Northern Harvey to as high as

479   0.833 in the Mandurah Channel and 0.883 in the Eastern Peel (Table 6). In each region, the

480    $\bar{R}$-statistic values for each pairwise comparison between the ichthyofaunal compositions in

481   the three periods exceeded 0.500 in all cases except those involving the Western Peel

482   (Table 6). In the case of seasons in each region, the $\bar{R}$ statistic was always < 0.500 and the

483   differences were significant only in the Mandurah Channel and Eastern Peel (Table 6).

484   The basis for the differences between the composition in 1980-81 and both 1996-97

485   and 2008-10, derived from the data for the 102.5 m seine, can be seen visually on the

486   respective regional MDS ordination plots, with the points for the samples in the first period in

487   each region showing a very marked tendency to lie to the left of those for the last two periods

488   (Fig. 5a-e). Furthermore, the samples for 2008-10 formed particularly tight and essentially

489   discrete groups on the plots for each region, except the Mandurah Channel.

490   In two-way crossed Period × Season ANOSIM tests, using data derived from the

491   21.5 m seine samples in each region in 1996-97 and 2008-10, the $\bar{R}$-statistic value for Period

492   exceeded 0.500 in the Mandurah Channel, Northern Harvey and Southern Harvey (Table 7).

493   These inter-period differences are reflected, on the MDS ordination plots, by the discreteness

494   of the samples for the two periods being greatest in those three regions (Fig. 5f-h).

495

Species responsible for period, regional and seasonal differences

497   The trends exhibited by the abundance of the various fish species on the shade plot,

498   derived from the 102.5 m seine samples, provide a visual demonstration of the species mainly

499   responsible for the differences between the ichthyofaunal compositions of the estuary in

500   1980-81, 1996-97 and 2008-10 (Fig. 6). Thus, for example, species such as *Hyporhamphus*

501   *regularis, Sillago schomburgkii, Gerres subfasciatus* and *Contusus brevicaudus* were far

502   more abundant in 1980-81 than in 1996-97 and 2008-10. The fauna in 1996-97 was

503   characterised by a small suite of species, comprising *Pseudorhombus jenynsii, Favonigobius*

504   *lateralis, T. pleurogramma* and *L. presbyteroides,* that were consistently abundant throughout

505   the estuary. Species such as *Gymnapistes marmoratus, Ostorhinchus rueppellii, Haletta*

506   *semifasciata* and *Pelates octolineatus* were numerous in 2008-10 and 1980-81, but present in

507   only low numbers in 1996-97 (Fig. 6).

508   The strong regional effect on the ichthyofaunal compositions in 1980-81 and 2008-10

509   reflected, in part, the marked tendency for species such as *Aldrichetta forsteri* and *H. vittatus*

510   to occur predominantly in the Mandurah Channel in both of these periods and in the Eastern

511   Peel in the first period (Fig. 6). While *G. marmoratus, O. rueppellii* and *Haletta semifasciata*

512   were caught mainly in the Western Peel and Northern Harvey in 1980-81 and 2008-10, they

513   were more widely distributed in the latter period. The significant and marked seasonal effect

514   in 2008-10 was attributable, in particular, to *P. octolineatus, Sillaginodes punctatus,*

515   *G. marmoratus, O. rueppellii* and *H. semifasciata* being represented by large densities in

516   summer and autumn and either fewer or no fish in winter (Fig. 6).

517   In the 21.5 m seine catches, species such as *F. lateralis, T. pleurogramma* and

518   *L. presbyteroides* were particularly abundant in both 1996-97 and 2008-10, whereas species

519   such as *Stigmatopora argus*, *O. rueppellii*, *H. semifasciata* and *G. marmoratus* were far more

520   numerous in 2008-10 (Fig.7). The regional effect in both periods was due, in particular, to

521   species such as *S. schomburgkii, Atherinomorus vaigiensis* and *Sillago vittata* being largely

522   confined to the Mandurah Channel. In 2008-10, *Hyporhamphus melanochir* and *C.*

523   *mugiloides* were most abundant in the Northern Harvey and Southern Harvey, whereas the

524   densities of *S. punctatus* were greatest in the Western Peel and Northern Harvey (Fig. 7). In

525   terms of season, *H. vittatus*, *O. rueppellii* and *G. marmoratus* were absent or in very low

526   numbers during winter in 1996-97 and 2008-10 in certain regions, in which these species

527   were abundant in other seasons. In 1996-97, *A. elongata* was most abundant in summer,

528   whereas *Leptatherina wallacei* was most abundant in winter.

529   The trends exhibited in the segmented bubble plots in Fig. 8 emphasize how the

530   relative contributions of six key species in three regions (Mandurah Channel, Eastern Peel

531   and Southern Harvey) changed between 1980-81, 1996-97 and 2008-10. Thus, for example,

532   while *T. pleurogramma* was recorded only in the Mandurah Channel in 1980-81 (but in

533   substantial numbers), it was abundant in each region in 1996-97 and 2008-10. Although

534   *F. lateralis* was recorded in each region in each period, its relative contribution increased

535   markedly in the Eastern Peel and Southern Harvey in 2008-10. The abundance of

536   *H. regularis* in those same two regions declined between 1980-81 and 2008-10.

537

538

539   **Discussion**

540   This study has demonstrated statistically the ways in which the ichthyofaunal characteristics

541   of a large microtidal estuary changed over three decades, during which part of that system

542   was subjected to radical structural changes aimed at reducing the extent of eutrophication,

543   and which led to major environmental changes in the estuary as a whole. Particular emphasis

544   was placed on elucidating the influence of the construction of a large additional entrance

545   channel, which increased flushing and salinity, and that of subsequent changes brought about

546   by more persistently high salinities, caused by reductions in rainfall, and increases in seagrass

547   and macroalgal biomass. As the large basins of the Peel-Harvey Estuary have water depths

548   less than ~2 m and mostly < 1 m (Hale and Bucher, 2007), they do not contain sustain

549   substantial numbers of large, mobile fish species. Thus, the use of a small (21.5 m long) and

550   far larger (102.5 m long) seine, both of which sample to a depth of 1.5 m, is regarded as

551   having sampled relatively effectively the fish species present throughout the water column

552   within the dominant component of this estuary, i.e. the basins.

553

554   *Numbers of species and individuals in the various guilds*

555   Species accumulation curves, derived from the 102.5 m seine samples, demonstrate

556   that the number of species in the Peel-Harvey Estuary increased progressively between 1980-

557   81, 1996-97 and 2008-10 and that this rise was almost exclusively due to increases in the

558   number of species of marine straggler. The rise in the number of these stragglers following

559   the opening of the Dawesville Channel, some distance from the natural Mandurah entrance

560   channel, is precisely what would be expected as this construction resulted in increases in tidal

561   exchange with the ocean and the persistence, for longer during the year, of high salinities

562   throughout the large basins of this estuary (Brearley, 2005; Ruibal-Conti, 2014). This trend

563   closely parallels the increase that occurred in the number of species of benthic

564   macroinvertebrates from 28 in 1986-87 to 63 in 2003-04, with the previously unrecorded

565   species in the latter period being low in abundance and typically representing marine species,

566   which had probably been transported into the estuary as planktonic larvae through tidal action

567   (Wildsmith et al., 2009; Tweedley et al., 2012). The increase in the number of marine

568   straggler fish species, recorded in the 102.5 m seine samples between 1996-97 and 2008-10,

569   was paralleled by the corresponding trend in the 21.5 m seine samples. This increase was

570   probably attributable to the maintenance of high salinities throughout both years in 2008-10

571   (Fig. 2) and an increase in habitat complexity through the development of appreciable areas

572   of macrophytes. Thus, macroalgal growths became particularly prominent near the point

573   where rivers discharge into the basins and seagrass beds developed near the Dawesville

574   Channel, where water clarity and thus light penetration was greatest (Pedretti et al., 2011). As

575   rainfall and thus the volume of freshwater discharge is declining (Veale, 2013) and salinities

576 are consistently higher, it seems likely that that the overall number of marine stragglers will

577 continue to increase.

578   In contrast to the trend exhibited by marine stragglers, the species representing the

579 marine estuarine-opportunist guild in the 102.5 m seine samples were very similar in 1980-

580 81, 1996-97 and 2008-10. Thus, among the 18 marine estuarine-opportunists recorded in the

581 Peel-Harvey Estuary, as many as 16, i.e. all except *Arripis georgianus* and *Arripis truttaceus,*

582 were caught in each period and were often relatively abundant in at least two of the three

583 periods. The finding that, unlike the situation with marine stragglers, the number of marine

584 estuarine-opportunist species did not increase between the three periods was predictable as,

585 by definition, these species are those that regularly use estuaries as nursery areas (Potter et

586 al., 2015b) and would thus always tend to be found in permanently-open systems, such as the

587 Peel-Harvey Estuary. The number of marine estuarine-opportunists species in the 21.5 m

588 seine samples in 1996-97 (19) and 2008-10 (17) were essentially the same as those in the

589 102.5 m seine samples in 1980-81, 1996-97 and 2008-10, reflecting the restricted and largely

590 common range of species that represent this guild.

591   As with marine estuarine-opportunists in the 102.5 m seine samples, the number of

592 species comprising the estuarine & marine, estuarine & freshwater and solely estuarine

593 guilds, which collectively represent the species that complete their life cycles within the Peel-

594 Harvey Estuary and thus constitute the estuarine category (Potter et al., 2015a), were similar

595 in each period. Furthermore, 12 of the 18 species comprising the estuarine category,

596 subsequently referred to as estuarine residents, were found in each of the three periods and

597 four in two of those periods and thus only two species were restricted to one period.

598 Irrespective of period, the number of species representing each guild in the estuarine category

599 in the 21.5 m seine samples is the same or differs by only one from that recorded using the

600 102.5 m seine. The finding that the number of species in the various guilds comprising the

601 estuarine category remained essentially the same between 1980-81 and 2008-10 was not

602 surprising as there appears to be no a priori reason why the presence of such species should

603 be markedly influenced by increased tidal exchange with the ocean or higher salinities.

604   In terms of the number of individuals, the samples obtained by the 102.5 m seine in

605   each period, and particularly in 1980-81 and 1996-97, were dominated by marine estuarine-

606   opportunists and the same was true for those using the 21.5 m seine in 1996-97. The finding

607   that, in the 21.5 m seine samples, the contribution of this guild in 2008-10 was approximately

608   half that in 1996-97 was due to a pronounced decline in the abundance of a single species, the

609   clupeid *H. vittatus*, whose density in nearby coastal marine waters also declined between

610   those periods (Smith et al., 2008; Valesini and Tweedley, 2015).

611   The estuarine & marine guild was the second most important guild in terms of

612   abundance in the 102.5 m seine samples in each period and markedly so in 1980-81 (23%)

613   and 2008-10 (32%) and the same was marginally true for those taken by the 21.5 m seine in

614   1996-97 (16%). Although the contribution made by individuals of species in this guild to the

615   21.5 m seine samples in 2008-10 was as high as 24%, this value was far less than the

616   corresponding contribution of 38% by the solely estuarine guild in that period, which was due

617   to exceptionally large numbers of the atherinid *C. mugiloides*.

618   It is relevant that the contributions of the solely estuarine guild to the number of

619   individuals caught by the 21.5 m seine in 1996-97 and 2008-10 were greater than those with

620   the 102.5 m seine in those two periods and in 1980-81. This trend is attributable, in particular,

621   to differences in the abundances of the main species caught by the smaller seine, which

622   samples along the shoreline, and those taken by the larger seine, which samples much further

623   outwards from the shore and includes some deeper water. Among the estuarine category, the

624   most abundant species along the shoreline comprised predominantly small-bodied atherinids,

625   such as *A. elongata* and *C. mugiloides*, which are confined to estuaries. The most abundant

626   estuarine-resident species in waters extending further offshore include species such as the

627   deep-bodied *O. rueppellii*.

628   Although the number of species in each guild, except marine stragglers, was very

629   similar in 1980-81, 1996-97 and 2008-10, the abundance of certain species in particularly the

630   marine estuarine-opportunist, solely estuarine and estuarine & marine guilds, which

631   dominated the catches, varied. These differences, rather than variations in the number of

632   species in those guilds, are thus responsible for the differences in species composition.

633 Although the number of marine stragglers increased progressively with period, the

634 abundances of these adventitious species were low and thus had minimal influence on the

635 variations in ichthyofaunal composition in different periods.

636

637 *Ichthyofaunal composition*

638 The distinctness of the groups of points on nMDS ordination plots for samples, collected

639 from the five regions in the Peel-Harvey Estuary using the 102.5 m seine, demonstrate that

640 ichthyofaunal composition changed markedly between 1980-81, 1996-97 and 2008-10, and

641 that, on the basis of the plots derived from data for the 21.5 m seine samples, the same is true

642 for the samples obtained in the last two periods. The strong Period effect is further

643 emphasized by the results of ANOSIM tests, which, for the 102.5 and also 21.5 m seine

644 samples, yielded far greater $\bar{R}$ values for Period than for either Region or Season, with the

645 value for Year particularly low. The differences in ichthyofaunal composition between

646 periods is further illustrated by the finding that, from data for the 102.5 m seine samples, the

647 composition in the Mandurah Channel and three of the four basin regions, i.e. Eastern Peel,

648 Northern Harvey and Southern Harvey, each differed significantly between periods. The

649 changes that occurred in the composition of the fish fauna of the Peel-Harvey Estuary, after

650 the opening of the Dawesville Channel and a consequent reduction in eutrophication, provide

651 some parallels with those brought about in the Mondego Estuary in Portugal by structural

652 changes that facilitated greater flow and thus a reduction in residence time and eutrophication

653 (Castro et al., 2016).

654 The trends exhibited by the relative abundance of species in the shade plot (Fig. 6)

655 highlight the species that made important contributions to inter-period differences in the

656 102.5 m seine samples. For a number of species, such differences can be related to changes in

657 the environment, which were associated with the increases in tidal and salinity regimes

658 produced by the construction of the Dawesville Channel, and to subsequent changes in

659 macrophytes biomass. These species include the tetrapontid *P. octolineatus* and apogonid

660 *O. rueppellii* and, to a lesser extent, the odacid *H. semifasciata* and scorpaenid

661 *G. marmoratus*, which were all relatively more numerous in 1980-81 and 2008-10 than in

662   1996-97. As macrophytes were most abundant in 1980-81 and 2008-10 (Wilson et al., 1999;

663   Pedretti et al., 2011), it is relevant that these four species are typically associated with aquatic

664   vegetation (Travers and Potter, 2002; Valesini et al., 2004; Gomon et al., 2008; Veale et al.,

665   2014; 2015). Thus, for example, *P. octolineatus* lives predominantly and is abundant in

666   seagrass, both along the lower west coast of Australia, into which the Peel-Harvey Estuary

667   discharges (Valesini et al., 2004; Veale et al., 2015), and in the large marine embayment of

668   Shark Bay ~ 800 km further north (Burkholder et al., 2012), where this tetrapontid feeds

669   mainly on seagrass and algae (Bessey and Heithaus, 2015). Furthermore, *O. rueppellii* was

670   found almost exclusively over seagrass during extensive trawling of shallow, inshore

671   vegetated and unvegetated areas in Shark Bay, in which it was the second most abundant

672   species sampled overall (Travers and Potter, 2002). The impact that a reduction and

673   subsequent increase in macroalgae and seagrass can have on the abundance of a species is

674   particularly well illustrated by the decline and then rise that occurred in the catches of the

675   Tiger Prawn *Penaeus esculentus,* when such changes in macrophytes took place in a large

676   embayment in north-western Australia (Loneragan et al., 2013).

677   The above trends exhibited by species on the shade plot are consistent with those for

678   the untransformed overall densities and percentage contributions (Table 1). Thus, the

679   densities and percentage contributions of *P. octolineatus* were greatest in 1980-81 and less in

680   1996-97 than in 2008-10, with this tetrapontid ranking first in terms of density in 1980-81,

681   when it contributed a remarkable 37% to the total catch in that period and thus when

682   macrophyte biomass was greatest. Furthermore, this species ranked higher in terms of

683   abundance (7) and contributed more to the total catch (2.5%) in 2008-10 than in 1996-97,

684   when it ranked 10 and contributed only 1% and therefore when the extent of macrophyte

685   growth was not as extensive as in 1980-81, but still greater than in 1996-97. As with

686   *P. octolineatus*, the ranking by abundance and contribution to the total catch of *O. rueppellii*

687   were substantially greater in both 1980-81 and 2008-10 than in 1996-97.

688   In contrast to the trends exhibited by the above macrophyte-associated species, the

689   tetraodontid *T. pleurogramma* was relatively far less abundant in 1980-81 than in 2008-10

690   and even more particularly in 1996-97, and thus when the area covered by macrophytes was

691 least. This converse trend strongly suggests that *T. pleurogramma* 'prefers' unvegetated

692 substrata. Such a view is consistent with the high abundances of this species over sand in the

693 Swan River Estuary, just to the north of the Peel-Harvey (Potter et al., 1988), and in the

694 Noosa River Estuary in eastern Australia (Miller and Skilleter, 2006). Furthermore, this

695 species was almost invariably caught over sand rather than seagrass during trawling over

696 those two habitats in Shark Bay (Travers and Potter, 2002) and is known to bury in sand and

697 to feed on polychaetes, amphipods and molluscs in and on the sediment (Potter et al., 1988;

698 Miller and Skilleter, 2006). Although *T. pleurogramma* was scarcely caught in the basin of

699 the Peel-Harvey Estuary in 1980-81, it was so abundant in the Mandurah Channel in that

700 period that it was a diagnostic species for the ichthyofauna of that region (Loneragan et al.,

701 1986). It is thus relevant that, in marked contrast to the large basin areas, the Mandurah

702 Channel did not house massive macroalgal growths in 1980-81 and thus contained substantial

703 areas of unvegetated substrata (McComb and Lukatelich, 1995). The negative relationship

704 between the abundance of *T. pleurogramma* and extent of macroalgal growths and the

705 positive relationship between the abundance of this species and salinity (Potter et al., 1988),

706 allied with the maintenance of higher salinities throughout the basin in 1996-97 and 2008-10,

707 account for the densities of this tetraodontid being far greater in these latter two periods.

708   As *F. lateralis* also has a strong preference for a sandy substrate and its densities are

709 likewise positively related to salinity (Gill and Potter, 1993), the basis for this gobiid

710 becoming more widespread in the estuary in 1996-97 and 2008-10 than in 1980-81 is

711 apparently the same as for *T. pleurogramma,* i.e. a preference for unvegetated soft substrata

712 and high salinities. Furthermore, as with *T. pleurogramma, F. lateralis* was very abundant in

713 the Mandurah Channel in 1980-81, paralleling the situation in the Swan River Estuary, in

714 which this species is largely confined to the high salinities and sandy substrata of its entrance

715 channel (Gill and Potter, 1993).

716   In contrast to *T. pleurogramma* and *F. lateralis*, the hemiramphid *H. regularis* was

717 never caught in the Mandurah Channel in any of the three periods and its abundance in the

718 basins was less in 1996-97 and 2008-10 than in 1980-81. These trends are consistent with this

719   so called "river garfish" typically occurring in reduced salinities and in association with

720   macrophytes, which house their food source (Gomon, 2011).

721   The data derived from the 102.5 and 21.5 m seine samples provided strong evidence

722   that the atherinid *C. mugiloides* was relatively more abundant in 2008-10 than in earlier

723   periods, thereby paralleling the trend in the Swan River Estuary (Loneragan et al., 1989;

724   Valesini et al., 2009; 2014). Furthermore, while this species was not recorded in 1994 in the

725   Leschenault Estuary, ~75 km to the south of the Peel-Harvey, it was very abundant in this

726   system in 2008-10 (Veale et al., 2014). This suggests that increases in the abundance of

727   *C. mugiloides* in the Swan River and Peel-Harvey estuaries in the most recent period and the

728   southwards extension of this tropical species into the Leschenault Estuary are related to

729   increases in water temperature associated with climate change in south-western Australia

730   (Lough et al., 2012).

731   The results of this study emphasise the value of acquiring data at key intervals over

732   time to be able to predict, in the future, the ways in which extreme structural modifications

733   and climate change will influence the fish faunas of particularly microtidal estuaries.

734

735

736   **Acknowledgments**

746

References

748 Able, K.W., Fahay, M.P., 2010. Ecology of Estuarine Fishes: temperate waters of the western
749   north Atlantic. Johns Hopkins University Press, Baltimore, USA. pp. 584.

750 Anderson, M.J., 2001. A new method for non-parametric multivariate analysis of variance.
751   Austral Ecology 26, 32-46.

752 Anderson, M.J., Gorley, R.N., Clarke, K.R., 2008. PERMANOVA+ for PRIMER: guide to
753   software and statistical methods. PRIMER-E, Plymouth, UK. pp. 214.

754 Beck, M.W., Heck Jr, K.L., Able, K.W., Childers, D.L., Eggleston, D.B., Gillanders, B.M.,
755   Halpern, B., Hays, C.G., Hoshino, K., Minello, T.J., Orth, R.J., Sheridan, P.F.,
756   Weinstein, M.P., 2001. The identification, conservation, and management of estuarine
757   and marine nurseries for fish and invertebrates. BioScience 51, 633-641.

758 Bessey, C., Heithaus, M.R., 2015. Ecological niche of an abundant teleost *Pelates*
759   *octolineatus* in a subtropical seagrass ecosystem. Marine Ecology Progress Series 541,
760   195-204.

761 Blaber, J.M., 1980. Fish of the Trinity Inlet system of north Queensland with notes on the
762   ecology of fish faunas of tropical Indo-Pacific estuaries. Australian Journal of Marine
763   and Freshwater Research 31, 137-146.

764 Blaber, S.J.M., Blaber, T.G., 1980. Factors affecting the distribution of juvenile estuarine and
765   inshore fish. Journal of Fish Biology 17, 143-162.

766 Brearley, A., 2005. Ernest Hodgkin's Swanland, 1st ed. University of Western Australia
767   Press, Crawley. Pp. 550.

768 Burkholder, D.A., Heithaus, M.R., Fourqurean, J.W., 2012. Feeding preferences of
769   herbivores in a relatively pristine subtropical seagrass ecosystem. Marine and
770   Freshwater Research 63, 1051-1058.

771 Castro, N., Félix, P.M., Neto, J.M., Cabral, H., Marques, J.C., Costa, M.J., Costa, J.L., 2016.
772   Fish communities' response to implementation of restoring measures in a highly
773   artificialized estuary. Ecological Indicators 67, 743-752.

774 Claridge, P.N., Potter, I.C., Hardisty, M.W., 1986. Seasonal changes in movements,
775   abundance, size composition and diversity of the fish fauna of the Severn Estuary.
776   Journal of the Marine Biological Association of the United Kingdom 66, 229-258.

777 Clarke, K.R., Green, R.H., 1988. Statistical design and analysis for a 'biological effects'
778   study. Marine Ecology Progress Series 46, 213-226.

779 Clarke, K.R., Warwick, R.M., 2001. Change in marine communities: An approach to
780   statistical analysis and interpretation, 2nd edition PRIMER-E, Plymouth. pp. 174.

781 Clarke, K.R., Chapman, M.G., Somerfield, P.J., Needham, H.R., 2006. Dispersion-based
782   weighting of species counts in assemblage analyses. Marine Ecology Progress Series
783   320, 11-27.

784 Clarke, K.R., Tweedley, J.R., Valesini, F.J., 2014a. Simple shade plots aid better long-term
785   choices of data pre-treatment in multivariate assemblage studies. Journal of the Marine
786   Biological Association of the United Kingdom 94, 1-16.

787 Clarke, K.R., Gorley, R.N., Somerfield, P.J., Warwick, R.M., 2014b. Change in Marine
788   Communities: an Approach to Statistical Analysis and Interpretation, 3rd edition.
789   PRIMER-E Ltd, Plymouth, UK. pp. 262.

790 Clarke, K.R., Gorley, R.N., 2015. PRIMER v7: User Manual/Tutorial. PRIMER-E,
791   Plymouth. pp. 296.

792 Costanza, R., Fisher, B., Mulder, K., Liu, S., Christopher, T., 2007. Biodiversity and
793   ecosystem services: A multi-scale empirical study of the relationship between species
794   richness and net primary production. Ecological Economics 61, 478-491.

795 Dadswell, M.J., Rulifson, R.A., 1994. Macrotidal estuaries: a region of collision between
796   migratory marine animals and tidal power development. Biological Journal of the
797   Linnean Society 51, 93-113.

798 Duarte, C., 2009. Coastal eutrophication research: a new awareness, in: Andersen, J.H.,
799   Conley, D.J. (Eds.), Eutrophication in Coastal Ecosystems. Springer Netherlands, pp.
800   263-269.

801 Eby, L.A., Crowder, L.B., 2002. Hypoxia-based habitat compression in the Neuse River
802   estuary: context-dependent shifts in behavioural avoidance thresholds. Canadian
803   Journal of Fisheries and Aquatic Sciences 59, 952-965.

804 Elliott, M., Hemingway, K.L., 2002. Fishes in Estuaries. Blackwell Science, Oxford. pp. 636.

805 Elliott, M., Mander, L., Mazik, K., Simenstad, C., Valesini, F., Whitfield, A., Wolanski, E.,
806   2016. Ecoengineering with ecohydrology: successes and failures in estuarine
807   restoration. Estuarine, Coastal and Shelf Science 176, 12-35.

808 França, S., Vasconcelos, R.P., Tanner, S., Máguas, C., Costa, M.J., Cabral, H.N., 2011.
809   Assessing food web dynamics and relative importance of organic matter sources for
810   fish species in two Portuguese estuaries: A stable isotope approach. Marine
811   Environmental Research 72, 204-215.

812 Gill, H.S., Potter, I.C., 1993. Spatial segregation amongst goby species within an Australian
813   estuary, with a comparison of the diets and salinity tolerance of the two most abundant
814   species. Marine Biology 117, 515-526.

815   Gilles, M., Galloway, D., Horwitz, P., Larson, A., 2004. Reintegrating Coastal Development
816   and Public Health in Western Australia. EcoHealth 1, 340-350.

817   Gomon, M.F., Bray, D.J., Kuiter, R.H., 2008. Fishes of Australia's Southern Coast New
818   Holland, Chatswood, New South Wales. pp. 928

819   Gomon, M.F., 2011. River Garfish, *Hyporhamphus regularis*. Fishes of Australia.

820   Haedrich, R.L., 1983. Estuarine fishes, in: Ketchun, B. (Ed.), Estuaries and Enclosed Seas.
821   Elsevier, Amsterdam, pp. 183-207.

822   Hale, J.,Butcher, R., 2007. Ecological character description of the Peel-Yalgorup Ramsar site.
823   Report to the Department of Environment and Conservation and the Peel-Harvey
824   Catchment Council. Perth, Western Australia. pp. 184.

825   Heip, C.H.R., Goosen, N.K., Herman, P.M.J., Kromkamp, J., Middelburg, J.J., Soetaert, K.,
826   1995. Production and consumption of biological particles in temperate tidal estuaries.
827   Oceanography and Marine Biology: An Annual Review 33, 1-149.

828   Jackson, J.B.C., Kirby, M.X., Berger, W.H., Bjorndal, K.A., Botsford, L.W., Bourque, B.J.,
829   Bradbury, R.H., Cooke, R., Jon, E., Estes, J.A., Hughes, T.P., Kidwell, S., Lange, C.B.,
830   Lenihan, H.S., Pandolfi, J.M., Peterson, C.H., Steneck, R.S., Tegner, M.J., Warner,
831   R.R., 2001. Historical overfishing and the recent collapse of coastal ecosystems.
832   Science 293, 629-638.

833   Kurup, R.G., Hamilton, D.P., 2002. Flushing of dense, hypoxic water from a cavity of the
834   Swan River Estuary, Western Australia. Estuaries 25, 908-915.

835   Le Pape, O., Chauvet, F., Mahévas, S., Lazure, P., Guérault, D., Désaunay, Y., 2003.
836   Quantitative description of habitat suitability for the juvenile common sole (*Solea*
837   *solea*, L.) in the Bay of Biscay (France) and the contribution of different habitats to the
838   adult population. Journal of Sea Research 50, 139-149.

839   Lek, E., Fairclough, D.V., Platell, M.E., Clarke, K.R., Tweedley, J.R., Potter, I.C., 2011. To
840   what extent are the dietary compositions of three abundant, co-occurring labrid species
841   different and related to latitude, habitat, body size and season? Journal of Fish Biology
842   78, 1913-1943.

843   Lepesteur, M., Wegner, A., Moore, S.A., McComb, A., 2008. Importance of public
844   information and perception for managing recreational activities in the Peel-Harvey
845   estuary, Western Australia. Journal of Environmental Management 87, 389-395.

846   Loneragan, N.R., Potter, I.C., Lenanton, R.C.J., Caputi, N., 1986. Spatial and seasonal
847   differences in the fish fauna in the shallows of a large Australian estuary. Marine
848   Biology 92, 575-586.

849 Loneragan, N.R., Potter, I.C., Lenanton, R.C.J., 1989. Influence of site, season and year on
850   contributions made by marine, estuarine, diadromous and freshwater species to the fish
851   fauna of a temperate Australian estuary. Marine Biology 103, 461-479.

852 Loneragan, N.R., Kenyon, R.A,, Haywood, M.D.E., Kangas, M., Caputi, N., Sporer, E.,
853   2013. Impact of cyclones and macrophytes on the recruitment and landings of tiger
854   prawns, *Penaeus esculentus*, in Exmouth Gulf Western Australia. Estuarine Coastal
855   and Shelf Science 127, 46-58.

856 Lough, J.M., Gutpa, A.S., Hobday, A.J., 2012. Temperature, in: Poloczanska, E.S., Hobday,
857   A.J. (Eds.), Marine Climate Change in Australia: Impacts and Adaptation Responses
858   2012 Report Card. Commonwealth Scientific and Industrial Research Organisation,
859   Collingwood, Victoria. Pp. 402.

860 Lukatelich, R.J., McComb, A.J., 1986. Nutrient levels and the development of diatom and
861   blue-green algal blooms in a shallow Australian estuary. Journal of Plankton Research
862   8, 597-618.

863 Maes, J., Stevens, M., Ollevier, F., 2005. The composition and community structure of the
864   ichthyofauna of the upper Scheldt Estuary: synthesis of a 10-year data collection (1991-
865   2001). Journal of Applied Ichthyology 21, 86-93.

866 McComb, A., Humphries, R., 1992. Loss of nutrients from catchments and their ecological
867   impacts in the Peel-Harvey estuarine system, Western Australia. Estuaries 15, 529-537.

868 McComb, A.J., Atkins, R.P., Birch, P.B., Gordon, D.M., Lukatelich, R.J., 1981.
869   Eutrophication in the Peel-Harvey Estuarine System, Western Australia, in: Neilson, B.,
870   Cronin, L. (Eds.), Estuaries and Nutrients. Humana Press, pp. 323-342.

871 McComb, A.J., Lukatelich, R.J., 1995. The Peel-Harvey estuarine system, Western Australia,
872   in: McComb, A.J. (Ed.), In Eutrophic Estuaries and Lagoons. CRC Press, Florida, pp.
873   5-18.

874 Miller, S.J., Skilleter, G.A., 2006. Temporal variation in habitat use by nekton in a
875   subtropical estuarine system. Journal of Experimental Marine Biology and Ecology
876   337, 82-95.

877 Paerl, H., Hall, N., Peierls, B., Rossignol, K., 2014. Evolving Paradigms and Challenges in
878   Estuarine and Coastal Eutrophication Dynamics in a Culturally and Climatically
879   Stressed World. Estuaries and Coasts 37, 243-258.

880 Patchineelam, S.M., Kjerfve, B., Gardner, L.R., 1999. A preliminary sediment budget for the
881   Winyah Bay estuary, South Carolina, USA. Marine Geology 162, 133-144.

882 Pedretti, Y.M., Kobbryn, H.T., Sommerville, E.F., Wienczugow, K., 2011. Snapshot survey
883   of the distribution and abundance of seagrass and macroalgae in the Peel-Harvey

884   Estuary from November/December 2009. Marine and Freshwater Research Laboratory,
885   Institute for Environmental Science, Murdoch University, Perth, Western Australia.Pp.
886   81.

887   Potter, I.C., Loneragan, N.R., Lenanton, R.C.J., Chrystal, P.J., 1983. Blue-green algae and
888   fish population changes in a eutrophic estuary. Marine Pollution Bulletin 14, 228-233.

889   Potter, I.C., Cheal, A.J., Loneragan, N.R., 1988. Protracted estuarine phase in the life cycle of
890   a marine pufferfish (*Torquigener pleurogramma*). Marine Biology 98, 317 329.

891   Potter, I.C., Beckley, L.E., Whitfield, A.K., Lenanton, R.C., 1990. Comparisions between the
892   roles played by estuaries in the life cycles of fishes in temperate Western Australia and
893   Southern Africa. Environmental Biology of Fishes 28, 143-178.

894   Potter, I.C., Hyndes, G.A., 1999. Characteristics of the ichthyofaunas of southwestern
895   Australian estuaries, including comparisons with holarctic estuaries and estuaries
896   elsewhere in temperate Australia: a review. Austral Ecology 24, 395-421.

897   Potter, I.C., Warwick, R.M., Hall, N.G., Tweedley, J.R., 2015a. The physico-chemical
898   characteristics, biota and fisheries of estuaries, in: Craig, J. (Ed.), Freshwater Fisheries
899   Ecology. Wiley-Blackwell, pp. 48-79.

900   Potter, I.C., Tweedley, J.R., Elliott, M., Whitfield, A.K., 2015b. The ways in which fish use
901   estuaries: a refinement and expansion of the guild approach. Fish and Fisheries 16, 230-
902   239.

903   Rabalais, N.N., Turner, R.E., Díaz, R.J., Justić, D., 2009. Global change and eutrophication
904   of coastal waters. ICES Journal of Marine Science: Journal du Conseil 66, 1528–1537.

905   Ruibal-Conti, A., 2014. Connecting land to the ocean: a retrospective analysis of nutrient flux
906   pathways within the Peel-Harvey catchment-estuary system, University of Western
907   Australia. University of Western Australia, Perth, Western Australia.

908   Schelske, C.L., Odum, E.P., 1961. Mechanisms maintaining high productivity in Georgia
909   estuaries. Proceedings of the Gulf and Caribbean Fisheries Institute 14, 75-80.

910   Sheaves, M., Baker, R., Nagelkerken, I., Connolly, R.M., 2014. True value of estuarine and
911   coastal nurseries for fish: incorporating complexity and dynamics. Estuaries and
912   Coasts, 1-14.

913   Smith, K.A., Brown, J., Hammond, M., Nardi, A., 2008. Development of cost-effective
914   indices to monitor the nearshore fish communities of the Swan Region. Department of
915   Fisheries Western Australia, Perth, Western Australia, pp. 121.

916   Somerfield, P.J., Clarke, K.R., 2013. Inverse analysis in non-parametric multivariate
917   analyses: distinguishing groups of associated species which covary coherently across
918   samples. Journal of Experimental Marine Biology and Ecology 449, 261-273.

919 Steckis, R.A., Potter, I.C., Lenanton, R.C.J., 1995. The commercial fisheries in three south-
920   western Australian estuaries exposed to different degrees of eutrophication, in:
921   McComb, A.J. (Ed.), Eutrophic Shallow Estuaries and Lagoons. CRC Press, Boca
922   Raton, pp. 189-203.

923 Thiel, R., Potter, I.C., 2001. The ichthyofaunal composition of the Elbe Estuary: an analysis
924   in space and time. Marine Biology 138, 603-616.

925 Travers, M.J., Potter, I.C., 2002. Factors influencing the characteristics of fish assemblages in
926   a large subtropical marine embayment. Journal of Fish Biology 61, 764-784.

927 Tweedley, J.R., Warwick, R.M., Valesini, F.J., Platell, M.E., Potter, I.C., 2012. The use of
928   benthic macroinvertebrates to establish a benchmark for evaluating the environmental
929   quality of microtidal, temperate southern hemisphere estuaries. Marine Pollution
930   Bulletin 64, 1210-1221.

931 Tweedley, J.R., Warwick, R.M., Clarke, K.R., Potter, I.C., 2014. Family-level AMBI is valid
932   for use in the north-eastern Atlantic but not for assessing the health of microtidal
933   Australian estuaries. Estuarine, Coastal and Shelf Science 141, 85-96.

934 Tweedley, J.R., Warwick, R.M., Potter, I.C., 2016a. The contrasting ecology of macrotidal
935   and microtidal estuaries. Oceanography and Marine Biology: An Annual Review 54,
936   73-170

937 Tweedley, J.R., Hallett, C.S., Warwick, R.M., Clarke, K.R., Potter, I.C., 2016b. The dramatic
938   effect of an extreme weather event on the benthos of a microtidal estuary. Marine and
939   Freshwater Research 67, 327-341.

940 Ugland, K.I., Gray, J.S., Ellingsen, K.E., 2003. The species–accumulation curve and
941   estimation of species richness. Journal of Animal Ecology 72, 888-897.

942 Valesini, F.J., Potter, I.C., Clarke, K.R., 2004. To what extent are the fish compositions at
943   nearshore sites along a heterogeneous coast related to habitat type? Estuarine, Coastal
944   and Shelf Science 60, 737-754.

945 Valesini, F.J., Coen, N.J., Wildsmith, M.D., Hourston, M., Tweedley, J.R., Hallett, C.S.,
946   Linke, T.E., Potter, I.C., 2009. Relationships between fish faunas and habitat type in
947   south-western Australian estuaries. Project 2004/045. Report for Fisheries Research and
948   Development Corporation. Murdoch University, Perth.

949 Valesini, F.J., Tweedley, J.R., Clarke, K.R., Potter, I.C., 2014. The importance of regional,
950   system-wide and local spatial scales in structuring temperate estuarine fish
951   communities. Estuaries and Coasts 37, 525-547.

952 Valesini, F.J., Tweedley, J.R., 2015. Effect of the Becher Point boat ramp on the food
953   resources of Little Penguins on Penguin Island. . Murdoch University, Perth, Western
954   Australia. Pp. 121.

955 Veale, L., Tweedley, J.R., Clarke, K.R., Hallett, C.S., Potter, I.C., 2014. Characteristics of the
956   ichthyofauna of a temperate microtidal estuary with a reverse salinity gradient,
957   including inter-decadal comparisons. Journal of Fish Biology 85, 1320-1354.

958 Veale, L., Coulson, P., Hall, N., Hesp, A., Potter, I.C., 2015. Age and size compositions,
959   habitats, growth and reproductive characteristics of a terapontid (*Pelates octolineatus*)
960   in coastal waters. Marine and Freshwater Research 66, 535-548.

961 Veale, L.J., 2013. Inter-period comparisons of the ichthyofaunas of two nearby, modified
962   estuaries and the biology of *Pelates octolineatus* (Terapontidae). Murdoch University,
963   Perth, Australia. pp. 260.

964 Veale, L.J., Coulson, P.G., Hall, N.G., Potter, I.C., 2016. Recruitment, emigration and
965   seasonal growth of a marine estuarine-opportunist fish species in a microtidal estuary,
966   including comparisons with coastal waters and among decades. Marine and Freshwater
967   Research.

968 Whitfield, A.K., 1999. Ichthyofaunal assemblages in estuaries: a South African case study.
969   Reviews in Fish Biology and Fisheries 9, 151-186.

970 Whittaker, R.H., 1952. A study of summer foliage insect communities in the Great Smoky
971   Mountains. Ecological Monographs 22, 1-44.

972 Wildsmith, M.D., Rose, T.H., Potter, I.C., Warwick, R.M., Clarke, K.R., Valesini, F.J., 2009.
973   Changes in the benthic macroinvertebrate fauna of a large microtidal estuary following
974   extreme modifications aimed at reducing eutrophication. Marine Pollution Bulletin 58,
975   1250-1262.

976 Wilson, C., Hale, J., Paling, E.I., 1999. Macrophyte abundance, distribution and composition
977   of the Peel-Harvey Estuary: comparisons before and after the opening of the
978   Dawesville Channel (July 1985 to June 1999). Marine and Freshwater Research
979   Laboratory, Murdoch University, Perth, Western Australia, pp. 63.

980 Wilson, C.C., Latchford, J., Paling, E., 1997. Macrophyte abundance and composition in the
981   Peel-Harvey Estuarine System from July 1996 to June 1997. Marine and Freshwater
982   Laboratories, Murdoch University, Perth, Western Australia, pp. 63.

983 Yamashita, Y., Tominaga, O., Takami, H., Yamada, H., 2003. Comparison of growth,
984   feeding and cortisol level in *Platichthys bicoloratus* juveniles between estuarine and
985   nearshore nursery grounds. Journal of Fish Biology 63, 617-630.

986   Young, G.C., Potter, I.C., 2003a. Induction of annual cyclical changes in the ichthyofauna of
987   a large microtidal estuary following an artificial and permanent increase in tidal flow.
988   Journal of Fish Biology 63, 1306-1330.

989   Young, G.C., Potter, I.C., 2003b. Influence of an artificial entrance channel on the
990   ichthyofauna of a large estuary. Marine Biology 142, 1181-1194.

991   Zammit, C., Bussemaker, P., Hall, J., 2006. Establishment of a Decision Support System for
992   Water Quality Improvement and Protection of the Peel Inlet and Harvey Estuary.
993   Department of Environment, NRM and Salinity Division, Aquatic Science Branch. pp.
994   69

1023 **Figure 6.** Shade plot of the abundance for 41 fish species (those occurring in more than 4

1024 replicates) derived from 102.5 m seine samples from the four seasons (Su: Summer, A:

1025 Autumn, W: Winter, Sp: Spring) and five regions (MC, EP, WP, NH, SH, as in Fig. 1) in

1026 each of the three periods (1980-81, 1996-97, 2008-10). Density of each species has been

1027 divided by the dispersion weighting factor shown after the species name, square root

1028 transformed and averaged over replicates and the two years in each Season × Region × Period

1029 combination, and the result represented by the colour shading shown in the key.

1030

1031 **Figure 7.** Shade plot of the abundance for 30 fish species (those occurring in more than four

1032 replicates) derived from 21.5 m seine samples in each of the two periods (1996-97, 2008-10).

1033 Construction as in legend to Fig. 6.

1034

1035 **Figure 8.** Centroid nMDS as in Fig. 4 but (for greater clarity) for only three of the five

1036 regions, spanning the regional conditions. Superimposed is a segmented bubble plot where

1037 segment size reflects the dispersion weighted then root-transformed abundances, averaged

1038 over years and seasons, for six species (selected from the shade plot of Fig. 6, as important in

1039 distinguishing these regions and/or the period changes). The segment sizes in the key

1040 correspond to a value of 1 on this weighted, transformed scale, the same for all species.

Table 1
Click here to download Table(s): Peel Table 1_Revised.docx

Table 1. Life cycle guilds (LC), rankings by ordered density (*Rk*), mean densities (*N*; numbers of fish 100 m^{-2}) and percentage contributions to the total catch (*%*) of the fish species caught in the Peel-Harvey Estuary using a 102.5 m seine seasonally during two consecutive years, i.e. 1980-81, 1996-97 and 2008-10. In this and subsequent Tables, life cycle guilds are abbreviated as follows. MS, marine straggler; MEO, marine estuarine-opportunist; E&M, estuarine & marine; E, solely estuarine; E&F, estuarine & freshwater and SA, semi-anadromous.

Species	LC	1980-1981			1996-1997			2008-2010		
		Rk	*N*	*%*	*Rk*	*N*	*%*	*Rk*	*N*	*%*
Torquigener pleurogramma	MEO	**6**	**2.6**	**5.7**	**1**	**5.6**	**41.8**	**1**	**13.3**	**30.7**
Ostorhinchus rueppellii	E&M	**2**	**6.4**	**14.3**	**7**	**0.5**	**3.3**	**2**	**10.7**	**24.6**
Hyperlophus vittatus	MEO	**4**	**3.1**	**6.8**	**2**	**2.3**	**16.9**	**3**	**7.2**	**16.5**
Atherinosoma elongata	E	**10**	**1.0**	**2.2**	**4**	**1.3**	**9.3**	**4**	**2.8**	**6.5**
Leptatherina presbyteroides	E&M	11	1.0	2.2	**3**	**1.3**	**9.4**	**5**	**2.2**	**5.1**
Atherinomorus vaigiensis	MEO	**8**	**1.4**	**3.1**	15	<0.1	0.5	**6**	**1.1**	**2.5**
Pelates octolineatus	MEO	**1**	**16.4**	**36.6**	10	0.1	1.0	**7**	**1.1**	**2.5**
Favonigobius lateralis	E&M	**5**	**2.6**	**5.8**	**8**	**0.3**	**2.5**	**8**	**1.1**	**2.5**
Craterocephalus mugiloides	E	22	0.1	0.3	30	<0.1	<0.1	**9**	**0.8**	**1.9**
Aldrichetta forsteri	MEO	**7**	**2.2**	**5.0**	**5**	**0.6**	**4.2**	**10**	**0.6**	**1.5**
Gymnapistes marmoratus	MEO	13	0.4	0.9	12	0.1	0.9	11	0.6	1.5
Haletta semifasciata	MEO	23	0.1	0.2	31	<0.1	<0.1	12	0.3	0.8
Gerres subfasciatus	MEO	**3**	**3.9**	**8.8**	**6**	**0.6**	**4.1**	13	0.3	0.7
Sillaginodes punctatus	MEO	20	0.1	0.3	16	<0.1	0.4	14	0.3	0.6
Hyporhamphus melanochir	E&M	24	0.1	0.2	21	<0.1	0.1	15	0.2	0.5
Pseudogobius olorum	E&F	15	0.3	0.6	20	<0.1	0.2	16	0.2	0.4
Spratelloides robustus	MS				35	<0.1	<0.1	17	0.1	0.3
Rhabdosargus sarba	MEO	26	<0.1	0.1	**9**	**0.2**	**1.2**	18	<0.1	0.2
Callogobius depressus	E&M	31	<0.1	<0.1	32	<0.1	<0.1	19	<0.1	0.2
Sillago vittata	MS				29	<0.1	<0.1	20	<0.1	<0.1
Pseudorhombus jenynsii	MEO	21	0.1	0.3	17	<0.1	0.4	21	<0.1	<0.1
Sillago schomburgkii	MEO	12	0.5	1.2	18	<0.1	0.3	22	<0.1	<0.1
Scobinichthys granulatus	MS	36	<0.1	<0.1	32	<0.1	<0.1	23	<0.1	<0.1
Sillago burrus	MEO	34	<0.1	<0.1	13	<0.1	0.7	24	<0.1	<0.1
Arenigobius bifrenatus	E&M	18	0.1	0.3	26	<0.1	<0.1	25	<0.1	<0.1
Acanthaluteres brownii	MS							26	<0.1	<0.1
Stigmatophora argus	MS							27	<0.1	<0.1
Cnidoglanis macrocephalus	E&M	29	<0.1	<0.1	35	<0.1	<0.1	28	<0.1	<0.1
Leptatherina wallacei	E&F	17	0.2	0.3	28	<0.1	<0.1	29	<0.1	<0.1
Arripis georgianus	MEO				23	<0.1	0.1	30	<0.1	<0.1
Hyporhamphus regularis	E	19	0.1	0.3	27	<0.1	<0.1	31	<0.1	<0.1
Monacanthus chinensis	MS							32	<0.1	<0.1
Mugil cephalus	MEO	14	0.3	0.8	23	<0.1	0.1	33	<0.1	<0.1
Meuschenia freycineti	MS				39	<0.1	<0.1	34	<0.1	<0.1
Sillago bassensis	MS	**9**	**1.1**	**2.5**	14	<0.1	0.6	35	<0.1	<0.1
Engraulis australis	MS	30	<0.1	<0.1	11	0.1	0.9	36	<0.1	<0.1
Acanthopagrus butcheri	E							36	<0.1	<0.1
Ammotretis elongatus	MS	32	<0.1	<0.1	22	<0.1	0.1	36	<0.1	<0.1
Callogobius mucosus	E&M							39	<0.1	<0.1
Pseudocaranx wrighti	MS							40	<0.1	<0.1
Platycephalus laevigatus	MS							41	<0.1	<0.1
Lesueurina platycephala	MS							41	<0.1	<0.1
Myliobatis australis	MS							43	<0.1	<0.1
Siphamia cephalotes	E&M				39	<0.1	<0.1	43	<0.1	<0.1
Arripis truttaceus	MEO	37	<0.1	<0.1				43	<0.1	<0.1
Favonigobius punctatus	MS							43	<0.1	<0.1
Contusus brevicaudus	MEO	25	0.1	0.2	23	<0.1	0.1	43	<0.1	<0.1
Filicampus tigris	MS							48	<0.1	<0.1
Pomatomus saltatrix	MEO	27	0.1	0.1	19	<0.1	0.2	48	<0.1	<0.1
Notolabrus parilus	MS							48	<0.1	<0.1
Brachaluteres jacksonianus	MS	37	<0.1	<0.1	43	<0.1	<0.1	48	<0.1	<0.1
Iso rhothophilus	MS							52	<0.1	<0.1
Pentapodus vitta	MS							52	<0.1	<0.1
Neatypus obliquus	MS							52	<0.1	<0.1
Enoplosus armatus	MS				39	<0.1	<0.1	52	<0.1	<0.1
Diodon nicthemerus	MS							52	<0.1	<0.1
Heterodontus portusjacksoni	MS				43	<0.1	<0.1			
Sardinops neopilchardus	MS	32	<0.1	0.0						
Nematalosa vlaminghi	SA	35	<0.1	0.0	35	<0.1	<0.1			
Urocampus carinirostris	E&M	37	<0.1	<0.1	43	<0.1	<0.1			
Platycephalus speculator	MS				35	<0.1	<0.1			
Amniataba caudavittata	E	16	0.2	0.5	32	<0.1	<0.1			
Pseudocaranx dentex	MS				39	<0.1	<0.1			
Upeneus tragula	MS				43	<0.1	<0.1			
Afurcagobius suppositus	E&F	28	<0.1	0.1	43	<0.1	<0.1			
Number of samples			**62**			**120**			**155**	
Number of species			**39**			**47**			**56**	
Number of fish			**44,386**			**25,792**			**107,670**	
Mean number of fish 100 m^{-2}			**44**			**13**			**44**	

Table 2
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Table 2. Life cycle guilds (LC), rankings by density (Rk), mean densities (N, number of fish 100 m^{-2}) and percentage contributions to the total catch (%) of the fish species caught in the Peel-Harvey Estuary using a 21.5 m seine over two consecutive years, i.e. 1996-97 and 2008-10.

Species	LC	1996-1997			2008-2010		
		Rk	N	%	Rk	N	%
Atherinosoma elongata	E	2	27.2	12.1	1	76.5	27.1
Hyperlophus vittatus	MEO	1	130.9	58.4	2	62.6	22.2
Leptatherina presbyteroides	E&M	3	24.4	10.9	3	37.2	13.1
Craterocephalus mugiloides	E	22	0.1	<0.1	4	31.9	11.3
Ostorhinchus rueppellii	E&M	7	3.8	1.7	5	19.8	7.0
Torquigener pleurogramma	MEO	4	12.2	5.4	6	13.9	4.9
Aldrichetta forsteri	MEO	5	9.9	4.4	7	13.7	4.8
Favonigobius lateralis	E&M	6	7.0	3.1	8	9.7	3.4
Atherinomorus vaigiensis	MEO	8	2.6	1.2	9	7.8	2.7
Gymnapistes marmoratus	MEO	10	0.6	0.3	10	2.2	0.8
Haletta semifasciata	MEO	18	0.1	<0.1	11	1.2	0.4
Pelates octolineatus	MEO	15	0.2	0.1	12	1.2	0.4
Leptatherina wallacei	E&F	9	2.6	1.1	13	1.1	0.4
Sillaginodes punctatus	MEO	13	0.2	0.1	14	1.0	0.3
Pseudogobius olorum	E&F	11	0.5	0.2	15	0.8	0.3
Mugil cephalus	MEO	16	0.2	0.1	16	0.4	0.1
Stigmatophora argus	MS	37	<0.1	<0.1	17	0.3	0.1
Hyporhamphus melanochir	E&M	19	0.1	<0.1	18	0.2	0.1
Sillago burrus	MEO	20	<0.1	<0.1	19	0.1	<0.1
Sillago vittata	MEO	14	0.2	0.1	20	0.1	<0.1
Callogobius mucosus	E&M				20	0.1	<0.1
Rhabdosargus sarba	MEO	21	<0.1	<0.1	22	0.1	<0.1
Ammotretis elongatus	MS	17	0.2	0.1	23	<0.1	<0.1
Cnidoglanis macrocephalus	E&M	34	<0.1	<0.1	24	<0.1	<0.1
Arenigobius bifrenatus	E&M	26	<0.1	<0.1	24	<0.1	<0.1
Arripis truttaceus	MEO				26	<0.1	<0.1
Engraulis australis	MS				27	<0.1	<0.1
Scobinichthys granulatus	MS	34	<0.1	<0.1	28	<0.1	<0.1
Pseudorhombus jenynsii	MEO	12	0.4	0.2	29	<0.1	<0.1
Hyporhamphus regularis	E	30	<0.1	<0.1	29	<0.1	<0.1
Gerres subfasciatus	MEO	22	<0.1	<0.1	29	<0.1	<0.1
Sillago schomburgkii	MEO	24	<0.1	<0.1	32	<0.1	<0.1
Spratelloides robustus	MS	39	<0.1	<0.1	33	<0.1	<0.1
Omobranchus germaini	MS				34	<0.1	<0.1
Contusus brevicaudus	MEO	31	<0.1	<0.1	35	<0.1	<0.1
Urocampus carinirostris	E&M	27	<0.1	<0.1	36	<0.1	<0.1
Pugnaso curtirostris	E				36	<0.1	<0.1
Lesueurina platycephala	MS				36	<0.1	<0.1
Meuschenia freycineti	MS				36	<0.1	<0.1
Acanthaluteres brownii	MS				36	<0.1	<0.1
Monacanthus chinensis	MS				36	<0.1	<0.1
Siphamia cephalotes	E&M				42	<0.1	<0.1
Platycephalus laevigatus	MS	37	<0.1	<0.1	43	<0.1	<0.1
Acanthopagrus butcheri	E				43	<0.1	<0.1
Enoplosus armatus	MS				43	<0.1	<0.1
Acanthaluteres vittiger	MS				43	<0.1	<0.1
Arripis georgianus	MEO	31	<0.1	<0.1			
Brachaluteres jacksonianus	MS	39	<0.1	<0.1			
Callogobius depressus	E&M	34	<0.1	<0.1			
Afurcagobius suppositus	E	28	<0.1	<0.1			
Gonorynchus greyi	MEO	31	<0.1	<0.1			
Nematalosa vlaminghi	SA	39	<0.1	<0.1			
Petroscirtes breviceps	MS	39	<0.1	<0.1			
Pomatomus saltatrix	MEO	28	<0.1	<0.1			
Sillago bassensis	MS	25	<0.1	<0.1			
Sardinops neopilchardus	MS	39	<0.1	<0.1			
Number of samples			240			155	
Number of species			43			46	
Number of fish			62,350			50,845	
Mean number of fish 100 m^{-2}			224			283	

Table 3
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Table 3. Number of species and number of individuals of each life cycle guild in samples collected from the Peel-Harvey Estuary using a 102.5 m seine in 1980-81, 1996-97 and 2008-10 and a 21.5 m seine in the last two periods.

| | (a) 102.5 m seine | | | | | | | (b) 21.5 m seine | | | |
| | 1980-81 | | 1996-97 | | 2008-10 | | | 1996-97 | | 2008-10 | |
LC Guild	*N*	%	*N*	%	*N*	%		*N*	%	*N*	%
Species											
MS	6	15.4	13	27.7	23	39.3		9	20.9	13	28.3
MEO	17	43.6	17	36.2	18	33.9		19	44.2	17	37.0
E&M	8	20.5	9	19.1	9	16.1		8	18.6	9	19.6
E	4	12.8	4	10.6	4	7.1		4	9.3	5	10.9
E&F	3	5.1	3	4.3	2	3.6		2	4.7	2	4.3
A	1	2.6	1	2.1	0	0		1	2.3	0	0
Total	**39**		**47**		**56**			**43**		**46**	
LC Guild	*D*	%	*D*	%	*D*	%		*D*	%	*D*	%
Individuals											
MS	1.4	3.0	0.7	4.7	1.2	2.6		0.6	0.3	0.9	0.3
MEO	31.5	69.7	10.0	67.8	25.3	56.4		158.0	70.3	104.6	36.9
E&M	10.4	22.9	2.4	16.3	14.5	32.2		35.5	15.8	67.2	23.7
E	1.5	3.2	1.5	10.2	3.7	8.2		27.4	12.2	108.6	38.3
E&F	0.5	1.1	0.1	0.7	0.3	0.6		3.1	1.4	1.9	0.7
SA	0.1	0.1	0.1	0.3	0	0		<0.1	<0.1	0	0
Total	**45.4**		**14.8**		**45.0**			**225**		**283.1**	

Table 4
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Table 4. Mean squares (MS), Pseudo-F (pF) values, components of variation (COV) and significance levels (P) for the four-factor PERMANOVA tests on the Bray-Curtis similarity matrices constructed from fish abundances for the five regions of the Peel-Harvey Estuary using (a) 102.5 m seine seasonally over two consecutive years in three periods, i.e. 1980-81, 1996-97 and 2008-10, and (b) 21.5 m seine seasonally in 1996-97 and 2008-10. df = degrees of freedom. Clearly significant results (at the $P < 0.005$ level) are highlighted in bold. P values marked with an asterisk are from tests on low numbers of df, so are generated by the Monte Carlo method, which involves an extra degree of approximation.

| | (a) 102.5 m seine | | | | | (b) 21.5 m seine | | | | |
Main effects	*df*	MS	*pF*	COV	*P*	*df*	MS	*pF*	COV	*P*
Period	2	**53409**	**8.8**	**447**	**0.001***	1	**21526**	**3.7**	**116**	**0.003***
Season	3	**15920**	**2.8**	**123**	**0.002**	3	**13112**	**3.2**	**132**	**0.004**
Region	4	**13568**	**3.8**	**152**	**0.001**	4	**14110**	**5.4**	**209**	**0.001**
Year (Period)	3	**6241**	**2.9**	**74**	**0.001**	2	**5912**	**2.8**	**55**	**0.001**
Interactions										
Period × Season	6	5811	1.2	30	0.238	3	6381	1.6	72	0.094
Period × Region	8	**9501**	**3.0**	**301**	**0.001**	4	**6877**	**2.7**	**159**	**0.002**
Season × Region	12	3098	1.3	43	0.032	12	3674	1.4	78	0.010
Year (Period) × Season	9	**5096**	**2.4**	**214**	**0.001**	6	**3974**	**1.9**	**107**	**0.001**
Year (Period) × Region	12	3168	1.5	91	0.001	8	2581	1.2	32	0.085
Period × Season × Region	24	2808	1.2	89	0.038	12	2895	1.1	46	0.219
Year (Period) × Season× Region	35	2354	1.1	71	0.082	24	2592	1.2	133	0.008
Residuals	218	2154		2154		195	2136		2136	

Table 5
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Table 5. $\bar{R}$ and significance level (P) values, derived from two-way crossed ANOSIM tests of the abundances of the various fish species caught in the Peel-Harvey Estuary using (a) 102.5 m seine in 1980-81, 1996-97 and 2008-10 and (b) 21.5 m seine 1996-97 and 2008-10. Significant results for region and season are highlighted in grey.

(a)	1980-81	1996-97	2008-10
Region	0.405	0.028	0.523
Season	0.076	0.129	0.417

(b)		1996-97	2008-10
Region		0.403	0.283
Season		0.363	0.425

Table 6
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Table 6. Average and pairwise $\bar{R}$ statistic and significance level (P) values, derived from two-way crossed ANOSIM tests for Period and Season, separately for each region, based on abundances of the various fish species caught using a 102.5 m seine in 1980-81, 1996-97 and 2008-10, with the values for pairwise period and seasonal comparisons given below.

Mandurah Channel

Period	$\bar{R} = 0.833$	$P = 0.1\%$		Season	$\bar{R} = 0.479$	$P = 0.2\%$	
					Su	A	W
	1980-81	1996-97		A	0.750		
1996-97	0.938			W	0.500	0.417	
2008-10	1.000	0.500		Sp	0.667	0.500	0.250

Eastern Peel

Period	$\bar{R} = 0.883$	$P = 0.1\%$		Season	$\bar{R} = 0.486$	$P = 0.4\%$	
					Su	A	W
	1980-81	1996-97		A	0.417		
1996-97	0.813			W	0.667	0.583	
2008-10	1.000	0.750		Sp	0.500	0.583	0.167

Western Peel

Period	$\bar{R} = 0.153$	$P = 9.5\%$		Season	$\bar{R} = 0.076$	$P = 31.3\%$	
					Su	A	W
	1980-81	1996-97		A	-0.167		
1996-97	0.313			W	0.167	0.250	
2008-10	0.188	0.000		Sp	-0.167	0.417	0.000

Northern Harvey

Period	$\bar{R} = 0.583$	$P = 0.1\%$		Season	$\bar{R} = 0.111$	$P = 22.8\%$	
					Su	A	W
	1980-81	1996-97		A	-0.083		
1996-97	0.625			W	0.583	0.083	
2008-10	0.563	0.750		Sp	-0.083	-0.167	0.083

Southern Harvey

Region	$\bar{R} = 0.508$	$P = 0.1\%$		Season	$\bar{R} = 0.144$	$P = 15.8\%$	
					Su	A	W
	1980-81	1996-97		A	-0.333		
1996-97	0.540			W	0.208	0.167	
2008-10	0.611	0.563		Sp	0.605	0.507	-0.395

Table 7
Click here to download Table(s): Peel Table 7.docx

Table 7. Average and pairwise $\bar{R}$ statistic and significance level (P) values, derived from two-way crossed ANOSIM tests for Period and Season, separately for each region, based on abundances of the various fish species caught using a 21.5 m seine in 1996-97 and 2008-10, with the values for pairwise seasonal comparisons given below.

Mandurah Channel

	Su	A	W
Period	$\bar{R}=0.938$ $P=1.2\%$		
Season	$\bar{R}=0.792$ $P=0.2\%$		
A	0.875		
W	1.000	0.625	
Sp	0.750	0.875	0.500

Eastern Peel

	Su	A	W
Period	$\bar{R}=0.375$ $P=1.2\%$		
Season	$\bar{R}=0.188$ $P=15.3\%$		
A	0.625		
W	0.250	0.250	
Sp	-0.375	0.500	-0.250

Western Peel

	Su	A	W
Period	$\bar{R}=0.313$ $P=16\%$		
Season	$\bar{R}=0.208$ $P=11.3\%$		
A	0.500		
W	0.375	0.125	
Sp	0.250	0.250	0.000

Northern Harvey

	Su	A	W
Period	$\bar{R}=0.563$ $P=6.2\%$		
Season	$\bar{R}=0.094$ $P=32.2\%$		
A	-0.375		
W	0.625	-0.250	
Sp	0.125	-0.250	0.500

Southern Harvey

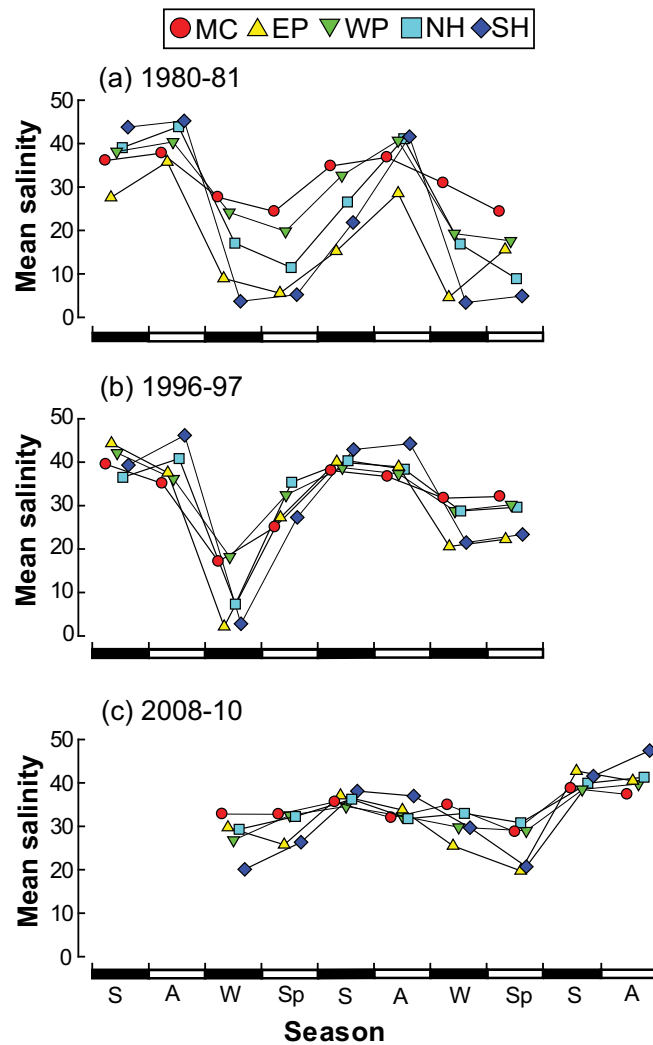|	Su	A	W
Period	$\bar{R}=0.750$ $P=1.2\%$		
Season	$\bar{R}=0.448$ $P=0.3\%$		
A	0.375		
W	0.625	0.000	
Sp	0.250	0.500	0.500

Figure 1
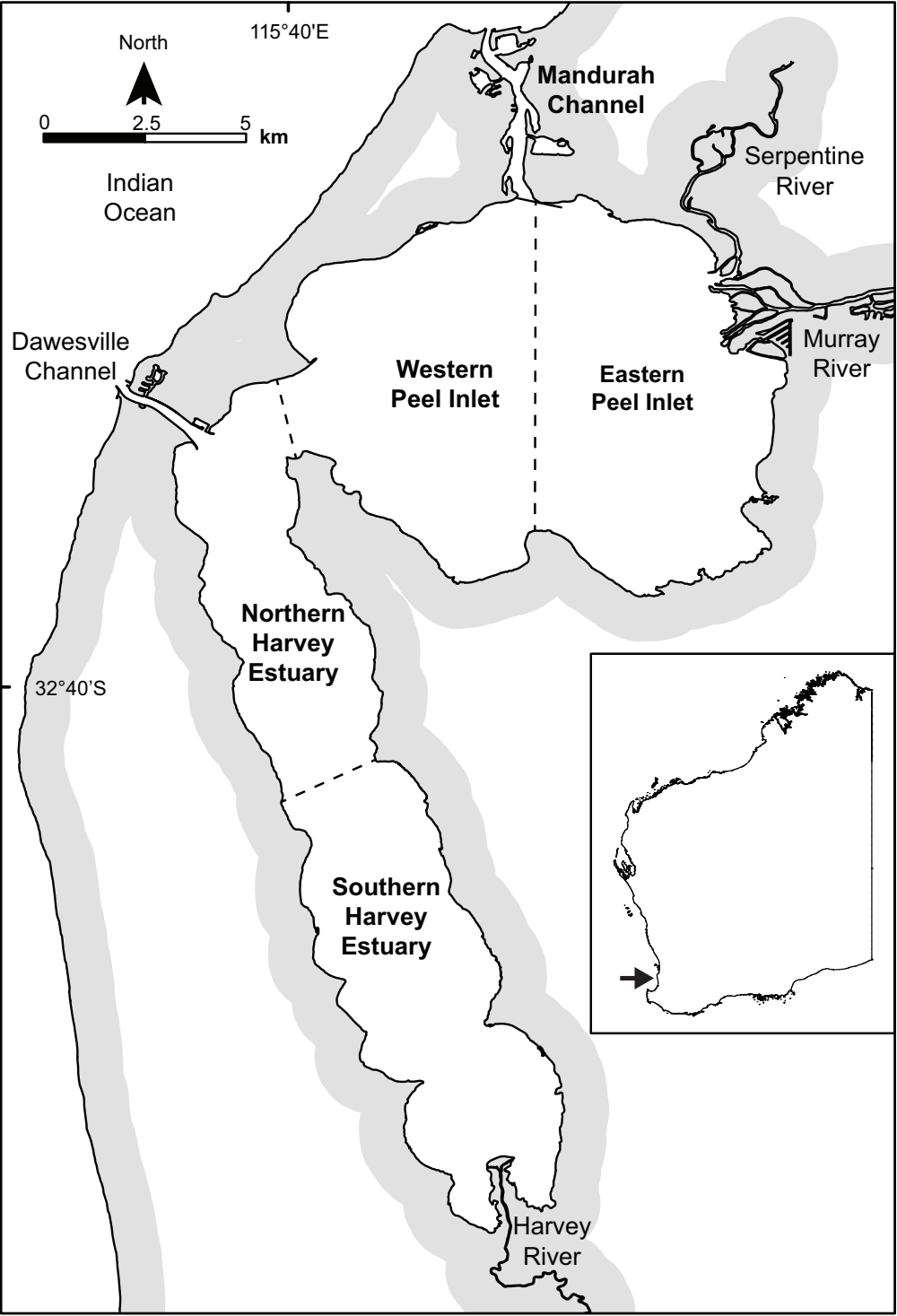
Figure. 1

Figure 2_Colour

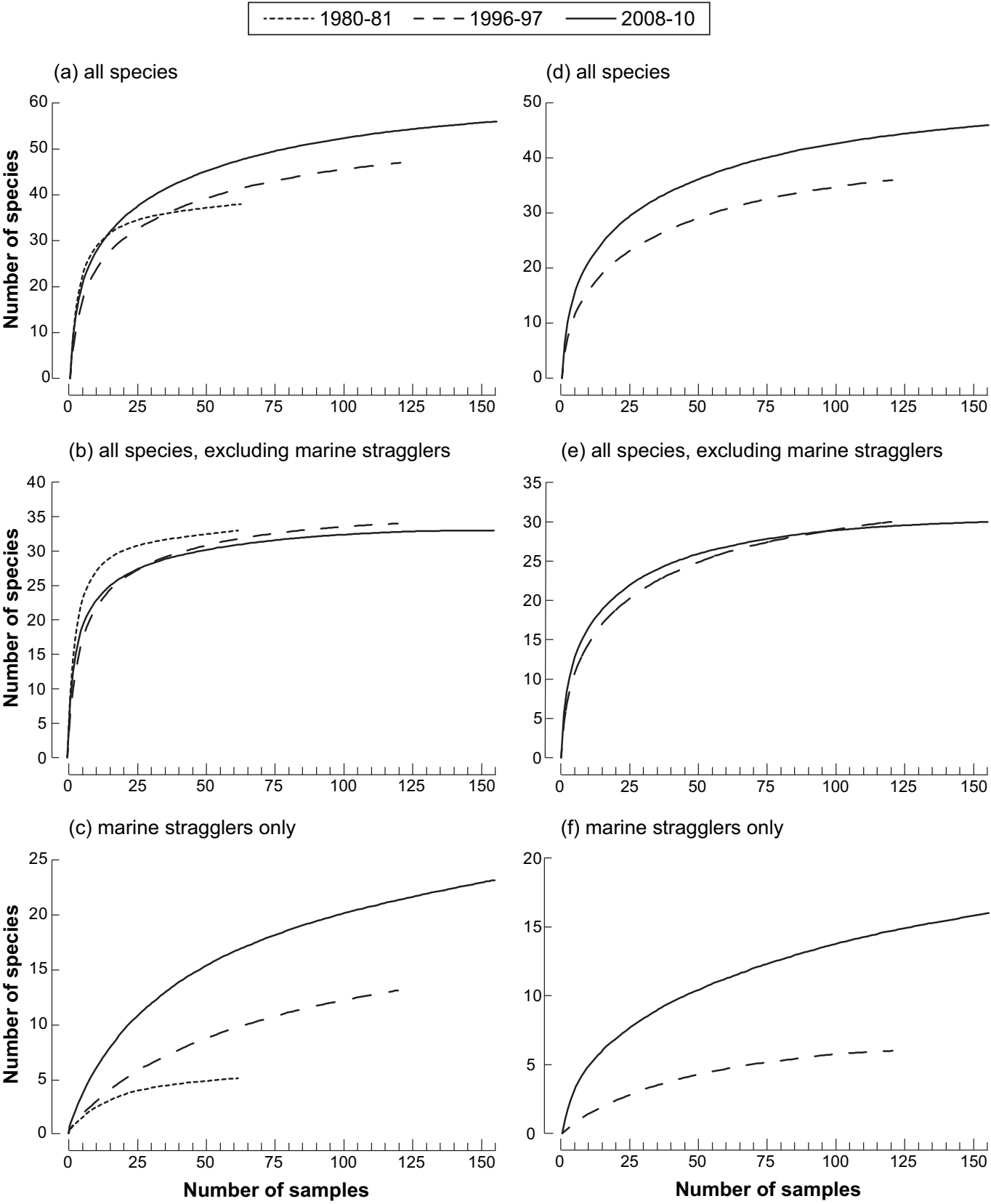Figure. 2

Figure 2_Black & White
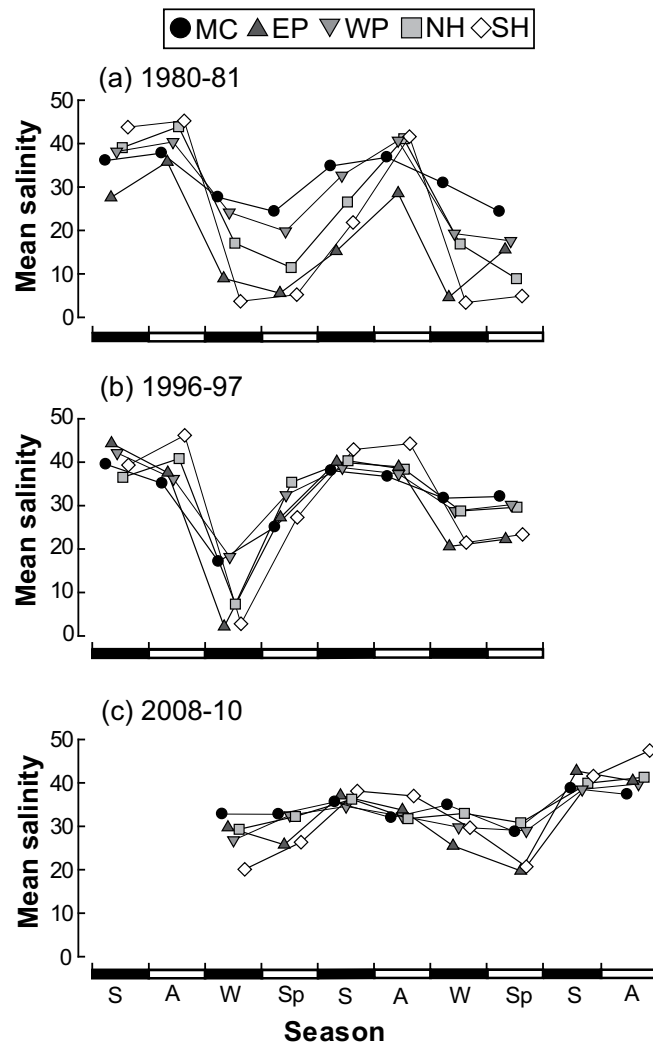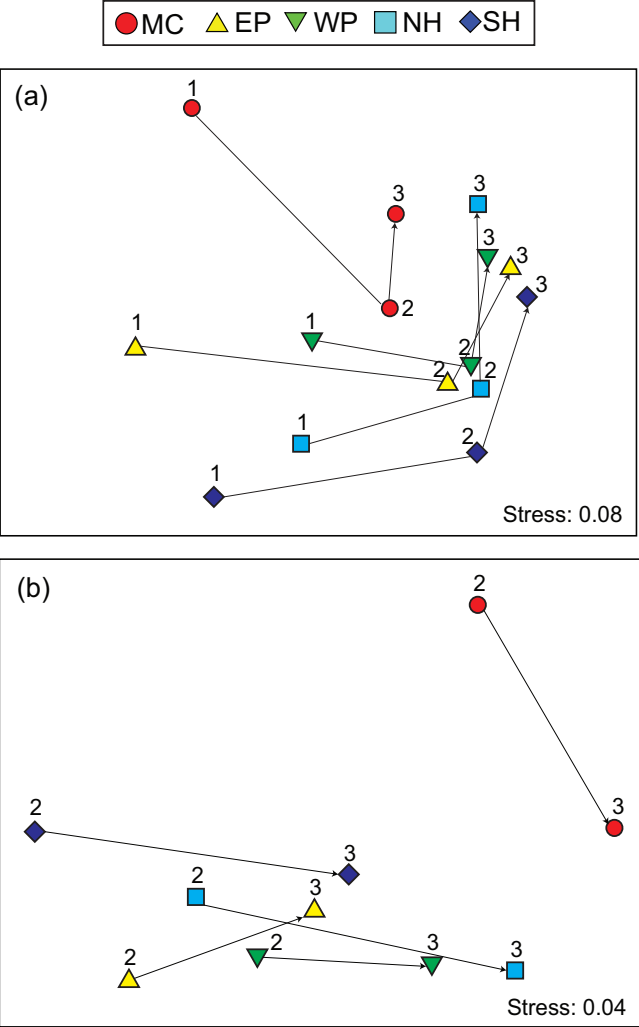

Figure. 2

Figure 3

Figure 3

Figure 4_Colour

Figure. 4

Figure 4_Black & White
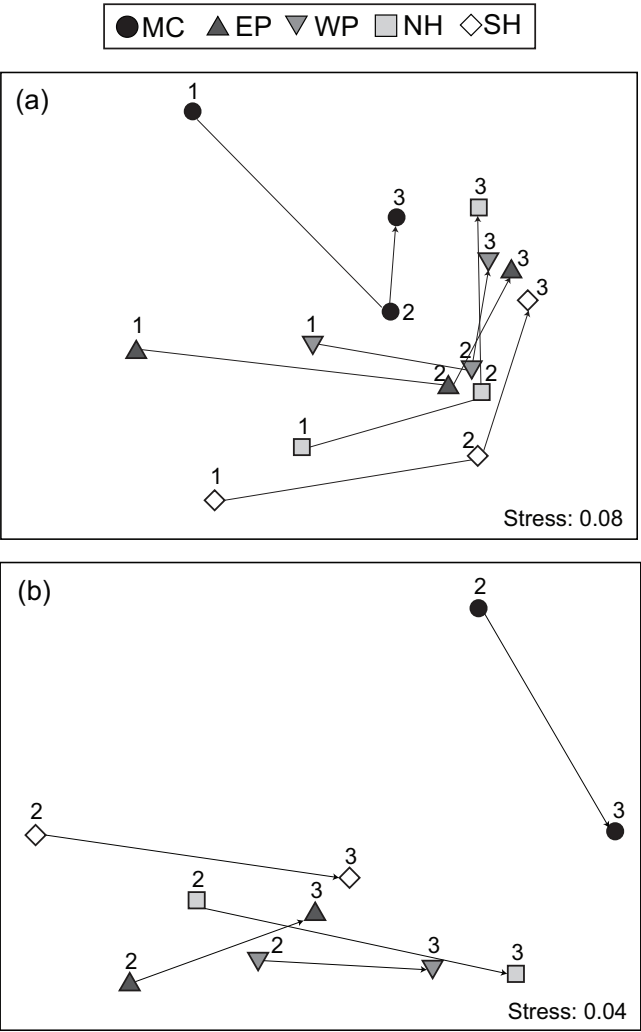
Figure. 4

Figure 5
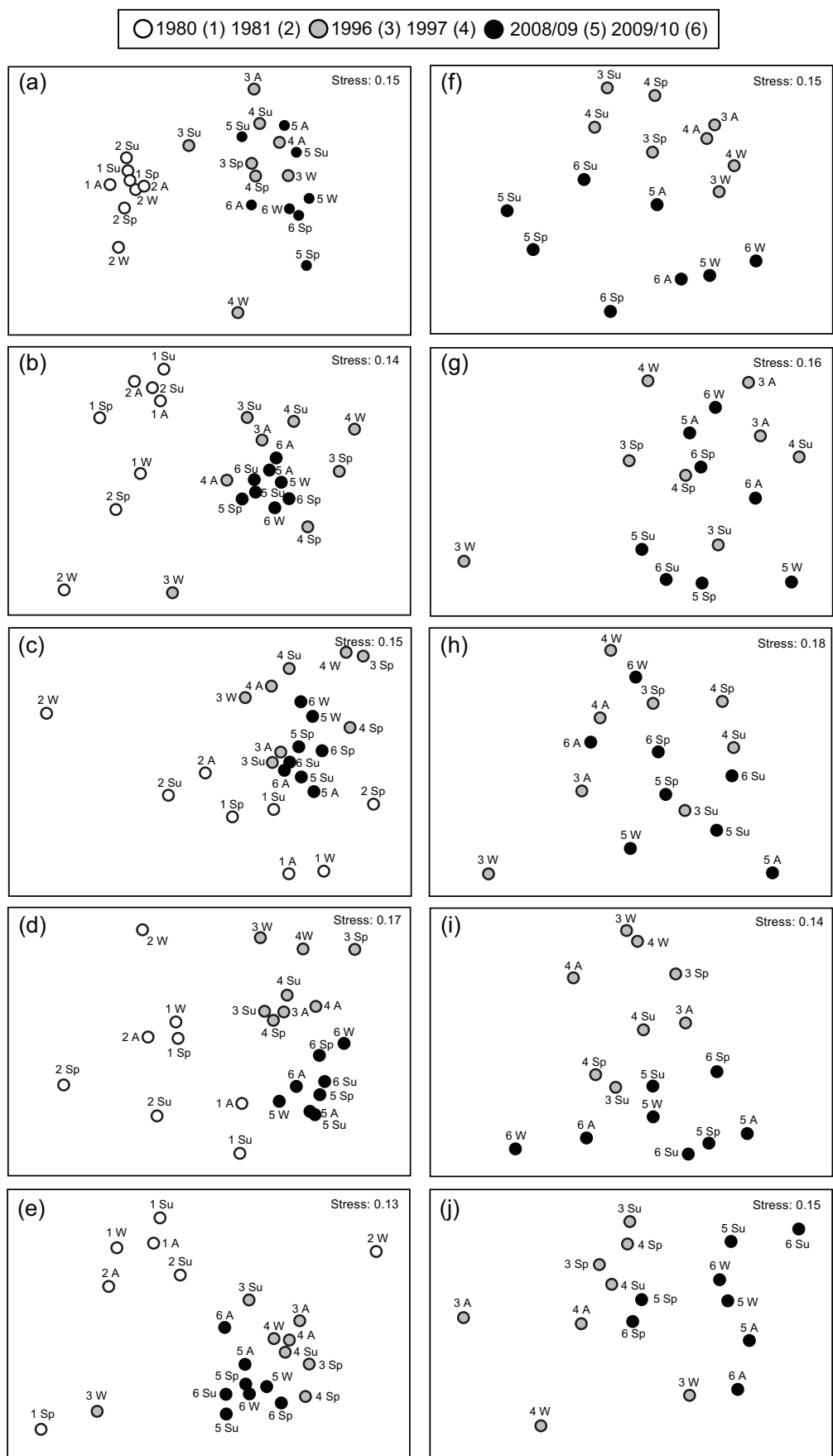
Figure 5

Figure 6
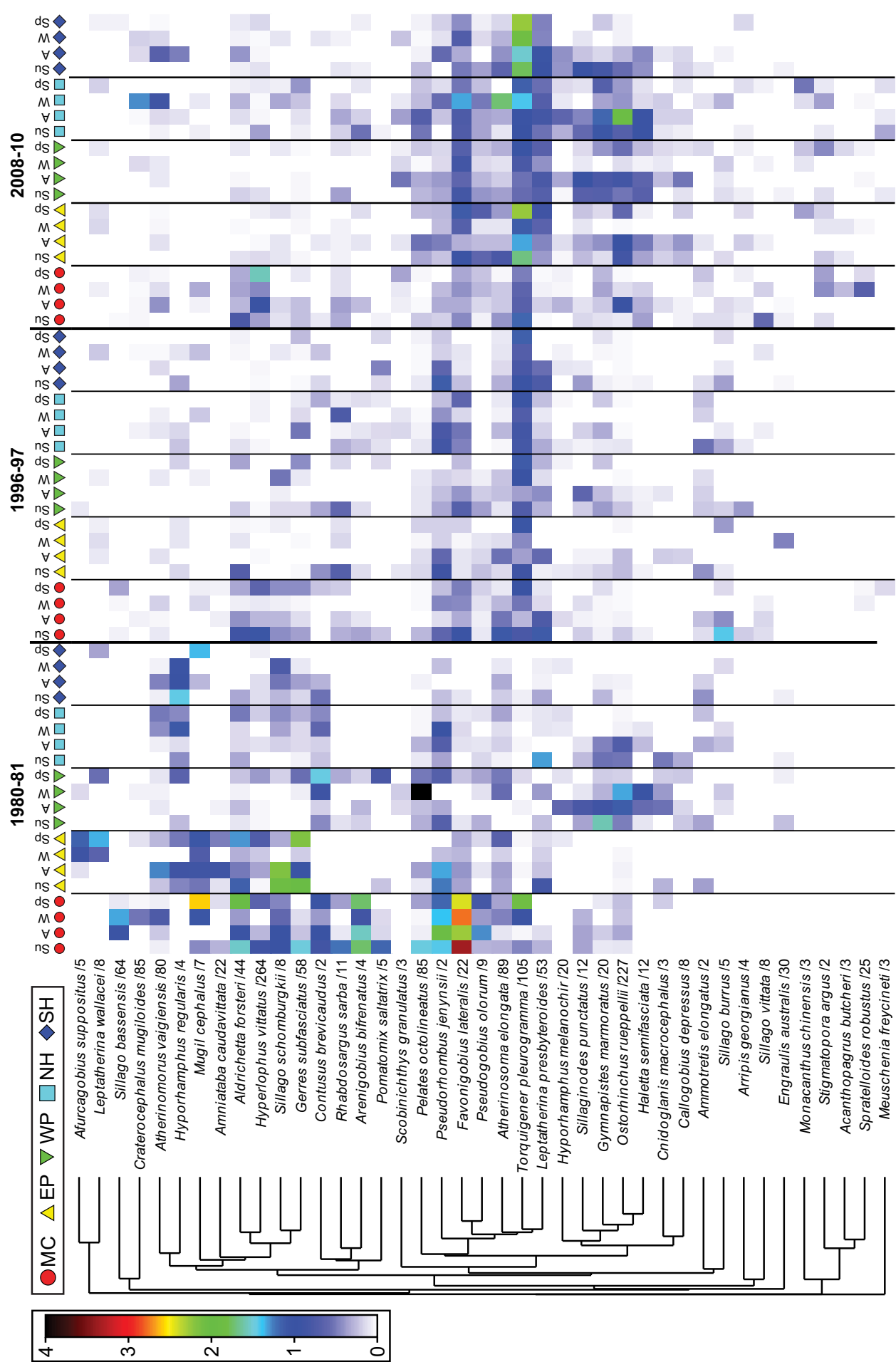
Figure 6

Figure 7

Figure 7

Figure 8

A. *Pelates octolineatus*
B. *Favonigobius lateralis*
C. *Torquigener pleurogramma*
D. *Mugil cephalus*
E. *Ostorhinchus rueppellii*
F. *Hyporhamphus regularis*

Stress: 0.08

Figure. 8