

1 Expanding fish productivity in Tasmanian saltmarsh wetlands
2 through tidal re-connection and habitat repair

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12

13 **Abstract**

14 Fish use of coastal saltmarsh wetlands has been documented for many parts of
15 Australia with the notable exception of Tasmania. An initial investigation to examine
16 the diversity, density and patterns of fish use in the Circular Head coast saltmarshes of
17 north-west Tasmania was undertaken. To aid decision making in repair strategies, the
18 effect of saltmarsh condition on fish assemblages was studied using paired sites of
19 predominantly unaltered and altered saltmarshes where levees were present. A total of
20 851 fish from 11 species were caught in 37 of the 48 pop nets. Three species,
21 *Aldrichetta forsteri*, *Arripis truttaceus* and *Rhombosolea tapirina*, are important to
22 commercial and recreational fisheries and contributed about 20% of the total catch
23 numbers. The mean density of > 72 fish per 100 m² is the highest yet reported from
24 Australian studies and indicates that Tasmanian saltmarshes provide higher value
25 habitat for fish compared to elsewhere in Australia, likely due to more frequent and
26 prolonged flooding together with the lack of adjacent mangroves. There was no
27 significant difference in fish assemblages between unaltered and altered marshes. The
28 results suggest that restoring basic saltmarsh structure through tidal re-connection will
29 deliver substantial benefits for fish productivity through habitat expansion.

30

31

32 **Additional key words:** biodiversity, coastal management, ecological restoration,
33 ecosystem services, seascapes, salt marsh, temperate fish communities, wetland
34 conservation

35

36 **Running head:** Repairing saltmarsh wetlands for fish use

37 Introduction

38 Saltmarsh wetlands are well recognised as fish nurseries globally, with a growing
39 literature documenting the importance of these habitats for itinerant fish use (e.g.
40 Connolly 2009; Raposa and Talley 2012). The general expectation is that saltmarshes,
41 and their associated tidal channels, provide both secure and productive habitat and
42 food resources. For example, Kneib (1997), Deegan *et al.* (2000) and Valiela *et al.*
43 (2000) detail how fish utilise these seascapes at varying spatial and temporal scales.
44 In Australia, there is now an increasing number of studies to support this expectation,
45 with accounts of fish visiting and feeding in saltmarshes (Crinall and Hindell 2004;
46 Hollingsworth and Connolly 2006; Mazumder *et al.* 2006a; Platell and Freewater
47 2009; Mazumder *et al.* 2011; McPhee *et al.* 2015). As elsewhere, Australian
48 saltmarshes have also been documented to export food resources (plant and animal
49 matter) to coastal waters through tides, thereby improving overall seascape
50 productivity (Melville and Connolly 2003; Svensson *et al.* 2007).

51
52 While more research is being undertaken in Australia, the majority of research on
53 saltmarsh fish has been focused elsewhere, particularly in North America. A review
54 by Connolly (1999) indicates that, of literature published before 2000, 90% of studies
55 were from North America, 7% from Europe and 3% from the southern hemisphere
56 including Australia (although additional work has since been published). Contrasts
57 exist in habitat type between Australian and North American saltmarshes, including
58 differences in typical elevation, water depth and plant assemblages (Connolly 2009),
59 making comparisons problematic between international studies. Australian studies
60 have primarily been undertaken in tropical, subtropical and temperate waters in
61 Queensland, New South Wales, Victoria and South Australia (Davis 1988; Connolly
62 *et al.* 1997; Thomas and Connolly 2001; Crinall and Hindell 2004; Mazumder *et al.*
63 2006b).

64
65 Australian literature reporting on the fish use of temperate saltmarshes record up to 35
66 species with densities of up to 56 fish per 100 m⁻² (Connolly 2009; Wegscheidl *et al.*
67 2017). In terms of patterns of fish use, spatial and temporal differences between
68 regions are apparent, including varying effects of seasonality, tide cycle, water depth,
69 diel time, temperature and salinity on fish assemblages (Morton *et al.* 1987; Davis
70 1988; Connolly *et al.* 1997; Thomas and Connolly 2001; Crinall and Hindell 2004;
71 Mazumder *et al.* 2005a). Although a major focus of North American research has
72 explored differences in fish use between varying saltmarsh conditions (e.g. Raposa
73 and Talley 2012), there are few comparable studies from Australia (Connolly 2005;
74 Mazumder *et al.* 2006b). There still remains a lack of directed studies relating
75 saltmarsh condition to fish assemblages in Australia (Connolly 1999; Kelleway *et al.*
76 2017).

77
78 To our knowledge, and certainly in the scientific literature, there have been no prior
79 studies of fish use of Tasmanian coastal saltmarshes, with no previous record of fish
80 species diversity, density, patterns of use and preference between varying habitat
81 conditions. As both saltmarshes and mangroves have been found to host many fish
82 species (Mazumder *et al.* 2005a; Saintilan *et al.* 2007), and given the absence of
83 mangroves in Tasmania, measuring the diversity, density and patterns of fish use of
84 saltmarshes (where no adjoining mangrove habitat is present) is important. As well as
85 the absence of mangroves, Tasmania's saltmarshes differ in their seascape context to
86 those found in mainland Australia. In comparison, Tasmanian saltmarshes are situated

87 slightly lower on the tidal frame (thus being subject to a different flooding regime)
88 and contain different vegetation assemblages compared to many of their mainland
89 counterparts (Boon *et al.* 2015; Saintilan *et al.* 2009; Mount *et al.* 2010).

90
91 An understanding of fish use is particularly important where saltmarshes have
92 declined most rapidly due to tidal restriction as part of agricultural development, as in
93 the Circular Head coast saltmarshes of north-west Tasmania (Pahalad 2014). These
94 low lying agricultural areas that are affected by salinization and flooding could easily
95 be repaired in terms of tidal ventilation. The benefits of re-connecting tidal flows in
96 the form of increased fish production through expanded habitat would potentially
97 offset any loss in agricultural outputs, as well as provide additional ecosystem
98 services (Creighton *et al.* 2015; Kelleway *et al.* 2017; Wegscheidl *et al.* 2017).
99 Saltmarsh rehabilitation would also assist in building resilience to climate change and
100 relative sea level rise (Pahalad *et al.* 2015).

101
102 The following questions underpinned our Circular Head study: (1) what is the
103 diversity and density of fish in the saltmarshes? (2) are there any observable patterns
104 of fish use relative to location, tide cycle, water depth, diel time, temperature and
105 salinity? (3) is there differences in fish use between saltmarshes of varying condition?
106 (4) what are the implications for biodiversity repair and coastal management, and
107 what additional research and on-ground activities might be required? In addressing
108 these questions, the study also explored whether Tasmanian saltmarshes supported
109 different assemblages and densities of fish taxa compared to lower latitude Australian
110 sites.

111

112 **Materials and methods**

113 **Study area**

114 The Circular Head coastal area is located in the far north-west of Tasmania, between
115 Woolnorth Point and the small town of Stanley (Fig. 1). The area is well sheltered
116 from the high-energy wave climate of Bass Strait and contains an expansive seascape
117 matrix of tidal flats, seagrass beds, saltmarshes and *Melaleuca ericifolia* swamp
118 forests on the landward margin (Mount *et al.* 2010; Pahalad *et al.* 2015). The
119 saltmarshes in the Circular Head coastal area occupy 1326 ha, as part of 23 distinct
120 clusters associated with creek/river mouths, embayments, sheltered passages or tidal
121 islands, and account for nearly a quarter of all saltmarsh mapped across Tasmania
122 (Pahalad 2016). The area has a semi-diurnal tidal cycle with a mesotidal range of up
123 to 3.1 m, the largest on the Tasmanian coast (Donaldson *et al.* 2012). Within the tidal
124 frame, saltmarshes occur over a 0.5 m range in elevation and are flooded partially
125 during neap tides and almost fully during high spring tides (Mount *et al.* 2010). The
126 low marsh is characterised by succulent mats of *Sarcocornia quinqueflora* often co-
127 occurring with *Samolus repens*, and about 10-20 cm high (when flooded). The high
128 marsh and back marsh areas are dominated by the succulent shrub *Tecticornia*
129 *arbuscula* often mixed with halophilic grasses and sedges, about 50-150 cm high.

130

131 **Fig. 1**

132

133 *M. ericifolia* swamp forests dominate the landward margins of the tidal frame
134 occupying the low lying coastal floodplain areas and competing with saltmarsh at the
135 upper limits of the tidal extent. A large part of the swamp forests and the adjoining
136 saltmarsh has, however, been cleared and drained for agricultural purposes, with over

137 25 km of levees built to restrict tidal flooding (Pralhad 2014). Earliest evidence of
138 levee building was observed from old aerial imagery dating from the late 1960s, while
139 the most extensive period of clearing and draining was during the 1980s. The
140 estimated absolute loss of saltmarsh between 1952 and 2006 is 219 ha (16%), with
141 752 ha (65%) of the remaining saltmarshes subject to impacts including clearing,
142 drainage ditching, cattle grazing and buffer zone removal (Pralhad 2014). Levee
143 building has continued, for example, with a 2 ha area of saltmarsh lost between 2013
144 and 2016 (unpublished data). The Circular Head coastal area has been specifically
145 selected for this study for having the largest extent of saltmarsh with rehabilitation
146 potential in the State. The area is also of considerable importance to commercial and
147 recreational fishers (Mount *et al.* 2010). There are also oyster farms in the area which
148 depend on good water quality as part of a healthy seascape.

149

150 **Sampling methods**

151 Methods used to sample fish in saltmarshes include fyke nets, seine nets, pop nets, lift
152 nets, block nets, flume nets, flume weir, drop samplers, traps, dip nets and hand
153 trawls, and also poisoning (Connolly 1999, 2009). Of these, pop nets are now used in
154 Australia more than other techniques (e.g. Connolly 2005; Mazumder *et al.* 2005b;
155 Saintilan *et al.* 2007), as they are easily portable for sampling replications and provide
156 a density measure (fish per m⁻²) that is directly comparable to other studies
157 (Wegscheidl *et al.* 2017). Although studies have used different pop net types and
158 sampling regimes, the general tendency has been to use a larger sample area (~25 m⁻²)
159 to avoid small scale patchiness, with a fine mesh size (~2 mm) to catch juvenile fish
160 and a remotely controlled release. In this study, we employed four custom made
161 buoyant floorless pop nets, each covering an area of 25 m⁻² (with 5 m long x 1 m high
162 walls) and with a mesh size of 2 mm. The bottom of the net walls contained a lead-
163 core rope that was tucked under the saltmarsh substrate and pegged down by 10-12
164 weed mat pins on each side. This helped avoid excessive soil disturbance (cf.
165 Connolly 2005). The top of the net walls contained a sleeve suitable for a 20 mm PVC
166 pipe that was inserted in-situ and sealed for floatation. The net was neatly folded
167 under the PVC pipe so that the installation sat flat on the marsh surface as much as
168 possible. Weights were placed on the PVC pipe to keep it from floating with the
169 incoming tide until the nets were ready to be popped. The installation was completed
170 during low tide and took about 60 mins per net with two people working in tandem.

171

172 The four nets were used concurrently at the nearby paired sites of unaltered and
173 altered saltmarshes, located in Robbins Passage, Big Bay and Perkins Passage (see
174 Fig. 1). The three locations were 2.5-10 km apart from each other and selected on the
175 basis of being representative of the saltmarshes of the Circular Head coast. Unaltered
176 saltmarshes had no hydrological alterations due to levees and other human impacts
177 (such as drainage ditches, clearing, grazing), were surrounded by a contiguous native
178 buffer vegetation zone, and were relatively unfragmented being part of a larger
179 saltmarsh cluster. Altered marshes had significant hydrological alterations due to
180 levees and other human impacts (such as drainage ditches, clearing, grazing), had a
181 little to no native buffer vegetation being juxtaposed to agricultural land used largely
182 for cattle grazing, and belonged to highly fragmented saltmarsh clusters of variable
183 size (Table 1).

184

185 **Table 1.**

186

187 Sampling procedure

188 At slack high tide, the fully installed nets were released remotely (10-15 m) by two
189 field personnel pulling the strings connected to the weights at the same time. The nets
190 popped instantaneously (~1 second) and were then surveyed for entrapped fish,
191 mostly at the downstream side(s) into which they were channelled as the tide receded.
192 Fish were collected at regular intervals using hand-held dip nets to mitigate loss due
193 to predation by birds and crabs inside the net. Some of the larger and more active
194 crabs were evicted from the nets to prevent predation on fish when the water levels
195 were low. Depending on the tide height, it took between 1-2 hrs for the flood tide to
196 recede fully from the marsh surface. A thorough final inspection was made before
197 concluding each sampling effort by checking all four walls and tiny depressions
198 inside the net for camouflaged species. Collected fish were identified in the field,
199 recorded and released. A few representative samples of each species were taken to
200 confirm field identification by fish experts (following Gomon *et al.* 2008). These fish
201 were terminally anaesthetised in the field using a lethal dose of AQUI-S[®], a
202 commercially available derivative of clove oil. Specimens were preserved
203 immediately into a solution of 95% ethanol. Size range measurements of the fish from
204 both the preserved samples and photographic evidence collected during field work
205 helped in inferring the likely age of the fish.

206
207 Fish were sampled from four nets concurrently released in both unaltered and altered
208 sites, at two replicate nets per site. The replicates were located randomly on the marsh
209 flats and spaced no further than 25 m apart (cf. Thomas and Connolly 2001).
210 Sampling was conducted during both high tides (night and day) of the semi-diurnal
211 tidal cycle. The same procedure was repeated on successive days at the three study
212 locations, yielding 24 samples during the neap tide cycle in April 2017. Sampling
213 effort was doubled to 48 net releases in the following spring tide cycle in May 2017
214 following the same procedure. The neap tidal cycle samples were located near the
215 seaward edge of the marsh expecting lower water levels and the spring tidal cycle
216 samples were located slightly higher on the marsh platform expecting higher water
217 levels (with distance to seaward edge proportional to the paired unaltered and altered
218 marshes). Water temperature, salinity and time of net release (diel time) were
219 recorded at each sampling location on all 12 sampling occasions. Water depth was
220 recorded at each net as the mean of maximum and minimum depth, as the marsh
221 surface was sloped.

222
223 Data analysis

224 Summary statistics were used to gain an overall impression of the fish community.
225 To gauge the completeness of the sampling, a species accumulation curve (collector's
226 curve) was produced using *specaccum* in the *vegan* library (Oksanen *et al.* 2011).
227 Samples taken when the maximum water depth was less than 5 cm (mean water depth
228 < 3 cm) were excluded from further analysis as they yielded no fish due to lack of
229 access. To explore the relationship between the environmental variables and fish
230 species abundance within the overall assemblage, we related four response variables -
231 fish species richness per sample, fish catch per sample and the abundance of the two
232 most common species - using generalised linear models (GLMs) to a suite of
233 predictor environmental variables - location, condition status, tide cycle (spring vs
234 neap), diel phase (night vs day), water salinity and mean water depth. Since the
235 response variables were based on count data, Poisson or quasi-Poisson models with a
236 log link function were applied as appropriate. We used a Wilcoxon Rank Sum test to

237 explore for differences in total catch between diel phase, tide cycle and saltmarsh
238 condition.

239

240 The multiple response permutation procedure (MRPP) in *vegan* was used to test for
241 any significant difference between the unaltered and altered sites based upon their fish
242 assemblages. The Bray–Curtis dissimilarity measure and 999 permutations were
243 employed. The MRPP statistic delta is the overall weighted mean of within-group
244 means of the pairwise dissimilarities among the sampling units. A is a chance-
245 corrected estimate of the proportion of the distances explained by group identity, a
246 value analogous to a coefficient of determination in a linear model (Oksanen *et al.*
247 2011). The degree to which the fish assemblages varied between unaltered and altered
248 sites was assessed using nMDS ordination based on the Bray-Curtis dissimilarity
249 measure (Clarke and Warwick 2001). Fish counts were not transformed since the
250 range of values was not extreme. The stress level of 0.1909 in 2 dimensions was
251 acceptable (Quinn and Keogh 2002). Analyses were carried out in the R statistical
252 environment (R Foundation for Statistical Computing, Vienna, Austria).

253

254 Results

255 A total of 851 fish of 11 species from 8 families were caught (Table 2.). All the
256 individuals caught were either juveniles or sub-adults. The species accumulation
257 curve (Fig. 2) estimates a total of 12 species and suggests the number of samples
258 collected was satisfactory to reveal most of the fish taxa present at the sites.

259

260 The profile of the saltmarsh fish fauna reflected strong differences in the relative
261 abundance of particular species (Fig. 3). The family Atherinidae contributed 3 species
262 and 74% of the total catch numbers, of which *Atherinosoma microstoma* and
263 *Leptatherina presbyteroides* were most abundant (57% and 16% respectively). Two
264 members of the family Gobiidae, *Pseudogobius* sp. and *Nesogobius maccullochi*,
265 contributed 3% and 2% of the total respectively. Three species, *Aldrichetta forsteri*
266 (Mugilidae), *Arripis truttaceus* (Arripidae) and *Rhombosolea tapirina*
267 (Pleuronectidae) are of direct commercial and recreational value (Lyle *et al.* 2014).
268 These fishery valued species contributed about 20% of the total catch. *A. forsteri* was
269 both common and dominant, present in 24 (65%) of the 37 nets that caught fish and
270 made up 19% of the total catch. Palaemonid shrimps (*Palaemon* sp.) were observed in
271 most of the nets, sometimes in large numbers (~200) but not censused as the study
272 was restricted to finfish. Crabs were also observed in all of the nets and have been
273 inventoried for the Circular Head saltmarshes by Richardson *et al.* (1997).

274

275 Table 2.

276

277 Fig. 2.

278

279 Fig. 3.

280

281 The pop nets were very effective at catching fish with 37 of the 48 net releases
282 returning between 3 and 69 fish per net. One of the nets failed in the Robbins Passage
283 unaltered saltmarsh during the neap tide night-time sample. The mean density of fish
284 caught with the exception of one net that failed to set properly was 72.4 fish per 100
285 m⁻² (Table 2.). Because the maximum water depth was less than 5 cm (average water
286 depth < 3 cm) on 5 occasions where the high tide mark did not fully extend to the area

287 covered by the nets our sampling of population density is probably an under-estimate.
288 When corrected for these 5 samples, the mean density is 83 fish per 100 m⁻². In
289 addition, it is likely that Gobiidae were probably undersampled on occasions where
290 they were hiding in crab holes well after the marsh flat had drained after the spring
291 high tide. Mugilidae may also have been undersampled given their ability to jump,
292 however, our regular sampling regime would have mitigated against this risk. We
293 conclude the mean density of fish caught to be > 72 fish per 100 m⁻².

294

295 The mean catch and species richness \pm SE per net/sample was 18.11 \pm 2.58 individual
296 fish and 2.60 \pm 0.22 taxa respectively. Both the catch ($r = 0.6113$, $p < 0.01$) and species
297 richness ($r = 0.5131$, $p < 0.01$) were positively correlated with mean water depth.
298 However, there was no correlation between water salinity and either catch ($r =$
299 0.0842 , $p > 0.05$) or species richness ($r = -0.0249$, $p > 0.05$). The range in salinity
300 level was modest across the samples (33.1 to 36.6 ppt). Temperature ranged from 9 to
301 18.9 °C (mean of 14.4 °C), however this was not a significant variable. Only two of
302 the environmental variables were significant in the generalised linear models (Table
303 3). Fewer fish and slightly lower species richness were apparent in the daylight
304 sampling compared to night-time of the diel phase. Similarly, mean water depth had a
305 strong positive effect on all four response variables. Notably, *A. microstoma* was
306 caught in greater numbers in night-time samples ($p < 0.001$), while *A. forsteri* catch
307 was slightly higher at night-time ($p < 0.05$), both species responding positively to
308 water depth ($p < 0.001$). The effect of location was only noticeable in the case of *A.*
309 *forsteri* with marginally greater numbers recorded at Perkins Passage ($p < 0.10$).

310

311 The Wilcoxon test confirmed that total catch per sample was related to the diel phase
312 ($W = 296$, $p = 0.001$). However, although more fish were caught during the spring
313 tide cycle ($n = 526$) than neap tide ($n = 325$), tide cycle ($W = 169$, $p = 0.215$) was not
314 a significant factor on total catch per sample. Similarly, more fish were caught in
315 altered sites ($n = 493$) compared to unaltered sites ($n = 358$), yet saltmarsh condition
316 ($W = 260$, $p = 0.319$) did not significantly affect total catch per sample. Water depth
317 was able to better explain catch numbers for both spring and neap tide cycles and for
318 altered and unaltered sites examined separately (Fig. 4a-b).

319

320 Table 3.

321

322

323 Fig. 4a-b.

324

325 MRPP showed there was no significant difference between the unaltered and altered
326 sites based upon their fish assemblages (chance corrected within-group agreement $A =$
327 -0.0120 , based on observed delta = 0.6353 and expected delta = 0.6278, the
328 significance of delta = 0.917). Ordination results further confirmed that there were no
329 discernible differences in the fish assemblages between unaltered and altered sites
330 (Fig. 5).

331

332 Fig. 5.

333

334 Discussion

335 *Fish species composition and density*

336 As the initial study of fish assemblages of Tasmanian saltmarshes it provides an
337 excellent baseline for further investigations. The species encountered in this study
338 largely overlap with those reported from other temperate Australian saltmarshes
339 (Connolly 2009). The fish assemblage is dominated by species from the families
340 Atherinidae, Gobiidae and Mugilidae. Of the other common fish families reported in
341 temperate Victorian (Crinall and Hindell 2004) and New South Wales saltmarshes
342 (Mazumder *et al.* 2005a, Mazumder *et al.* 2006b), Ambassidae, Gerridae and
343 Sparidae were absent because their geographic range does not extend to Tasmania.
344 Local species of the families Sillaginidae and Tetraodontidae were also not
345 encountered in our study, although, the tetraodontid *Tetractenos glaber* (Smooth
346 Toadfish), was observed adjacent to the nets both in Robbins Passage and Big Bay.
347 Notably, our study provided a rare record in Australian saltmarshes of a member of
348 the commercially and recreationally valuable family Arripidae. The two other species
349 of commercial and recreational value, *A. forsteri* and *R. tapirina*, are also found in
350 other temperate Australian saltmarshes. The relative abundance of *A. forsteri* in our
351 total catch (19%) is, however, comparatively much higher for a member of the
352 Mugilidae (cf. 2-6% of total catch by Crinall and Hindell 2004 using fyke nets in
353 Victoria, and by Mazumder *et al.* 2005a, 2005b using pop nets and Mazumder *et al.*
354 2006b using fyke nets in New South Wales). The variable sizes (~ 4-20 cm total
355 length) of individuals caught suggest this abundance is not related to life history
356 phases based on inferred age (Chubb *et al.* 1981).

357
358 In terms of species richness, the 11 species recorded in our single season of sampling
359 compares well with other temperate Australian studies. Reports range from 10 species
360 collected from fyke nets in Victoria (Crinall and Hindell 2004) to 14-15 species
361 collected from pop nets in New South Wales (Mazumder *et al.* 2005a, 2005b;
362 Saintilan *et al.* 2007). Comparable pop net studies from Queensland have reported 23-
363 19 species (Thomas and Connolly 2001; Connolly 2005), indicating a latitudinal trend
364 in diversity of saltmarsh fish along the east coast of Australia (Table 4). Another
365 latitudinal trend is the marked change in *A. microstoma* as the most numerically
366 dominant species in higher temperate latitudes in Tasmania (present study), Victoria
367 (Crinall and Hindell 2004) and South Australia (Bloomfield and Gillanders 2005), to
368 the ambassid *Ambassis jacksoniensis* (Port Jackson Glassfish), in lower temperate
369 latitudes in New South Wales (Mazumder *et al.* 2005a, 2005b; Platell and Freewater
370 2009). The similarity in the relative abundance of these two species at different
371 latitudes indicates an equivalence of ecosystem structure whereby functionally related
372 species perform comparable roles. The minor component of Gobiidae and Mugilidae
373 is also reflected in other studies.

374
375 Our reported density of > 72 fish per 100 m² is higher than from other Australian
376 saltmarshes, including subtropical locations (Table 4). This could be a seasonal
377 outcome where sampling in autumn returned high fish catches, although there is little
378 evidence for significant seasonal variations in fish on temperate saltmarshes in
379 Australia. Mazumder *et al.* (2005a) showed seasonal variation in fish abundance in
380 mangroves near Sydney, peaking in summer, but not in the case of the adjoining
381 saltmarshes. Bloomfield and Gillanders (2005) also reported no significant
382 differences in fish richness and abundance in saltmarshes from South Australia
383 between months. A more plausible explanation for the high fish density reported in
384 this study could be the unique position of Tasmanian coastal saltmarshes as part of
385 seascapes where mangroves are absent. Consequently, Tasmanian saltmarshes occur

386 slightly lower on the tidal frame. In our study area with a mesotidal range,
387 saltmarshes are partially flooded even during neap tides unlike most mainland
388 Australian counterparts which only flood in spring tides (Bloomfield and Gillanders
389 2005; Connolly 2009). Saltmarshes of Tasmania would seem to provide a higher
390 habitat value for fish per hectare, due to longer availability of flooded habitat together
391 with the lack of any complementary habitat such as mangroves.

392

393 **Table 4.**

394

395 *Patterns of fish use and implications for tidal restoration*

396 It is well documented that coastal saltmarsh rehabilitation through restoring tidal
397 flows ensures benefits for fish through expanded habitat (Roman *et al.* 2002; Raposa
398 and Talley 2012). Our study reinforces this expectation, firstly through the strong
399 effect that water depth has on fish density and richness found in this and some other
400 studies (Thomas and Connolly 2001; Connolly 2005). When tide-restricted areas are
401 open to flooding, they can accommodate the spread of a given volume of water
402 (entering the embayment or sheltered passage) over a greater surface area. Tidal
403 restoration, therefore, opens up more shallow, sheltered environments, rich in food
404 sources, preferred by juvenile and sub-adult fish species (e.g. *A. forsteri* and *Mugil*
405 *cephalus*, Sea Mullet: Chubb *et al.* 1981). Secondly, there was only a minor effect of
406 the sampling location on both fish richness and density. Given that the study area has
407 in excess of 25 km of levees traversing multiple freehold properties, coastal
408 rehabilitation works could be initiated wherever site specific opportunities arise with
409 likely benefits for local fish productivity through expanded habitat. While the
410 saltmarsh area already lost to clearing was 221 ha, a further 629 ha (55% of current
411 extent) is affected by impaired tidal flows (Pralhad 2014). These areas can benefit
412 from simple on ground works (e.g. levee breaching) aimed at tidal restoration.

413

414 In a broader seascape context, an ongoing debate on fisheries centres on the relative
415 importance of different habitat types, including saltmarshes, to the marine food web
416 (Kelleway *et al.* 2017). Only a few Australian studies have simultaneously compared
417 saltmarsh with other nearby habitats (mangroves, seagrass and unvegetated/open
418 water) with respect to fish use. Bloomfield and Gillanders (2005) noted that saltmarsh
419 had the least number of fish (a solitary *A. microstoma* for a saltmarsh area of 270 m²),
420 compared to mangroves, seagrass and unvegetated habitats of a South Australian
421 estuary. Similarly, Saintilan *et al.* (2007) reported fewer fish in a New South Wales
422 saltmarsh compared to adjacent mangrove and seagrass. The latter study however
423 showed that fish moved between these habitats and that saltmarsh plays both a
424 complementary role in terms of additional food resource and also a refuge role for
425 smaller fish during spring tides (when the seagrass habitat is 'exposed' to larger
426 predatory fish). Mazumder *et al.* (2005a) also reported more fish in mangroves
427 bordering saltmarsh in the same New South Wales location, although, acknowledged
428 that fish density was higher in the saltmarsh when corrected for water volume. A
429 common emphasis of these and some overseas studies (e.g. Valiela *et al.* 2000), has
430 been on the role of a permeable seascape matrix of adjacent habitats for fish to access
431 at varying timescales. The value of saltmarsh for fish and the marine food web is very
432 likely higher in the Tasmanian context because of the absence of mangroves.

433

434 *Difference in fish use between unaltered and altered saltmarshes*

435 This study is also the first in Australia to document differences in fish use between
436 paired unaltered and altered saltmarshes (Connolly 1999, 2009). Our findings indicate
437 that altered marshes can support high densities of fish and of comparable species
438 richness to unaltered marshes. One of the known reasons for high fish numbers in our
439 altered marshes could be due to the greater marsh to edge ratio, a product of habitat
440 fragmentation, allowing greater access to fish (Minello *et al.* 1994). A more
441 substantive reason, however, could be just that altered marshes can provide similar
442 habitat functions for fish use if they are subject to a natural tidal regime comparable to
443 its unaltered counterparts. There is considerable evidence, such as from temperate
444 North America, of restoring saltmarshes having similar fish habitat value to reference
445 sites (Raposa and Talley 2012). Further, re-connection of tide-restricted marshes has
446 been shown to return fish richness and density to levels comparable to unaltered ones
447 within one year (Roman *et al.* 2002). Indeed, our spring tide samples from altered
448 sites in Robbins Passage and Perkins Passage were both located immediately behind
449 the breached levees, and still returned high fish density and species richness. It must
450 be noted though that these altered sites had a similar tidal regime, vegetation and
451 crustacean activity to their paired unaltered sites (an indication of some functional
452 equivalence). A comparative study of three saltmarshes of the Sydney region
453 indicated that one of the marshes reclaimed from dredge spoil had significantly lower
454 diversity and abundance of fish, possibly due to lack of functional equivalence
455 (Mazumder *et al.* 2006b). The contrasting results from these two studies indicate an
456 unexplored threshold effect in saltmarsh condition, likely context specific (e.g. with
457 and without fringing mangroves), which can help explain relative fish habitat value
458 and guide tidal restoration efforts.

459

460 *Implications for coastal management*

461

462 The priority for management must be the conservation of existing saltmarshes and
463 their tidal connectivity (e.g. Boon *et al.* 2015). The Boullanger Bay and Robbins
464 Passage areas which are least affected by levees and associated clearing and drainage
465 ditching activities (see Fig. 1 and Prahalad 2014) are particularly significant. Targeted
466 tidal restoration can be undertaken in Big Bay, Perkins Passage, and other nearby
467 areas of Duck Bay and West Inlet. In addition, rehabilitation of the buffering *M.*
468 *ericifolia* swamp forests could benefit the broader functioning of the local seascape,
469 through enhanced detrital pathways (e.g. Svensson *et al.* 2007), or reduced nutrient
470 stress on the seascape from the nearby beef and dairy farms (Holz 2009).

471 Rehabilitation of saltmarsh and adjacent swamp forests would also assist in mitigating
472 the effects of climate change and relative sea level rise already affecting the Circular
473 Head coastal area (Prahalad *et al.* 2015). Science communication is also essential.

474 Public understanding of both the high fish density and species richness in the
475 saltmarsh and of the links to commercial and recreational fisheries, including oyster
476 farming, would increase broad community motivation for seascape conservation and
477 repair (Creighton *et al.* 2015). North-west Tasmania is renowned for its popular
478 fishing culture, and this may well be an important and locally unexploited avenue for
479 stakeholder engagement in tidal restoration and coastal management (Wegscheidl *et*
480 *al.* 2017).

481

482 **Conclusion**

483 This study reveals a hitherto unrecognised aspect of Tasmanian saltmarshes and
484 provides a foundation for further research coupled with rehabilitation efforts. Clearly
485 Tasmanian saltmarshes are important for our coastal biodiversity, providing nursery
486 grounds and key food chain elements to Tasmania's coastal fisheries. Sampling across
487 the year and similar surveys of other sites would expand our knowledge substantially.
488 Our expectation is that such studies would reinforce and possibly increase the
489 fisheries and marine biodiversity values of these coastal wetland systems. From a
490 repair perspective, this study also provides evidence that re-connecting tidal flows and
491 re-establishing wetland function and vegetation would deliver benefits to coastal
492 fisheries. Re-connecting tidal flows to marshes isolated by levees would markedly
493 expand the habitat suitable for fish use. This is despite the historically 'altered'
494 condition due to tidal isolation, clearing, drainage ditching and rough grazing. Should
495 Tasmania seek to optimise ecosystem services, marine biodiversity, fisheries
496 productivity and flow on economic outcomes then a major program of saltmarsh
497 repair should be initiated. Fish remain a compelling subject with broad resonance and
498 can be used as a surrogate for the broader values of ecosystem services that these
499 seascapes provide. Additional studies to document fish use of saltmarshes and the
500 benefits of protection and repair could raise much needed public awareness and
501 material support for saltmarsh repair.

502

503 **Conflict of interest**

504 This manuscript is an edited version of the same study available in a report form (see
505 Creighton *et al.* 2017).

506

507 **Acknowledgements**

508

509 Laura Van Galen, Zhi Loh, Alistair Deane and Larissa Giddings provided assistance
510 with fieldwork. Jeremy Ward and the Circular Head Landcare Group also assisted
511 with fieldwork. Debashish Mazumder (ANSTO) assisted with sampling methods.
512 John Pogonoski (CSIRO) provided fish identification guidance. Protocols included
513 approval (ref: A16284) from UTAS Animal Ethics Committee and permit (no: 17012)
514 from Wild Fisheries Management Branch of Tasmanian Government. Funding was
515 provided by the Australian Government's National Environmental Science
516 Programme: Marine Biodiversity Hub and Australian Government Research Training
517 Program (RTP) Scholarship. Three reviewers provided valuable comments.

518

519

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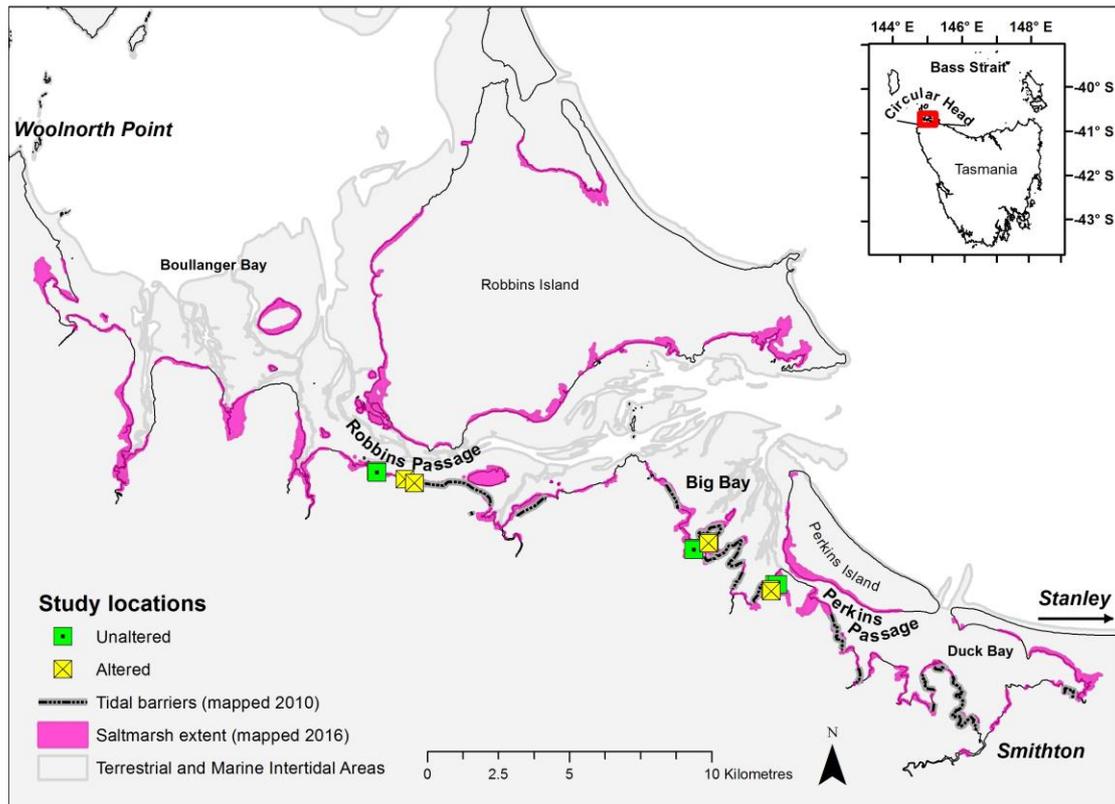
710 **Figures and tables**

711

712 **Fig. 1.** The three saltmarsh study locations and their paired unaltered and altered sites
713 used in the Circular Head coastal area of north-west Tasmania. Base data from
714 theLIST, © State of Tasmania.

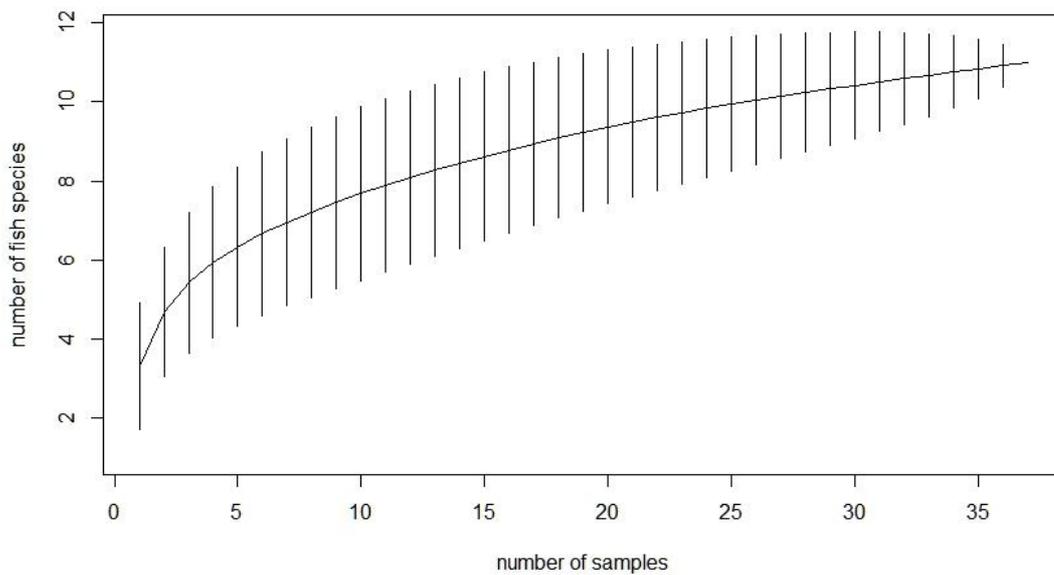
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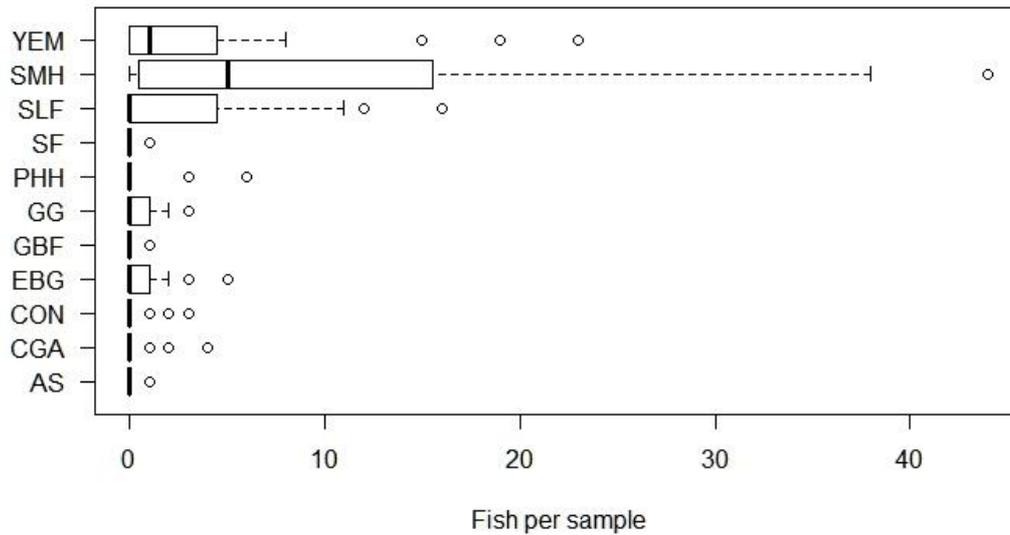
Fig. 2. Species accumulation curve (with SD) for fish species sampled on the Circular Head coast saltmarshes of north-west Tasmania, during April-May 2017.



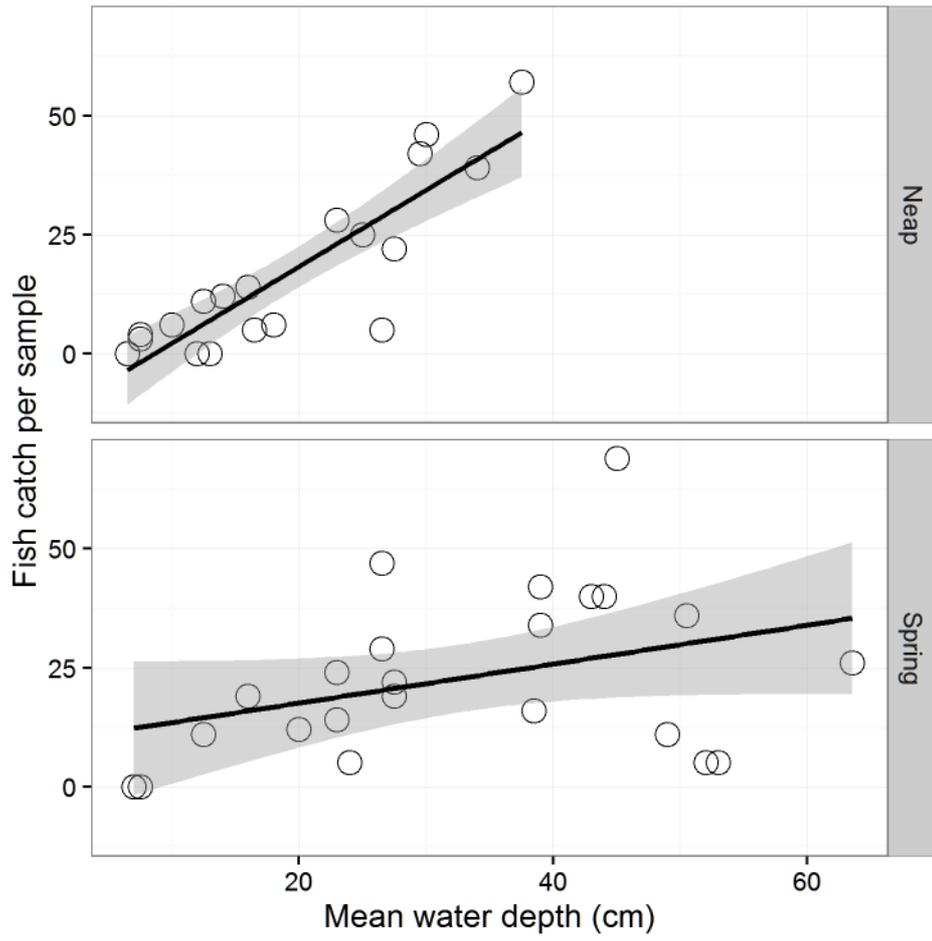
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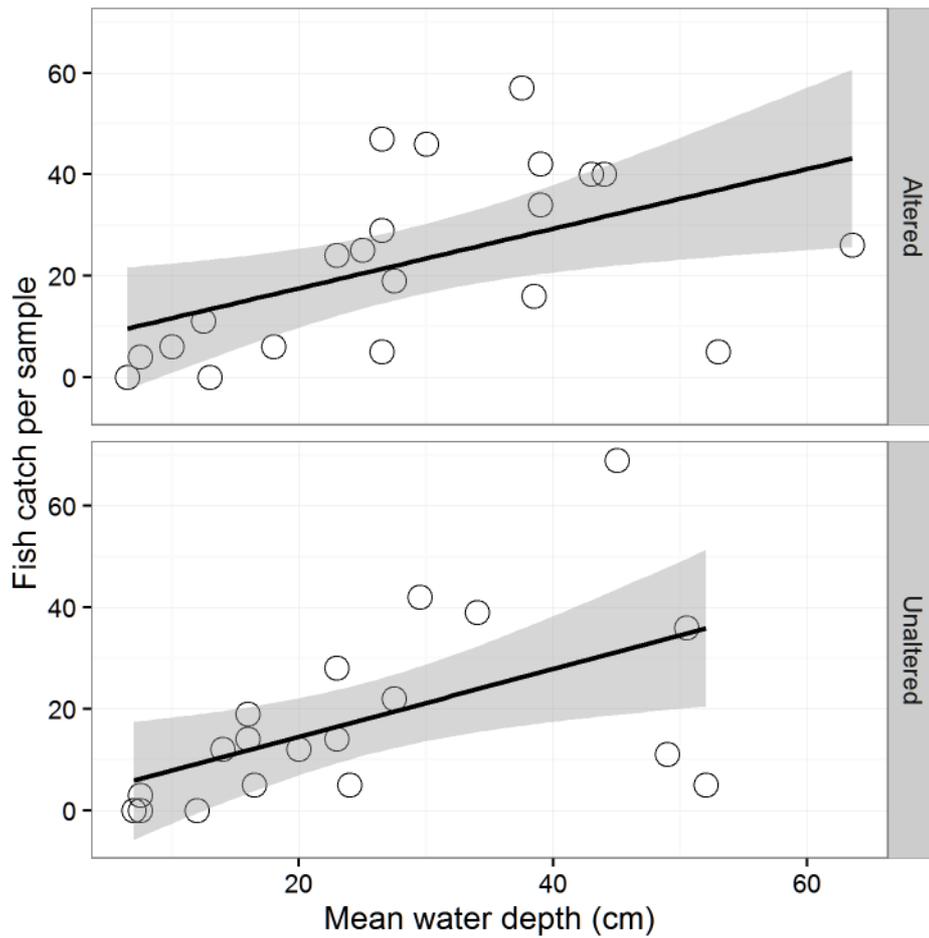
730 **Fig. 3.** Boxplot of the fish taxa sampled from the Circular Head coast saltmarshes,
 731 north-west Tasmania. The boxes contain 50% of the observations, the median is
 732 shown by a vertical line, the circles show the range of values. Common name codes
 733 used are YEM: Yellow-eye Mullet, SMH: Smallmouth Hardyhead, SLF: Silver Fish,
 734 SF: Soldierfish, PHH: Pikehead Hardyhead, GG: Girdled Goby, GBF: Greenback
 735 Flounder, EBG: Eastern Bluespot Goby, CON: Congolli, CGA: Common Galaxias,
 736 AS: Australian Salmon.



737 **Fig. 4a-b.** Relationships between fish catch per sample and mean water depth: (a)
 738 neap (n = 19; $r^2 = 0.763$; $p < 0.001$) and spring tide samples (n = 23; $r^2 = 0.137$; $p =$
 739 0.083); (b) altered (n = 22; $r^2 = 0.265$; $p < 0.05$) and unaltered status (n = 20; $r^2 =$
 740 0.298; $p < 0.05$).
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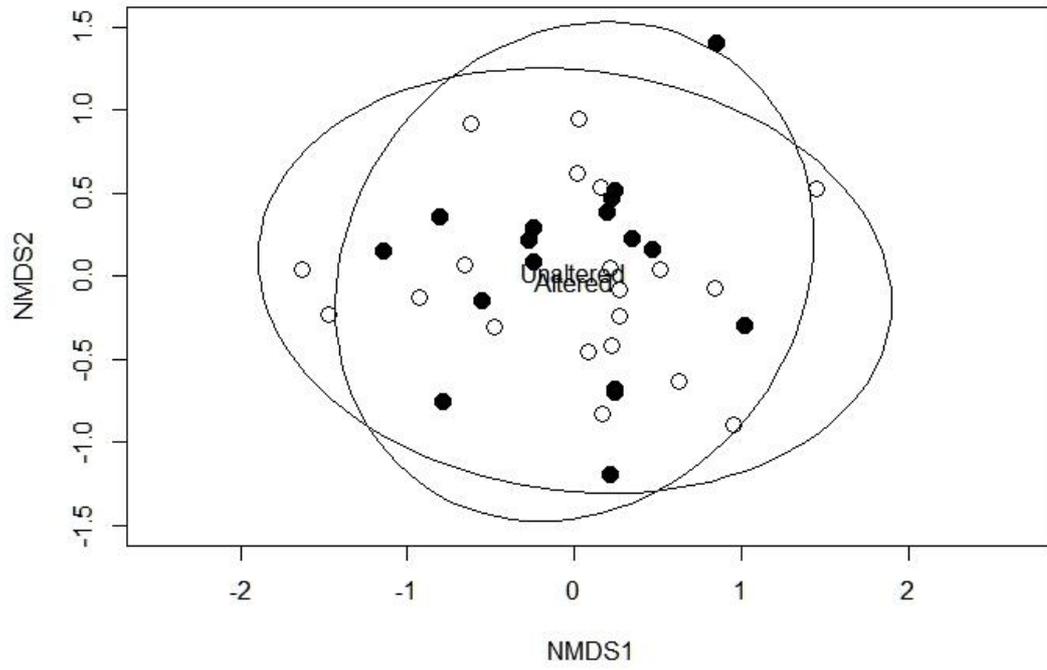


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Fig. 5. nMDS ordination of the pop net samples based upon their fish communities from 37 of the 48 net releases which caught fish. Stress in 2D = 0.1909. Samples from unaltered sites by closed circles, altered sites are represented by open circles. Status labels are plotted at their respective centroids.



750

Table 1 Condition of saltmarshes used in the study. Sites pairs were selected primarily based on the presence and absence of levees.

Site	Condition class and variables				
	Location	Class	Levees ¹	Buffer zone ²	Saltmarsh fragmentation ³
Robbins Passage	Unaltered	Absent	Present	Absent	12.1 ha
	Altered	Broken levees	Present but limited	Medium	35.5 ha
Perkins Passage	Unaltered	Absent	Present	Medium	13.5 ha
	Altered	Broken levees	Absent	High	18.9 ha
Big Bay	Unaltered	Absent	Present but limited	Medium	15 ha
	Altered	Intact levees	Absent	High	1.7 ha

¹Broken levees are regularly breached by incoming tide.

²Buffer zone, e.g. *Melaleuca ericifolia* swamp forest.

³Degree of fragmentation of marsh and associated tidal creeks by levees since 1960's.

⁴Area of saltmarsh, contiguous but spread along the coast with a high marsh area to edge ratio.

Table 2 Fish caught using custom made buoyant floorless pop nets on saltmarsh flats on the Circular Head coast of north-west Tasmania, during April-May 2017. Species identification and naming follows Gomon *et al.* (2008).

Family	Genus/species	Common name	Contribution to catch													
			Robbins Passage				Perkins Passage				Big Bay				Total	
			Unaltered		Altered		Unaltered		Altered		Unaltered		Altered			
			Total	%	Total	%	Total	%	Total	%	Total	%	Total	%	Total	%
Atherinidae	<i>Atherinosoma microstoma</i> (Günther, 1861)	Smallmouth Hardyhead	37	55.2	129	64.2	21	34.4	47	34.8	146	63.5	102	65.0	482	56.6
	<i>Kestratherina esox</i> (Klunzinger, 1872)	Pikehead Hardyhead	0	0	3	1.5	3	4.9	0	0	0	0	6	3.8	12	1.4
	<i>Leptatherina presbyteroides</i> (Richardson, 1843)	Silver Fish	7	10.4	50	24.9	6	9.8	15	11.1	39	17.0	18	11.5	135	15.9

Gobiidae	<i>Nesogobius maccullochi</i> (Hoese and Larson, 2006)	Girdled Goby	2	3.0	2	1.0	2	3.3	7	5.2	5	2.2	0	0	18	2.1
	<i>Pseudogobius</i> sp.	Eastern Bluespot Goby	10	14.9	7	3.5	1	1.6	4	3.0	0	0	6	3.8	28	3.3
Mugilidae	<i>Aldrichetta forsteri</i> (Valenciennes, 1836)	Yellow-eye Mullet*	10	14.9	10	5.0	27	44.3	50	37.0	40	17.4	23	14.6	160	18.8
Pleuronectidae	<i>Rhombosolea tapirina</i> (Günther, 1862)	Greenback Flounder*	0	0	0	0	0	0	1	0.7	0	0	0	0	1	0.1
Pseudaphritidae	<i>Pseudaphritis urvillii</i> (Valenciennes, 1832)	Congolli	0	0	0	0	0	0	5	3.7	0	0	1	0.6	6	0.7
Tetrarogidae	<i>Gymnapistes marmoratus</i> (Cuvier, 1829)	Soldierfish	0	0	0	0	0	0	0	0	0	0	1	0.6	1	0.1
Arripidae	<i>Arripis truttaceus</i> (Cuvier, 1829)	Australian Salmon*	1	1.5	0	0	0	0	0	0	0	0	0	0	1	0.1
Galaxiidae	<i>Galaxias maculatus</i> (Jenyns, 1842)	Common Galaxias	0	0	0	0	1	1.6	6	4.4	0	0	0	0	7	0.8
Total catch per sample type			67		201		61		135		230		157		851	
Fish density per 100m ⁻²			38.3		100.5		30.5		67.5		115		78.5		72.4	
Fish density per 100m ⁻² (excluding nets with less than 5 cm water depth)			44.7		100.5		40.7		67.5		115		104.7		83.0	

The asterisk (*) indicates species of recreational and commercial interest (Lyle *et al.* 2014).

Table 3. Coefficients for GLMs relating fish species richness, catch and the abundance of the two most common fish species to environmental variables. Values have not been exponentiated. The model for species richness uses Poisson regression, the other response variables follow a quasi-Poisson distribution. WDmean = mean water depth. Significance levels are indicated as: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, . $p < 0.10$.

	Estimate	SE	t value	Pr(> t)	signif.
Species Richness					
(Intercept)	-1.7124	8.7227	-0.196	0.8444	
Location: Perkins Passage	0.0653	0.3400	0.192	0.8476	
Location: Robbins Passage	0.0750	0.3618	0.207	0.8357	
Status: Unaltered	-0.0613	0.1858	-0.330	0.7415	
Tide: Spring	-0.0782	0.4972	-0.157	0.8751	
Phase: Light	-0.6144	0.2487	-2.471	0.0135	*
Salinity	0.0660	0.2369	0.279	0.7806	
WDmean	0.0204	0.0077	2.639	0.0083	**
Catch Numbers					
(Intercept)	-7.5104	7.9607	-0.943	0.3510	
Location: Perkins Passage	0.0757	0.3289	0.230	0.8190	
Location: Robbins Passage	0.1768	0.3317	0.533	0.5970	
Status: Unaltered	-0.1332	0.1735	-0.768	0.4470	
Tide: Spring	0.0933	0.4700	0.198	0.8440	
Phase: Light	-1.4914	0.2993	-4.983	0.0000	***
Salinity	0.2643	0.2158	1.225	0.2280	
WDmean	0.0458	0.0080	5.719	0.0000	***
Smallmouth Hardyhead					
(Intercept)	-5.5752	9.0677	-0.615	0.5420	
Location: Perkins Passage	-0.5936	0.4059	-1.462	0.1520	

Location: Robbins Passage	-0.0056	0.3742	-0.015	0.9880	
Status: Unaltered	-0.1959	0.2030	-0.965	0.3410	
Tide: Spring	-0.2365	0.5553	-0.426	0.6730	
Phase: Light	-1.5162	0.3424	-4.429	0.0001	***
Salinity	0.1989	0.2461	0.808	0.4240	
WDmean	0.0521	0.0097	5.395	0.0000	***
Yellow-eye Mullet					
(Intercept)	-10.0165	18.8957	-0.530	0.5991	
Location: Perkins Passage	1.4328	0.7216	1.985	0.0542	.
Location: Robbins Passage	0.1393	0.9812	0.142	0.8878	
Status: Unaltered	0.3963	0.3192	1.242	0.2218	
Tide: Spring	1.1728	0.9923	1.182	0.2444	
Phase: Light	-3.5222	1.3271	-2.654	0.0114	*
Salinity	0.2367	0.5092	0.465	0.6446	
WDmean	0.0576	0.0146	3.946	0.0003	***

Table 4. Compilation of fish data and key study design attributes from existing literature that report using pop nets on saltmarsh flats in Australia (cf. Connolly 2009; Wegscheidl *et al.* 2017). Given all previous pop nets studies have been done only during spring tides, we report our spring tide samples separately to assist comparison.

Region	State	Reference	No of releases	Fish caught in total numbers	Diversity (number of species)	Mean density (fish per 100m ²)	Pop net size (m ²)	Temporal context (sampling month)	Spatial context (with mangroves etc.)	Mean water depth (proxy for volume)
Subtropical	QLD	Thomas and Connolly 2001	134	577	23	17.2	5 x 5	August, January	Flats	4-72cm
		Connolly 2005	88	1073	19	48.8	5 x 5	May,	Flats, adjacent	6-48cm

								December	runnels and mangrove-lined creeks	
Temperate	NSW	Mazumder <i>et al.</i> 2005a	48	818	14	56	5.5 x 5.5	Year round (monthly)	Flats, adjacent mangroves	Not reported
		Mazumder <i>et al.</i> 2005b	48	766	15	52.8	5.5 x 5.5	Year round (monthly)	Flats, adjacent mangroves	Not reported
		Saintilan <i>et al.</i> 2007	36	~568	14	52.2	5.5 x 5.5	Year round (monthly)	Flats, adjacent mangroves and seagrass	Not reported
	SA	Connolly <i>et al.</i> 1997	48	19	2	4.4	3 x 3	April-July	Flats with creeks, adjacent mangroves and seagrass	10-30cm
		Bloomfield and Gillanders 2005	30	1	1	0.4	3 x 3	July, August, December-February	Flats, adjacent mangroves and seagrass	>70cm
	TAS	Present study	48	851	11	72.4	5 x 5	April, May	Flats	0-64cm
	TAS	Present study (neap tide only)	24	325	9	56.5	5 x 5	April	Flats	0-38cm
	TAS	Present study (spring tide only)	24	526	9	87.7	5 x 5	May	Flats	2-64cm