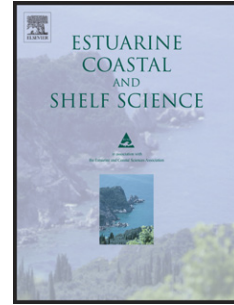


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Impact of climate variability on ichthyoplankton communities: an example of a small temperate estuary

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25 **ABSTRACT**

26 Recent variations in the precipitation regime across southern Europe have led to changes in river
27 fluxes and salinity gradients affecting biological communities in most rivers and estuaries. A
28 sampling programme was developed in the Mondego estuary, Portugal, from January 2003 to
29 December 2008 at five distinct sampling stations to evaluate spatial, seasonal and interannual
30 distributions of fish larvae. Gobiidae was the most abundant family representing 80% of total catch
31 and *Pomatoschistus* spp. was the most important taxon. The fish larval community presented a clear
32 seasonality with higher abundances and diversities during spring and summer seasons. Multivariate
33 analysis reinforced differences among seasons but not between years or sampling stations. The taxa
34 *Atherina presbyter*, *Solea solea*, *Syngnathus abaster*, *Crystallogobius linearis* and *Platichthys flesus*
35 were more abundant during spring/summer period while *Ammodytes tobianus*, *Callionymus* sp.,
36 *Echiichthys vipera* and *Liza ramada* were more abundant in autumn/winter. Temperature,
37 chlorophyll *a* and river flow were the main variation drivers observed although extreme drought
38 events (year 2005) seemed not to affect ichthyoplankton community structure. Main changes were
39 related to a spatial displacement of salinity gradient along the estuarine system which produced
40 changes in marine species distribution.

41
42 **Key words:** Ichthyoplankton; seasonality; environmental factors; drought; Mondego estuary

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1. Introduction

Nearshore estuarine and marine ecosystems serve many important functions in coastal waters. Often referred to as nurseries, estuaries play an important role in many species lifecycles, including fish (Beck et al., 2001; Elliott and McLusky, 2002; Martinho et al., 2007a) providing food abundance and shelter to marine fish larvae and juveniles and therefore maximizing their survival (Whitfield, 1999; Elliott and McLusky, 2002). Larval fish dynamics contribute significantly to understanding the ecology of fish populations (Doyle et al., 2002) as they can indicate the spawning-stock biomass and recruitment in adult fish stocks (Hsieh et al., 2005). Initial development stages of fishes are particularly vulnerable and are influenced by physical and biological processes. Indeed, several factors have already been related to survival and distribution of ichthyoplankton (e.g. hydrological conditions, transport processes, seasonal variability, spawning patterns of adults, food availability) (Franco-Gordo et al., 2002; Alemany et al., 2006; Sabatés et al., 2007; Isari et al., 2008). The effects of climate on fish populations can also be shown by long term trends in ichthyoplankton populations. Lower trophic level organisms should be more sensitive in reflecting environmental perturbations more quickly than higher trophic levels but early life stages may be environmentally sensitive prior to buffering through density-dependent mechanisms and community effects (Boeing and Duffy-Anderson, 2008). Thus a knowledge of the ichthyoplankton community dynamics are important in understanding changes in fish communities.

Recent studies indicate that the Mondego estuary (40° 08' N, 8° 50' W), Portugal, is an important nursery ground for several commercial fish species (e.g. *Dicentrarchus labrax*, *Platichthys flesus* and *Solea solea*) (Leitão et al., 2007; Martinho et al., 2007a). Studies on ichthyoplankton started with Ribeiro (1991) but recently only Marques et al. (2006) referred to these communities. Previous works focused on community assemblages but information of the way environmental factors force community structure is still limited. In addition, Portugal recently has been under varying precipitation regimes with values of 45–60% below average in the hydrological year 2004/2005 producing the biggest drought in a century (Portuguese Weather Institute: <http://www.meteo.pt/en/index.html>) and thus providing a unique opportunity to investigate ichthyoplankton responses to extreme events. Hence this study aimed to characterize ichthyoplankton assemblages, to evaluate environmental influence in its structure and establish the consequences of extreme events, such as droughts, on estuarine fish larvae communities. The hypothesis tested was that reduced river flow resulted from the decrease of precipitation mean levels lead to changes on community structure and longitudinal displacement of species according to salinity gradients.

2. Material and Methods

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80 2.1. Study area

81 The Mondego estuary, located on the Atlantic coast of Portugal (40° 08' N, 8° 50' W), consists of
82 two channels (northern and southern) with different hydrological characteristics separated by the
83 Murraceira Island (Fig. 1). The north channel is deeper (4–8 m depth at high tide) has lower
84 residence times (<1 day) and constitutes the main navigation channel, while the south channel is
85 shallower (2–4 m deep, at high tide), has higher residence times (2–8 days) and is almost silted up
86 in the upper areas. Most of the freshwater discharge is throughout the northern channel since it is
87 directly connected with the Mondego River. In the southern channel, water circulation is mostly due
88 to tides and the freshwater input from a small tributary, the Pranto River which is small and
89 artificially regulated by a sluice. Previous studies demonstrated that distinct environmental factors
90 provide a large variety of aquatic habitats for populations of marine, brackish and freshwater
91 zooplankton species, mainly due to salinity and water temperature gradients (Azeiteiro et al., 1999;
92 Marques et al., 2006; Primo et al., 2009).

93 2.2. Sample collection

94 Sampling was carried out monthly during daylight at high tide, from January 2003 to December
95 2008 at five stations distributed throughout both arms (Fig. 1). Samples were collected by
96 horizontal subsurface tows (Bongo net: mesh size 335 μm , mouth diameter: 0.5 m, tow speed: 2
97 knots), equipped with a Hydro-Bios flowmeter (the volume filtered averaged 45 m^3) and preserved
98 in a 4% buffered formaldehyde seawater solution. Additionally, at each site, salinity, water
99 temperature ($^{\circ}\text{C}$), dissolved oxygen (mg l^{-1}), pH and turbidity (Secchi disc depth, m) were also
100 recorded. Subsurface water samples were also collected for subsequent determination in the
101 laboratory for chlorophyll *a* (mg m^{-3}) and total suspended solids (mg l^{-1}). In the laboratory, the
102 ichthyoplankton was sorted, counted (number of individuals per 100 m^3) and identified to the
103 highest possible taxonomic separation (Petersen, 1919; Fives, 1970; Nichols, 1976; Demir, 1976;
104 Russell, 1976; Ré, 1999; Ré and Meneses, 2008). Copepod densities (ind m^{-3}) were also recorded.
105 Monthly precipitation values were acquired from INAG – Instituto da Água (<http://snirh.pt/>)
106 measured at the Soure 13 F/01G station and the freshwater discharge from the Mondego River was
107 obtained from INAG station Açude Ponte Coimbra 12G/01AE.

108 2.3. Data analysis

109 Sampling months were combined into four conventional seasons: winter (W) included December,
110 January and February; spring (S), March, April and May; summer (SM), June, July and August and
111 autumn (A), September, October and November. Species were characterized in three main

114 ecological guilds (adapted from Elliott et al., 2007): marine stragglers (MS - Species that spawn at
115 sea and typically enter estuaries in low numbers occurring frequently in the lower reaches), marine
116 migrants (MM - Species that spawn at sea and often enter estuaries in large numbers) and estuarine
117 species (ES – including estuarine species capable of completing their entire life cycle within the
118 estuarine environment and those with stages of their life cycle completed outside the estuary).

119 Salinity anomalies were calculated by subtracting the mean seasonal value from the mean value of
120 the given time period. The differences between seasons and years in each sampling station were
121 tested by Analysis of Variance (ANOVA) for environmental factors. Log (x+1) transformation was
122 performed and for pairwise multiple comparisons the Holm-Sidak method was applied. Temporal
123 and spatial ichthyoplankton distribution maps were obtained by Sigmaplot software as well as
124 diversity, expressed by Shannon-Wiener Index (\log_2).

125 PERMANOVA+ for PRIMER software (PRIMER v6 & PERMANOVA+ v1, PRIMER-E Ltd.) was
126 used to perform a non-parametric permutational multivariate analysis of variance (PERMANOVA)
127 to test for differences in the assemblage structure between years, seasons and sampling stations. The
128 analysis was based on Bray-Curtis similarities between samples, after a fourth root transformation
129 of abundance data, considering all the factors (year, season, station) as fixed and unrestricted
130 permutations of raw data. When necessary, *a posteriori* multiple comparisons were used to test for
131 differences between/within groups for pairs of levels of factors.

132 The effects of environmental variables on the larval fish assemblage were analyzed with canonical
133 correspondence analysis (CCA) using software CANOCO (version 4.5, Microcomputer Power).
134 Environmental variables included salinity (Sal), water temperature (T) dissolved oxygen (O₂), pH,
135 turbidity (Secchi), chlorophyll *a* (Chl *a*), total suspended solids (TSS), copepod densities (Cop),
136 freshwater discharge (Runoff) and precipitation (PP). Seasons were also included as nominal
137 variables. All species were used and a new category coded as “no fish” was created to prevent
138 CANOCO from eliminating samples containing no fish. “No fish” was assigned the minimum
139 possible weight (density=0.001) to prevent an otherwise uniform concentration in samples from
140 driving the ordination (Grothues and Cowen, 1999). Larval abundances were $\ln(2x+1)$ transformed
141 and environmental variables were standardized by subtracting the mean and dividing by the
142 standard deviation. A forward stepwise selection procedure of explanatory variables was applied
143 and a CCA triplot scaling with focus interspecies distances was performed.

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3. Results

3.1. Environmental conditions

The Mondego estuary has a typical seasonal pattern of precipitation and freshwater discharge throughout the six-year period with higher values during winter and lower during summer. However, 2004, 2005 and 2008 showed below-average precipitation and a low freshwater discharge, particularly in 2005 (Fig. 2). The salinity was highly variable between years with 2005 and 2008 presenting positive anomalies in all sampling sites during almost all seasons indicating higher salinity values than average (Fig. 3). Salinity values recorded at sampling stations M and S2 in 2005 were significantly higher than in 2006 (post hoc test $p < 0.05$ and $p < 0.01$, respectively). Also, the upstream sampling station N2 had significant higher salinity in 2005 and 2008 than in 2003 and 2006 (post hoc test $p < 0.01$). Seasonally, only sampling stations M and N2 had significant differences with winter having lower salinity than summer, autumn and spring (post hoc test $p < 0.01$).

All sampling stations showed significant differences in water temperature (Fig. 3) between seasons with winter being lower values than summer, autumn and spring (post hoc test $p < 0.001$). No significant differences were detected between years at any sampling station ($p > 0.05$).

Chlorophyll *a* reached higher values in the most upstream sampling stations (Fig. 3) although no significant differences were detected between years ($p > 0.05$) and only sampling station N2 had significantly higher chlorophyll *a* in summer than in autumn ($F = 3.826$, $p < 0.05$; post hoc test $p < 0.01$).

3.2. Seasonal and spatial patterns of larval distribution

During the study period, a total of 7211 fish larvae were collected in Mondego estuary and identified to 31 different taxa (Table I). Unidentified larvae represented 8.75% of the total catch and were generally yolk-sac or damaged larvae. The most abundant family was Gobiidae (80%) followed by Blenniidae (3%), Soleiidae (3%) and Engraulidae (2%). *Pomatoschistus* spp. was the most abundant taxon accounting for 63.4% of all fish larvae caught, followed by *Pomatoschistus microps* (6.02%), unidentified Gobiidae (4.65%), *Gobius niger* (3.57%), *Engraulis encrasicolus* (1.96%) and *Parablennius pilicornis* (1.88%). These species contributed for 81% of the total catch and are present in almost every seasons and sampling stations. Summer and spring had a higher species richness as well as sampling station S1 while autumn had a lower diversity. Species such as *Atherina presbyter*, *Solea solea*, *Symphodus melops*, *Syngnathus abaster*, *Crystallogobius linearis*, *Platichthys flesus* and *Arnoglossus thori* were exclusively captured during spring and summer.

180 Conversely, *Solea senegalensis*, *Ammodytes tobianus*, *Callionymus* spp., *Echiichthys vipera* and
181 unidentified Ammodytidae were more abundant in winter.

182 Fish larvae density clearly showed seasonality with higher densities during spring and summer (Fig.
183 4). According to the ecological guilds, estuarine species showed greatest densities during the whole
184 study period except for 2008 where marine straggler abundance reached maximum values. The
185 estuarine taxa showed peaks of densities during summer except in 2004 and 2005 where higher
186 values occurred early in spring (Fig. 4). In general, these species were well distributed along the
187 estuary with highest densities in the downstream south arm station (S1) and in the upstream estuary
188 (S2 and N2) (Fig.5A). The marine stragglers occurred mainly at station S1 reaching the upstream
189 stations only in year 2008 (Fig. 5B). The same happened with marine migrant species which during
190 2005 and 2008 reached the upper estuary (N1, N2 and S2) (Fig. 5C).

191 *Pomatoschistus* spp. abundance and distribution mimic the total fish larvae pattern since this is the
192 most important species in Mondego estuary (Fig. 6). Sampling station S1 had higher abundances
193 across the years. *Engraulis encrasicolus* attained higher densities during 2008 and was found
194 especially in the upper south arm (station S2) (Fig. 6). *Solea senegalensis* presented seasonal peaks
195 mainly in summer and spring but occasionally also in winter and autumn (Fig. 6). Its spatial
196 distribution was generally restricted to the downstream sampling stations M and S1 but in 2005 and
197 2008 it reached high densities in the upstream sampling stations S2 and N2. Seasonality was also
198 shown by the Shannon-Wiener diversity index with higher values in spring/summer (Fig.6).

199 3.3. Community structure and relation with environmental variables 200

201 The PERMANOVA results showed significant differences in community structure between years
202 and seasons, as well as significant interactions between the factors “year” and “season” (Pseudo F=
203 1.429, $p(\text{perm}) < 0.05$). A pairwise *a posteriori* comparison revealed that in the summer, the 2003
204 community differed from the other years ($t < 2.060$, $p(\text{perm}) < 0.05$). Autumn and winter showed no
205 differences between years ($p(\text{perm}) > 0.05$) and in spring only pairwise comparison for 2003/2008
206 presented significant differences ($t = 1.582$, $p(\text{perm}) < 0.05$). In addition 2003, 2006 and 2007 showed
207 differences between seasons with summer having a community differing from autumn and winter
208 ($p(\text{perm}) < 0.05$). In 2008, the summer presented differences only from the winter ($p(\text{perm}) < 0.01$)
209 and in 2004 and 2005 no seasonal differences were detected ($p(\text{perm}) > 0.05$).

210 Community differences between sampling stations were also detected (Pseudo F= 2.003,
211 $p(\text{perm}) < 0.01$) but only between M and S1 (Pairwise *a posteriori* comparison $t = 2.186$,
212 $p(\text{perm}) < 0.001$).

213 A Monte Carlo test of F-ratio showed that only six environmental variables contributed
214 significantly to explaining the species distribution ($p < 0.05$) (winter, salinity, temperature,

chlorophyll *a*, summer and runoff). Taken together, the environmental variables considered in the final CCA explained 8% of the total variation in fish larvae assemblages. The first two CCA axes accounted for 57% of the variability explained. The first axis is correlated with winter while the second axis is positively correlated with summer, temperature, chlorophyll *a* and salinity and negatively with runoff. The right hand side of ordination diagram of the first two axes grouped winter samples characterized by low temperatures and high river flow (Fig. 7). Species such as *Echiichthys vipera*, *Callionymus* spp. and *Liza ramada* were more prevalent in winter whereas summer samples clustered in the upper left side and are more related to *Atherina presbyter*, *Crystallogobius linearis*, *Syngnathus abaster*, *Syngnathus acus* or *Solea solea* (Fig. 7).

4. Discussion

The larval fish assemblages of the Mondego estuary supported 31 taxa dominated by *Pomatoschistus* spp. Dominance by few species and presence of a high number of rare species is a common feature observed in estuaries around the world either in larval or juvenile fish populations (e.g. Barletta-Bergan et al., 2002; Strydom et al., 2003; Selleslagh et al., 2009). *Pomatoschistus* spp. larvae dominance has been encountered in other Portuguese estuaries (e.g. Faria et al., 2006; Ramos et al., 2006) and the success of gobies in estuarine environment may be related to their benthic reproductive strategy ensuring that eggs are not flushed out from the estuary and are less exposed to salinity and temperature fluctuations, which are more pronounced in surface waters (Ribeiro et al., 1996). Mazzoldi and Rasotto (2001) also suggested that in highly productive habitats with warm summers, the long breeding season of short-lived species (such as *P. microps*) can give rise to more than one spawning peak in the breeding period, which may be the case of *P. microps* in the Mondego estuary as already been noticed by Dolbeth et al. (2007). In the Mondego estuary, *Pomatoschistus microps* and *P. minutus* are amongst the most abundant species in estuarine fish assemblages (Leitão et al., 2007; Martinho et al., 2007a) but, unfortunately, during early life stages these species cannot be easily differentiated.

Ribeiro and Gonçalves (1993) found that *Engraulis encrasicolus* captures in the Mondego estuary accounted for 44% of total fish larvae while in the present study the species only represents 2% of the total capture. This reduction was also recently recorded in the Guadiana estuary (Faria et al., 2006) and in the Lima estuary where this species was present occasionally and in low numbers (<1%) (Ramos et al., 2006). The abundance and distribution of anchovy is closely related with environmental factors as temperature, turbidity, salinity or prey availability (Ribeiro et al., 1996, Chícharo et al., 2001; Drake et al., 2007) and salinity gradient changes due to dry periods may have stimulated anchovy to spawn in inner parts since *E. encrasicolus* can modify its spatial position in

250 order to remain within limited salinity bands (Drake et al., 2007). Anchovy abundances increased in
251 coastal areas adjacent to the Guadiana estuary during high river flow periods and it is suggested that
252 a reduction of inflow may have more negative consequences for eggs and larval stages that are more
253 susceptible (Chícharo et al., 2001).

254 Most taxa displayed a seasonal pattern presenting higher abundances during spring and summer and
255 the multivariate analysis confirmed distinct seasonal communities. However, this seasonal sign
256 decreases during years with low freshwater discharges and consequent higher salinity anomalies.
257 Indeed differences among seasons were higher than across years or sampling stations. Several
258 studies have already shown that temporal changes in composition and abundance are mostly related
259 to spawning patterns of adult fishes (e.g. Barletta-Bergan et al., 2002; Ramos et al., 2006; Sabatés et
260 al., 2007). Hence, *Atherina presbyter*, *Solea solea*, *Syngnathus abaster*, *Crystallogobius linearis*
261 and *Platichthys flesus* were more abundant during spring/summer period while *Ammodytes*
262 *tobianus*, *Callionymus* sp., *Echiichthys vipera* and *Liza ramada* were more abundant in
263 autumn/winter. The spatial distribution indicated that fish larvae predominated in inner areas of
264 estuary, mainly in the south arm probably due to the higher residence time thus avoiding being
265 washed out by river flux. Conversely, station M, at the mouth of the estuary, had a different fish
266 larval assemblage with fewer species and abundances.

267 Seasonal changes in temperature, chlorophyll *a* and runoff were found to be the main factors
268 forcing larval fish assemblage distributions leading to a decrease in abundance and diversity in fish
269 larval communities during colder months. Seasonal variations in environmental parameters seemed
270 to influence the assemblage structure but there was not a similar set of inter-annual changes in the
271 last six years. The Mondego estuary has recently experienced periods of low precipitation resulting
272 in reduced freshwater runoff and consequently changes in salinity gradients; this has influenced
273 estuarine communities at different trophic levels (e.g. Marques et al., 2007; Martinho et al., 2007b;
274 Cardoso et al., 2008). In the 2004/2005 dry years there was an increase in zooplankton density, a
275 higher abundance and prevalence of marine species throughout the year and a replacement of the
276 freshwater community by one predominantly dominated by estuarine organisms in the most
277 upstream areas (Marques et al., 2007; Primo et al., 2009). However, the main drought-induced
278 effects detected on juvenile fish assemblages were related to a depletion of freshwater species and
279 an increase in marine straggler species (Martinho et al., 2007b). The absence of a close correlation
280 between fish populations and environmental signals is a sign that species might show nonlinear
281 responses to external forcing (Hsieh et al., 2005) and the incidence of droughts may have a similar
282 impact on larval fish assemblages. Despite the community structure remaining relatively
283 unchanged, as indicated by multivariate analysis, the main effects detected were observed in the
284 species distribution. During years with positive salinity anomalies (mainly 2005 and 2008), marine

285 species (both stragglers and migrants) were able to reach the upper estuary in higher densities. Short
286 term fluctuations in larval abundances are mostly related to reproductive output or geographic shifts
287 (Hsieh et al., 2005) and Fernández-Delgado et al. (2007) suggest that temporal changes in
288 freshwater discharge cause longitudinal displacement of the estuarine salinity gradient leading to
289 related changes in marine species distribution. Also, during 2004 and 2005 the seasonal peak
290 occurred in spring regardless of summer conditions, as recorded during all the other years. The
291 early timing of seasonal peaks is an important response to climate change since it can influence
292 trophic interactions eventually leading to ecosystem-level changes (Edwards and Richardson,
293 2004). Short-term drought events seem to have a little influence on fish communities probably
294 because fish species are characterized by a slow response time to disturbance (Cabral et al., 2001).
295 Also, the number of influencing factors is too large and individual species may differ very widely in
296 their response. Nevertheless longer time-series are necessary to detect more significant impacts and
297 long term effects of climate change on larval fish assemblages in contrast to other trophic levels.

299 5. Conclusions

300 Mondego estuary fish larvae assemblages displayed a clear seasonal pattern presenting higher
301 abundances and diversities during warmer months. The main effects of dry events apparently did
302 not affect fish larval community structure but changes in estuarine salinity gradient appear to lead to
303 related changes in marine species distribution. Therefore, river flow played a key role in structuring
304 the ichthyoplankton assemblage thus representing also an important retention mechanism
305 responsible for a successful larval development and recruitment.

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314 References

315 Alemany, F., Deudero, S., Morales-Nin, B., López-Jurado, J.L., Jansà, J., Palmer, M., Palomera, I.,
316 2006. Influence of physical environmental factors on the composition and horizontal distribution of
317 summer larval fish assemblages off Mallorca Island (Balearic archipelago, western Mediterranean).
318 *Journal of Plankton Research* 28(5), 473-487.

- 319 Azeiteiro, U.M., Marques, J.C., Ré, P., 1999. Zooplankton annual cycle in the Mondego river
320 estuary (Portugal). *Arquivos do Museu Bocage* 3, 239–263.
- 321 Barletta-Bergan, A., Barletta, M., Saint-Paula, U., 2002. Structure and seasonal dynamics of larval
322 fish in the Caeté river estuary in North Brazil. *Estuarine, Coastal and Shelf Science* 54, 193–206.
- 323 Beck, M.W., Heck, K.L., Able, K.W., Childers, D.L., Eggleston, D. B., Gillanders, B. M., Halpern,
324 B., Hays, C. G., Hoshino, K., Minello, T. J., Orth, R. J., Sheridan, P. F., Weinstein, M. R., 2001.
325 The identification, conservation, and management of estuarine and marine nurseries for fish and
326 invertebrates. *BioScience* 51, 633–641.
- 327 Blaber, S.J.M., 1987. Factors affecting recruitment and survival of mugilids in estuaries and coastal
328 waters of Southeastern Africa. *American Fisheries Society Symposium* 1, 507–518.
- 329 Boeing, W.J., Duffy-Anderson, J.T., 2008. Ichthyoplankton dynamics and biodiversity in the Gulf
330 of Alaska: Responses to environmental change. *Ecological Indicators* 8, 292–302.
- 331 Cabral, H.N., Costa, M.J., Salgado, P., 2001. Does the Tagus estuary fish community reflect
332 environmental changes? *Climate Research* 18, 119-126.
- 333 Cardoso, P.G., Raffaelli, D., Pardal, M.A., 2008. The impact of extreme weather events on the
334 seagrass *Zostera noltii* and related *Hydrobia ulvae* population. *Marine Pollution Bulletin* 56, 483-
335 492.
- 336 Chícharo, L., Chícharo, M.A., Esteves, E., Andrade, J.P., Morais, P., 2001. Effects of alterations in
337 freshwater supply on the abundance and distribution of *Engraulis encrasicolus* in the Guadiana
338 Estuary and adjacent coastal areas of south Portugal. *Ecohydrology Hydrobiology* 1, 341–345.
- 339 Clarke, K.R. and Warwick, R.M., 2001. *Changes in Marine Communities: An Approach to*
340 *Statistical Analysis and Interpretation*. Plymouth Marine Laboratory, Plymouth, 172 pp.
- 341 Demir, N., 1976. Callionymidae of the northeastern Atlantic. *Fiches d'Identification du*
342 *Zooplankton* 148, 1-5.
- 343 Dolbeth, M., Martinho, F., Leitão, R., Cabral, H., Pardal, M.A., 2007. Strategies of *Pomatoschistus*
344 *minutus* and *Pomatoschistus microps* to cope with environmental instability. *Estuarine, Coastal and*
345 *Shelf Science* 74, 263–273.
- 346 Doyle, M.J., Mier, K.L., Busby, M.S., Brodeur, R.D., 2002. Regional variation in springtime
347 ichthyoplankton assemblages in the northeast Pacific Ocean. *Progress in Oceanography* 53, 247–
348 281.
- 349 Drake, P., Borlán, A., González-Ortegón, E., Baldó, F., Vilas, C., Fernández-Delgado, C., 2007.
350 Spatio-temporal distribution of early life stages of the European anchovy *Engraulis encrasicolus* L.
351 within a European temperate estuary with regulated freshwater inflow: effects of environmental
352 variables. *Journal of Fish Biology* 70, 1689–1709.

- 353 Edwards, M., Richardson, A.J., 2004. Impact of climate change on marine pelagic phenology and
354 trophic mismatch. *Nature* 430, 881–884.
- 355 Elliott, M., McLusky, D.S., 2002. The need for definitions in understanding estuaries. *Estuarine,*
356 *Coastal and Shelf Science* 55, 815–827.
- 357 Elliott, M., Whitfield, A.K., Potter, I.C., Blaber, S.J.M., Cyrus, D.P., Nordlie, F.G., Harrison, T.D.,
358 2007. The guild approach to categorizing estuarine fish assemblages: a global review. *Fish and*
359 *Fisheries* 8, 241–268.
- 360 Faria, A., Morais, P., Chícharo, M.A., 2006. Ichthyoplankton dynamics in the Guadiana estuary and
361 adjacent coastal area, South-East Portugal. *Estuarine, Coastal and Shelf Science* 70, 85–97.
- 362 Fernandez-Delgado, C., Baldo, F., Vilas, C., Garcia-Gonzalez, D., Cuesta, J.A., Gonzalez-Ortegon,
363 E., Drake, P., 2007. Effects of the river discharge management on the nursery function of the
364 Guadalquivir river estuary (SW Spain). *Hydrobiologia* 587, 125–136.
- 365 Fives, J.M., 1970. Blenniidae of the North Atlantic. *Fiches d'Identification du Zooplancton*, 3, 1–4.
- 366 Franco-Gordo, C., Godinez-Dominguez, E., Suarez-Morales, E., 2002. Larval fish assemblages in
367 waters off the central Pacific coast of Mexico. *Journal of Plankton Research* 24, 775–784.
- 368 Hsieh, C., Reiss, C., Watson, W., Allen, M.J., Hunter, J. R., Lea, R. N., Rosenblatt, R. H., Smith, P.
369 E., Sugihara, G., 2005. A comparison of long-term trends and variability in populations of larvae of
370 exploited and unexploited fishes in the Southern California region: a community approach. *Progress*
371 *in Oceanography* 67, 160–185.
- 372 INAG – Instituto Nacional da Água. Portuguese Water Institute. <http://snirh.pt/>. (Accessed
373 08.01.10)
- 374 Isari, S., Fragopoulou, N., Somarakis, S., 2008. Interrannual variability in horizontal patterns of larval
375 fish assemblages in the northeastern Aegean Sea (eastern Mediterranean) during early summer.
376 *Estuarine, Coastal and Shelf Science* 79, 607–619.
- 377 Leitão, R., Martinho, F., Cabral, H., Jorge, I., Marques, J.C., Pardal, M.A., 2007. The fish
378 assemblage of the Mondego estuary: Composition, structure and trends over the past two decades.
379 *Hydrobiologia* 587, 269–279.
- 380 Marques, S.C., Azeiteiro, U.M., Marques, J.C., Neto, J.M., Pardal, M.A., 2006. Zooplankton and
381 ichthyoplankton communities in a temperate estuary: spatial and temporal patterns. *Journal of*
382 *Plankton Research* 28, 297–312.
- 383 Marques, S.C., Azeiteiro, U.M., Martinho, F., Pardal, M.A., 2007. Climate variability and
384 planktonic communities: the effect of an extreme event (severe drought) in a southern European
385 estuary. *Estuarine, Coastal and Shelf Science* 73, 725–734.
- 386 Martinho, F., Leitão, R., Neto, J.M., Cabral, H., Marques, J.C., Pardal, M.A., 2007a. The use of
387 nursery areas by juvenile fish in a temperate estuary, Portugal. *Hydrobiologia* 587, 281–290.

- 388 Martinho, F., Leitão, R., Viegas, I., Dolbeth, M., Neto, J.M., Cabral, H.N., Pardal M.A., 2007b. The
389 influence of an extreme drought event in the fish community of a southern Europe temperate
390 estuary. *Estuarine, Coastal and Shelf Science* 75, 537-546.
- 391 Mazzoldi, C., Rasotto, M.B., 2001. Extended breeding season in the marbled goby, *Pomatoschistus*
392 *marmoratus* (Teleostei: Gobiidae), in the Venetian Lagoon. *Environmental Biology of Fishes* 61,
393 175-183.
- 394 Nichols, J.H., 1976. Soleidae of the Eastern North Atlantic. Fiches d'Identification du Zooplankton
395 150-151, 1-10.
- 396 Petersen, C.G.J., 1919. Our gobies (Gobiidae). From the egg to the adult stages. *Rep. Dan. biol.*
397 *Stn.*, **26**, 45-66.
- 398 Portuguese Weather Institute. <http://www.meteo.pt/en/index.html> (Accessed 08.01.07).
- 399 Primo, A.L., Azeiteiro, U.M., Marques, S.C., Martinho, F., Pardal, M.A., 2009. Changes in
400 zooplankton diversity and distribution pattern under varying precipitation regimes in a southern
401 temperate estuary. *Estuarine, Coastal and Shelf Science* 82, 341–347.
- 402 Ramos, S., Cowen, R.K., Ré, P., Bordalo, A.A., 2006. Temporal and spatial distribution of larval
403 fish assemblages in the Lima estuary (Portugal). *Estuarine, Coastal and Shelf Science* 66, 303-313.
- 404 Ré, P., 1999. Ictioplâncton estuarino da Península Ibérica. Guia de identificação dos ovos e estados
405 larvares planctónicos. Câmara Municipal de Cascais, Cascais, 163 pp.
- 406 Ré, P., Meneses, I., 2009. Early stages of marine fishes occurring in the Iberian Peninsula.
407 IPIMAR/IMAR, Lisboa, 282 pp.
- 408 Ribeiro, R., 1991. Ictioplâncton do estuário do Mondego e Resultados. *Revista de Biologia: Actas*
409 *do I Encontro de Planctologistas Portugueses* 4, 233-244.
- 410 Ribeiro, R., Gonçalves, F., 1993. Padrões espacio-temporais na diversidade da comunidade larvar
411 de teleósteos no estuário do Mondego. *Boletim Uca* 1, 490-506.
- 412 Ribeiro, R., Reis, J., Santos, C., Gonçalves, F., Soares, A.M.V.M., 1996. Spawning of anchovy
413 *Engraulis encrasicolus* in the Mondego estuary, Portugal. *Estuarine, Coastal and Shelf Science* 42,
414 467-482.
- 415 Russell, F.S., 1976. *The Eggs and Planktonic Stages of British Marine Fishes*. Academic Press,
416 London, 539 pp.
- 417 Sabatés, A., Olivar, M.P., Salat, J., Palomera, I., Alemany, F., 2007. Physical and biological
418 processes controlling the distribution of fish larvae in the NW Mediterranean. *Progress in*
419 *Oceanography* 74, 355-376.
- 420 Selleslagh, J., Amara, R., Laffargue, P., Lesourd, S., Lepage, M., Girardin, M., 2009. Fish
421 composition and assemblage structure in three Eastern English Channel macrotidal estuaries: A
422 comparison with other French estuaries. *Estuarine, Coastal and Shelf Science* 81, 149–159.

- 423 Strydom, N.A., Whitfield, A.K., Wooldridge, T.H., 2003. The role of estuarine type in
424 characterizing early stage fish assemblages in warm temperature estuaries, South Africa. *African*
425 *Zoology* 38, 29–43.
- 426 Whitfield , A.K., 1999. Ichthyofaunal assemblages in estuaries: a South African case study.
427 *Reviews in Fish Biology and Fisheries* 9, 151-186.

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FIGURE CAPTIONS

Fig. 1 – Map of the Mondego estuary, located on the western coast of Portugal. Sampling stations surveyed in this study are indicated (M, mouth station; S1 and S2, southern arm stations; N1 and N2, northern arm stations).

Fig. 2 – Seasonal water runoff (m^3) and average of precipitation (mm) in Mondego estuary during the study period.

Fig. 3 – Seasonal average water temperature ($^{\circ}\text{C}$), chlorophyll *a* (mg/m^3) and salinity anomalies in Mondego estuary during the study period.

Fig. 4 – Seasonal density (larvae 100m^{-3}) of total fish larvae and of each main ecological guild. ES – Estuarine species; MS – Marine Stragglers; MM – Marine Migrants.

Fig. 5 – Interannual and spatial density (larvae 100m^{-3}) distribution of the three main ecological guilds. (A) Estuarine Species; (B) Marine Stragglers; (C) Marine Migrants.

Fig. 6 – Temporal and spatial density (larvae 100m^{-3}) distributions of *Pomatoschistus* spp., *Engraulis encrasicolus*, *Solea senegalensis* and Shannon Wiener index (\log_2) in the Mondego estuary.

Fig. 7 – Triplot ordination diagram of the larval fish assemblages in Mondego estuary using the first two canonical correspondence axes. Samples were classified in winter, spring, summer and autumn. Significant environmental variables are plotted as arrows (T – temperature; Chl *a* – chlorophyll *a*; Sal – salinity; Runoff – river discharge) or nominal variables (W – winter; SM – summer). Species codes are presented in Table I.

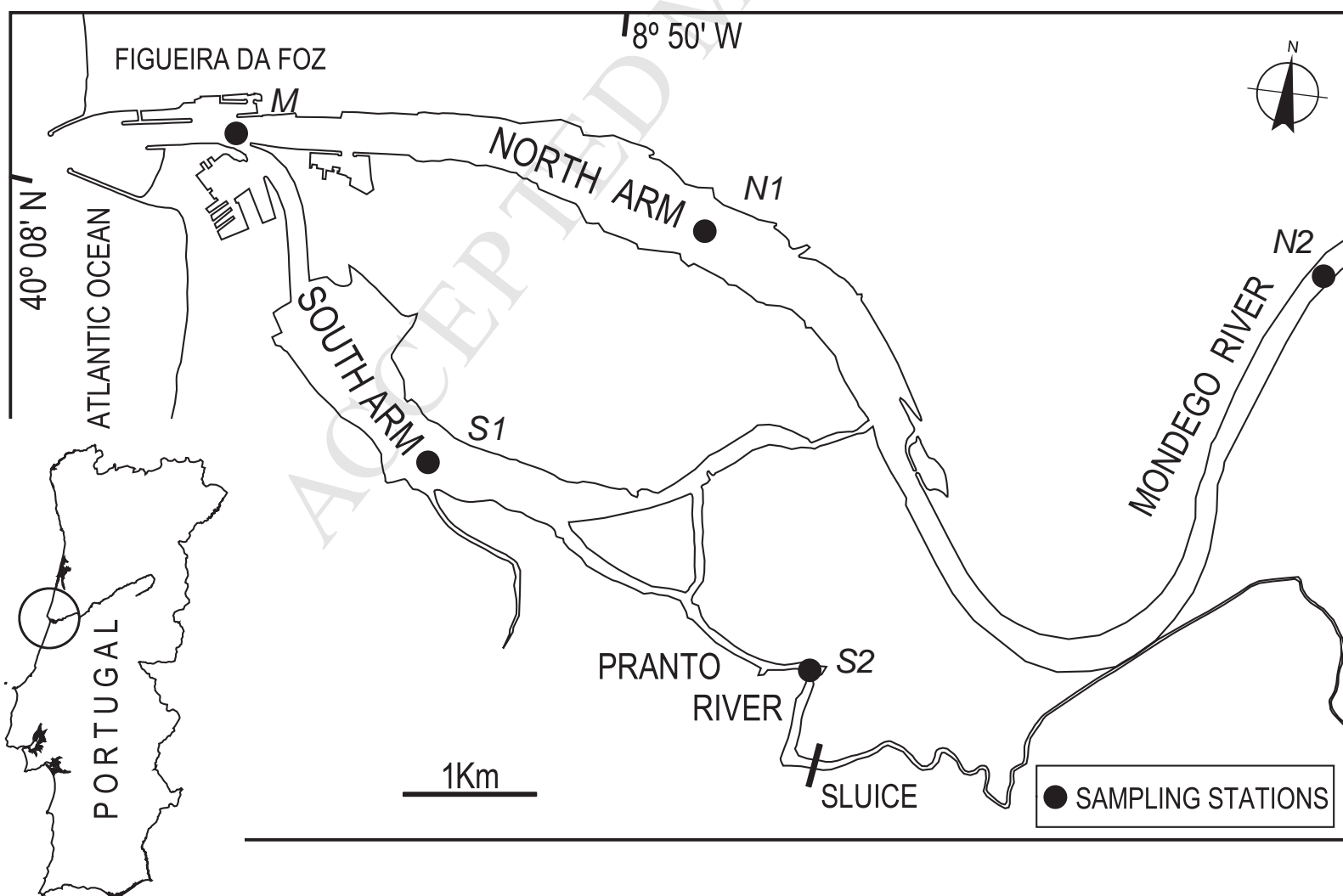


Figure 2

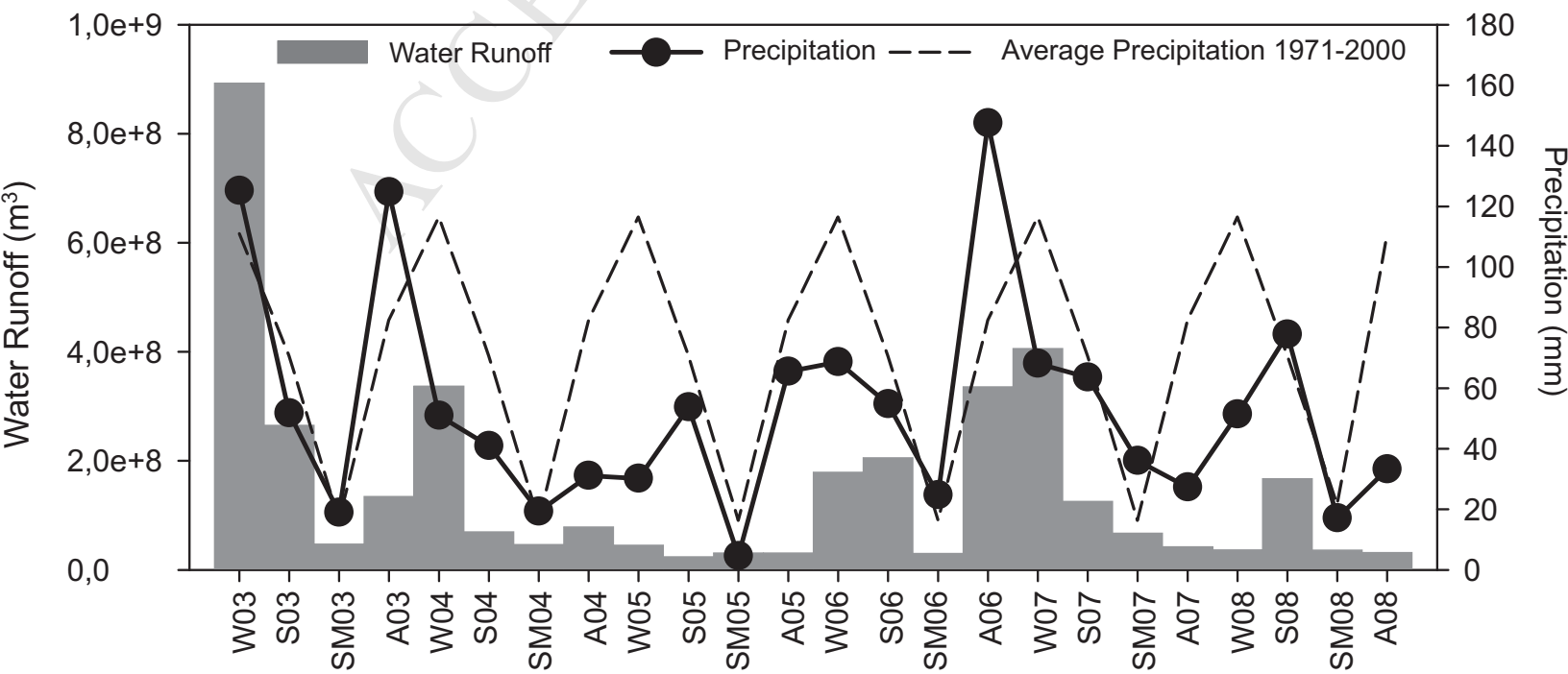
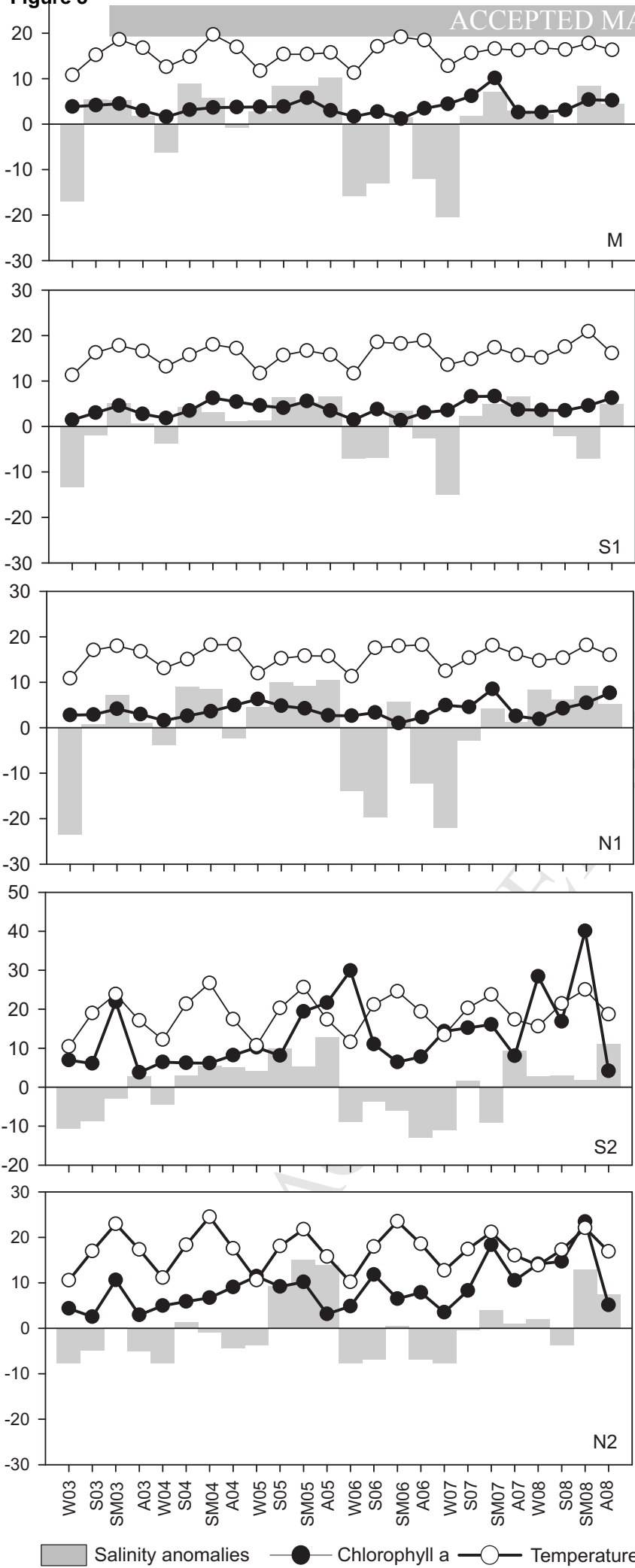
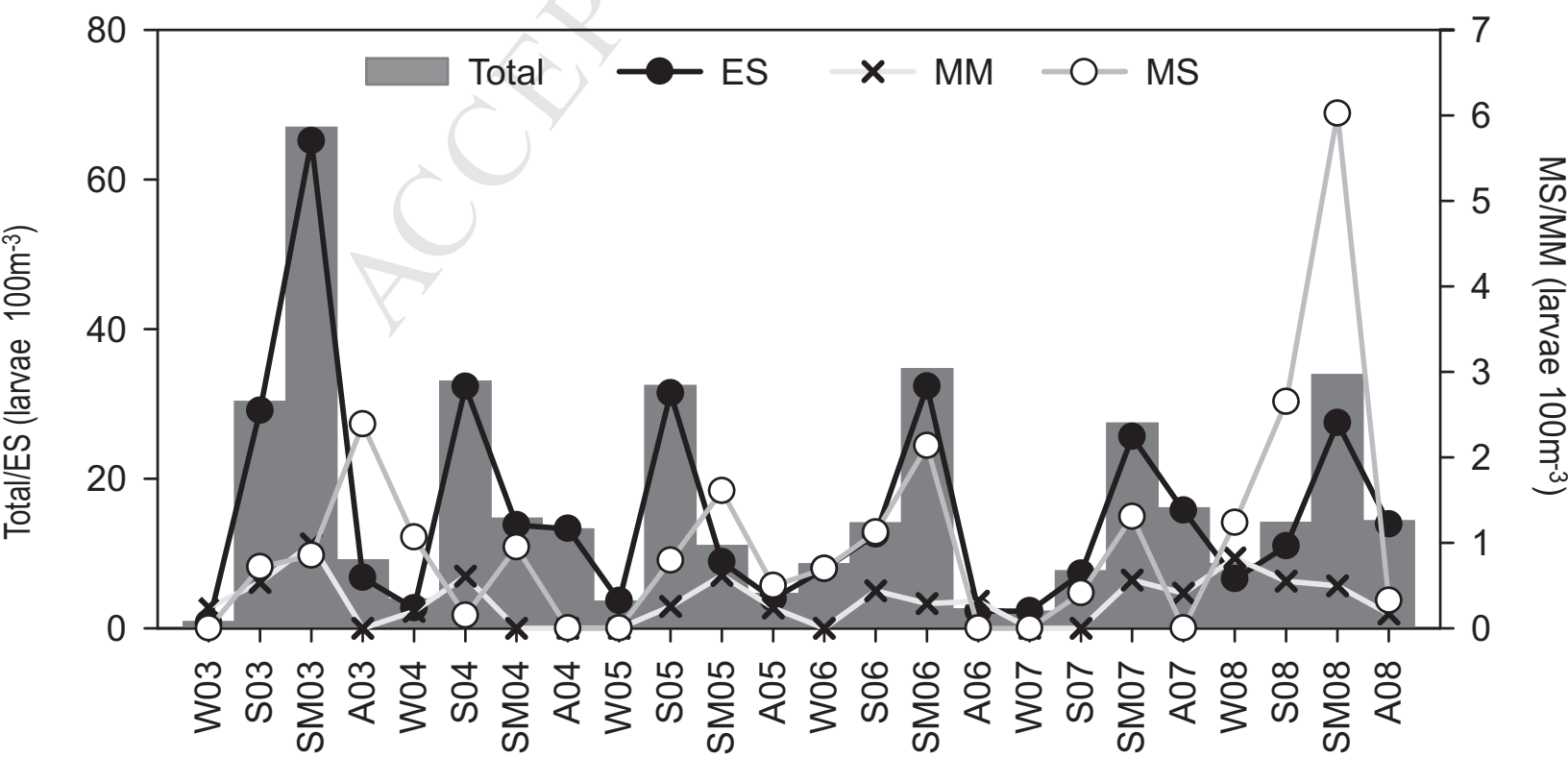


Figure 3



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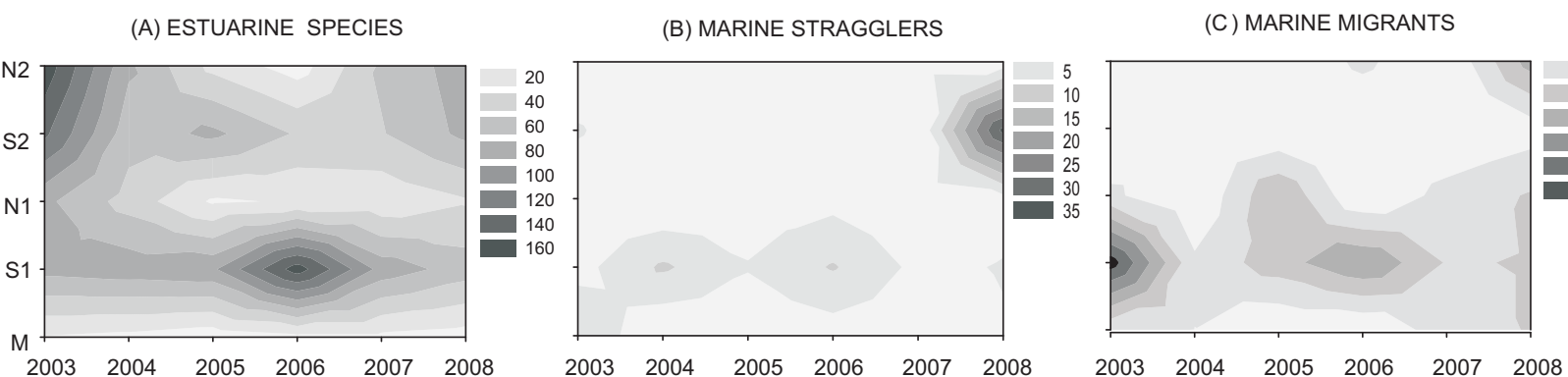
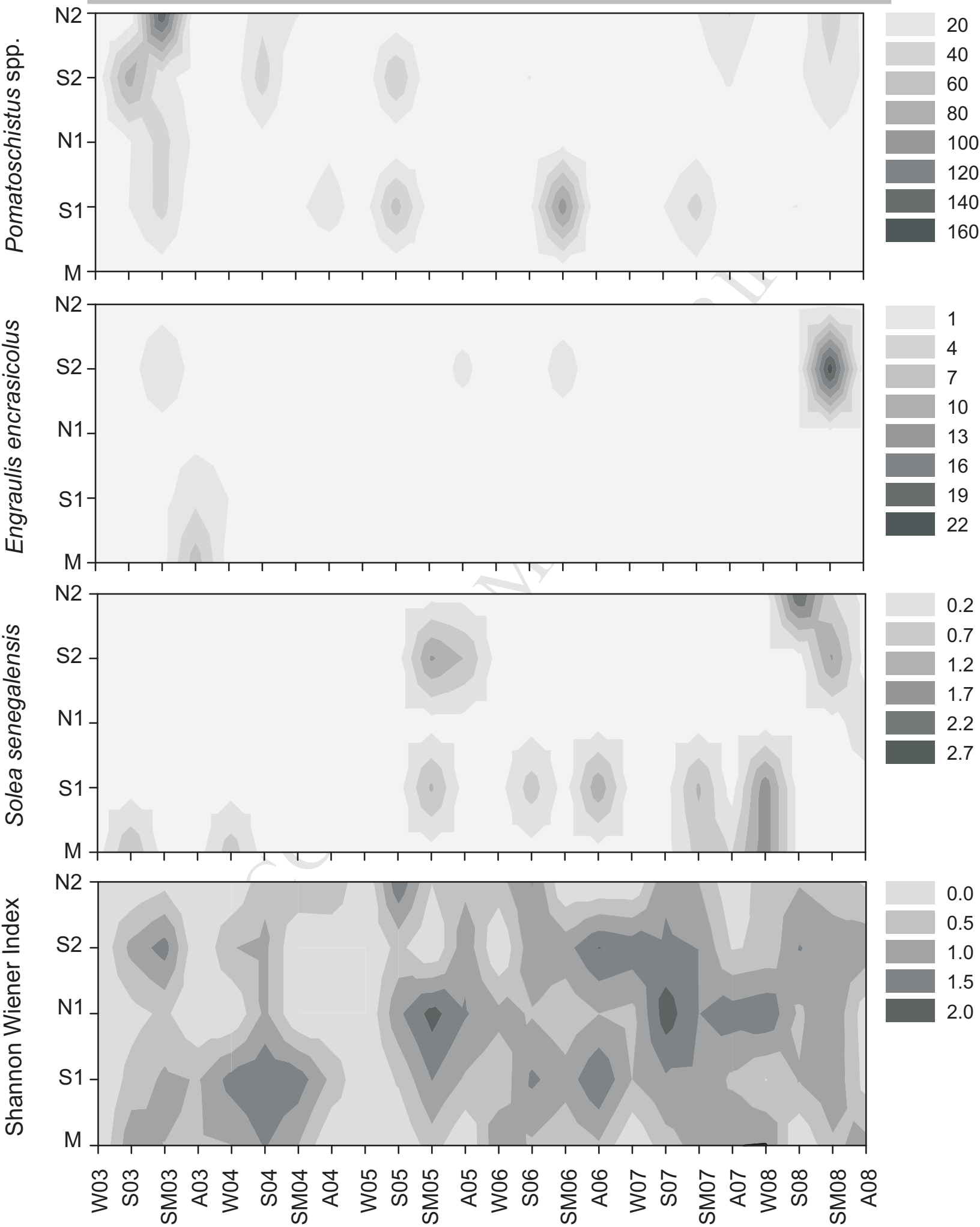


Figure 6

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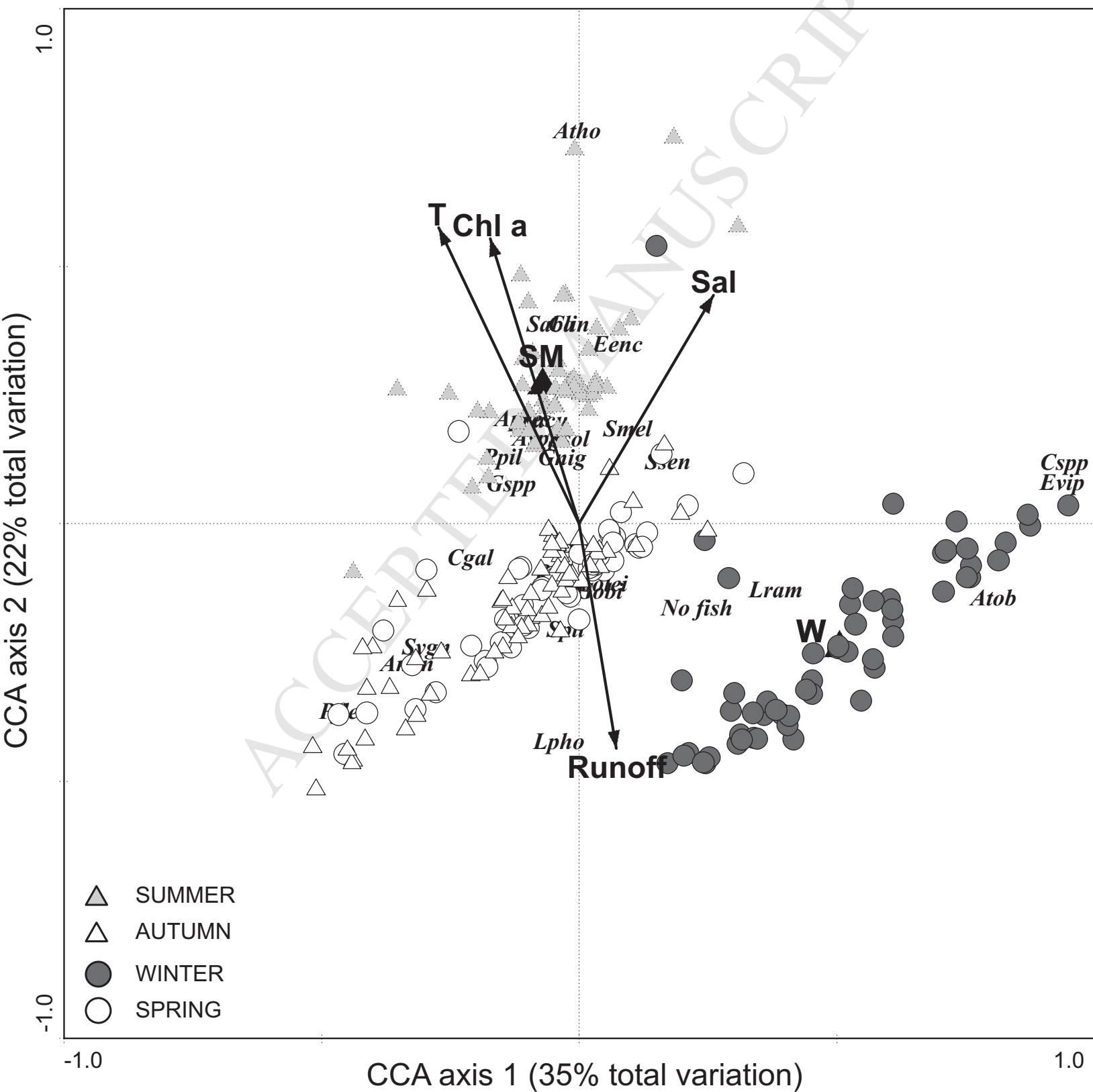


Table I: Mean Density (larvae 100m⁻³) of species caught during the sampling period and relative contribution (%) to the total catch in whole estuary, in each season and sampling station. MD – Mean Density; W – winter; S – spring; SM – summer; A – autumn.

Family	Species	CCA CODE	Ecological guild	Total catch		Season (%)				Sampling station (%)				
				MD	%	W	S	SM	A	M	S1	S2	N1	N2
Gobiidae	<i>Pomatoschistus</i> spp.	Psp	ES	70.65	63.40	54.42	58.26	68.52	65.39	3.19	18.52	16.35	7.74	17.59
Not identified	Not identified	-		9.52	8.75	6.69	13.54	4.20	12.31	3.82	2.20	1.01	1.50	0.22
Gobiidae	<i>Pomatoschistus microps</i>	Pmic	ES	6.63	6.02	3.44	9.92	3.20	6.76	0.05	0.98	2.61	1.39	0.98
Gobiidae	Gobiidae not identified	Gobi	ES	5.37	4.65	15.29	4.49	3.23	3.09	0.74	0.40	2.56	0.50	0.46
Gobiidae	<i>Gobius niger</i>	Gnig	ES	3.79	3.57	1.22	2.85	5.59	0.62	0.06	1.62	1.24	0.29	0.36
Engraulidae	<i>Engraulis encrasicolus</i>	Eenc	MS	2.01	1.96	0.49	-	4.16	0.83	-	0.12	1.78	-	0.06
Blenniidae	<i>Parablennius pilicornis</i>	Ppil	MS	2.02	1.88	-	1.36	3.08	0.60	0.13	0.93	0.10	0.24	0.47
Gobiidae	<i>Gobius</i> spp.	Gspp	ES	2.49	1.86	1.17	2.05	1.63	2.52	0.07	0.90	0.73	0.11	0.04
Soleidae	<i>Solea senegalensis</i>	Ssen	MM	1.51	1.33	3.19	0.55	1.37	1.97	0.32	0.44	0.04	0.39	0.14
Soleidae	Soleidae not identified	Solei		1.32	1.06	1.65	0.86	0.26	3.60	0.09	0.48	0.16	0.28	0.06
Syngnathidae	<i>Syngnathus acus</i>	Sacu	ES	0.96	0.85	-	0.37	1.55	0.40	0.04	0.17	0.16	0.24	0.24
Gobiidae	<i>Aphia minuta</i>	Amin	MS	0.61	0.59	-	1.73	-	-	-	0.08	0.51	-	-
Blenniidae	<i>Coryphoblennius galerita</i>	Cgal	MS	0.55	0.49	-	0.75	0.42	0.42	0.27	0.08	-	0.10	0.05
Clupeidae	<i>Sardina pilchardus</i>	Spil	MM	0.50	0.42	0.40	0.50	0.18	0.97	-	0.17	0.04	0.17	0.04
Blenniidae	<i>Lipophrys pholis</i>	Lpho	MS	0.38	0.38	2.38	0.44	-	0.22	0.12	0.15	-	0.08	0.03
Ammodytidae	<i>Ammodytes tobianus</i>	Atob	MS	0.35	0.32	3.86	-	-	-	-	0.27	-	0.06	-
Atherinidae	<i>Atherina presbyter</i>	Apres	ES	0.32	0.28	-	0.30	0.40	-	0.19	0.08	-	-	-
Atherinidae	<i>Atherina</i> spp.	Aspp	ES	0.44	0.27	-	0.12	0.52	-	-	0.15	-	0.12	-
Soleidae	<i>Solea solea</i>	Ssol	MM	0.26	0.26	-	0.15	0.48	-	-	0.26	-	-	-
Gobiidae	<i>Pomatoschistus minutus</i>	Pmin	ES	0.23	0.23	-	0.68	-	-	-	0.10	0.09	0.04	-
Syngnathidae	<i>Syngnathus</i> spp.	Sygn	ES	0.22	0.21	-	0.44	0.14	-	-	0.19	-	-	0.02
Blenniidae	Blenniidae n. id	Blenn		0.23	0.17	1.35	0.17	-	-	-	-	0.06	-	0.11
Mugilidae	<i>Liza ramada</i>	Lram	CA	0.20	0.16	1.07	-	0.17	-	0.07	-	0.09	-	-
Labriidae	<i>Symphodus melops</i>	Smel	MS	0.15	0.15	-	0.17	0.22	-	-	0.15	-	-	-
Syngnathidae	<i>Syngnathus abaster</i>	Saba	ES	0.26	0.13	-	-	0.30	-	-	0.07	-	-	0.06
Callionymidae	<i>Callionymus</i> spp.	Cspp	ES	0.17	0.11	1.35	-	-	-	0.06	-	-	0.06	-
Trachinidae	<i>Echiichthys vipera</i>	Evip	MS	0.17	0.11	1.35	-	-	-	0.06	-	-	0.06	-
Gobiidae	<i>Crystallogobius linearis</i>	Clin	MS	0.24	0.11	-	-	0.25	-	-	0.07	0.04	-	-
Pleuronectidae	<i>Platichthys flesus</i>	Pfle	MM	0.10	0.10	-	0.30	-	-	-	-	-	-	0.10
Ammodytidae	Ammodytidae n. id.	Amm		0.09	0.06	0.68	-	-	-	-	-	-	-	0.06
Bothidae	<i>Arnoglossus thori</i>	Atho	MS	0.05	0.05	-	-	0.12	-	-	-	0.05	-	-
Blenniidae	<i>Lipophrys</i> spp.	Lspp	MS	0.04	0.04	-	-	-	0.29	-	-	0.04	-	-
Total Number of Larvae				7211		608	2449	3112	1042	669	2060	1995	965	1522
Number of Species				31		17	22	22	15	17	25	19	18	19