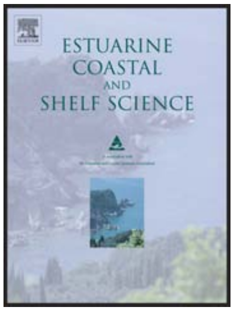

Effects of local and large-scale climate patterns on estuarine resident fishes: the example of *Pomatoschistus microps* and *Pomatoschistus minutus*

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PII: S0272-7714(13)00478-2
DOI: 10.1016/j.ecss.2013.10.030
Reference: YECSS 4303

To appear in: *Estuarine, Coastal and Shelf Science*

Received Date: 1 February 2013

Accepted Date: 25 October 2013

Please cite this article as: Nyitrai, D., Martinho, F., Dolbeth, M., Rito, J., Pardal, M.A., Effects of local and large-scale climate patterns on estuarine resident fishes: the example of *Pomatoschistus microps* and *Pomatoschistus minutus*, *Estuarine, Coastal and Shelf Science* (2013), doi: 10.1016/j.ecss.2013.10.030.

Effects of local and large-scale climate patterns on estuarine resident fishes: the example of *Pomatoschistus microps* and *Pomatoschistus minutus*

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Abstract

Large scale and local climate patterns are known to influence several aspects of the life cycle of marine fish. In this paper, we used a 9-year database (2003 to 2011) to analyse the populations of two estuarine resident fishes, *Pomatoschistus microps* and *Pomatoschistus minutus*, in order to determine their relationships with varying environmental stressors operating over local and large scales. This study was performed in the Mondego estuary, Portugal. Firstly, the variations in abundance, growth, population structure and secondary production were evaluated. These species appeared in high densities in the beginning of the study period, with subsequent occasional high annual density peaks, while their secondary production was lower in dry years. The relationships between yearly fish abundance and the environmental variables were evaluated separately for both species using Spearman correlation analysis, considering the yearly abundance peaks for the whole population, juveniles and adults. Among the local climate patterns, precipitation, river runoff, salinity and temperature were used in the analyses, and North Atlantic Oscillation (NAO) index and sea surface temperature (SST) were tested as large-scale factors. For *P. microps*, precipitation and NAO were the significant factors explaining abundance of the whole population, the adults and the juveniles as well. Regarding *P. minutus*, for the whole population, juveniles and adults river runoff was the significant predictor. The results for both species suggest a differential influence of climate patterns on the various life cycle stages, confirming also the importance of estuarine resident fishes as indicators of changes in local and large-scale climate patterns, related to global climate change.

Keywords: *Pomatoschistus microps*, *Pomatoschistus minutus*, Mondego estuary, environmental variables, river runoff, NAO

1. Introduction

Climate change has significant impacts on marine and estuarine ecosystems (Harley et al. 2006, Montoya and Raffaelli 2010). These impacts can be induced by the alterations in local climate patterns such as temperature, freshwater flow, wind, tidal circulation and currents (e.g. Henderson and Seaby, 2005; Martinho et al. 2009), or by changes in large-scale factors such as North Atlantic Oscillation (NAO) and sea surface temperature (SST) (Attrill and Power, 2002; Vinagre et al. 2009). In addition, local stochastic events such as weather extremes (e.g. droughts, floods, heat/cold waves) can induce fluctuations in the conditioning factors, influencing the biological processes and ecosystem development of estuaries (Kantoussan et al. 2012; Pasquaud et al.2012).

As transitional areas, estuaries are among the most productive ecosystems of the world, supporting important ecological links with other environments (McLusky and Elliott, 2004; Able, 2005). These areas support high abundance of different biological communities, of which fish are a very important component (Whitfield, 1999). In particular, estuaries provide nursery and reproduction grounds for several species, offering a favourable habitat for resident species, juveniles of marine species and migratory routes for catadromous and anadromous species (Elliott and McLusky, 2002; Martinho et al. 2007). Nevertheless, the functioning of these transitional systems is strongly affected by environmental pressures linked to eutrophication, industrial pollution, overfishing and climate change (Martinho et al. 2008, Dolbeth et al. 2010).

Estuarine fish populations are highly dynamic and characterized by changing levels of recruitment and migration (Costa et al. 2002), being highly affected by hydrological parameters and climate (Costa et al. 2007; Martinho et al. 2009). In particular, fish dynamics, growth and production of estuarine ecosystems seem to be strongly affected by altered hydrology patterns, which can be regulated by floods and drought events (Whitfield 2005; Dolbeth et al. 2008a, 2010; Baptista et al. 2010). Fish recruitment, growth and production can also be influenced directly by changes in physico-chemical parameters, such as salinity, turbidity and dissolved oxygen (Pampoulie et al. 2001; Selleslagh and Amara, 2008) or indirectly, through changes in food availability (Whitfield, 2005). Temperature has also important effects on fish reproduction, growth and migration patterns (Attrill and Power, 2002; Vinagre et al. 2009). Therefore fishes are widely used as indicators of environmental changes (e.g. Martinho et al. 2008; Ramos et al. 2012), as they provide the possibility to evaluate the condition of the environment without having to capture the full complexity of the system (Whitfield and Elliott, 2002).

In most European estuaries, the common goby *Pomatoschistus microps* and the sand goby *Pomatoschistus minutus* are ubiquitous and abundant species (Bouchereau and Guelorget, 1998; Leitão et al. 2006). In general, these species spend their entire life cycle within estuaries, showing relatively short life spans and distinct behavioural characteristics (Bouchereau and Guelorget, 1998; Leitão et al. 2006; Dolbeth et al. 2007). In addition, gobies are also important for the estuarine foodweb as intermediate predators (Dolbeth et al. 2008b). Taking into account these characteristics, it is important to better understand their life cycle and to evaluate their responses to different environmental scenarios.

Based on the mentioned above, the overall aims of the present study were to evaluate the effects of climatic variations on two estuarine resident fish species, and to highlight the important role of estuarine residents fishes as indicators of environmental changes. More specifically, the main objectives were (1) to evaluate the abundance, growth and production patterns of *P. microps* and *P. minutus* over a nine year period (June 2003 to June 2011); (2) to estimate the responses of the two species to different environmental variables, including local and large-scale climate patterns; (3) to assess the distinct response patterns to the environmental variables by the different life stages of each species.

2. Materials and methods

2.1 Study site

The Mondego estuary is a small intertidal estuary of 8.6 km^2, located on the Atlantic coast of Portugal (40^0 08′N, 8^0 50′W). The estuary is divided in two distinct arms (north and south) in the terminal part at about 7 km from the shore that join again near the mouth (Fig. 1). The north arm is deeper, with 5-10 m depth at high tide, with a tidal range of 2-3 m, while the south arm is shallower, with 2-4 m during high tide, and a tidal range of 1-3 m. The north arm constitutes the main navigation channel and the location of the Figueira da Foz commercial harbour. The constant dredging and shipping that occur in this area causes physical disturbance of the bottom. The south arm is characterized by large areas of intertidal mudflats that comprise about 75% of the total area. Freshwater flows mainly through the north arm, as the south arm is almost silted up in the upstream areas. The water circulation on the south arm is mainly dependent on the tides and on the small freshwater input from the Pranto River, which is a small tributary system, regulated by a sluice according to the water needs in the surrounding rice fields. In 2006, the connection between the two arms was enlarged, allowing a higher water circulation through the south arm.

2.2 Sampling and laboratory procedures

Sampling was conducted monthly from June 2003 until January 2007, and then bimonthly until June 2011 (except in July, September, October and December 2004, October and November 2008, September and November 2010 and March 2011, owing to technical constraints or bad weather conditions). Fishing took place during the night at five sampling stations (Fig. 1), at high water of spring tides, using a 2-m beam trawl with one tickler chain and 5-mm stretched mesh size in the cod end. At each sampling station, three hauls were towed at the speed of two knots for an average of 3 minutes each, covering at least an area of 500 m^2. Samples were transported in iceboxes to the lab, where fish were sorted, and all *P. microps* and *P. minutus* present in the samples were measured (total length to nearest 1mm) and weighted (wet weight, 0.01 g precision). Bottom water was analyzed for temperature and salinity at each sampling station during the fishing campaigns.

2.3 Acquisition of environmental data

Freshwater runoff was acquired from the Portuguese Water Institute (INAG; http://snirh.inag.pt; 12.03.2012) station Açude Ponte Coimbra 12G/01A, near the city of Coimbra, located 40 km upstream of the estuary. Monthly precipitation was obtained from the Soure 13F/01G station (INAG), and the long-term average precipitation (1971-2000) was obtained in http://www.meteo.pt from Coimbra station (IM).

The North Atlantic Oscillation (NAO) index (defined as the pressure difference between Lisbon, Portugal, and Reykjavik, Iceland) data were supplied by NOAA / National Weather Service – Climate Prediction Centre (http://www.cdc.noaa.gov, 21.03.2012). Sea surface temperature (SST) data concerning the 1º Lat × 1º Long square in the Portuguese coast nearest to the Mondego estuary were obtained from the International Comprehensive Ocean-Atmosphere Data Set (ICOADS) online database (http://dss.ucar.edu/pub/coads, Slutz et al. 1985; 09.03.2012).

2.4 Data analysis

For both species, monthly density data (individuals per 1000 m^2) were calculated by averaging the total number of individuals in relation to the five sampling stations. Mean annual densities were calculated by averaging the monthly data from each year (from January to December).

The population structure of both species was determined by tracking recognizable cohorts from the consecutive sampling dates. Each spatial sample was aggregated and analyzed using the size frequency distribution of the consecutive sampling dates. Cohorts were determined using the FAO - ICLARM Stock Assessment Tools software (FISAT II, http://www.fao.org/fi/statist/fisoft/fisat/index.htm). Bhattacharya's method was used at first to identify the location of the modes, and then the estimated mean length for each age group was refined with the NORMSEP procedure, which separates normally distributed components of the size-frequency samples (Gayanilo et al. 2005). This analysis provides the mean length, standard deviation, population sizes and the separation indices for the identified age groups.

After identification of the cohorts, annual production was calculated using the cohort increment summation method (Winberg 1971), according to:

$$P_{cn} = \sum_{t=0}^{T-1} \left(\frac{N_t + N_{t+1}}{2} \right) \times \left(\overline{w}_{t+1} - \overline{w}_t \right)$$

where P_{cn} is the growth production (g ww 1000 m^{-2} year $^{-1}$) of cohort *n*; *N* is the density (ind 1000 m^{-2}), $\overline{w}$ is the mean individual weight (g ww), and *t* and *t*+1, consecutive sampling dates. Population production estimates correspond to the sum of each cohort production (P_{cn}). Negative production values were not included in the overall estimates and were considered as zero production. Annual production was calculated for each year, from June to May.

The mean annual biomass ($\overline{B}$) was estimated according to:

$$\overline{B} = \left(\frac{1}{T} \right) \times \sum_{n=1}^{N_c} \left(\overline{B}_{cn} t_{cn} \right)$$

where *T* is the period of study, which is always 365 days (yearly cycles) as the mean annual biomass is being computed; N_c is the number of cohorts found in the study period; $\overline{B}_{cn}$ is the mean biomass (g ww 1000 m^{-2}) of cohort *n*; t_{cn} is the time period of the cohort *n* (days), from the first appearance of individuals until they disappeared.

For each cohort, absolute growth rates (AGR, cm day^{-1}) were calculated, according to:

$$AGR = \frac{L_{t+1} - L_t}{t+1-t}$$

where L_{t+1} and L_t are the total length at time *t*+1 and *t* respectively.

The relationships between the fish densities and environmental variables were analyzed with Spearman correlations using R software (R Development Core Team, 2008). These analyses were performed separately for the two species, considering the population as a whole, and then adults and juveniles separately. The separation between adults and juveniles was determined taking into account the minimum length of the last maturation stage found for each species (for *P. microps*, 2.5 cm; for *P. minutus*, 3.9 cm), previously defined by Dolbeth et al. 2007. The explanatory variables for these analyses included precipitation, freshwater runoff, mean estuarine salinity, mean estuarine temperature, the North Atlantic Oscillation (NAO) index and sea surface temperature (SST) in the coastal area near the estuary. For each year, the sampling date with the highest density value of each species was used in the analyses (whole population, adults and juveniles separately)

(Table 1), and compared against the monthly average values of each environmental variable of the corresponding date. We also tested a time-lag of one and two months to detect small time scale patterns, and six and twelve months in order to detect larger time scale patterns, since it has been recognized that the environmental background may influence fish spawning and larval immigration, and hence, fish recruitment over a wider time frame (e.g. Vinagre et al. 2009; Martinho et al. 2012). For the mean estuarine salinity and temperature, only the monthly average values of the corresponding date with the highest density values were used in the models. A significance level of 0.05 was considered in all test procedures.

3. Results

3.1 Environmental characterization

Both precipitation and freshwater runoff showed clear seasonal fluctuations, characteristic of temperate regions, along the 9-year study period (Fig. 2A). In the periods with higher precipitation, freshwater runoff increased and consequently salinity decreased inside the estuary, while during periods of low precipitation an opposite pattern could be observed. In general, 2003, 2006 and 2009 were considered as regular hydrologic years regarding precipitation, 2004, 2005, 2007, 2008 and 2011 were dry years, and 2010 was considered as rainy year, by comparing against the mean precipitation regime for central Portugal during the period of 1971-2000 (INAG; http://snirh.inag.pt). The harshest drought occurred in 2005, when precipitation values were far below the long-term average, considered the worst drought since 1931 in the Portuguese territory (Fig. 2A). The highest precipitation values were observed in the autumns of 2003 and 2006 and in the winter of 2009/2010 (Fig. 2A), when some of the highest levels occurred since 1970, inducing an abrupt increase in river runoff (Fig. 2A) and consequent decrease in salinities (Fig. 2B).

The mean estuarine water temperature was in general lower than the SST in the adjacent coastal area (varying between 9ºC and 23℃, compared to 11ºC and 29℃, respectively) (Fig. 3A). Estuarine water temperature was the lowest in January 2005, while the highest values were observed in July 2005, with 2005 characterized by the highest variation in temperature along the year (Fig. 3A). SST was the lowest in the winter of 2004 and 2005, while the highest values occurred in the summer of 2003 (Fig. 3A). The highest annual range variation of SST was observed in 2009 (13ºC in January and 28℃ in August) (Fig. 3A).

The NAO index ranged from -2.69 to 2.55 and showed a general decreasing tendency towards the end of the study period, denoting a transition from a positive to a negative phase (Fig. 3B).

3.2 Abundance, population structure and absolute growth rates

In general, *P. microps* was more abundant than *P. minutus* (Fig. 4A). Both species had high densities in 2003, after which they decreased and showed constant values. Apart from this, *P. microps* was also more abundant in 2004, 2006 and in 2011, showing the highest values along the study period (Fig. 4A). Both adults and juveniles of *P. microps* showed similar abundances, but between 2007 and 2010, juveniles occurred in lower densities (Fig. 4B). In 2011, juveniles occurred in higher densities than the adults (Fig. 4B). *P. minutus* was more abundant in 2003, 2004, 2006 and in 2010 (Fig. 4A), mainly due to juveniles (Fig. 4C). In 2003, 2005 and between 2007 and 2009, *P. minutus* juveniles were less abundant than the adults (Fig. 4C).

P. microps had three recruitment periods per year (January, April and June/July), while for *P. minutus* only two recruitment periods were observed (April and November) (Fig. 5A, B). Smaller juveniles of both species were not detected between 2007 and 2009 (Fig. 5A, B). Larger individuals were observed in 2006, 2007 and 2009 for both species, as well as in 2003 for *P. minutus* (Fig. 5A, B).

For *P. microps*, the mean growth rate of January recruits was similar to those of the April and the June/July recruits (0.007, 0.008 and 0.008 cm.day^{-1}, respectively). Regarding *P. minutus*, the April and November recruits showed also similar growth rates (0.010 and 0.011 cm.day^{-1}, respectively).

3.3 Production dynamics

The mean annual production and biomass of *P. microps* were highly variable along the study period, with the maximum values observed in 2006/07 (Table 2). High production values were observed in 2003/04, 2004/05, 2005/06 and 2006/07, while the lowest values were obtained in 2008/09 (Table 2). Mean biomass was highest in 2003/04, 2006/07 and at the end of the study period in 2010/11 (Table 2). The lowest mean annual biomass values were obtained in 2008/09. $P/\overline{B}$ ratios were higher in 2005/06 and 2009/10, while the lowest values were observed in 2008/09 and 2010/11 (Table 2).

For *P. minutus*, both mean annual production and biomass were the highest at the beginning of the study period (2003/04), and then presented constant values (Table 2). Nevertheless, annual production was the lowest in

2005/06, while mean biomass had the lowest values in 2008/09. The highest $P/\overline{B}$ ratios were observed in 2003/04 and in 2008/09, and the lowest in 2005/06 (Table 2). In general, both production and mean biomass values were higher for *P. minutus* than for *P. microps* (Table 2).

3.4 Relation between environmental parameters and fish abundance

According to the Spearman correlation analysis, the different life stages of *P. microps* and *P. minutus* showed different response patterns to the environmental variables (Table 3). Regarding the total *P. microps* population, both precipitation and NAO two months prior to the peak abundance were significant factors explaining year-to-year variations in abundance (Table 3): in years of high precipitation and positive NAO values, higher abundance of *P. microps* was observed.

For the *P. microps* juveniles, precipitation two months prior and NAO one month prior to the highest abundance peak were significant factors explaining abundance (Table 3). For the adult *P. microps* individuals, the NAO index with a time lag of twelve months and precipitation two months prior to the highest abundance peak were significant predictors (Table 3). In particular, higher abundances were observed during positive NAO values and higher precipitation.

Concerning the whole population of *P. minutus*, river runoff with a time lag of six months to the highest abundance peak was the only significant predictor (Table 3). Likewise, for the *P. minutus* adults and juveniles, the same parameter was also significant. In general, higher abundance of *P. minutus* was observed in periods with higher river runoff (Table 3).

4. Discussion

4.1 Abundance, growth and production

Estuarine resident fish species, such as those in the present study, are highly abundant across European estuaries (e.g. França et al. 2010; Henderson et al. 2011). Similarly also to most European estuaries, *P. microps* was more abundant than *P. minutus* in the Mondego estuary, which can be related to the particular physiological characteristics of the two species: *P. microps* tolerates a wider range of temperature and salinity variations, which seems an advantage towards *P. minutus* (Dolbeth et al. 2007, 2010).

The abundance peaks observed for both species occurred in years with higher precipitation and river runoff levels (2003, 2004, 2006, 2010 and 2011). Although 2004 and 2011 were considered as dry years, high precipitation and river runoff were observed in summer and autumn, which could have influenced the abundance patterns of the two species by reducing the overall salinity within the estuary for *P. microps*, or increasing food availability from allochthonous sources. Salinity plays an important role on the egg development of Gobidae fish, whose survival is lower at higher salinities for *P. microps* (Fonds and Van Buurt, 1974). In fact, the juveniles of both species appeared with lower densities in the years with higher salinity levels within the estuary, mainly in the driest years (e.g. 2005, 2007, 2009 and 2010). According to Maes et al. (1998), besides the adults, the juveniles of *P. minutus* also undertake migrations to the coastal area to avoid predation and to find food, which could also explain the lower abundance of juveniles during this period. However, predation pressure might also have been higher during the droughts (as hypothesised for the extreme drought of 2005 by Dolbeth et al. 2007), which could have contributed to the eventual migration or mortality of juveniles in those years.

For both species, higher annual productions were observed in years when precipitation was higher and salinities consequently decreased inside the estuary. This pattern confirms the important role of freshwater flow that has both direct and indirect effects on fish abundance (Costa et al. 2007; Martinho et al. 2007) and production (Dolbeth et al. 2008, 2010). For *P. microps*, mean annual production and biomass were relatively constant along the study period, confirming the higher resilience of this species to temperature and salinity variations (Riley 2003, Dolbeth et al. 2007). Both annual production and mean biomass of *P. minutus* were the highest at the beginning of the study period, and then remained constant. Contrary to *P. microps*, this species is less tolerant to the interrelated environmental variations that were relatively strong during the study period, mainly precipitation, freshwater flow and salinity. On the other hand, the lowest production values in 2005/06 could be attributed to predation, as during this extreme drought period some piscivorous species appeared inside the estuary, exploiting the temporarily available suitable habitat created by a higher salinity incursion, which might have caused a higher predation pressure on the resident species (Dolbeth et al. 2007; Martinho et al. 2010).

4.2 Relationship between environmental variables and fish abundance: the role of local and large-scale climate patterns

Both species provided different responses to the selected environmental variables, suggesting different tolerance thresholds and adaptation strategies to the surrounding environment. For the whole population, juveniles and adult individuals of *P. microps*, the NAO with a time lag of two, one and twelve months respectively, and precipitation with a time lag of two months prior to the year-to-year abundance peak were significant factors explaining interannual variability in abundance. The significant effects of NAO on the abundance patterns of *P. microps* show that large-scale factors can influence fish species over a prolonged time frame (Ottersen et al. 2001; Vinagre et al. 2009), and also suggest its influence on local climate patterns: in the central Atlantic region, the NAO is responsible for changes in sea surface temperature (SST) and also for wind and current patterns (Stenseth et al. 2002; Henriques et al. 2007). In addition, recent studies highlighted the indirect effects of NAO on the abundance and productivity of fish communities (Attrill and Power, 2002; Henriques et al. 2007) and also on the recruitment and migration patterns of species (Sims et al. 2004; Henderson and Seaby, 2005). Moreover, the relationship between the NAO and water temperature (Ottersen et al. 2001; Attrill and Power, 2002) might also contribute for the interannual variability of *P. microps*, as previous studies in the Mondego estuary described that abundance patterns of this species were positively correlated with water temperature (Dolbeth et al. 2007).

Our results also confirm the important regulating effects of local environmental processes on fish abundance, such as precipitation and consequently freshwater inflow (e.g. Costa et al. 2007; Gillson et al. 2009; Martinho et al. 2009), with consequent repercussion on the production levels (Dolbeth et al. 2007, 2010), as observed by the increased production of *P. microps* in the years with higher precipitation levels. In general, higher river flow is responsible for an increased transport of organic matter towards estuaries, inducing an increase in primary and secondary production that provides higher food availability for fishes (Costa et al. 2007; Baptista et al. 2010, Dolbeth et al. 2010).

For the whole population, juveniles and adults of *P. minutus*, river runoff with a time lag of six months prior to the yearly abundance peak was the only significant factor explaining abundance. Higher abundances of *P. minutus* adults were observed during periods with higher river runoff, confirming the important effects of freshwater flow on fish abundance, as sources of primary and secondary production available for fish consumption (Costa et al. 2007; Gillson et al. 2009). In addition, the winter reproductive migrations of this species could also have been influenced by river runoff, as during higher river runoff food availability might increase, which may have induced the migration of larvae and young individuals towards the estuary.

Surprisingly, there were no significant relationships between fish abundance and temperature, although previous studies found positive relation between fish production and temperature (e.g. Dolbeth et al. 2007). As ectotherms, metabolic processes in fish are dependent on temperature (Fry, 1947; Neill et al. 1994), which include growth and reproduction. In addition, temperature has also been determined to be an important regulatory factor for egg size and developmental rates (Fox et al. 2003). However, the influence of temperature on the abundance patterns of both *Pomatoschistus* species might not be easily isolated, since they are relatively resilient to temperature fluctuations (Riley 2003, 2007), and the rate of regime shift is much slower when compared to the rapid changes in salinity or freshwater flow.

The present study showed that *Pomatoschistus* populations might be highly affected by climatic variability (associated with changes in precipitation, river runoff and large scale patterns such as the NAO), through changes in abundance patterns, growth and production potential. To a further extent, global climatic changes might induce notable alterations in estuarine fish assemblages, which could have significant effects on the structure and functioning of coastal marine ecosystems (e.g. Philippart et al. 2011; Rose and Allen, 2013).

Acknowledgements

The authors would like to thank all colleagues who helped in field and laboratory work. This work was supported by the FCT (Portuguese Foundation for Science and Technology) through a PhD grant attributed to D. Nyitrai (SFRH/BD/48742/2008), a post-doc grant attributed to F. Martinho (SFRH/BPD/63527/2009) and BIOCHANGED project (PTDC/MAR/111901/2009), with funds from POPH (Portuguese Operational Human Potential Program), QREN Portugal (Portuguese National Strategic Reference Framework), and MCTES (Portuguese Ministry of Science, Technology, and Higher Education).

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Figure Captions

Figure 1. The Mondego estuary with the location of the five sampling stations.

Figure 2. Monthly variation of A) precipitation and river runoff (cubic decameter, dam^3) during the study period and average precipitation values during the period of 1971-2000 in the Mondego river basin; B) salinity at stations M (farthest downstream station), N2 (furthest upstream station) and estuarine average salinity values.

Figure 3. Estuarine average temperature in the Mondego estuary and sea surface temperature (SST) in the adjacent coastal area A); monthly variation of the North Atlantic Oscillation index (NAO index) B) during the study period.

Figure 4. Total annual density (± standard deviation) of A) *Pomatoschistus microps* and *P. minutus*; B) *P. microps* adults and juveniles and C) *P. minutus* adults and juveniles from 2003 to 2011.

Figure 5. Mean cohort length of *Pomatoschistus microps* A) and *P. minutus* B) (± standard deviation) with indication of the cohorts (C).

Table 1. Annual density peaks of *Pomatoschistus microps* and *Pomatoschistus minutus* (total population, juveniles and adults) and the respective sampling date they were recorded.

	***P. microps* total population**		***P. microps* juveniles**		***P. microps* adults**	
Year	Highest density	Date	Highest density	Date	Highest density	Date
2003	48.69	29-Jun	29.80	29-Jun	18.89	29-Jun
2004	20.73	06-Jul	16.53	23-Apr	13.20	07-Dec
2005	14.39	21-Jul	12.62	24-Mar	6.77	22-Aug
2006	41.73	26-Jun	19.29	29-May	22.60	26-Jun
2007	7.30	22-Mar	0.99	29-Oct	6.31	22-Mar
2008	5.97	04-Aug	2.10	04-Aug	5.97	04-Aug
2009	8.08	23-Sep	1.77	23-Sep	5.93	28-May
2010	5.90	15-Jul	0.65	15-Jul	5.48	15-Jul
2011	40.64	20-Apr	24.57	03-Jun	16.07	20-Apr
	***P. minutus* total population**		***P. minutus* juveniles**		***P. minutus* adults**	
Year	Highest density	Date	Highest density	Date	Highest density	Date
2003	28.34	29-Jun	16.51	29-Jun	11.83	29-Jun
2004	10.72	23-Apr	9.83	23-Apr	4.52	19-Feb
2005	2.44	24-Mar	0.92	26-May	2.44	24-Mar
2006	13.58	29-May	11.34	29-May	6.23	26-Sep
2007	2.83	29-Oct	0.36	28-Nov	2.74	29-Oct
2008	1.85	04-Aug	0.65	04-Aug	1.69	04-Aug
2009	5.00	23-Sep	2.14	28-May	5.00	23-Sep
2010	42.44	15-Jul	24.50	15-Jul	18.27	15-Jul
2011	2.35	03-Jun	1.59	03-Jun	0.92	03-Jun

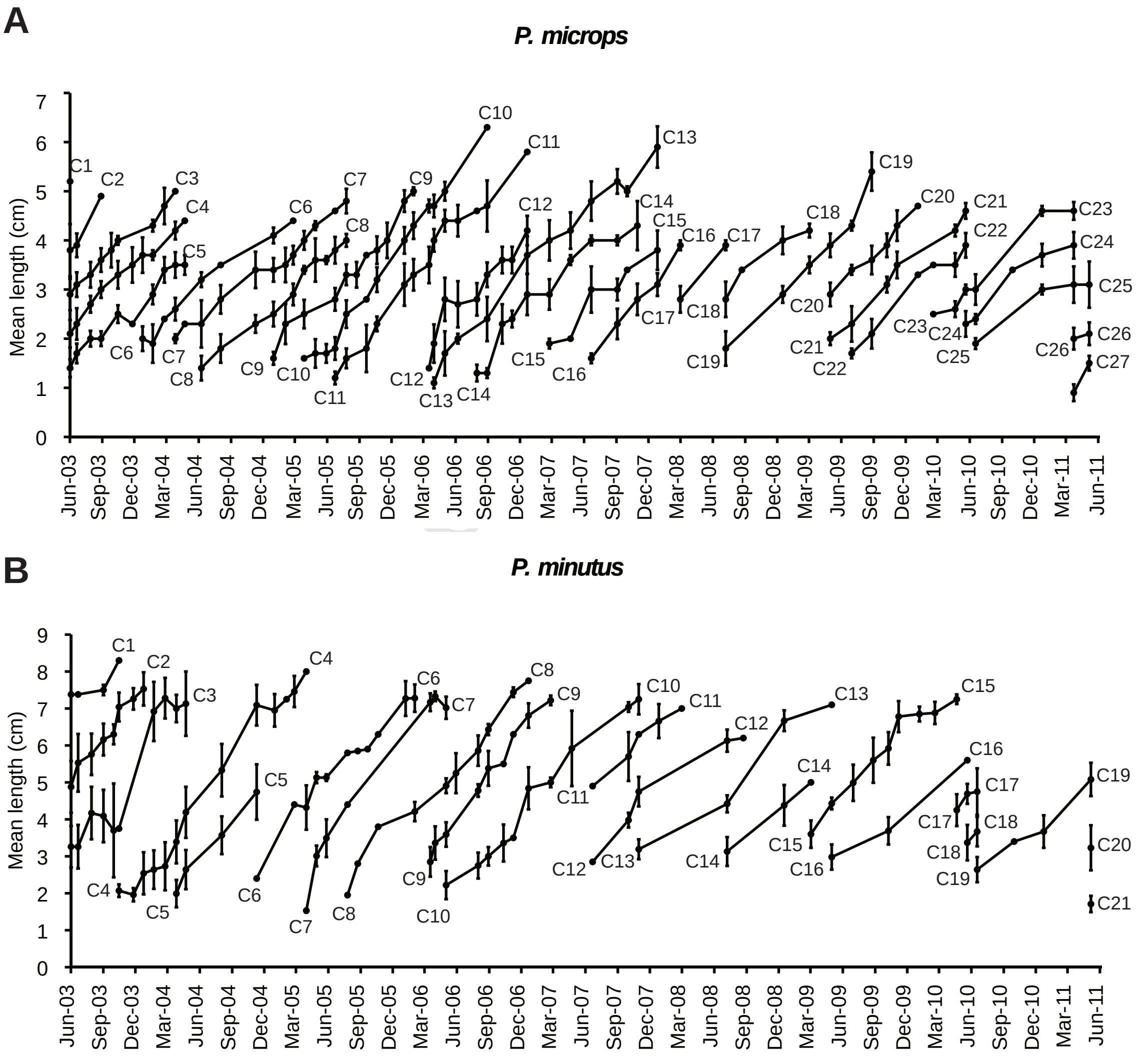
Table 2. Production values (g ww 1000 m^{-2} $year^{-1}$), mean biomass (g ww 1000 m^{-2}) and $P/\overline{B}$ ratios for *Pomatoschistus microps* and *Pomatoschistus minutus* for each year (Jun-May) during the study period.

	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11
Production								
(g ww 1000 m^{-2} $year^{-1}$)								
P. microps	3.61	3.04	3.09	5.00	1.47	0.91	2.60	2.43
P. minutus	16.41	4.26	1.58	5.69	2.31	2.52	4.14	2.55
Biomass								
(g ww 1000 m^{-2})								
P. microps	1.39	1.28	0.96	2.00	0.77	0.62	0.80	1.74
P. minutus	5.04	1.84	1.20	2.05	0.86	0.75	1.73	0.91

P/B								
(year^{-1})								
P. microps	2.6	2.4	3.2	2.5	1.9	1.5	3.2	1.4
P. minutus	3.3	2.3	1.3	2.8	2.7	3.4	2.4	2.8

Table 3. Spearman correlations fitted to the abundance data of *Pomatoschistus microps* and *Pomatoschistus minutus* (total population, juveniles and adults). (* - Significance codes: 0 '***' 0.001 '**' 0.01 '*')

Species	Parameters	Spearman correlations
P. microps total population	NAO (time-lag 2 months)	0.70*
	Precipitation (time-lag 2 months)	0.90***
P. microps adults	NAO (time-lag 12 months)	0.72*
	Precipitation (time-lag 2 months)	0.81**
P. microps juveniles	NAO (time-lag 1 month)	0.74*
	Precipitation (time-lag 2 months)	0.87**
P. minutus total population	River runoff (time-lag 6 months)	0.85**
P. minutus adults	River runoff (time-lag 6 months)	0.81**
P. minutus juveniles	River runoff (time-lag 6 months)	0.75*


A
P. microps
Mean length (cm)
0
1
2
3
4
5
6
7
C1
C2
C3
C4
C5
C6
C7
C8
C9
C10
C11
C12
C13
C14
C15
C16
C17
C18
C19
C20
C21
C22
C23
C24
C25
C26
C27
Jun-03
Sep-03
Dec-03
Mar-04
Jun-04
Sep-04
Dec-04
Mar-05
Jun-05
Sep-05
Dec-05
Mar-06
Jun-06
Sep-06
Dec-06
Mar-07
Jun-07
Sep-07
Dec-07
Mar-08
Jun-08
Sep-08
Dec-08
Mar-09
Jun-09
Sep-09
Dec-09
Mar-10
Jun-10
Sep-10
Dec-10
Mar-11
Jun-11
B
P. minutus
Mean length (cm)
0
1
2
3
4
5
6
7
8
9
C1
C2
C3
C4
C5
C6
C7
C8
C9
C10
C11
C12
C13
C14
C15
C16
C17
C18
C19
C20
C21
Jun-03
Sep-03
Dec-03
Mar-04
Jun-04
Sep-04
Dec-04
Mar-05
Jun-05
Sep-05
Dec-05
Mar-06
Jun-06
Sep-06
Dec-06
Mar-07
Jun-07
Sep-07
Dec-07
Mar-08
Jun-08
Sep-08
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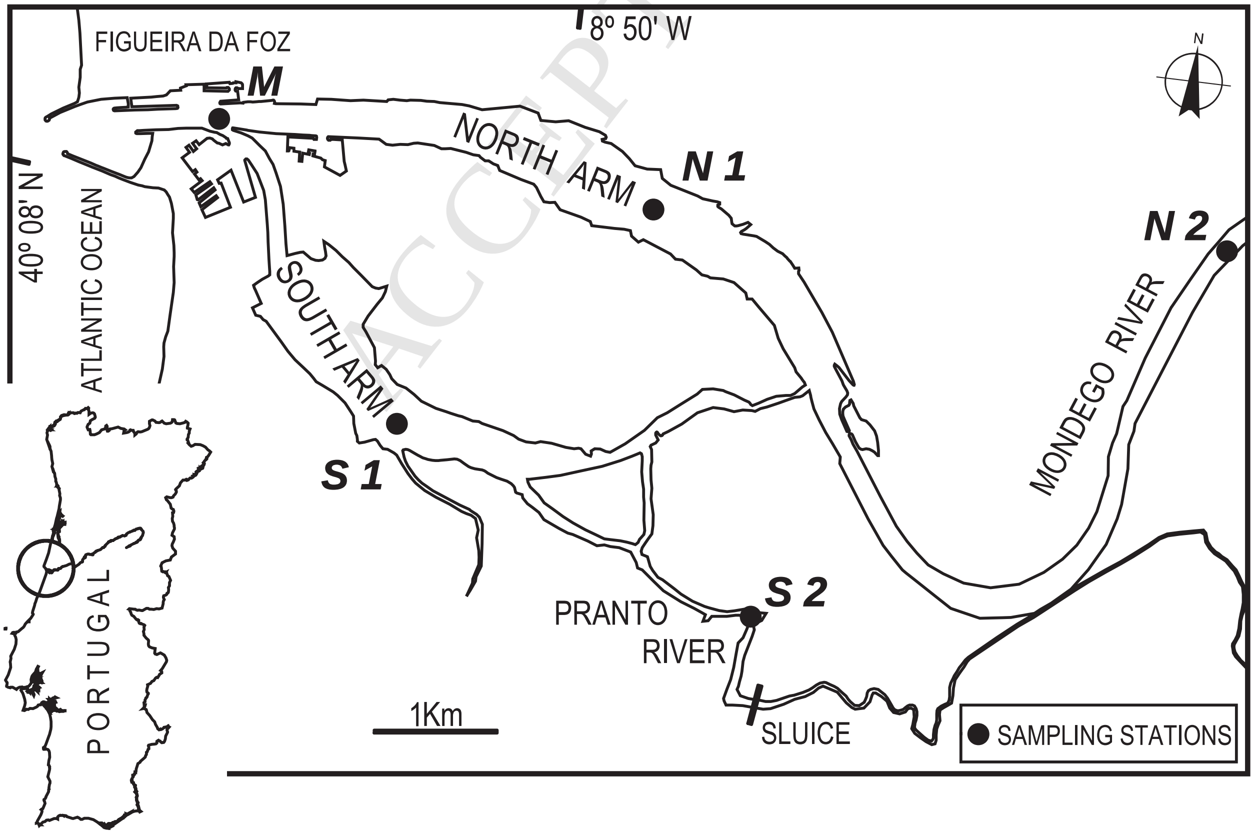
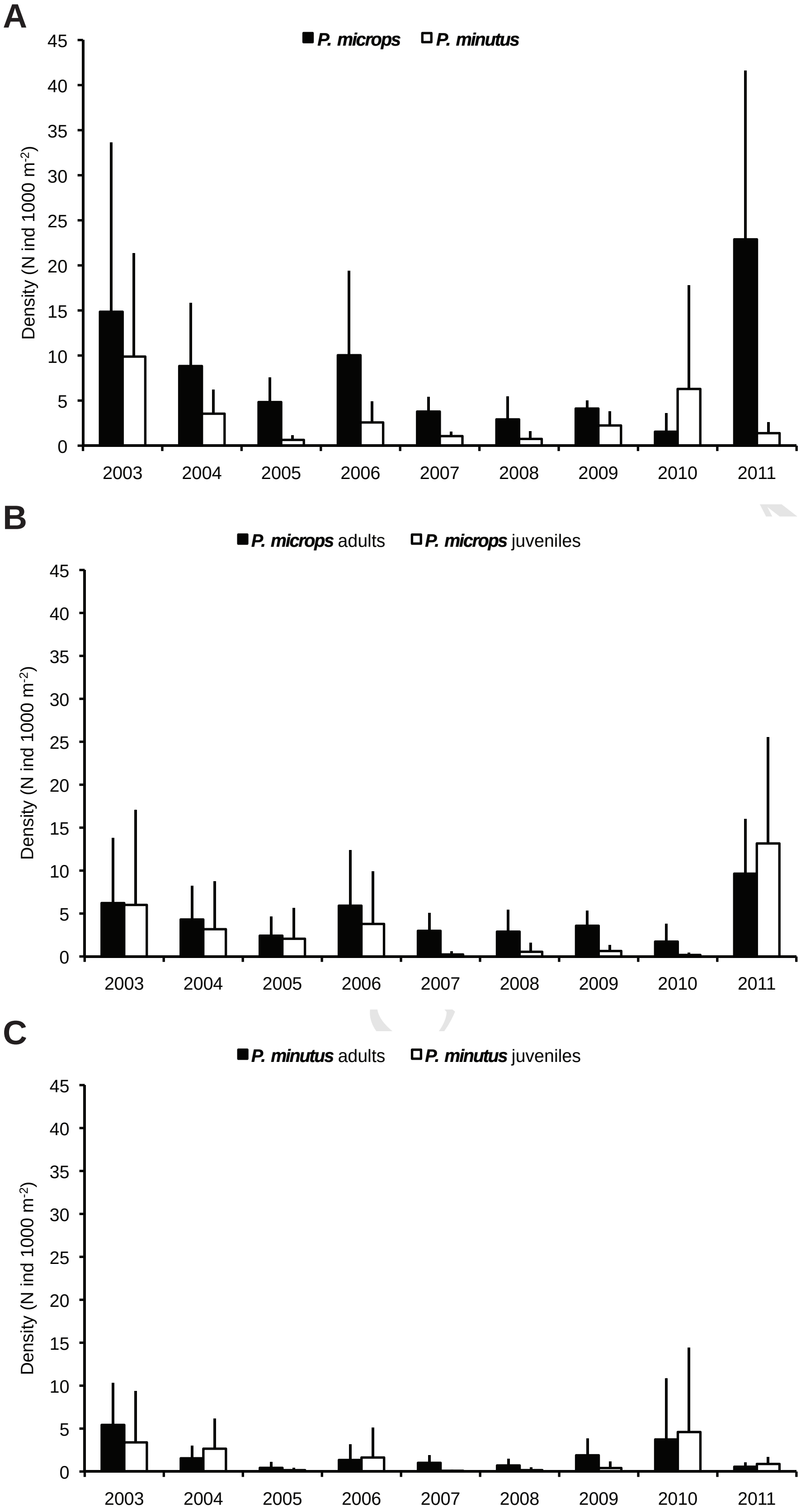
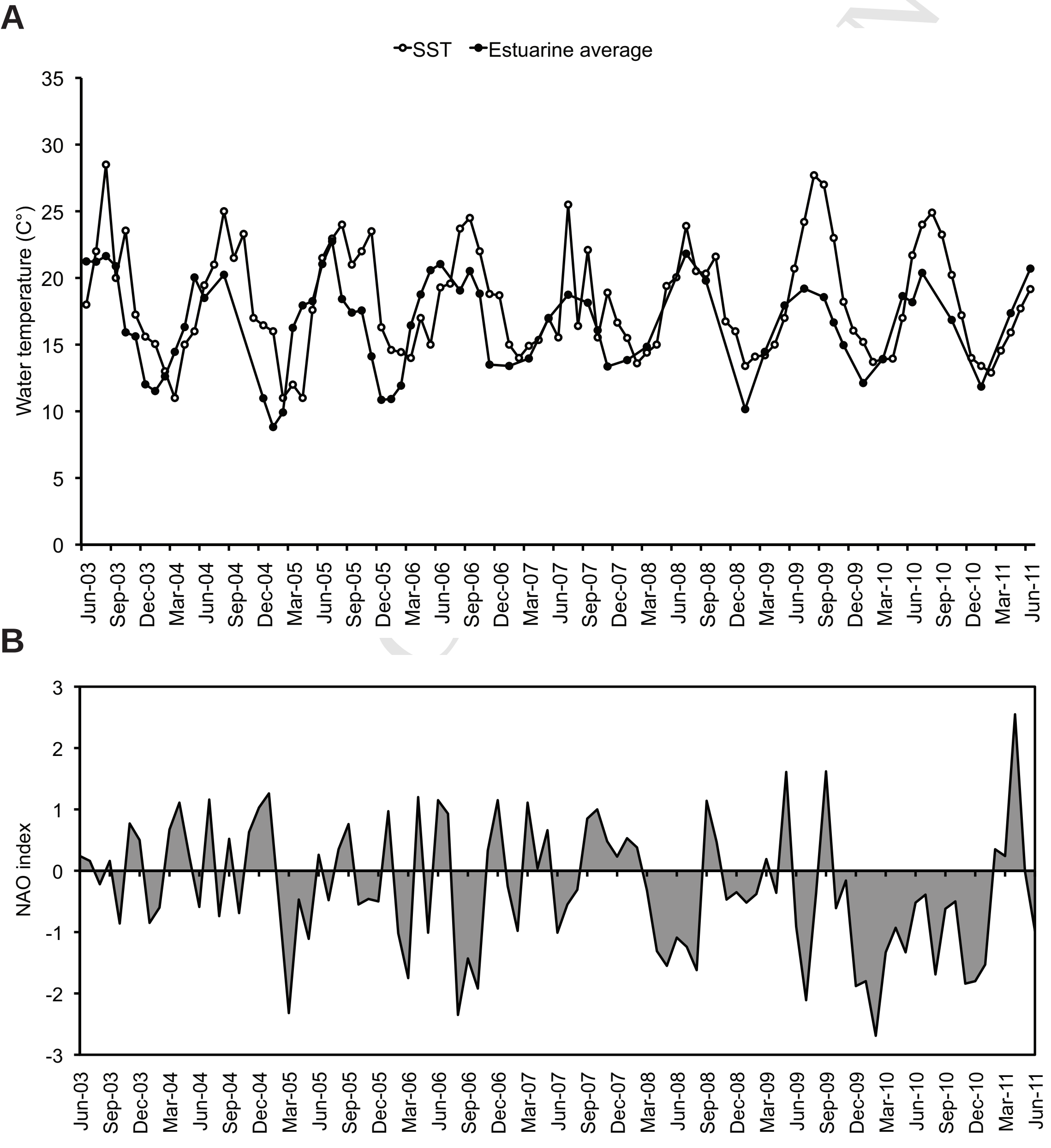
Mar-10
Jun-10
Sep-10
Dec-10
Mar-11
Jun-11


FIGUEIRA DA FOZ
8º 50' W
M
NORTH ARM
N 1
N 2
40º 08' N
ATLANTIC OCEAN
SOUTH ARM
S 1
MONDEGO RIVER
PORTUGAL
PRANTO
RIVER
S 2
SLUICE
1Km
● SAMPLING STATIONS
N


A
P. microps
P. minutus
Density (N ind 1000 m-2)
0
5
10
15
20
25
30
35
40
45
2003
2004
2005
2006
2007
2008
2009
2010
2011
B
P. microps adults
P. microps juveniles
Density (N ind 1000 m-2)
C
P. minutus adults
P. minutus juveniles
Density (N ind 1000 m-2)


A
SST
Estuarine average
Water temperature (C°)
35
30
25
20
15
10
5
0
Jun-03
Sep-03
Dec-03
Mar-04
Jun-04
Sep-04
Dec-04
Mar-05
Jun-05
Sep-05
Dec-05
Mar-06
Jun-06
Sep-06
Dec-06
Mar-07
Jun-07
Sep-07
Dec-07
Mar-08
Jun-08
Sep-08
Dec-08
Mar-09
Jun-09
Sep-09
Dec-09
Mar-10
Jun-10
Sep-10
Dec-10
Mar-11
Jun-11
B
NAO index
3
2
1
0
-1
-2
-3
Jun-03
Sep-03
Dec-03
Mar-04
Jun-04
Sep-04
Dec-04
Mar-05
Jun-05
Sep-05
Dec-05
Mar-06
Jun-06
Sep-06
Dec-06
Mar-07
Jun-07
Sep-07
Dec-07
Mar-08
Jun-08
Sep-08
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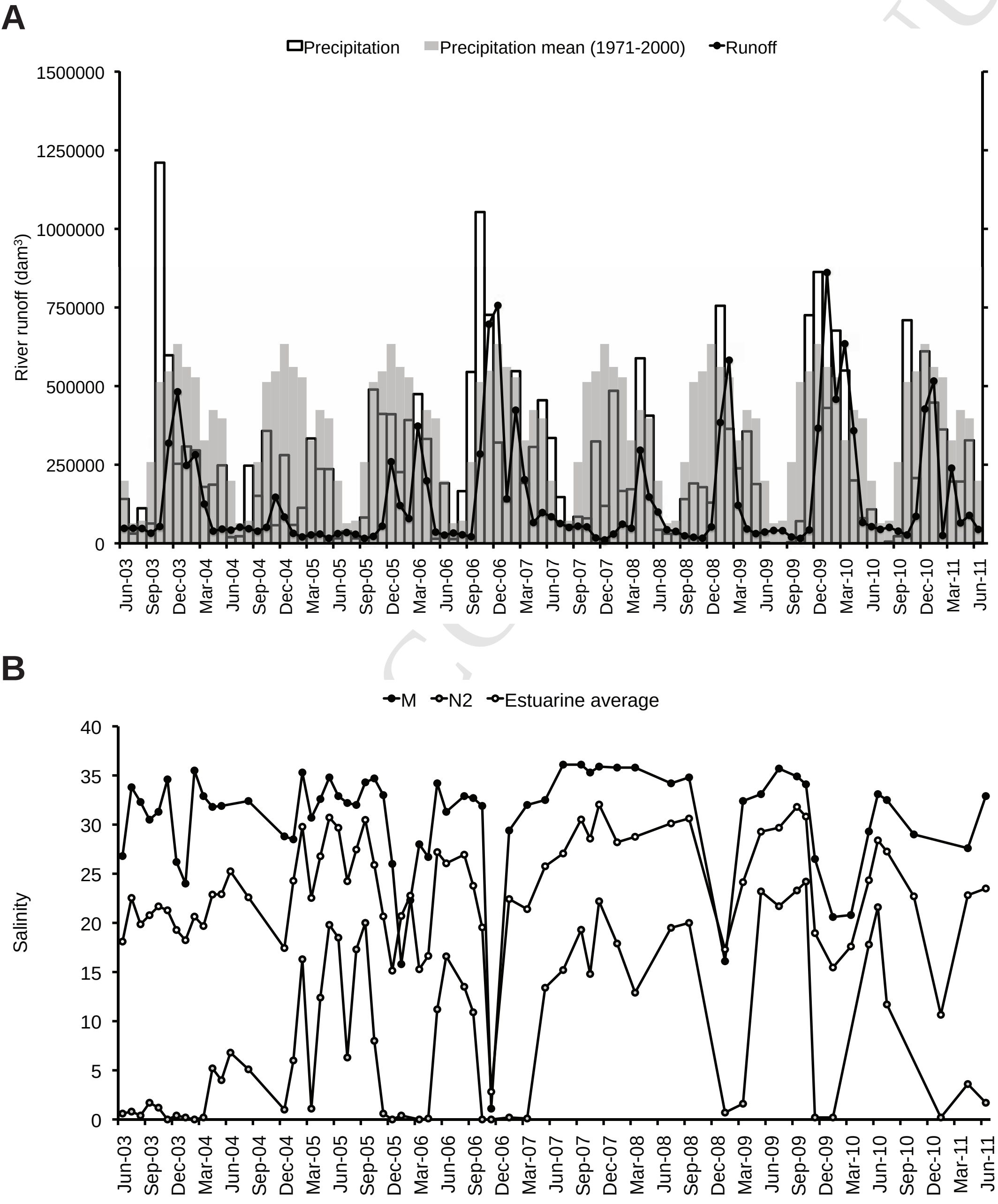
Mar-09
Jun-09
Sep-09
Dec-09
Mar-10
Jun-10
Sep-10
Dec-10
Mar-11
Jun-11


A
Precipitation
Precipitation mean (1971-2000)
Runoff
River runoff (dam^3)
Precipitation (mm)
1500000
1250000
1000000
750000
500000
250000
0
300
250
200
150
100
50
0
Jun-03
Sep-03
Dec-03
Mar-04
Jun-04
Sep-04
Dec-04
Mar-05
Jun-05
Sep-05
Dec-05
Mar-06
Jun-06
Sep-06
Dec-06
Mar-07
Jun-07
Sep-07
Dec-07
Mar-08
Jun-08
Sep-08
Dec-08
Mar-09
Jun-09
Sep-09
Dec-09
Mar-10
Jun-10
Sep-10
Dec-10
Mar-11
Jun-11
B
M
N2
Estuarine average
Salinity
40
35
30
25
20
15
10
5
0