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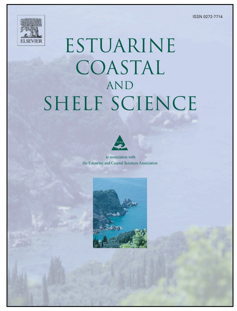

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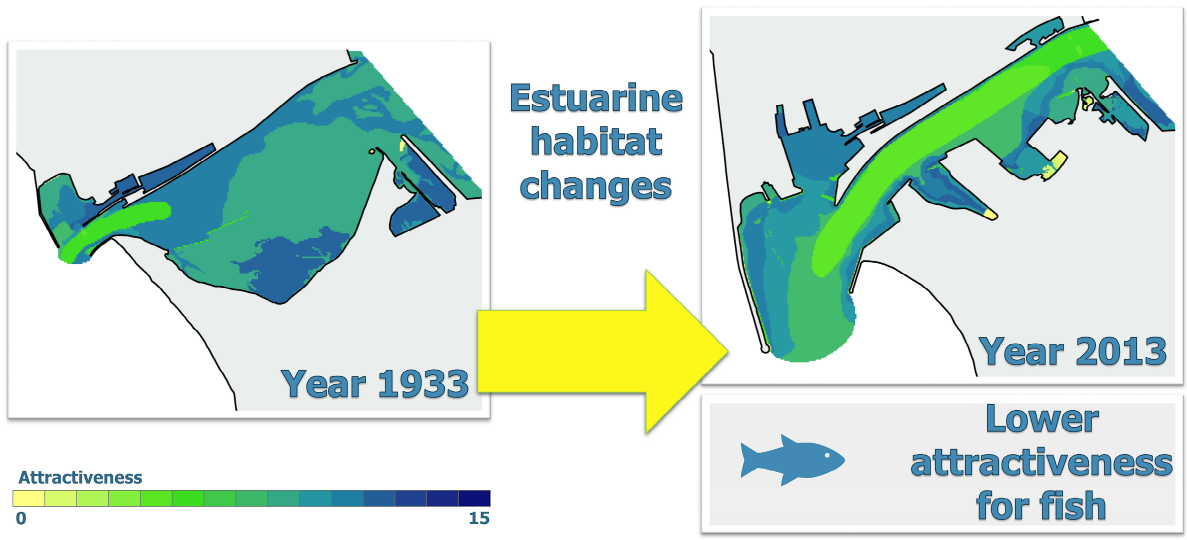
Estuarine
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Lower
attractiveness
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Attractiveness
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Habitat loss and gain: influence on habitat attractiveness for estuarine fish communities

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Abstract

Habitat structure and complexity influence the structuring and functioning of fish communities. Habitat changes are one of the main pressures affecting estuarine systems worldwide, yet the degree and rate of change and its impact on fish communities is still poorly understood. In order to quantify historical modifications in habitat structure, an ecohydrological classification system using physiotopes, i.e. units with homogenous abiotic characteristics, was developed for the lower Lima estuary (NW Portugal). Field data, aerial imagery, historical maps and interpolation methods were used to map input variables, including bathymetry, substratum (hard/soft), sediment composition, hydrodynamics (current velocity) and vegetation coverage. Physiotopes were then mapped for the years of 1933 and 2013 and the areas lost and gained over the 80 years were quantified. The implications of changes for the benthic and demersal fish communities using the lower estuary were estimated using the attractiveness to those communities of each physiotope, while considering the main estuarine habitat functions for fish, namely spawning, nursery, feeding and refuge areas and migratory routes. The lower estuary was highly affected due to urbanisation and development and, following a port/harbour expansion, its boundary moved seaward causing an increase in total area. Modifications led to the loss of most of its sandy and saltmarsh intertidal physiotopes, which were replaced by deeper subtidal physiotopes. The most attractive physiotopes for fish (defined as the way in

which they supported the fish ecological features) decreased in area while less attractive ones increased, producing an overall lower attractiveness of the studied area in 2013 compared to 1933. The implications of habitat alterations for the fish using the estuary include potential changes in the nursery carrying capacity and the functioning of the fish community. The study also highlighted the poor knowledge of the impacts of habitat changes on fish due to coastal development and urbanisation and emphasises that ecosystem management and conservation will benefit from a wider understanding of habitat functional roles and habitat changes influencing the functioning and structure of the fish communities.

Keywords: Estuaries; habitat changes; fish habitat attractiveness; physiotopes

1. Introduction

Habitat destruction has been taking place on a large scale over the past 300 years in many estuaries and coastal areas (Elliott and Cutts, 2004; Lotze et al., 2006) and it is recognised as one of the major threats to biodiversity, structure and functioning of marine ecosystems (Airoldi et al., 2008; Halpern et al., 2008; Wolanski and Elliott, 2015). In addition to supporting cities and harbours having a large economic and social importance (Airoldi and Beck, 2007), estuaries also have great ecological value and are among the most biologically productive and valuable habitats in temperate aquatic areas (Costanza et al., 1997). However, increasing human activity over recent centuries has increased the vulnerability of estuarine and coastal marine ecosystems to habitat degradation and loss (Lotze et al., 2006) and affected several critical ecosystem services (Barbier et al., 2011).

The modification of shorelines and the introduction of large amounts of physical materials and man-made structures adversely changes the functioning of the system. This is regarded as permanent habitat loss or change, given that it requires large-scale engineering works to be reversed; similarly it is a form of pollution under the definition of materials added to the natural system which result in harm to the biology of the system or to human welfare (Wolanski and Elliott, 2015). The impact of land claim in estuarine areas (i.e. the anthropogenic removal of estuarine area, such as wetlands, for space for urban or agricultural use; older literature use the term reclamation but it is argued her that an area is being claimed from the sea rather than reclaimed from it), causing habitat loss, has been greater than the effects of any polluting discharges (McLusky and Elliott, 2004). Major impacts to wetlands, including saltmarshes, seagrasses and soft-sediment habitats, have been caused by coastal development (e.g. construction of marinas, the widening and dredging of channels for navigation, tourist developments and infrastructures, aquaculture, etc.), and defence (e.g. breakwaters, seawalls, jetties, dykes) (Airoldi and Beck, 2007; Elliott et al., 2016; Wolanski and Elliott, 2015).

Estuaries are important as essential fish habitats providing nursery grounds, migration corridors, refuge and feeding areas for many species, as well as supporting their own resident fish community (Able and Fahay, 2010; Elliott and Hemingway, 2002; Potter et al., 2015). These functions are closely related to the physical and ecological structure of the estuary, which comprises a complex mixture of distinctive habitat types (Pihl et al., 2002). Alterations to estuarine habitats, or to the hydrophysical linkages between them, are likely to compromise the ability of fish larvae or young juveniles to reach favourable nursery habitats, which can have negative population effects, such as reduced recruitment success or near complete failure of a year class (Peterson, 2003). Additionally, the loss of structurally complex habitats, such as seagrasses and marshes, often leads to lower abundances and declines in species richness (Airoldi et al., 2008). Morphological pressures (i.e. changes to the shape, size and physical complexity of the areas such as seagrass habitat loss, bathymetric changes) have also had a main role in affecting potential habitat productivity in transitional waters through effects on biomass of resident and marine migrant fish (Franco et al., 2009a; Zucchetta et al., 2016).

Despite these evident changes, there is still limited knowledge and understanding of the magnitude and importance of habitat losses in coastal systems (Airoldi et al., 2008). The historical losses of soft-bottom habitats are poorly known (Airoldi and Beck, 2007), as well as the impacts of engineering structures on coastal habitats and their communities, such as how they change or introduce new ecosystem functions and services (Bulleri and Chapman, 2010; Dugan et al., 2011; Elliott et al., 2016; Perkins et al., 2015). Knowledge of the extent of changes is especially relevant given the fact that the implementation of conservation and management goals for the marine and estuarine ecosystems requires identifying baselines acting as reference conditions (Borja et al., 2012). Yet, this is often limited by the lack of historical data prior to large-scale human impacts and by the lack of information on the drivers of change

(Airoldi and Beck, 2007; Bianchi et al., 2014; Claudet and Fraschetti, 2010). Without long-term data series, change has been assessed by alternative means, such as anecdotal knowledge (Al-Abdulrazzak et al., 2012; Alleway and Connell, 2015; Katikiro, 2014) or expert opinion (Halpern et al., 2008).

Given the need to further understand the drivers and the level of habitat change, to help ecosystem management and conservation and restoration efforts, the present study aimed to test the hypothesis that historical habitat changes have the potential to affect the overall attractiveness of estuarine habitats for fish communities. To achieve this, the study quantified: i) the changes in habitat structure of an estuarine area over a period of 80 years, and ii) the attractiveness of each habitat and overall estuarine area for fish communities and potential implications of the changes observed.

2. Material and Methods

2.1. Methodological approach

The historical changes to an estuarine area were studied by applying an ecohydrological classification system in order to produce ecologically meaningful habitat maps for fish communities. The habitats created by this approach are units of homogenous physical characteristics that are referred to as physiotopes, after Bouma et al. (2005). The classification system was based on a hierarchical integration of variable-layers, allowing for an increasingly detailed level of description of habitat (Bouma et al., 2005; Stevens et al., 2008). The classification system was used to compare the habitat structure of the estuarine area between past (1933) and present (2013) scenarios, and estimate the area lost or gained for each physiotope. Due to the lack of historical data on fish communities using the estuary, and to further understand the potential implications of the changes observed on those fish communities, the attractiveness of the lower estuary to fish communities in both years (1933 and 2013) was estimated using a qualitative method, based on available information from literature review and expert judgment. This method scored each physiotope considering the main estuarine habitat functions for estuarine representative fish species, and its relative cover area. Finally, the physiotopes were clustered according to their attractiveness (see Fig. 1).

2.2. Study area

The Lima estuary (NW Portugal) is a small North Atlantic temperate system (approximately 20 km length) (Fig. 2) draining an international river basin. The tidal regime is mesotidal (average range of 3.7 m) and semidiurnal, with an annual average freshwater flow of 70 $m3\ s^{-1}$, regulated upstream by two hydroelectric dams. The estuary has three distinct morphological areas: the lower estuary (0-3 km from the mouth) is a narrow, deep and navigational channel with artificial banks; the middle estuary (3-7 km) is a broad shallow zone with salt marshes and tidal sandy islands; and the upper estuary (7-20 km) is a shallow and narrow channel with small sandy islands (Ramos et al., 2010). Historically, the middle and upstream areas have retained most of their natural banks (being part of the EU Natura network), while the lower estuary has been subject to extensive modification within the last century, with the building of walled banks, a large shipyard, a fishing harbour, a commercial seaport, two marinas and two jetties protecting the river mouth. Aerial photographs of the estuary comparing the past with the present situation have shown that the major modifications in the Lima estuary have occurred in the lower part. Additionally, given that more detailed historical information was available for this area (because it is the most urbanised), the ecohydrological classification system was applied to the lower estuary only (Fig. 2).

2.3. Ecohydrological classification system

The ecohydrological classification system used the following variables based on their importance to benthic and demersal fish communities: depth, substratum type, hydrodynamics (namely, water velocity) and vegetation cover. As the lower estuary covers from the mouth to 3 km upstream, salinity was considered to be homogeneous within a euhaline area. The variables and their threshold values selected were adapted from Bouma et al. (2005) and Stevens et al. (2008). Different methodologies (see below) were applied to obtain data layers of the spatial variability of each variable based on the available data. The spatial grid resolution for all variables was 9 x 9 m.

2.3.1. Present scenario - 2013

Depth

Bathymetric data were obtained as point records collected by a single beam echo sounder during 2013. Additionally, contour lines of the mean high water of spring tides and mean low water of spring tides were digitized from RGB orthophotos of the estuary obtained from public web mapping services of aerial and satellite imagery. The low water contour was obtained from the historical imagery of Google Earth (year of 2006) and the high water contour was obtained from the Portuguese Geographic Institute (IGP) imagery provided by ESRI online map service. The axial tidal influence was corrected from bathymetric data based on hydrodynamic models built for the Lima estuary (Falcão et al., 2013; Mazzolari et al., 2013; Rebordão and Trigo-Teixeira, 2009). Data were interpolated to a contiguous grid of 9 m resolution using ANUDEM (version 5.3) algorithm (Hutchinson, 1989; Hutchinson et al., 2011), which is implemented in ArcGIS 10.2 (ESRI, Redlands, CA) (Topo to Raster tool). This method was designed for creating hydrologically-correct DEMs (Digital Elevation Models) by using a discretized thin plate spline technique (data points and contour data lines were used). To evaluate the performance of the interpolation method, a subset of the input data points (100 out of 3428) were randomly removed from the dataset and later compared against the predicted values using the root mean squared error (RMSE) measure. Depth classes were chosen as follows to characterise the physiotopes: supratidal (above mean high water of spring tides); intertidal (between mean high water and mean low water of spring tides), and 3 subtidal classes, between mean low water of spring tides and 2 m depth (“shallow”), between 2 m and 5 m depth (“moderately deep”), and greater than 5 m depth (“deep”).

Hydrodynamics

Water velocity was used to describe the hydrodynamic conditions of the estuary, as a forcing function for many benthic species and fish ontogenetic development stages. Two classes were used: >0.8 m s-1 (“high dynamics”) and <0.8 m s-1 (“low dynamics”), 0.8 m s-1 being the boundary at which sediment is frequently stirred or suspended and the formation of megaripples occurs (Bouma et al., 2005). Water velocity in the estuary was determined from hydrodynamic models (Falcão et al., 2013; Mazzolari et al., 2013; Rebordão and Trigo-Teixeira, 2009) to show areas where depth averaged current velocity exceeds the above threshold.

Substratum

“Hard substrata” (rock, boulders) were delineated based on aerial imagery and field observations. In order to further characterise soft substratum, sediments were also classified using data from previous research projects from the Lima estuary. Samples were collected in 2010 (Mendes et al., 2014), 2013 and 2015, using a Petit Ponar grab and dried at 100 °C. Grain size was analysed by sieving (CISA Sieve Shaker Mod. RP.08) and the sediments were divided into three fractions: mud (<0.063 mm), sand (0.063–2.000 mm), and gravel (> 2.000 mm). Each fraction was weighed and expressed as a percentage of the total weight. These data were complemented with those from literature for 2002 (Sousa, 2003). A permutational multivariate analysis of variance (PERMANOVA), based on Euclidean distance matrices, was applied to test temporal differences between the years and seasons of the collections for the coincident sampling sites. No significant temporal differences ($p>0.05$) were detected between the sediment composition of the remaining non-coincident sites, and all datasets were used to create sediments maps. The spatial interpolation of the three fractions was performed using the Empirical Bayesian Kriging (EBK) method implemented in ArcGIS 10.2 (ESRI, Redlands, CA). While the classical kriging methods use a single semivariogram to predict the values at unknown locations, the EBK accounts for the uncertainty of semivariogram estimation, by estimating several semivariograms models through a process of subsetting and simulations (Krivoruchko, 2012). Cross-validation was used to assess the accuracy of the interpolations by evaluating the root mean square error (RMSE) and root mean square standardized error (RMSSE) values. Since kriging is not an exact interpolator, under- or over-estimations may occur, and the sum of the interpolated sediment fractions might not be 100 %. Therefore, each grid map was standardized (Jerosch, 2013), according to the following:

$$(interpolated\ fraction\ map / sum\ of\ the\ 3\ fractions) \times 100.$$

Finally, and to match with the classification of historical sediment data, sediment types were characterised using a simplified version of the Folk (1954) textural classification for soft sediment (as adapted from the classification of Connor et al. (2006), into the following classes: “coarse sediment”, “sand” and “mud”.

Vegetation cover

Vegetation cover, namely saltmarsh presence, was delineated based on aerial imagery and field expert knowledge. Two classes were used: “non-vegetated” and “saltmarsh”.

2.3.2. Past scenario – 1933

Historical data were retrieved from aerial imagery and cartography from 1933 of the Marinha Portuguesa (Portuguese Navy) and Instituto Geográfico do Exército (Geographic Institute of the Portuguese Army) (Fig. 2c). Information on currents, sediment, and depth (data points and contour lines, including low and high water contours) were retrieved from a hydrographic chart. Saltmarshes were delineated based on aerial imagery (black and white photogrammetric restitution), collected at low tide. The imagery were georeferenced using recognisable control points present on the imagery of both years (1933 and 2013) (e.g. road intersections, buildings, etc.). The relevant variables were digitised and classified according to the criteria described above.

2.3.3. Physiotopes

To obtain the final classification system, the layers of each variable were hierarchically integrated in the following order: depth, hydrodynamics, substratum and vegetation. The code for each physiotope was built by shortening the class name to one or two letters and adding them in hierarchical order. For example the physiotope Sh.lD.M.nV is composed of the classes “Shallow” (Sh), “low Dynamics” (lD), “Mud” (M) and “non-Vegetated” (nV).

2.4. Fish habitat attractiveness

The habitat attractiveness was evaluated based on a score attributed to all the physiotopes identified in the lower estuary. Each physiotope was scored for five estuarine habitat functions: nursery, feeding, refuge, spawning and migratory route. These were adapted from Pihl et al. (Pihl et al., 2002): spawning – areas with simultaneous presence of ripe adults and production of eggs; nursery – areas with high concentration of early juvenile stages, which are suitable for settlement, feeding and growing; feeding - habitats used by older juveniles and adults as a feeding ground (seasonal or permanent); refuge – areas used by older juveniles and adults to avoid predation and/or inter-species competition; and migratory route/corridors - use of a habitat as a migration route for diadromous species and marine migrants. Scores from 0 to 3 reflected the role that each physiotope plays for the different estuarine functions: 0 – not occurring; 1 – low; 2 – medium; and 3 – high. The scores were allocated based on the generic attractiveness of the physiotope, based on information derived from a literature review and expert knowledge (see S1 Table for the criteria used for each class composing the physiotope).

The scoring system was applied to five species, chosen due to their representativeness of the benthic and demersal fish occurring in estuaries, the main ecological guilds (Franco et al., 2008) and because they are typical of the study area and nearby estuaries (França et al., 2011; Ramos et al., 2012). The species chosen were: *Platichthys flesus* and *Dicentrarchus labrax* (marine migrants), *Pomatoschistus microps* (estuarine resident), *Callionymus lyra* (marine straggler) and *Anguilla anguilla* (catadromous) (see Table 1 for the scientific literature used to derive the attractiveness scores).

The resulting attractiveness scores were calculated for the years of 1933 and 2013, as follows:

(1) Species (z) attractiveness = $\sum_j\left[\left(\sum_i f_{ijz}\right)\cdot area_j\right]$;

(2) Overall attractiveness (lower estuary) $= \frac{\sum_z Species\ attractiveness_z}{Z}$;

Where f_{ijz} is the score given to the estuarine function i for physiotope j and species z, $area_j$ is the proportion of the estuarine area occupied by physiotope j in the Lima lower estuary in a given year and Z is the number of species considered for the assessment. Species (z) attractiveness (1) is the estuarine attractiveness for species z, and overall attractiveness (2) is the estuarine attractiveness for all the species considered.

2.5. Data analysis

Habitat areas in 1933 and 2013 were calculated using ArcGIS 10.2 (ESRI, Redlands, CA). Number of total physiotopes, physiotope density (number of physiotopes per 100 ha), patch density (number of physiotope patches per 100 ha, where a patch is an homogeneous area of a specific physiotope class that differs from its surroundings) and proportion of landscape occupied by each physiotope were calculated using FRAGSTATS (McGarigal, 2012). To understand the similarities between physiotopes regarding their generic attractiveness scores by function (using the average species scores), a hierarchical cluster analysis was performed in R (R Core Team, 2016) using the pvclust package (Suzuki and Shimodaira, 2006). Pvclust assesses the uncertainty in hierarchical cluster analysis by calculating approximately unbiased (AU) probability values for each cluster by multiscale bootstrap resampling (as an indication of how strong the cluster is supported by data). The cluster analysis was performed using Euclidean distances with Ward's minimum variance method and 10,000 bootstrap replicates. Cluster significance was assumed for AU probability values higher than 95 %.

The attractiveness assessment developed in this study may suffer from some degree of subjectivity from the evaluator allocating the scores, albeit supported by evidence from the literature. Therefore, a sensitivity analysis (Alvarez et al., 2013) was undertaken to assess how the attribution of scores to each function influenced the final attractiveness scoring. Two tiers of simulation were defined: tier 1 where f_{ijz} was changed, and tier 2 considering scenarios where the changes in the overall function scoring were applied to a different number of physiotopes amongst those contributing to the overall assessment of the lower estuary in a given year. In tier 1, as f_{ijz} could range between 0 and 3, and given that the allocation of each score was based on expert judgement supported by the literature, the maximum change of f_{ijz} allowed for the analysis was 1 point. Simulations included the best (B) and worst (W) case scenarios of change, i.e. only one of the five functions changes its score (hence $\sum_i f_{ijz}$ increases or decreases by 1 point; B(+) and B(-), respectively), or all the functions change their score (hence $\sum_i f_{ijz}$ increases or decreases by 5 points; W(+) and W(-), respectively). In tier 2, the four scenarios above were applied to (i) all the physiotopes included in the final assessment (All); (ii) only the physiotope with the largest cover area in 1933 and in 2013 (L1993 and L2013, respectively); and (iii) only the physiotope with the smallest cover area in 1933 and in 2013 (S1933 and S2013, respectively). This resulted in a total of 20 permutations of the scenarios that were applied to each assessment year (1993 and 2013). The scenarios were applied to by keeping all other scores as the average scores of the five representative species used in this study. The effect of each scenario on the performance of the attractiveness assessment was analysed by evaluating the relative response of each assessment (1933 and 2013), measured as a percentage deviation from its original value. The effect of each scenario was also evaluated on the difference of attractiveness between both years.

3. Results

3.1. Habitat loss and gain

3.1.1. Total area

Between 1933 and 2013, the lower estuary increased by 32.4 % in total area (Table 2). The north bank was moved forward by claiming area from the estuary (Fig. 2b). As a result, the mouth of the estuary was repositioned south, eliminating part of the southern sand bar and seashore beach that were located in the coastal area around the former estuary mouth. Also, the port was further developed, by building infrastructures on top of the northern rocky shore and developing a northern arm that terminates in a jetty parallel to the coast. Thus, the mouth of the estuary and its plume were deflected to the south. On the southern bank, the intertidal area was mostly dredged, to build a commercial port and industrial sand storage facilities. These changes led to an overall loss of 80 ha (73%) of intertidal habitat from the lower estuary, with additional loss also from the former adjacent coastal area (not estimated here). This loss was overcompensated by a marked increase (130 ha) in the extent of subtidal habitats (Table 2). In particular, there was an increase of the depth of the estuarine subtidal area, with the deep areas (higher than 5 m depth) and the moderately deep areas (between 2 and 5 m) occupying now 82 % of the subtidal, while previously, in 1933, they only occupied 9 % of the total estuarine subtidal (Table 2). Together with the changes in depth, there was an increase in the areas with high hydrodynamics (high energy areas) and an increase in the muddy areas, whereas sandy areas decreased overall. The saltmarsh coverage also decreased by 18.7 ha (87.8 %) between 1933 and 2013.

3.1.2. Physiotopes

The hierarchical integration of the variables identified 21 physiotopes in 1933 and 23 physiotopes in 2013 (Table 3), of which 16 were in common to both scenarios (Fig. 3). Physiotope density, however, was higher in 1933, with 12.5 physiotopes per 100 ha, against

10.3 physiotopes per 100 ha in 2013. The most common physiotope present in the lower estuary in 1933 was In.lD.S.nV (intertidal; low hydrodynamics; sand; non-vegetated) (Fig. 4), which covered 50.9 % of the total area, followed by Sh.lD.S.nV (shallow; low hydrodynamics; sand; non-vegetated), covering 25.1 %. In 2013, the most common physiotope was Md.lD.S.nV (moderately deep; low hydrodynamics; sand; unvegetated) followed by D.lD.S.nV (deep; low hydrodynamics; sand; unvegetated) (Fig. 4), covering 17.1 % and 13.2 % of the lower estuary, respectively. Patch density, representing the number of patches per 100 ha in the lower estuary, increased between 1933 and 2013 (Table 3).

3.2. Habitat attractiveness

The results obtained with the final weighted scores of habitat attractiveness for the lower Lima estuary were 9.25 in 1933 and 8.12 in 2013 (maximum of 15) (Table 3). In general, the attractiveness of estuarine habitats was highest in 1933, for all species. *P. microps* presented the largest difference in attractiveness (with 10.71 and 8.10 for 1933 and 2003, respectively), while *C. lyra* presented the closest values of attractiveness between 1933 and 2013 (8.46 and 8.40, respectively) (Table 3; S1-S5 Figures; Tables A-E in S2 Table). The scientific literature compiled in order to support the attribution of scores showed that the amount information available on estuarine habitat use is species specific: *P. flesus* and *A. anguilla* were the species with the highest amount of available information, while there was a lack of information for *C. lyra* (Table 1).

Physiotopes were grouped into four clusters (with AU probability values >95 %) according to their individual attractiveness scores (Group I to IV; see Fig. 5). The lowest scores were registered by the supratidal physiotopes, which are habitats that are rarely flooded and therefore can rarely be accessed by fish. Supratidal physiotopes were clustered as a group (Group IV) and separated first (Fig. 5). Group III, with the second lower scores, included all the physiotopes with high hydrodynamics. The highest scores were obtained for Sh.lD.M.nV (shallow; low dynamics; mud; non-vegetated), In.lD.M.Sm (intertidal; low dynamics; mud; saltmarsh) and In.lD.S.Sm (intertidal; low dynamics; mud; saltmarsh), with 12, 11.4 and 11.4 respectively (Fig. 5; S2 Table). These, together with the other intertidal soft substratum physiotopes and the shallow sandy and moderately deep muddy physiotopes were included in the group of higher attractiveness to fish (Group I). Of the four clusters, only Group I showed a net reduction (by 48 %) in total area between 1933 and 2013, while the cumulative area of the physiotopes in the remaining clusters increased (Fig. 5; S3 Table).

3.3. Sensitivity of the habitat attractiveness assessment

The manipulation of scores in the habitat attractiveness showed the strongest response when a change was applied to all the functions of all physiotopes included in the assessment (W – All, worst case scenario applied to all physiotopes; Fig 6), as it would be expected. The sensitivity of the assessment was also shown to be highly dependent on the annual area cover of the physiotope to which change is applied. The worst case scenario applied only to In.lD.S.nV (i.e. the most extensive physiotope present in 1933; W-L1933), elicited a weaker response of the final attractiveness score in 2013 (with a deviation of 3.8 %, positive or negative depending on the scenario) than in 1933 (deviation of 27.5 %) and this was due to the higher proportion of estuarine area covered by this physiotope in 1993 (50.9 %) compared to 2013 (6.2 %) (Fig. 6a,b). When the worst case scenario was applied to Md.lD.S.nV (i.e. the largest physiotope in 2013, with 17.1 % area cover in this year; W-L2013), the response deviation of the habitat attractiveness assessment score of 2013 was 10.5 %, whereas the deviation was 0.3 % in 1933, when this physiotope covered only 0.5 % of the lower estuary area.

The difference between the final scores of habitat attractiveness of the Lima estuary between 1933 and 2013 was 1.14 (Table 3). A positive difference (i.e. the final attractiveness score was higher in the 1933 assessment than in 2013 assessment) was observed for all the scenarios of change, except for scenario W – All (Fig. 6c). Under this scenario, that represents the very worst case of underestimation of all the function scores for all the physiotopes included in the assessment, there would have been an increase of habitat attractiveness for fish in the lower Lima estuary between 1933 and 2013.

4. Discussion

4.1. Estuarine habitats and their attractiveness for fish

Estuaries have long been regarded as highly attractive areas for fish, which use them in a variety of ways (Elliott and Hemingway, 2002; Potter et al., 2015). The scoring system used in this study aimed to reflect the role of different estuarine habitats for fish, while taking into account the different estuarine functions. As a result, saltmarshes and sandy and muddy intertidal and shallow areas were identified as being highly attractive (all clustered in Group I).

Sandy and muddy intertidal and shallow areas are suitable as nursery grounds and usually carry high abundances of juveniles (Cabral and Costa, 2001; Le Pape et al., 2003; Trimoreau et al., 2013; van der Veer et al., 2001). The preference for such habitats appears to be related to the interaction between refuge from predation, which is assumed to be low in shallow waters (Manderson et al., 2004; Ryer et al., 2010), and availability of food resources (Whitfield and Pattrick, 2015), which is assumed to be high in intertidal and shallow waters with fine sediments (Phelan et al., 2001; Vinagre et al., 2005). Benthic intertidal primary production has been shown to sustain juvenile fish food webs and therefore contribute to maintaining the nursery function of estuarine and coastal tidal ecosystems (Le Pape et al., 2013). The higher scores allocated to intertidal and shallow habitats, in contrast to deeper areas, reflect, therefore, the habitat use of the species considered in this study (e.g. *Pomatoschistus microps*, *Platichthys flesus*, *Dicentrarchus labrax*), which are representative of the small sized or young demersal fish species that dominate fish communities in the Lima and other European estuaries (França et al., 2011; Franco et al., 2008; Ramos et al., 2012).Estuarine saltmarshes are very productive ecosystems that convert nutrients into plant biomass, are an important source of organic matter to the estuary, and they trap sediments and absorb wave energy (McLusky and Elliott, 2004; Wolanski and Elliott, 2015). Their high productivity associated with a complex structure make saltmarshes important habitats for many fish and crustaceans, functioning as sites for reproduction, nursery, enhanced feeding, and refuge from predation and stressful environmental conditions (França et al., 2009; Franco et al., 2009b; Minello et al., 2003; Rountree and Able, 2007). For these reasons, saltmarshes are very attractive for fish and are usually areas of high fish densities within estuaries (França et al., 2009). High hydrodynamics were identified in the cluster group with the second lowest scores of attractiveness for benthic and demersal fish. Hydrodynamics are known to influence the distribution of fish in the estuary (Thiel et al., 1995) and, depending on the estuarine currents and species behaviour, can have a positive effect on transport towards inner nursery areas (Forward et al., 1999; Harrison et al., 2014; Jager, 1999). However, and given that estuaries have a net flow of water to the ocean, high current velocities may also have the opposite effect and reduce the access of the marine migrant early life stages to the vital estuarine nursery areas. While larvae have developed behaviour to overcome strong currents that frequently exceed larval swimming velocities (Forward et al., 1999), such as selective tidal stream transport (STST), they are still sensitive to increased river flow (Ramos et al., 2012) and can be easily flushed back to the ocean and prevented from reaching settlement areas.

4.2. How has the estuary changed?

As with many coastal and wetland areas, the Lima estuary has been modified over time by increased urbanisation and coastal development. In the past 80 years, the geomorphology of the lower Lima estuary has been altered, and its area has increased by claiming area from the ocean and estuary. The modifications have removed most of its sandy and saltmarsh intertidal areas, replaced by deeper areas continuously dredged to allow the operation of the port, commercial harbour and marina. In general, the attractiveness of the estuarine area decreased for fish, as shown by the scores obtained for each species and the final score. The results were calculated taking into account that, in addition to the presence (or absence) of certain types of physiotopes, the proportion of seascape occupied by each physiotope also contributes to the final attractiveness of the estuarine area. Although the lower estuarine area increased between 1933 and 2013, the density of physiotopes (number of physiotopes per 100 ha) has decreased. Patch density increased between the two dates. These results show a change in the spatial configuration of the lower estuary and suggest a potential fragmentation of habitats. Patch density is one of the basic descriptors of habitat subdivision, although it is limited as a habitat fragmentation quantitative indicator, given its correlation with habitat abundance (Wang et al., 2014). Fragmentation is regarded here as a complex and dynamic process that is the net result of interlinked changes such as habitat loss, increased isolation of patches and changes in the number, shape, size and quality of patches (Bostrom et al., 2011). Nevertheless, spatial features of habitat patches play an important role in structuring associated fish communities (Nagelkerken et al., 2015) and habitat fragmentation and the resulting loss of connectivity can potentiate the consequences of habitat loss.

Vegetated areas, i.e. saltmarsh areas, of the lower Lima estuary were reduced by 88 %. As in many other estuaries worldwide (Wolanski and Elliott, 2015), França et al. (2012) recognised land claim, together with nutrient input and changes in river flow, as the highest threats in other Portuguese estuarine sites and habitats. The impact of land claim was especially high for saltmarshes and mudflats, due to historical and current pressures claiming wetlands for agriculture, aquaculture and the construction of shoreline structures. Moreover, shoreline development may also lead to a decrease in densities of benthic prey and predators on the adjacent subtidal areas, when compared to the adjacent subtidal areas of natural saltmarshes (Seitz et al., 2006). Recently, a study carried in the sub-estuaries of Chesapeake Bay and the Delaware Coastal Bays, USA, showed that shoreline hardening (hard engineering structures at the top of the shore) affects adjacent local fish and crustacean assemblages, and that cumulative shoreline hardening negatively affects fauna at the sub-estuary system scale (Kornis et al., 2017). The attractiveness score system identified saltmarsh habitats present in the Lima lower estuary as highly attractive to fish (the second highest) and hence the loss of 88 % of these habitats is likely to have negatively affected the fish assemblages. Additionally, from 1933 to date there has been a large increase in coastal urbanisation. Land use of the southern bank changed from natural habitats (essentially pine forest with a low extent of corn and vegetables cultivated areas) to an urbanised area with hardened shorelines. The amount of urbanisation influences nekton assemblages, and intact natural saltmarsh landscapes support a nekton assemblage significantly different from those in partially or completely urbanised saltmarsh landscapes (Elliott et al., 2016; Lowe and Peterson, 2014).

The physiotopes of the lower Lima estuary (saltmarshes, intertidal and shallow subtidal habitats with fine sediments) were clustered in the group of physiotopes with higher attractiveness for fish. However, these were also the physiotopes that lost more area between 1933 and 2013. Given their high productivity, it is likely that these changes reduced the carrying capacity of the system for juvenile fish. Rochette et al. (2010) used a habitat suitability model based on bathymetry and sediment structure to hindcast the effect of nursery habitat degradation of the Seine estuary on Solea solea population. They suggested that, since 1850, the estuary nursery capacity has decreased by 42 % due to habitat loss. Considering that the physiotopes lost in the lower Lima were highly attractive for juveniles, the estuary is likely to have also lost some of its nursery capacity. The extent of available nursery area has a considerable influence on the recruitment level of marine fish populations (Rijnsdorp et al., 1992; Schmitt and Holbrook, 2000), therefore the protection of these essential fish habitats has currently high priority in conservation and management strategies (Beck et al., 2001; Nagelkerken et al., 2015).

In contrast, highly hydrodynamic areas increased in the lower Lima estuary, probably as an effect of the deepening of the channel and of the increasing of engineered structures in the estuary. Typically, engineered structures placed in a coastal site are expected to modify the hydrodynamics of the area, by altering the water flow, currents, sediment dynamics, grain size or depositional processes (Dugan et al., 2011; Gonzalez et al., 2001; Lesourd et al., 2001; Walker et al., 2008).

4.3. Implications of habitat changes for the structure and functioning of the fish communities

Habitats differ in their productivity and ecological services and functions that they deliver (Peterson and Lowe, 2009; Turner and Schaafsma, 2015). Thus, the loss of different habitats will have different impacts on the fish communities although functional redundancies among habitat types could decrease the negative effects of habitat changes (Camp et al., 2013). The ability to recreate habitats as compensation or biodiversity offsets for those lost during development has been increasing (Elliott et al., 2016; Wolanski and Elliott, 2015). In the lower Lima estuary, the physiotopes most attractive to fish decreased by 48 % in their total area and the loss of saltmarshes and intertidal areas cannot be compensated by the gain of deep subtidal physiotopes, given their different functional roles for fish. Hence, even if the total carrying capacity of the system had increased with the increase in total area, the structure of the fish community will probably have changed. However, the functional roles of many habitats are not yet fully understood and therefore the consequences of habitat changes become difficult to predict (Camp et al., 2013).

Villéger et al. (2010) showed that, following habitat degradation in a tropical estuary, there was a loss of functional diversity resulting from a loss of functional specialisation in fish communities, and that the species turnover observed was determined by habitat-trait relationships. Habitat changes can, therefore, alter the functional structure of the community by removing species with traits that are poorly adapted to the new habitat and allowing colonization by better adapted species (Mouillot et al., 2013). Baptista et al. (2015) reported changes in the structure and function of an estuarine fish community in a temperate estuary due to hydrological changes caused by man-induced alterations and weather extremes. Zucchetta et al. (2016) also identified the potential of changes in habitat morphology (e.g. bathymetric changes, loss of intertidal or seagrass habitat) to affect the functioning of transitional water habitats (namely their secondary production) by affecting the biomass of estuarine resident and migratory species (including also the European Eel *Anguilla anguilla*) in a temperate lagoon system. On the other hand, areas that have been modified due to the introduction of man-made structures have started to receive attention as potential artificial habitats, combining engineering and ecological principles in an attempt to minimize their negative impacts (Browne and Chapman, 2011; Elliott et al., 2016).

Although it was not possible to quantitatively evaluate the extent of changes to the ecosystem functioning following the extensive habitat changes observed in the lower Lima estuary due to the lack of reference data, it is hypothesised that functional changes of the fish community had occurred.

4.4. Limitations of the approach

The lack of historical data hinders direct empirical studies evaluating the impacts of habitat loss on diversity changes (Airoldi et al., 2008). Given the lack of historical data on fish assemblages of the studied area, historical comparisons of fish community data were not possible. Under these conditions, that may be also common in other estuarine systems, the present study aimed to define an alternative approach to investigate changes in the estuarine functioning for fish as associated with changes in the physical habitat of the estuary. Physical habitat change was assessed by a snapshot of two points in time (year of 1933 and year of 2013), using historical and contemporary data sources to create the physiotopes. While historical map data, such as military maps are unlikely to contain systematic biases (Vellend et al., 2013), data acquisition strategies and processing, such as determination of bathymetry, characterisation of sediments and currents, were most likely different between 1933 and 2013. Therefore, the observed changes in area of each physiotope could be confounded, to an extent, by differences in data sources.

The method for evaluating the attractiveness of habitats was based on the knowledge of a few representative species using the estuary. Although it covered the major estuarine use guilds (Elliott et al., 2007; Potter et al., 2015), it does not entirely reflect the complexity of the whole assemblage and functional diversity. In fact, ecological guilds are only one of the functional traits that can be used to evaluate functional diversity. In addition to the ecological guilds, the trait vertical distribution (Elliott and Dewailly, 1995) was considered by choosing two species to cover the benthic and demersal guild (*Platichthys flesus* and *Dicentrarchus labrax*) as these are more likely to be linked the structure of the habitat. Nevertheless, the attribution of attractiveness scores highlighted the scarcity of information available about the functional roles of the different habitats to individual species, as indicated elsewhere (Seitz et al., 2014). The present study showed this was evident for the least commercially important species (therefore least studied).

The study gives a partial representation of the estuarine habitats, by investigating the lower estuary only. Although natural habitats in the upper/middle estuary have undergone minor changes, their exclusion from the analysis does not account for their relative importance (in terms of area and functionality) compared to the lower estuary, therefore the understanding of the overall loss of attractiveness of the whole estuary is limited. Furthermore, attractiveness has been associated to physiotopes, irrespective of their location within the estuary. The location of a physiotope along the estuarine gradient, or in relation to its adjacent habitats, might affect this value. For example, the attractiveness of intertidal, low dynamics physiotopes in brackish areas might be different from those in the lower euhaline estuary, as juveniles of some marine migrant species, like *Platichthys flesus*, may be attracted by freshwater cues (Amorim et al., 2016; Zucchetta et al., 2010). Given that a generic assessment of the habitat attractiveness has been undertaken and the literature review/expert knowledge used is also likely to include information from brackish habitats that are not presented in this study, attractiveness might be over- or under-estimated. The lower estuary was assumed homogenous within a euhaline area in both years, however it is likely that in 2013 the estuary presented a greater saline penetration than in 1933 due to the deepening of the channel. Therefore, this likely salinity change between 1933 and 2013 might have also affected the habitat attractiveness in the lower estuary, a factor that could not be accounted for by the assessment in the present study.

The sensitivity analysis showed that the habitat attractiveness assessment can be sensitive to the choice of the function scores allocated to the physiotopes, although only the worst-case scenarios led to high deviations from the original result. These scenarios assumed that the experts undertaking the assessment misjudged the scores of all habitat functions for all the physiotopes (by either always underestimating or overestimating them), and therefore are considered to be very unlikely cases. When considering individual physiotopes, those with the bigger area cover in the estuary appeared to be most influential in the assessment, as it would be expected given that area cover was used to weight the contribution of each physiotope to the overall estuarine attractiveness. One way to avoid these types of errors could be, for example, to use a Delphi approach by asking multiple experts to attribute scores to the functions of the physiotopes and use averaged scores in the assessment.

Based on the major functions of estuarine habitats, the Lima estuarine area became less attractive for fish representing the major ecological groups using the estuary. However, it is also of note that habitat attractiveness may be determined by features and/or environmental parameters additional to the physical attributes that were used in this approach to define physiotopes. These may be biotic factors (e.g. species interactions such as competition or predation) or other abiotic factors that may affect the physiotope attractiveness to fish. For example, anthropogenic pressures such as dredging, regulated river flow and water quality may reduce habitat attractiveness for fish. The lower Lima estuary is subjected to constant dredging for navigation, which is known to affect macrobenthic assemblages, modify sediment and biogeochemical characteristics and resuspend fine sediment, nutrients and pollutants (Gray and Elliott, 2009; Ponti et al., 2009; Quigley and Hall, 1999). The river flow of the Lima is regulated by two large hydroelectrical dams and the freshwater inputs are recognized to affect estuarine fish communities (Ramos et al., 2006) by influencing salinity fluctuations in estuaries (Drake et al., 2002; Wolanski and Elliott, 2015). Water quality, nutrient inputs, hypoxia or eutrophication symptoms restrict fish access to suitable habitats (Elliott and Hemingway, 2002). A lack of historical and quantitative information on these pressures prevented the use of such additional factors in defining physiotopes in this study, and hampered further knowledge of their impacts on habitat attractiveness and degradation, and changes to the structure and functional properties of fish communities of the estuary. The potential contribution of these additional factors however cannot be disregarded and future research efforts should aim at integrating these elements in the assessment of fish habitat attractiveness.

5. Conclusions

Hydrophysical factors are a major determinant of habitat structure and may therefore influence the establishment, development and functioning of fish communities. The availability of food, shelter and refuge from predation allow for different uses of each habitat (Wolanski and Elliott, 2015). The lower Lima estuary suffered extensive modifications in its habitat structure between 1933 and 2013, mostly due to the increase of the total area and the change of the system from one dominated by intertidal and shallow subtidal habitats with soft sediment and saltmarsh, to one dominated by moderately deep / deep subtidal habitats. Considering the main estuarine habitat functions, the physiotopes lost were the most attractive to the benthic and demersal fish communities using the estuary. These physiotopes were replaced by others with lower attractiveness and different functional roles for fish, for example hard substrata. Consequently, these decreased the overall attractiveness of the estuarine area since 1933.

This study highlights the importance of understanding and tracking habitat loss and gains, particularly as habitat alterations also occur widely in many other nearshore environments as well as estuaries. These types of cumulative impacts are challenging because they are not immediately noted and build up over time to produce a more substantial impact at larger scales (Peterson and Lowe, 2009). Management and conservation strategies of coastal areas rely on a better understanding of habitat functional roles for fish species and further research is needed to identify how habitats are related to functional traits of the fish community to understand the consequences of habitat changes.

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Figure 1. The methodological framework to show the influence of historical habitat changes on the attractiveness of estuarine habitats for estuarine fish communities. Flowchart shapes: parallelogram – input/output data; rectangle - process; hexagon – preparation/initialisation; diamond – decision; rounded rectangle – terminator.

Figure 2. The lower Lima River Estuary. a) Location of the Lima Estuary in the Iberian Peninsula (*); **b)** Lima lower estuary presently – the orange line represents the delimitation of the lower estuary in 1933 and the arrows indicate the sites where major modifications occurred (basemap source: ESRI, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community). **c)** Photogrammetric restitution of the lower Lima estuary in 1933 (provided by Câmara Municipal de Viana do Castelo).

Figure 3. Physiotopes of the lower Lima estuary: 1933 and 2013. Class code names: Sp - supratidal; In – intertidal; Sh - shallow subtidal (<2 m); Md - moderately deep (2 – 5 m); D – deep (>5 m); lD - low dynamics (water velocity <0.8 m s^{-1}); hD - high dynamics (water velocity >0.8 m s^{-1}); R - hard substrata; G - Coarse sediment; S – sand; M – mud; Sm – saltmarsh; nV – non-vegetated.

Figure 4. Area (ha) of the physiotopes of the lower Lima estuary in 1933 and 2013. Class code names: Sp - supratidal; In – intertidal; Sh - shallow subtidal (<2 m); Md - moderately deep (2 – 5 m); D – deep (>5 m); lD - low dynamics (water velocity <0.8 m s^{-1}); hD - high dynamics (water velocity >0.8 m s^{-1}); R - hard substrata; G - Coarse sediment; S – sand; M – mud; Sm – saltmarsh; nV – non-vegetated.

Figure 5. Dendrogram of the results of the hierarchical cluster analysis performed on the attractiveness scores of Lima estuary physiotopes. Red boxes indicate clusters with unbiased (AU) probability values >95 %. GI – Group I; GII – Group II; GIII – Group III; and GIV – Group IV. Numbers in brackets show cumulative percentage (%) increase (positive values) or

decrease (negative values) in the area of the physiotopes of the corresponding group. Class code names: Sp - supratidal; In – intertidal; Sh - shallow subtidal (<2 m); Md - moderately deep (2 – 5 m); D – deep (>5 m); lD - low dynamics (water velocity <0.8 m s^{-1}); hD - high dynamics (water velocity >0.8 m s^{-1}); R - hard substrata; G - Coarse sediment; S – sand; M – mud; Sm – saltmarsh; nV – non-vegetated.

Figure 6. Results of the sensitivity analysis applied to the habitat attractiveness assessment. a) Tornado diagram showing the percentage of deviation of the habitat attractiveness assessment of the lower Lima estuary in 1933 under twenty scenarios of change; **b)** Tornado diagram showing the percentage of deviation of the habitat attractiveness assessment of the lower Lima estuary in 2013 under twenty scenarios of change; **c)** Radar plot showing how the difference between habitat attractiveness assessments in 1933 and 2013 (with a baseline value of 1.14, represented by the dashed line) changes under the twenty scenarios of change. W – worst case scenarios (tier 1); B – best case scenarios (tier 1); (+) and (-) – positive and negative scenarios of change (tier 1); All – tier 1 scenarios applied to all the physiotopes in the annual assessment; L – tier 1 scenarios applied to the physiotope with the largest cover area in a given year; S – tier 1 scenarios applied to the physiotope with the smallest cover area in a given year.

Table 1. Literature references used to derive the physiotopes attractiveness scores of the Lima estuary for the species *Anguilla anguilla*, *Callionymus lyra*, *Dicentrarchus labrax, Platichthys flesus* and *Pomatoschistus microps*.

A. anguilla	*C. lyra*	*D. labrax*	*P. flesus*	*P. microps*
Barry et al. (2015)	Griffin et al. (2012)	Cabral and Costa (2001)	Dando (2011)	Hampel and Cattrijsse (2004)
Bouchereau et al. (2009)	King et al. (1994)	Dando and Demir (1985)	Kristensen et al. (2014)	Nellbring (1986)
Harrison et al. (2014)	Prista et al. (2003)	Dufour et al. (2009)	Le Pichon et al. (2014)	Nellbring (1993)
Laffaille et al. (2004)	Van Der Veer et al. (1990)	Kelley (1988)	Mendes et al. (2014)	Polte et al. (2005)
Laffaille et al. (2003)		Laffaille et al. (2001)	Souza et al. (2013)	Tallmark and Evans (1986)
Schulze et al. (2004)		Martinho et al. (2007)	Vinagre et al. (2005)	
Walker et al. (2014)			Zucchetta et al. (2010)	

Table 2. Total area (ha) for each class variable of the Lima estuary and their change (ha and %) between 1933 and 2013. The abbreviation for each class used in the final physiotope codes is shown in square brackets [ ].

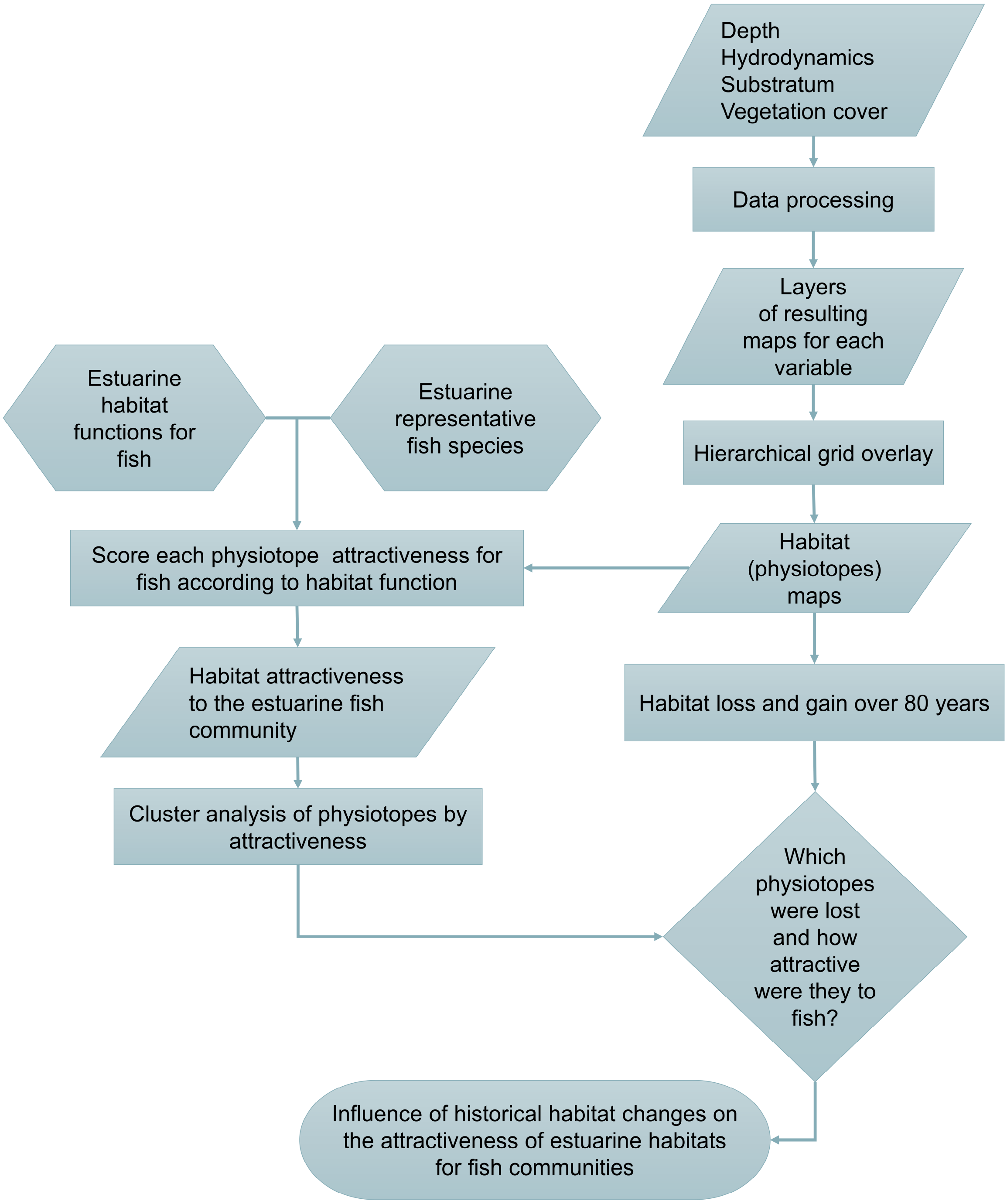
	Area (ha) 1933	Area (ha) 2013	Change (ha)	Change (%)
Total estuarine area	169.1	223.2	54.1	32
Supratidal [Sp]	0.4	4.5	4.1	945
Intertidal [In]	110.2	30.2	-79.9	-73
Subtidal	58.5	188.5	130.0	222
Shallow [Sh]	53.5	33.0	-20.5	-38
Moderately deep [Md]	4.9	74.5	69.6	1416
Deep [D]	0.1	81.0	80.9	71300
High hydrodynamics [hD]	7.2	51.7	44.5	616
Low hydrodynamics [lD]	162.0	171.5	9.6	6
Coarse sediment [G]	0.8	0.0	-0.8	-100
Sand [S]	150.7	136.7	-14.1	-9
Mud [M]	15.3	80.8	65.5	429
Hard substrata [R]	2.2	5.7	3.5	158
Saltmarsh [Sm]	21.3	2.6	-18.7	-88
Non-vegetated [nV]	147.7	220.6	72.9	49

Positive values represent increase and negative values decrease.

Table 3. Number and density of physiotopes (number per 100 ha), patch density (number per 100 ha) and attractiveness of the Lima estuary for fish (total and by species) for the years of 1933 and 2013.

	1933	2013
Number of physiotopes	21	23
Physiotopes density (number per 100 ha)	12.5	10.3
Patch density (number per 100 ha)	55.0	300.6
Attractiveness	9.26	8.12
Anguilla anguilla	8.66	8.21
Callionymus lyra	8.46	8.40
Dicentrarchus labrax	8.88	7.98
Platichthys flesus	9.58	7.93
Pomatoschistus microps	10.71	8.10

Note that the potential range of variability of the attractiveness score is 0-15.


Depth
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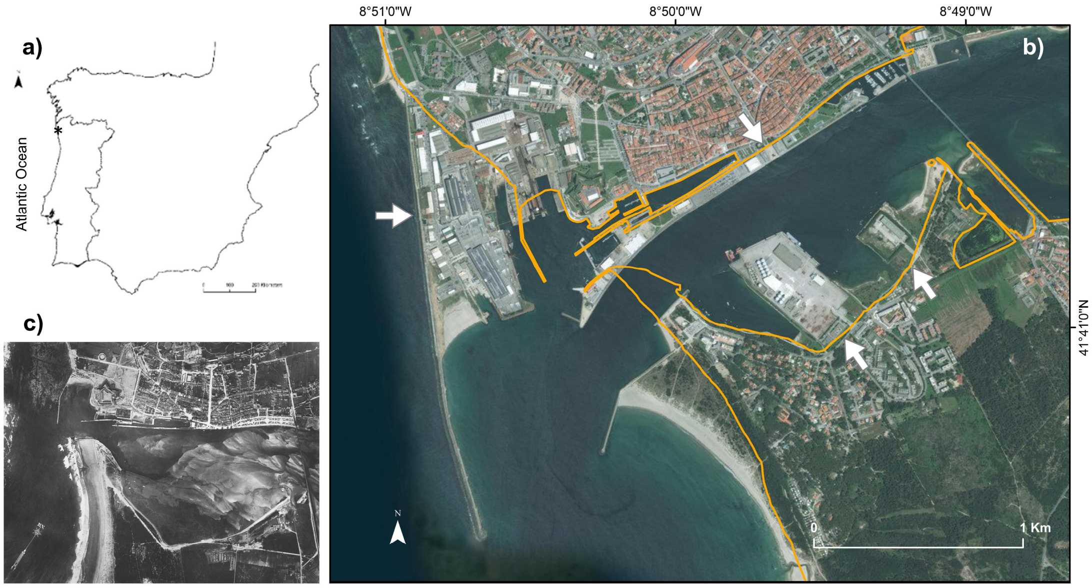
(physiotopes)
maps
Habitat loss and gain over 80 years
Estuarine
habitat
functions for
fish
Estuarine
representative
fish species
Score each physiotope attractiveness for
fish according to habitat function
Habitat attractiveness
to the estuarine fish
community
Cluster analysis of physiotopes by
attractiveness
Which
physiotopes
were lost
and how
attractive
were they to
fish?
Influence of historical habitat changes on
the attractiveness of estuarine habitats
for fish communities


a)
Atlantic Ocean
c)
8°51'0"W
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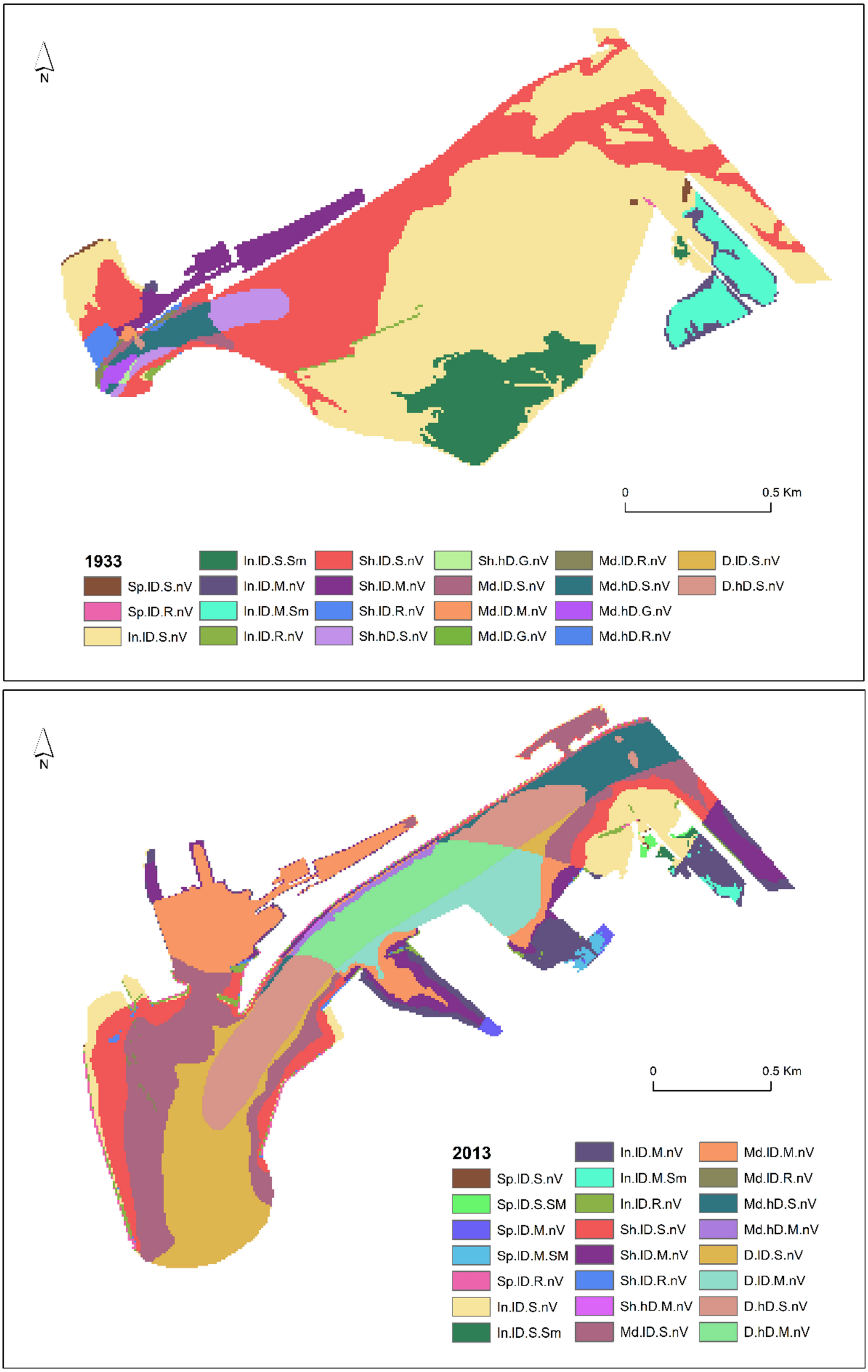
8°49'0"W
b)
41°41'0"N
0
1 Km
N


N
0
0.5 Km
1933
Sp.lD.S.nV
Sp.lD.R.nV
In.lD.S.nV
In.lD.S.Sm
In.lD.M.nV
In.lD.M.Sm
In.lD.R.nV
Sh.lD.S.nV
Sh.lD.M.nV
Sh.lD.R.nV
Sh.hD.S.nV
Sh.hD.G.nV
Md.lD.S.nV
Md.lD.M.nV
Md.lD.G.nV
Md.lD.R.nV
Md.hD.S.nV
Md.hD.G.nV
Md.hD.R.nV
D.lD.S.nV
D.hD.S.nV
N
0
0.5 Km
2013
Sp.lD.S.nV
Sp.lD.S.SM
Sp.lD.M.nV
Sp.lD.M.SM
Sp.lD.R.nV
In.lD.S.nV
In.lD.S.Sm
In.lD.M.nV
In.lD.M.Sm
In.lD.R.nV
Sh.lD.S.nV
Sh.lD.M.nV
Sh.lD.R.nV
Sh.hD.M.nV
Md.lD.S.nV
Md.lD.M.nV
Md.lD.R.nV
Md.hD.S.nV
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D.lD.S.nV
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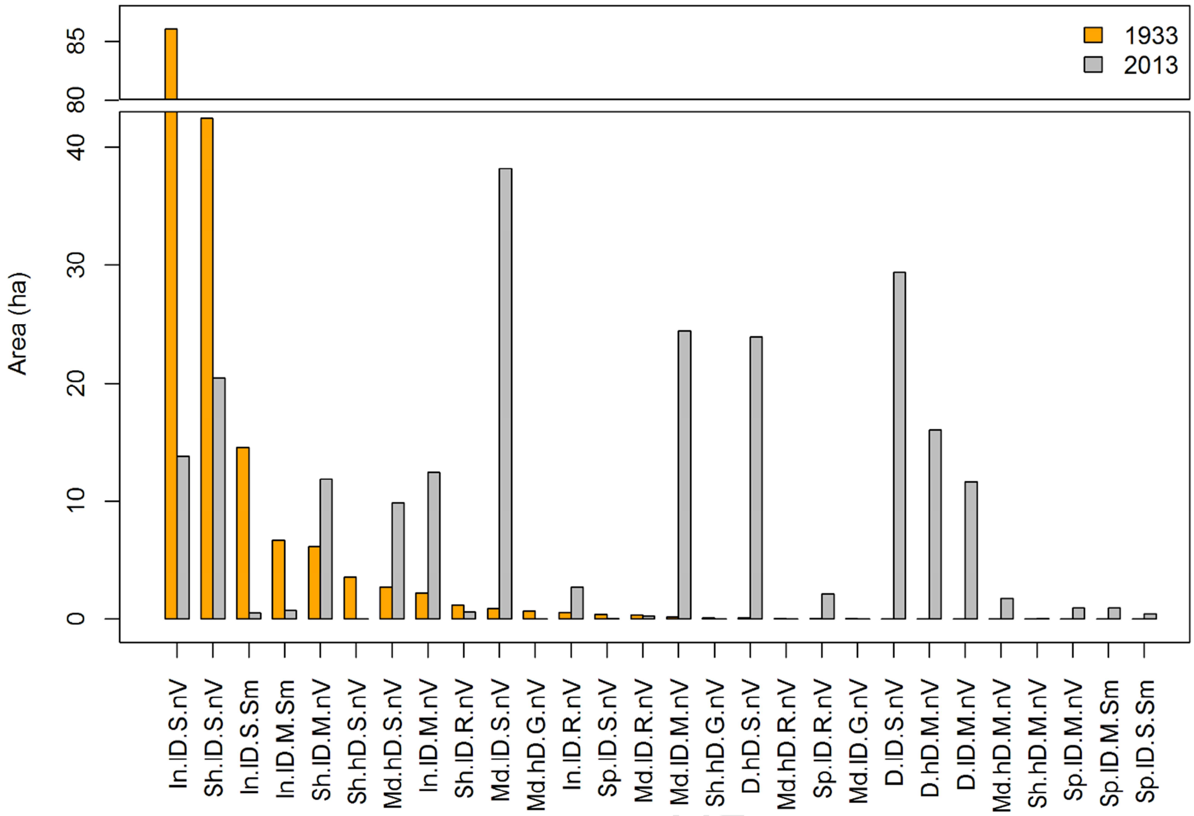
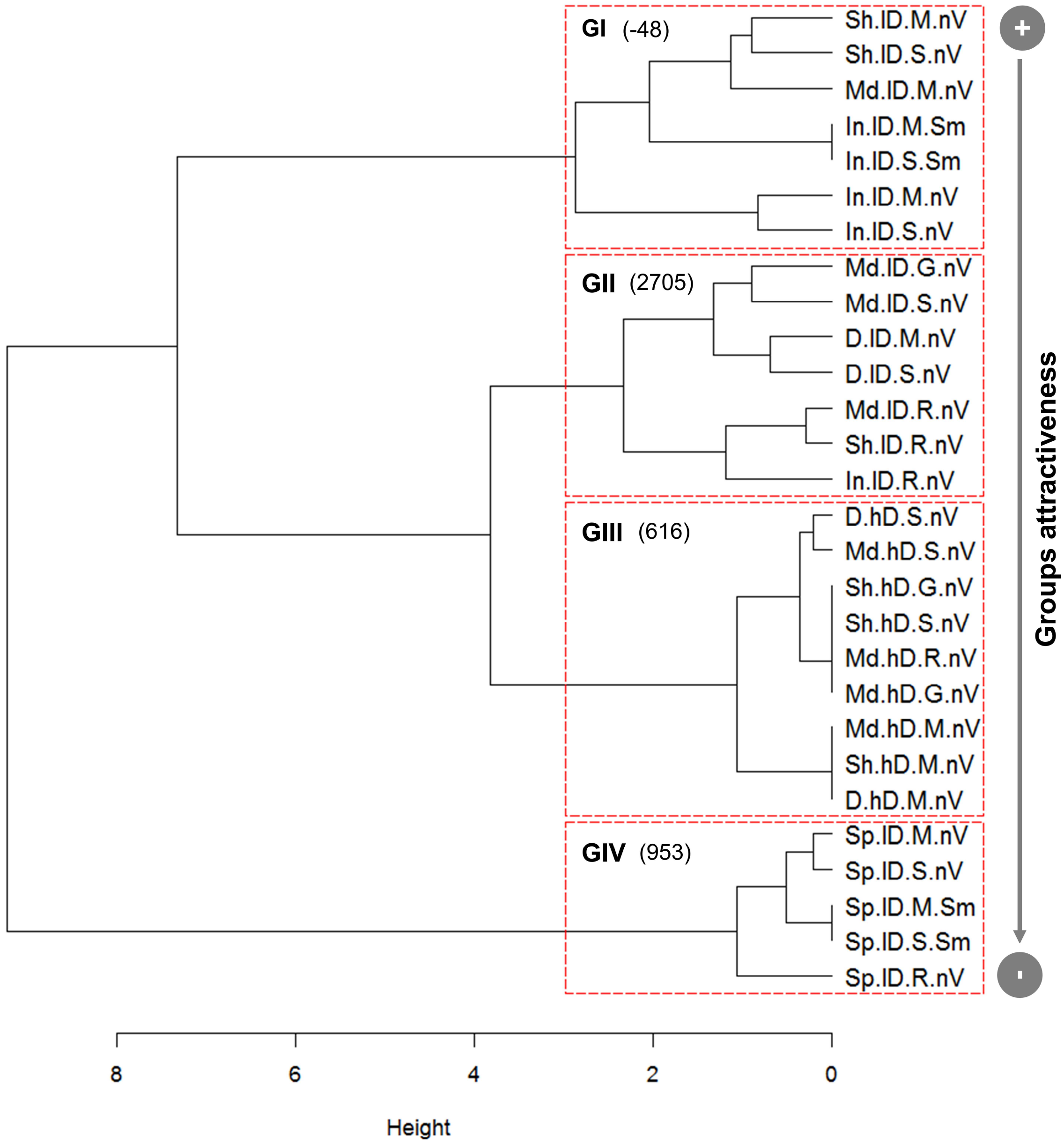
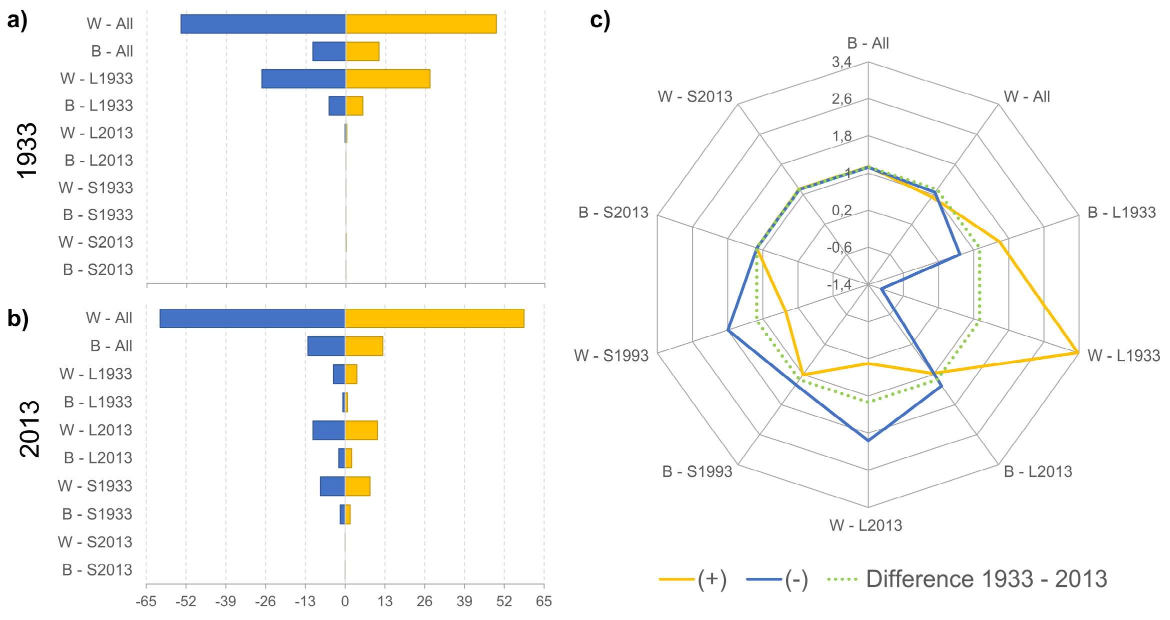
D.hD.M.nV



1933
2013
Area (ha)
0
10
20
30
40
80
85
In.lD.S.nV
Sh.lD.S.nV
In.lD.S.Sm
In.lD.M.Sm
Sh.lD.M.nV
Sh.hD.S.nV
Md.hD.S.nV
In.lD.M.nV
Sh.lD.R.nV
Md.lD.S.nV
Md.hD.G.nV
In.lD.R.nV
Sp.lD.S.nV
Md.lD.R.nV
Md.lD.M.nV
Sh.hD.G.nV
D.hD.S.nV
Md.hD.R.nV
Sp.lD.R.nV
Md.lD.G.nV
D.lD.S.nV
D.hD.M.nV
D.lD.M.nV
Md.hD.M.nV
Sh.hD.M.nV
Sp.lD.M.nV
Sp.lD.M.Sm
Sp.lD.S.Sm



GI (-48)
Sh.lD.M.nV
Sh.lD.S.nV
Md.lD.M.nV
In.lD.M.Sm
In.lD.S.Sm
In.lD.M.nV
In.lD.S.nV
GII (2705)
Md.lD.G.nV
Md.lD.S.nV
D.lD.M.nV
D.lD.S.nV
Md.lD.R.nV
Sh.lD.R.nV
In.lD.R.nV
GIII (616)
D.hD.S.nV
Md.hD.S.nV
Sh.hD.G.nV
Sh.hD.S.nV
Md.hD.R.nV
Md.hD.G.nV
Md.hD.M.nV
Sh.hD.M.nV
D.hD.M.nV
GIV (953)
Sp.lD.M.nV
Sp.lD.S.nV
Sp.lD.M.Sm
Sp.lD.S.Sm
Sp.lD.R.nV
Groups attractiveness
+
-
8
6
4
2
0
Height



a)
b)
c)
1933
2013
W - All
B - All
W - L1933
B - L1933
W - L2013
B - L2013
W - S1933
B - S1933
W - S2013
B - S2013
-65
-52
-39
-26
-13
0
13
26
39
52
65
W - S2013
W - All
B - L1933
W - L1933
B - L2013
W - L2013
B - S1993
W - S1993
B - S2013
3,4
2,6
1,8
1
0,2
-0,6
-1,4
(+)
(-)
Difference 1933 - 2013

Highlights

- Investigation of the habitat loss and gain of an estuarine area over 80 years.
- An ecohydrological classification system was used to quantify changes.
- The lower estuary was highly affected due to urbanisation and development.
- The most attractive physiotopes for fish decreased in area.
- Overall lower attractiveness of the studied area for fish in 2013 compared to 1933.