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Differential distribution pattern of native *Ruditapes decussatus* and introduced *Ruditapes phillippinarum* clam populations in the Bay of Santander (Gulf of Biscay): Considerations for fisheries management

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Abstract

The aim of the present study is to provide a first characterization of the grooved carpet shell clam *Ruditapes decussatus* (native) and the Manila clam *Ruditapes phillippinarum* (nonindigenous) populations in the Bay of Santander in order to improve the management of these commercially exploited resources. For this purpose a field survey was carried out in different fishing areas where samples were taken on transects, following artisanal shell-fisher exploitation techniques. Biometric relationships, size frequency distributions, densities and stocks were evaluated for different fishing zones. In addition, a hydrodynamic model was applied in order to understand larval transport and recruitment patterns associated to the tidal currents and water flow. Within this context, the first evaluation of the clam populations in the Bay of Santander showed: (a) that fishing activity is performed on individuals under the minimum legal size (40 mm) and in closed areas, (b) a significant differences on density by zone (c) a distribution pattern with areas where both species coexist and areas where one of them dominates, (d) *R. decussatus* occurs at relatively low density in stations near the culture parks and (e) a limited recruitment in the inner parts of Cubas tidal fresh for *R. phillippinarum* and in the southern zones for *R. decussatus*. Based on this study, some managing guidelines are presented mainly focused on avoiding the overfishing of the native clam *R. decussatus*.

Keywords: Clam, *Ruditapes decussatus, Ruditapes phillippinarum*, Coexistence, Management, Recruitment, Hydrodynamic model

1. Introduction

Natural populations of shellfish resources are coming under pressure as rising demand and prices for these generally high-value species leads to their overexploitation (Castilla and Defeo, 2001). The carpet shell clam (*Ruditapes decussatus*) and the Manila clam (*Ruditapes phillippinarum)* are highly exploited infaunal bivalves in Europe. The carpet shell clam is native to Europe, being found along the Atlantic coasts from the British Isles to as far south as Senegal and into the Mediterranean (Breber, 1985). The Manila clam is a native species of the Indo-Pacific coastal seas and it was introduced in Europe at the beginning of the 1970s for culture purposes (Flassch and Leborgne, 1992: Jensen et al., 2004). This clam naturalized in France, England, Spain and Italy and became a new commercially exploited resource (Dang et al., 2010) because its fast growth and important commercial value (Laing and Child, 1996; Usero et al., 1997).

Clam fisheries management

The need to establish management measures becomes evident to avoid a potential overexploitation and consequently its exhaustion (Bald *et al.*, 2009). Moreover, management measures are usually common (i.e. capture size, closure zones, etc) to both species regardless of biological aspects or if a species is more tracked to cultivation than other. This situation seems to have had negative consequences for the native species leading to a community structure where it is supplanted by a nonindigenous clam as it occurred in Arcachon Bay (Auby, 1993) and in the Lagoon of Venice (Marin et al., 2003).

In the Bay of Santander, estuarine populations of these two species have been largely exploited by professionals, usually women, and poachers in the intertidal zones using artisanal techniques such as looking for holes (i.e. marked by clam's siphons) and extracting clams using a knife or a hand rake. Besides, some culture parks are located on the central south-eastern part of the estuary, where high densities of Manila Clam are sowed. Until now the management of the clam fishery has been based on setting a minimal size of capture (total length of 40 mm) and seasonal closed areas by regional regulations regardless of the distribution patterns and biological differences between species. Moreover, the important role of fishermen in management (Brown, 2001; Scott, 2001) is not yet considered in this region, although some experiences in this direction have been very successful in the neighbour regions of Galicia where the government regulations promote a co-management system between fishers' organisations ("cofradías") and the fisheries authority (Meltzoff, 1995; Molares and Freire, 2003).

Stock assessment

Besides, an efficient management should be based on a good knowledge of: (i) the biology of the target species; (ii) the available resource through stock evaluations; (iii) the fishing pressure and activity. Although, the knowledge of the biology of the studied species is wide (e.g. Pérez-Camacho, 1979; Pérez-Camacho et al., 2002:2003; Solidoro et al., 2000; Melia et al., 2004.; Flye-Sainte-Marie, et al., 2007a,b) and several stock evaluations have been done in nearby estuaries in Spain and France (e.g. Borja, 1989:2000; Bald and Borja, 2001:2005; Caill-Milly et al., 2003:2006), the only available information in the Bay of Santander regarding this species is about their biometrical relationships of *R. decussatus* (Arnal and Fernández-Pato, 1977:1978) and clam (nonspecific) annual captures from fishery statistics data. Hence, the lack of data has not allowed the implementation of scientific-based management measures and not even the possibility of making a specific assessment of overexploitation or interaction effects between clam species.

In this sense, several studies on diverse topics of stock assessment methodologies on molluscs (Palacios *et al.*, 1994:2000; Rueda and Urban, 1998; Orensanz *et al.*, 2003) and different sampling methodologies (sampling grid, size of quadrat sampled, mesh size) (Byers, 2005; Lee, 1996; Borja and Bald, 2000; Bald and Borja, 2001:2005; Caill-Milly et al., 2006; Morsan, 2007) have been carried out for clam population evaluations. Moreover, the lack of a standardized sampling methodology and their expected high time and resource consumption for extent areas requires the implementation of assessment procedures that combine the appropriated technical design with the fishermen experience.

Larval dispersion and recruitment

Clam densities in culture zones and recruitment are other important aspects to take into account when managing these fisheries, since they play an important role in the distribution pattern of the clam populations. High densities of sowings of Manila clam in culture zones may have some effects in the reduction of surrounding native clam population, due to food shortage (Nizzoli et al., 2005) and the ingestion of bivalve larvae by high densities of filtering organisms (Bayne, 1964; Thorson, 1966). The importance of larval abundance and dispersion in determining the recruitment of benthic marine invertebrates, which presents a high spatial and temporal variability (Borsa and Millet, 1992; McLachlan et al., 1996; Ripley and Caswell, 2006; Herbert et al., 2012) and the structure of their communities has been emphasized by several authors (Roughgarden et al., 1988; Pineda, 2000; Roegner, 2000), noting that larval transport within an estuary is largely dependent on hydrodynamic patterns. Therefore, the analysis of the influence of the flow of water and tidal currents on the distribution pattern of clam populations appears to be essential to understand other aspects of the dynamics of these species that will aid in decision making for resource management.

Main goal of this study is to analyze the spatial distribution patterns, the population structure and the stocks of *R. decussatus* and *R. phillippinarum,* with particular attention in coexistence and the relationship between the hydrodynamic patterns and the current distribution of both species. It is expected that this information may also contribute to assess the feasibility of the new sampling methodology implemented to evaluate the performance of actual management measures and to allow for proposals of new management actions.

2. Material and methods

2.1. Study site

The study was conducted in the intertidal area of the Bay of Santander, the largest estuary in the North coast of Spain (Gulf of Biscay) with a surface of 2346 Ha (Figure 1). Its intertidal zone represents the 67 % of the total area of the bay (1573 ha) and it is concentrated mainly in the moor of the right margin. Galván et al. (2010) classified this estuary as morphologically complex and dominated by intertidal areas and tidal dynamic. In this intertidal zone the shellfishing of different species of bivalves (*Ruditapes phillippinarum, Ruditapes decussatus, Solen marginatus, Ensis spp*, etc) and bait for fishing (*Upogebia spp, Callianasa spp, Diopatra neapolitana*, *Arenicola marina, Sipunculus nudus, etc*) is done by fishermen using traditional techniques (i.e. looking for marks or holes, dropping salt into the holes, shoving or hand raking the sediment). The substratum of this area varies from sandy (northern open areas) to muddy sediments (southern an inner areas). Subtidal zones are dominated by shallow waters, with maximum depths of 10–12 m found along the navigation channel. Hydrodynamic conditions are controlled by a semidiurnal tidal regime and 3 m mean tidal range, interacting with variable freshwater inputs coming mainly from the river Miera through the Cubas area and, to a much lesser extent, from small streams through the Boo, Tijero and Solía tidal fresh areas (river inlets) (Puente et al., 2002). In these three tidal fresh areas and also in Pedrosa-Astillero zone the fishery was closed when the study was conducted due deficient sanitary condition of clams.

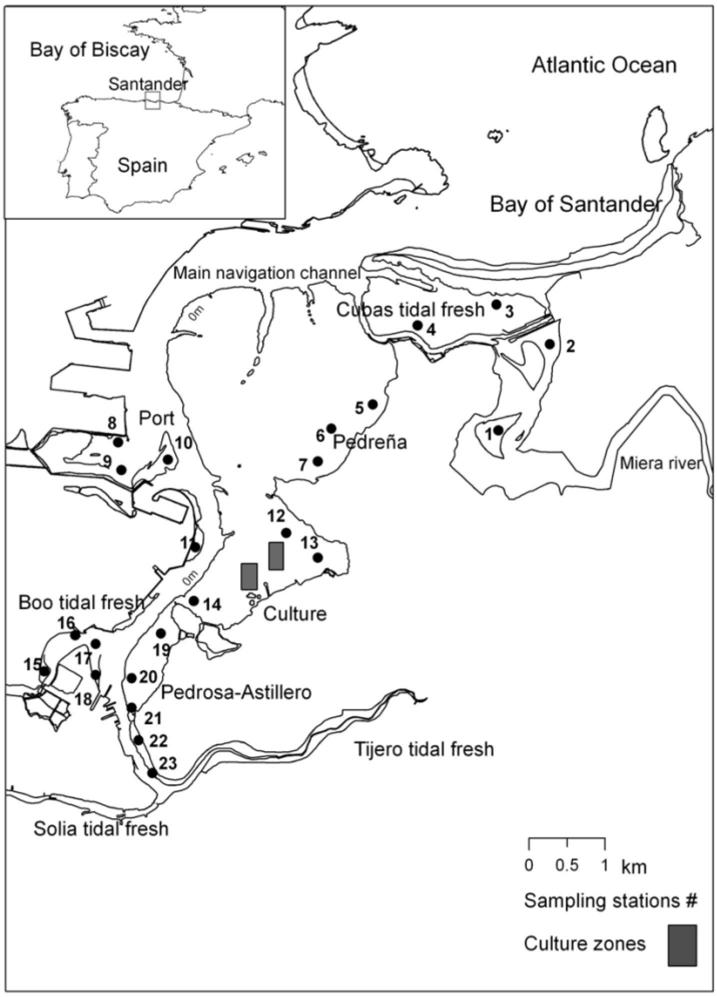

Figure 1. Location of sampling stations and clam culture zones in the Bay of Santander.

2.2. Sampling and laboratory procedures

Abundance, biomass, and biometric relations for carpet-shell clam and Manila clam were analyzed in 23 stations, placed in areas where commercial operation of the resource is conducted. These areas were selected by compiling information from shellfishers, fishing inspectors and technical staff of the Main Directorate of Fishing.

Sampling was conducted during low tides (semidiurnal tide) in April 2005. At each station individuals were extracted by a professional shell-fisherman by means of the hand raking of the sediment (upper 15 cm) in an unique 10 m x 1m transect. This operation was similar to their fishing extraction technique. Taxonomic determination of each individual was carried out in the laboratory, followed by fresh weight (FW, g) and shell length (±0,1 mm) measurements.

2.3. Data analysis

Total abundance of both species of clams collected in each station (i.e. 10 m^2 transect) was used to describe the general distribution pattern of clams in the Bay. Further analysis of the relative abundance of each species (i.e. ratio between *R. decussatus (RD)* and *R.phillippinarum* (RP) abundances) in each station was the base for establishing the criteria for dominance (RD/RP >0.8) or coexistence (0.2< RD/RP <0.8). The distribution pattern of this coexistence was used to group stations based on spatial proximity and similar characteristics in terms of species relative presence. Then, size frequency distributions density and standing stocks were analyzed by these zones.

Size frequency distributions were calculated to estimate recruitment patterns and potential effect of fisheries on clam population structure. A Kruskal-Wallis ANOVA by Ranks analysis was used to detect the effect of zone over the distribution of individuals above the minimum legal length for capture (i.e. 40 mm). The distribution pattern of the two bivalve populations was evaluated by calculating the variance-to-mean-ratio (Krebs, 1989; Schneider, 1994). Spearman Rank correlation between abundance of both species was calculated to explore whether there are indicators of a possible competition between the two bivalves (Wilson, 1983).

On the other hand, the following equation was used to calculate the stock (t) of species for each zone:

$S = (D \times FW \times A) \times 10^{-6}$ (1)

Where D is the density of the species standardized to nº of ind/m^2, FW (g) is the mean individual fresh weight on the established area and A is the area (m^2) of each fishing zone. All the information was placed in a GIS using the program ArcGis 9 (Figure 1), where the calculations of the surfaces of the fishing zones were carried out using the bathymetry of the Bay of Santander as the base and delimiting them by the lower and upper limit of the observed distribution of both species on the intertidal area (i.e. -0.5m – - 1.5m). Error of each variable was estimated by the standard deviation and coefficient of variation, following the Taylor's (1982) methods for products of variables in which the uncertainties are at random and there is independency. Therefore, the deviation of the coefficient of variation of the stock in each area was calculated, with an interval of confidence of 95 %, following the proposal of Hand and Bureau (2000). The total available stock of the estuary was considered as the sum of the stocks of all fishing zones. The coefficient of variation of the standing stock (CV_S) was calculated as it is shown in equation 2 for each zone.

$CV_s = \sqrt{CV_D^{\ 2} + CV_{FW}^{\ 2}}$ (2)

Where CV_D is the coefficient of variation of density and CV_{FW} is the coefficient of variation of fresh weight.

A Kruskal-Wallis ANOVA by Ranks analysis was used to analyze differences in clam mean density between the different zones. Moreover, a Mann-Whitney U Test between paired of zones was done to detect those with a significantly different density.

Finally, the highest and lowest flow situations, which can be observed at medium and high flood tide respectively, are analyzed in order to relate the tidal currents and flow with the spatial distribution of clams considered as recruiters. For this purpose, the individuals within the size class considered as the "recruitment length to the fishing gear" were considered as recruiters. This concept has been widely used in different species fisheries management (e.g. Gordoa & Molí, 1997; ICCAT, 2009) when the new recruits are not vulnerable to the fishing gear. This size class was estimated using a Spearman correlation analysis between different size classes' abundance and total abundance in each station. Thus, the smaller size class which was correlated ($p<0.05$) with the total abundance was selected as the recruitment length of the fishing gear. Secondly, water elevation and velocity fields were calculated using a two-dimensional hydrodynamic coastal and estuarine model, namely H2D model (Castanedo et al., 2006; Garcia et al., 2010). This model solves the two-dimensional vertically integrated hydrodynamic equations. The numerical computation was carried out on a spatial domain that represents the entire estuary through a finite-difference and two-dimensional grid, covering Bay of Santander and its adjacent coastal zone, represented horizontally using a mesh of 199 X 253 uniform grid squares each with a length of 50 m. The simulation was conducted for a complete 12 hour tidal event with fixed conditions of tidal wave amplitude (1.38 m) and Cubas river flow (1.158 m^3/s), obtaining hourly flow (m^3/s) and tidal current velocities (m/s) in each cell. These fixed conditions are the median values (percentile 50%) calculated for the time interval observed during the periods of release of *R. decussatus* and *R. phillippinarum* larvae (i.e. April-November 2003-4)(Rodrigues-Carballo et al., 1992; Rodríguez-Moscoso and Arnaiz, 1998; Urrutia *et al.*, 1999; Rodriguez-Moscoso *et al.*, 1992; Ojea *et al.*, 2005) related to the cohort which in April 2005 could be within the size class considered as recruitment length of the fishing gear. From these results, different hydrodynamic zones were defined according to their flow (m^3/s) and tidal current velocities (m/s) in the highest flow situation (medium flood tide) and the hydrodynamically most stable situations (high tide).

Considering that most of the larval pool is exported to the nearshore in ebb tide and the entrance of larvae in flood tide is correlated with the flow of water (Roegner, 2000), a Kruskal-Wallis ANOVA by Ranks and Mann-Whitney U Test analysis was used to explain differences of "recruitment" between previously defined hydrodynamic zones.

3. Results

3.1. Distribution patterns of clam populations

A total of 831 individuals of *Ruditapes decussatus* and 849 individuals of *Ruditapes phillipinarum* were collected, giving an approximate total *Ruditapes decussatus/Ruditapes phillipinarum* individuals ratio (RD/RP) of 1:1. The abundance of both species collected in each transect is shown in Figure 2. A higher abundance of total clams (i.e. sum of both species abundances) is observed in stations 4, 5, 6, 7 and 10, presenting between 100 and 300 total clams per station (10 m^2). Maximums of 293 and 98 individuals of *R. decussatus* were obsertved at stations 4 and 6, respectively and maximums of 85 and 223 individuals of *R. phillippinarum* at stations 5 and 7, respectively. The inner part of Cubas tidal fresh (stations 1, 2, 3), the zone around culture parks (stations 12,13,14), and southern inner areas (15,22,23) presented the lowest values of total clams (less than 50 individuals per 10 m^2).

Regarding the relative abundance for each station, the dominance of one species is found in two areas: *R. decussatus (RD)* dominantes in Cubas tidal fresh zone (stations 1-4) and *R. phillippinarum (RP)* in Culture zone (stations 11-14) (Figure 2), showing a mean RD/RP ratio of 0.96±0.05 and 0.10±0.08, respectively. Besides, coexistence of both species was observed on both margins of the central area of the Bay (i.e. in the Port zone, stations 8-10; Pedreña zone, stations 5-7), with 0.34±0.20 and 0.55±0.13 mean ratios, respectively, and mainly on the southern part of the Bay. In this latter area, two zones were defined: Boo tidal fresh zone (stations 15-18), where a clear coexistence pattern of clam species is observed (0.43±0.20) and Pedrosa-Astillero zone (stations 19-23), showing a mean RD/RP ratio of 0.28±0.20, although *R. phillippinarum* is the predominant species in two out of five stations. Abundances of both species showed significant deviation for randomness (Chi Square test for goodness-of-fit, $p<0.05$) with exceedingly large variance to mean ratios (*R. phillippinarum*: 5.53; *R. decussatus*: 10.24) which are significantly larger than 1, indicating a highly aggregated distribution of clams for both species. Spearman Rank correlation analysis between the total abundances of both clams for all stations (N=23) did not show any significant correlation (R=0.09, t (N-2)=0.42, p=0.67).

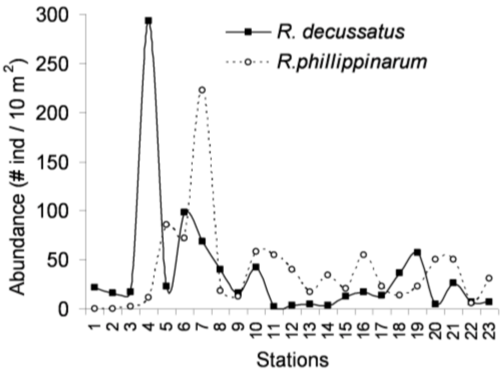

Figure 2. Abundance of *R. decussatus* and *R. philippinarum* at each station.

3.2. Population structure

Based on that division of zones within the Bay, the distribution of size frequency of both species for each zone are presented in Figure 3. The number of individuals of *R. decussatus* encountered in Culture zone (n=11) and of *R. phillippinarum* in Cubas zone (n=13) was considered too small for a reliable size frequency data analysis. The greater percentage of individuals of both species was set between 25 and 35 mm of size, falling drastically from the intervals 30-35 m. This fall is more accused in Cubas and Boo zones for R. *decussatus* and in Pedreña for *R. phillippinarum*.

Although this pattern was similar for both species, 25-30 mm was the class size with a slightly greater percentage of individuals for *R. decussatus* and 30-35 mm for *R. phillippinarum*. The abundance of individuals larger than 40 mm (legal size of capture) is not significantly different between zones: Kruskal Wallis ANOVA, for >40 mm, H(5, N=23)=3.79 p=0.58 and H(5, N=23)=6.20 p=0.28, respectively for *R. decussatus* and *R. phillippinarum*. Besides, it is observed a lack of individuals <20 mm and a total absence of individuals <10 m. The first size class presenting a significant percentage of individuals was 20-25 mm, which present a higher percentage of individuals for *R. decussatus* than for *R. phillippinarum.* The higher percentages of this class size are observed in the north and central zones for *R. decussatus* (Cubas, Port, Pedreña) and in the southern and inner zones for *R. philippinarum* (Culture, Boo and Pedrosa-Astillero).

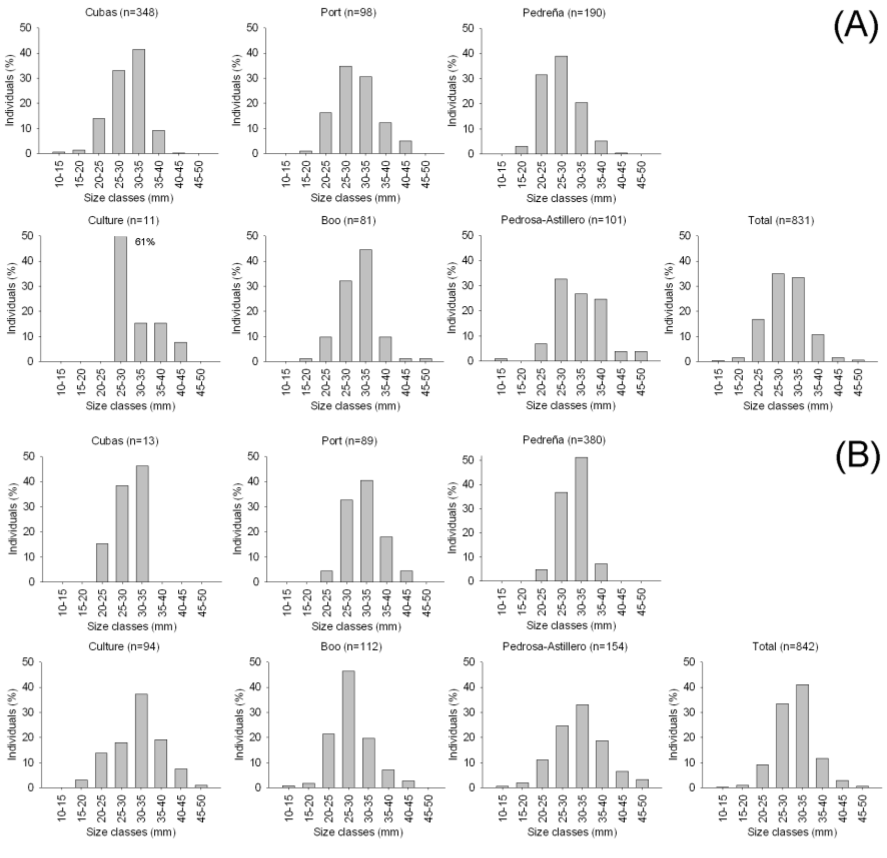

Figure 3. Size frequency distribution of *Ruditapes decussatus* (A) and *Ruditapes phillipinarum* (B) populations in each of the 6 fishing zones defined in the whole Bay area.

3.3. Densities and stocks evaluation

Considering results from all stations, the Mann-Whitney U Test showed that there was not a significant difference between densities of *R.decussatus* and *R.phillippinarum*. Besides, considering fishing zones, Manila clam showed the highest mean density in Pedreña and the highest individual mean biomass in Pedrosa-Astillero. This highest values were higher than *R. decussatus'* ones, which showed the highest density in Cubas and Pedreña and the highest biomass in Pedrosa-Astillero (Table 1). The coefficients of variation (CV) were not very different between species except in some zones (Boo, Port). In most of the cases CV (%) were about 40-70 %. The Kruskal-Wallis ANOVA by Ranks analysis shows significant differences in density between zones for *R. phillippinarum* (H (5, N=23)=14.33, p=0.013) and for *R. decussatus* (H (5, N=23)=14.12, p=0.014). For *R. decussatus* density was significantly lower in Culture zone when compared with the remainders (p=0.02-0.04). For *R .phillippinarum* density was significantly lower in Cubas (p=0.01-0.05) and was significantly higher in Pedreña (p=0.02-0.04).

The standing stocks of both species for each fishing zone are presented in Figure 4. The coefficients of variation for density and fresh weight were likely high and this aspect implies high values of the coefficient of variation of stock for all zones. The total stock (sum of all areas´ stocks) for *R. decussatus* was 58 t and 90 t for *R. phillippinarum*.

Table 1 - Summary of statistical parameters (mean, SD and CV) for densities (individuals/m^2) and mean individual biomass (FW,g) in each fishing zone together with their estimated areas (m^2).

Ruditapes decusssatus

Fishing zone	Density (ind/m^2)			Biomass (FW, g)			Area * 10^3(m^2)
	Mean	SD	CV	Mean	SD	CV	
Cubas	8.70	13.74	1.58	4.53	1.82	0.40	760
Pedreña	6.33	3.78	0.60	3.35	1.72	0.51	630
Port	3.27	1.45	0.44	4.63	2.52	0.55	400
Culture	0.33	0.13	0.39	5.49	2.61	0.48	880
Boo	2.30	2.24	0.97	5.08	2.23	0.44	220
Pedrosa-Astillero	2.03	1.13	0.56	7.52	4.80	0.64	320
Total	3.91	4.65	1.19	4.56	2.44	0.54	3210

Ruditapes phillippinarum

Fishing zone	Density (ind/m^2)			Biomass (FW, g)			Area * 10^3(m^2)
	Mean	SD	CV	Mean	SD	CV	
Cubas	0.33	0.53	1.62	5.18	2.23	0.43	760
Pedreña	12.67	8.37	0.66	5.55	1.82	0.33	630
Port	2.97	2.47	0.83	7.16	3.97	0.55	400
Culture	3.65	1.57	0.43	7.25	4.35	0.60	880
Boo	3.20	1.87	0.59	6.16	3.63	0.59	220
Pedrosa-Astillero	2.80	1.84	0.66	9.49	6.49	0.68	320
Total	3.61	6.08	1.68	6.66	4.02	0.60	3210

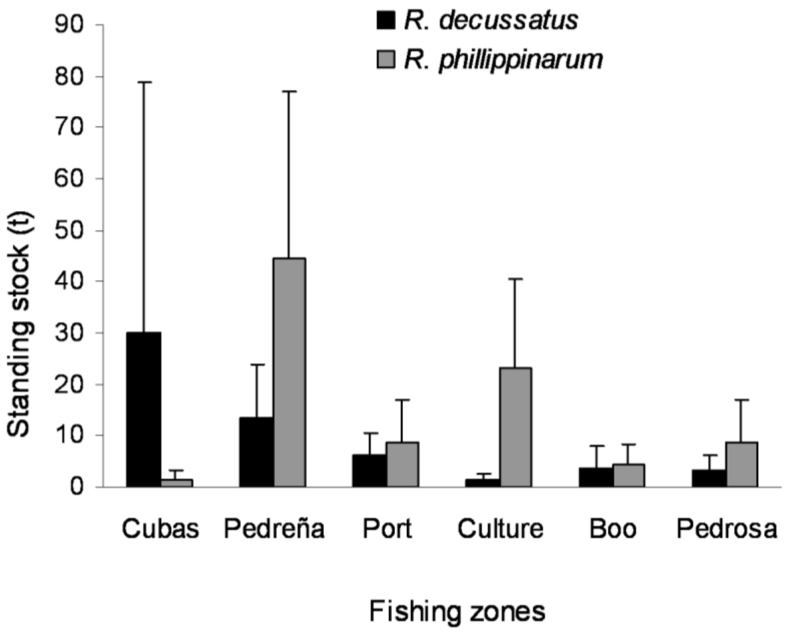

Figure 4. Estimation of standing stocks of *Ruditapes decussatus* and *Ruditapes phillippinarum* for each fishing zone. CV (%) of the standing stock is presented with error bars.

3.4. Relationship between hydrodynamics and spatial distribution of clams

Results of hydrodynamic modelling are presented in Figure 5. At medium flood tide a high flow of water (463 m^3/s) is observed from the mouth of the estuary to the main navigation channel (main flow). This water flow is the responsible of the water input to all zones except the Cubas zone. The secondary water flow at medium flood on Cubas tidal fresh mouth is significantly lower (53.5 m^3/s) (Fig. 5b). In this tidal situation the higher tidal current velocities are also located on the mouth of the Bay (0.83 m/s) and in the main navigation channel (0.30 m/s). Moreover, in the high tide the water flow and current velocities are much reduced all across the Bay, presenting a clear circulation cell (eddy) from the central to the northern part of the estuary affecting to Port and Pedreña zones (Fig. 5c). Kruskal-Wallis ANOVA by Ranks analysis shows significant differences in current velocities in high tide between Cubas zone, Port+Pedreña zone and

Culture+Boo+Pedrosa zone; H (2, N=23)=11.17, p=0.003), with lowest velocities encountered in this southern zone. Thus, three different zones were established in terms of observed flow and current values on clam sampling stations: Cubas zone (affected by secondary flow), Port and Pedreña zones (affected by the main flow and circulation cell or eddy in high tide), and Culture, Boo and Pedrosa zones (affected by main flow and with no eddy presence).

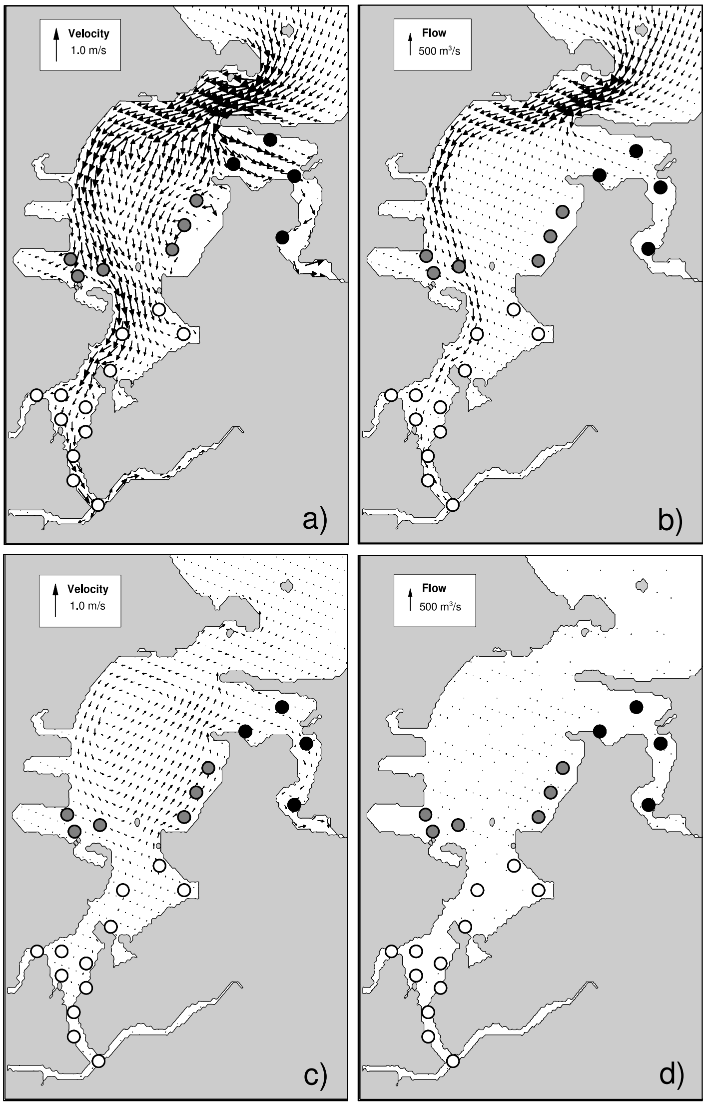

Figure 5. Graphic representation of tidal current velocity (m/s) (a,c) and water flow (m3/s) (b,d) values for medium flood tide (a,b) and high tide (c,d), coinciding with the highest flow and the most stable situation, respectively. Stations are coloured according to the main influence of water flow to Cubas tidal fresh (black), main channel flow (grey) or main flow + eddy (white) on their hydrodynamic features.

According to results of the correlation analysis (Table 2) the abundance of 20-25 mm clams was the smaller size class abundance significantly correlated with total abundance for both species (R=0,84 for *R. decussatus*, R=0,68 for *R. phillippinarum*, p<0,05*)*. In consequence, this size class was selected as the recruitment length of the fishing gear.

Table 2. Correlation coefficients of Spearman Rank analysis (R) between different size classes' abundance and total abundance for all stations (N=23) and both species. (* = p<0.05).

Size (mm)	*R*	
	R. decussatus	*R. phillippinarum*
10-15	-0.25	0.12
15-20	0.39	0.21
20-25	0.84 *	0.68 *
25-30	0.74 *	0.87 *
30-35	0.91 *	0.91 *
35-40	0.82 *	0.55 *
40-45	0.32	0.08
45-50	0.48 *	0.09

According to this concept, predominant recruitment of *R. decussatus* occurs in the northern area of the estuary corresponding to outsider station of Cubas (station 4), Pedreña and Port zones (5-10), with a low or null abundance of both species' recruiters in the inner stations of Cubas (1-3).

Besides, a predominant recruitment of *R. phillippinarum* occurs in Culture zone (11-14), Boo (15-18) and Pedrosa-Astillero (19-23), with a marked null presence of *R. decussatus* 20-25 mm individuals in Culture zone. Taking into account previously established hydrodynamic zones, the Kruskal-Wallis ANOVA by Ranks analysis showed significant differences in recruitment (abundance of 20-25 mm size clams) between these zones (H (2, N=23)=14.40, p=0.006) for *R. decussatus* and almost significant differences (H (2, N=23)=5.25, p=0.07) for *R. phillippinarum*. For *R. decussatus* Mann-Whitney U Test shows that abundance of 20-25 mm clams was significantly higher at stations influenced by secondary flow (Cubas zone) (U=7.5, Z=2.09, p=0.03) and by main flow with eddy (Pedreña + Port) (U=7.5, Z=2.76, p=0.005) when compared with stations influenced by main flow without eddy (Culture + Boo + Pedrosa-Astillero). For *R. phillippinarum* recruitment was higher at stations influenced by main flow (with and without eddy) when compared with stations influenced by Cubas flow (Figure 6).

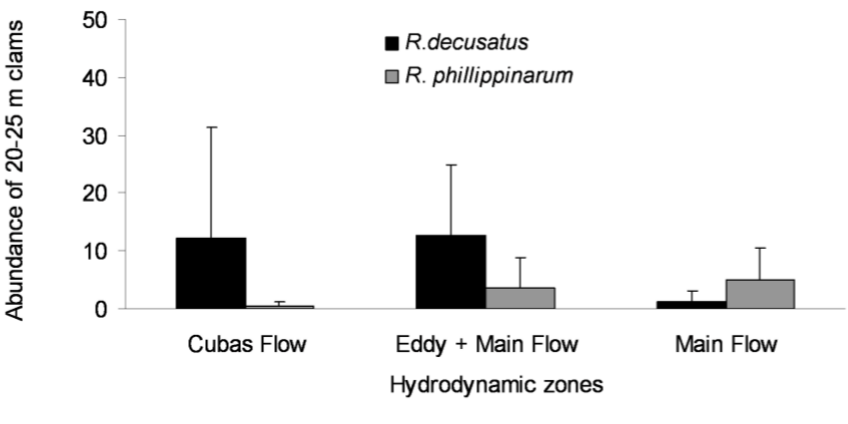

Figure 6. Abundance of 20-25 mm size (recruitment length of the fishing gear) individuals of Ruditapes decussatus and Ruditapes philippinarum at the defined hydrodynamic zones (Mean + SD): Cubas Flow zone (containing Cubas zone), Main Flow+ Eddy zone (containing Predreña

and Port zones) and Main Flow zone, without eddy (containing Culture, Boo and Pedrosa-Astillero zones).

4. Discussion

One of the possible reasons for the disappearance of native clam species in estuaries where Manila clam has been introduced (Aubby, 1993; Marin, 2003; Mistri, 2004) could be the lack of a management plan based on a scientific knowledge of the resource. In this context, in the Bay of Santander, a first characterization of the grooved carpet shell clam *Ruditapes decussatus* (native) and the Manila clam *Ruditapes phillippinarum* (nonindigenous) populations was advisable in order to base the management of these commercially exploited resources in scientific data and avoid its potential failure.

Clam abundance showed a significant deviation from randomness for both species, confirming the observations of previous authors on distribution patterns of clams, who found a high spatial variability regardless of the scale or the method of sampling used (Peterson, 1982; Thompson, 1995; Lee, 1996; Bald and Borja, 2001:2005). This fact is also consistent with the aggregated patterns showed by infaunal species (Golsling, 2003). Within this high spatial variability, a higher abundance of clams was observed in the central northern area of the estuary (i.e. Pedreña and Port) and in the mouth of Cubas tidal fresh. This pattern may be related to the tidal/fresh water influence and to the hydrodynamic conditions reflecting a classical estuarine gradient, as well as to the levels of pollutants which are higher in the inner southern parts of the estuary (Puente et al., 2002) and to the mean granulometry (Bald and Borja, 2000) which is higher in open zones (*unpublished data*). In order to reduce, as much as possible, this intra-zone variability, a delimitation of environmentally homogeneous areas should be done. For this purpose the determination of habitat suitability of *R. decussatus* and *R. phillippinarum* would be an useful tool as it is reported in many studies for bivalves (Soniat and Brody, 1988; Arnold *et al.*, 2000;

Peña *et al.*, 2005; Vincenzi *et al.*, 2006a; Vincenzi *et al.*, 2006b; Vincenzi *et al.*, 2007). This determination of habitat suitability for both species could be an advantage to improve a zone based management model.

This study has demonstrated that the abundance of the two species did not show any significant negative correlation, concluding that the interspecific competition for space or resource may not be present or is not intense. The same observation was detected by Peterson (1982), for the interaction between *Prothoaca staminea* and *Chione undatella* clams and by Lee (1996) for *Ruditapes phillippinarum* and *Anomalocardia squamosa*. Moreover, an interaction experimental study recently conducted in the Bay of Santander (Bidegain et al., *In preparation*) has confirmed this result.

The predomination of the native clam or the coexistence of both species in several areas of the Bay indicates that a drastic decline of *R. decussatus* is not observed, in contrast to occurred in other estuaries where Manila clam was introduced and where it clearly predominated over the native clams as *Ruditapes decussatus* or *Ruditapes aurea* (Aubby, 1993; Marin, 2003; Mistri, 2004; Caill-Milly *et al.*, 2006). This predomination or coexistence was variable depending on the region of the bay, showing a clear dominance of *R. decussatus* in the Cubas tidal fresh (northeast) and coexistence of both species in the rest of the estuary, except in the area around the culture parks where a clear predominance of *R. phillippinarum* exist. Thus, *R. decussatus* appeared to predominate in more freshwater-influenced areas of the bay pointing out that low salinity episodes due to floods may have a higher effect on the mortality of *R. phillippinarum*. It should be noted that inner part of Cubas with mean salinity values between 15 and 27.2% (Moreno-Ventas, 1998) suffered episodes where salinity values fell bellow 15% during the heavy rainy seasons, with ensuing mortality of Manila clam according to Kim et al. (2001) and Coughlan et al. (2009). These preliminary results could help in the first establishment of closed zones based on both species distribution patterns according to management options mainly directed to the sustainability of the native species fishery.

In relation to size structure, it was unbalanced for both species, showing very low percentages of large individuals >35 mm and a deficit of juveniles. The lack of adults from this size 35 mm may agree with the removal of individuals under the minimum legal size (40 mm). These illegal extractions have been also detected by the periodical inspections of the Fisheries Service (pers. comm). However, other factors as a low growth rate and natural mortality might also be affecting to this lack of large individuals. Besides, although a higher abundance of >35 mm individuals was observed, for both species, in the southern closed zones (i.e. Boo and Pedrosa-Astillero), the differences in abundance are not significant between open and closed zones. In these closed zones they were expected higher abundances of clams with sizes over the minimum legal size (40 mm) due to the reduction of the fishing effort. The high poaching activity detected by the Inspectors of the Fisheries Service (pers. comm) could be the reason of the non significant effect of the measure of closure of these zones. Moreover, the lack of juveniles or individuals <20 mm could be explained, in part, by the biased sampling towards adult sizes due to the fishing technique. Using a rake to flip the sediment and the eye detection joined to the custom of shellfishers to focus their fishery to large sizes may be the main reason of this bias. This fact eliminates the possibility of encounter newly (i.e. auttum 2004 or summer 2005) settled recruits resulting normally on bimodal size frequency distributions of clams (Sejr et al., 2002; Dang et al., 2010). The size class to estimate recruitment (i.e. recruitment length of the fishing gear) was 20-25 mm and it may contain recruiters of 2003 for *R.decussatus* and recruiters of auttum of 2003 and spring of 2004 for *R. phillippinarum*, according to the spawning season (Urrutia *et al.*, 1999; Ojea *et al.*, 2005) and growth (Spencer et al., 1991; Solidoro et al., 2000; Chessa et al., 2005) of these species.

In further studies, it will be necessary to discuss the need for design of newly settled clam sampling (<20mm, by sieving), without consuming much extra time and covering the whole distribution of sizes. In this manner, it would be obtained a better estimate of newly settlement specimens and of natural recruitment to understand the population dynamic and the distribution pattern in the estuary (Borsa and Millet, 1992; Olafsson *et al.*, 1994; Chícharo and Chícharo, 2001; Phillips, 2006; Humphreys *et al.*, 2007). On the other hand, it can be considered that the subestimation of stock is acceptable as the contribution to the total weight of the smaller sizes is low. However, the fact that sampling methodology is based on the shellfishers' resource extraction technique, can be an advantage over other sampling methodologies, to achieve a more realistic estimation of the commercial stock of these species, as the available stock will be potentially fished using this artisanal technique. This sampling method provides adequate data of abundance and density of adult (>20 mm) and commercial clams (>40 mm) and also of the exploitation situation of different zones in an extent estuary. However, the study of the early recruiter's abundance in each zone should be essential in further population assessments in order to estimate future stocks and adopt appropriate management measures.

The total stock was 58 t for *R. decussatus* and 90 t for *R. phillippinarum*. While the total abundance of both clams was similar, clam specific weights and differences in distribution patterns leads to observe a tendency of higher stock of Manila clam. This tendency could agree with the first clam specific captures data obtained by the Main Directorate of Fishing of the Government of Cantabria in 2007 (15 t of *R. decussatus* and 55 t of *R. phillippinarum*) (*unpublished data*). However, density and fresh weight coefficients of variation were generally high and this implies high values of the stock coefficients of variation for all zones, similar than those observed by Caill-Milly et al. (2006). Comparing the CVs, density contributes with the highest uncertainty, being in some cases higher than 1 (e.g. for *R. decussatus* in Cubas tidal fresh and Port; for *R. phillipinarum* in Cubas and Pedreña in zones). The higher values of the CVs for density observed in Cubas zone corresponds with the most heterogeneous area regarding to hydrodynamic, granulometry and salinity conditions, having stations located in inner or more estuarine areas and stations located in more oceanic areas.

Focusing on densities of both clams, it is remarkable that the mean densities of both species are low comparing to other estuaries of the Gulf of Biscay. In the estuaries of Plentzia and Mundaka Bald and Borja (2005) recorded higher densities of *R. decussatus*, probably related to the sampling method used which detects individuals larger than 1mm and to a lower fishing pressure, as there is no a shellfish professional activity. In Arcachon Bay Dang et al. (2010) observed higher densities of *R. phillippinarum*, which may be related to a most effective naturalization of this species comparing with the occurred in the Bay of Santander.

The relative low density of *R. decussatus* near the culture parks could be due to the effects produced by high densities of cultured Manila clam. High densities of cultivated bivalves are generally considered as “sinks” of oxygen and particulate organic matter (Richard et al., 2007a,b) and may cause a food shortage for the native species with high mortality rates of juvenile clams. The ingestion of bivalve larvae by filtering organisms such as *R. phillippinarum* is also known to be a significant mortality factor (Davenport et al., 2000; Lehane and Davenport, 2002). Jouffre (1989) also observed that the abundance of venerid larvae at the stations situated within intensive shellfish culture zones or at their nearest neighbours were significantly lower than the values reported at all other stations. However, the real spatial effect of this clam parks is unknown and also other settlement or post-setttlement factors could also drive this pattern. Thus, to conclude cause-effect it would require a study to compare areas of both similar larval supply and environmental characteristics with and without culture parks.

The highest pool of larvae coming from near high densities of reared adults, its higher growth rate compared to that of *Ruditapes decussatus* (Spencer et al., 1991) and its high filtration velocity (Zaklan and Ydenberg, 1997) could be some of the possible reasons to explain a better adaptation of *R. phillippinarum* in this zone and, hence, higher densities comparing to *R. decussatus*. With a shallower burial depth, *R. phillippinanrum* can filter food particles more quickly (Zaklan and Ydenberg 1997) and can invest less in the development of its siphon compared to a deeper clam with a longer siphon as *R. decussatus*. In this manner, the survival in a zone with a food shortage could be easier for this non native species.

In relation to the larval transport in estuaries, Roegner (2000) observed that it is highly correlated with the volume transport from coastal ocean during flood tide, considering that most of the larval pool is exported to the sea during ebb tide episodes. Therefore, the lowest recruitment of Manila clam and of carpet shell clam in the inner stations (1,2,3) of the Cubas tidal fresh may be also due to the reduced inflow during the medium flood tide, comparing to the main flow, and hence to the more limited arrival of larvae to these zone. Moreover, it should be noted that recruitment was estimated as the “recruitment to the fishing gear”. Therefore, post-settement mortality associated to low salinity episodes, depredation or disease may also be influencing on the distribution patterns of 20-25 mm individuals. However, in this study, in order to link the hydrodynamic regimes and larval transport with this size class, it was assumed that the effect of these factors on mortality of clams on the first 1-2 years could be of the same order of magnitude in all zones. This assumption was done taking into account that the differences in mortality between zones may be highly masked by the high variability in clam abundance within each fishing zone. However, this is a first approach for studying the effects of hydrodynamics on recruitment in the Bay of Santander and therefore, in order to reduce the uncertainty introduced by the assumption, it is essential to investigate larvae dispersal patterns, coupling a dispersion submodel to the hydrodynamic model and validating it by measuring newly recruited individuals (Ishii et al., 2001; Strasser and Günther, 2001; Siegel et al., 2003; Hinata et al., 2006).

The higher densities of Manila clam in Pedreña do not coincide with significant higher recruitment values in this zone. In fact, the recruitment of Manila clam is poor for the entire bay as it occurs in other estuaries as Arcachon Bay in France (Caill-Milly et al, 2006). Then, the higher density of Manila clam in Pedreña zone comparing to the inner zones could be explained by a compensation of the low recruitment by a faster growth and lower mortality (Dang et al., 2010). In this area, with more oceanic conditions, the role of the water circulation cell (eddy), helping the recirculation of larvae and the settlement-recruitment process, observed by Borsa and Millet (1992), was not detected for any species.

In the southern zone influenced by the main flow, the significant lowest success on recruitment of *R. decussatus* could be related to the limited arrival of larvae to this zones considering that the main spawning zone of this species (i.e. higher abundances of adult clams) are in the northern flats of the estuary.

5. Conclusions

The coexistence patterns of both clams in the Bay points out that the introduced nonindigenous Manila Clam has not yet supplanted the *R. decussatus* native clam by occupying entirely its ecological niche and relegating it to occupy very restricted areas as it has occurred in other estuaries or lagoons of Europe. *R. decussatus* appeared to be the dominating species in more oceanic and freshwater-influenced areas. In this line, the performed fishing activity on individuals under the minimum legal size could lead to a decline of both populations but especially of the native clam, affecting considerably the actual coexistence pattern. Establishing specific measures for each species appears to be essential to maintain this coexistence pattern stable. Although the total low density of both species is similar, the estimated higher total stock and captures of *R. phillippinarum* indicates the increasing importance of the introduced species in the shellfishery, in contrast to past two decades when the native clam was the main harvested species. The sampling method provides adequate data of abundance and density of adult (> 20mm) and commercial clams (> 40 mm) and has shown its feasibility to estimate standing stocks and to know exploitation situation of different zones in an extent estuary.

The coastal circulation model used in this work to study the relationship between the hydrodynamic patterns and recruitment (i.e. recruitment to the fishing gear) provides a first attempt to introduce this tool on these species fishery management models, although an estimate of newly settlement specimens should be essential in the future to better understand the population dynamic and the distribution pattern in the estuary.

To conclude, some nonspecific and specific clam management proposals are drawn out on the light of the obtained results and mainly focused on the conservation of the native species:

(i) A strict control on the minimum legal capture size should be established to avoid the actual situation of non respect of the minimum size of capture and to achieve increments in total stock. This control may be even more important for *R. decussatus* as it has a slower growth rate than *R. phillippinarum* and has not the extra larval supply of Manila clam coming from the intensive cultured zones.

(ii) The current closure zones are non specific since they were established regardless the relative abundance between species. Therefore, it is important to direct policy efforts towards establishing specific closure zones in areas where the native clam population densities and recruitment are high like a conservation measure. Outside of Cubas tidal fresh and Pedreña are potentially the most important spawning and settlement areas for this species.

(iii) In the same way, they should be considered a higher control of sowings and sustainable densities of cultivated bivalves and/or a dispersion of cultivation zones locations to reduce the potential effects of high densities on surrounding natural populations of the native clams.

These management proposals require a high government involvement in enforcement and they must go hand in hand with the shellfishers' collaboration. Therefore, the incorporation of shellfishers in a co-management of the shellfishery should be an essential step to be taken by means of using territorial user rights for fishing, where responsibility for the exploitation of clams could be shared between fishers' guilds ("cofradías"), fishers' organisations supervised by the regional government) and fishery authorities, as it has been done in the neighbour region of Galicia (N Spain). Thus, shellfishers would collaborate with the government fishery inspection service to avoid intrusions of illegal fishers. Furthermore, they could have external technical support to design and implement exploitation plans in their fishing grounds. Overall, co-management is supposed to increase rationality in management and create more legitimate regulations, thereby motivating user groups to follow regulations.

These proposals together with the future co-management should be integrated into an "adaptive management" process relying on systematic feedback learning and a progressive accumulation of knowledge for improved fisheries management. Thus, this process should be participatory involving both fishermen and competent authorities.

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