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Clam farmers and Oystercatchers: Effects of the degradation of *Lanice conchilega* beds by shellfish farming on the spatial distribution of shorebirds

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ABSTRACT

The Manila clam *Ruditapes philippinarum* cultivation is an original shellfish farming activity strongly mechanized. In the Chausey archipelago (France) this activity settles on the *Lanice conchilega* beds, habitat known to host a rich and diversified benthic macrofauna and which is an attractive feeding ground for birds. A first study highlighted that this activity had strong negative effects on the *L. conchilega* beds and their associated benthic macrofauna. Here we assess the impacts of such an activity on the Eurasian Oystercatcher *Haematopus ostralegus* for which Chausey is one of the most important national breeding sites and which is also a common species in winter, spring and autumn migrations. We found that Oystercatchers significantly selected the *L. conchilega* beds to feed and that their spatial distribution was significantly modified after the creation of new clam concessions. In a context of a growing disappearance of pristine coastal ecosystems for the benefit of anthropo-ecosystems, we discuss the problem of the degradation of such benthic habitats with a low resilience which may loose their high functional value.

1. Introduction

Mainly in response to the overexploitation of natural stocks of living marine resources, aquaculture activities are a growing and diversified industry which settles all over the world on the coastal zones (FAO, 1997). Assessing the impacts of such activities is all the more important on the littoral because it is a sensitive and a narrow space where human activities quickly develop. Several authors have shown that aquaculture may have negative ecological (Kaiser et al., 1998) but also socio-economic impacts (Naylor et al., 2000) ranging from minor (Crawford et al., 2003; Danovaro et al., 2004) to important (Newell, 2004). The studies about the ecological impacts of aquaculture mainly concern the effects of: (1) fish farming (e.g., Chang and Thonney, 1993; Krost et al., 1994; Crawford et al., 2001; Wildish et al., 2001; Brooks et al., 2003), (2) mussel farming (e.g., Kaspar et al., 1985; Baudinet et al., 1990; McKindsey et al., 2006; Richard et al., 2007) and (3) oyster farming (e.g., Nughes et al., 1996; Forest and Creese, 2005). The studies mainly focus on the consequences of the biodeposits of cultivated bivalves and on the organic matter enrichment they induce (e.g., Tenore et al., 1982; Mattsson and Linden, 1983; Kaspar et al., 1985; Grant et al., 1995; Chamberlain et al., 2001; Callier et al., 2006). Moreover, the studies dealing with the impacts on fauna concern essentially the macrobenthic compartment (Pearson and Rosenberg, 1978; Tenore et al., 1982; Mattsson and Linden, 1983; Kaspar et al., 1985; Jaramillo et al., 1992; Grant et al., 1995; Simenstad and Fresh, 1995; Nughes et al., 1996).

The potential effects of aquaculture on birds are less studied and the few existing studies are recent. They concern fish farming (Kelly et al., 1996; Buschmann et al., 2006), mussel culture (Caldow et al., 2003; Roycroft et al., 2004) and oyster culture (Hilgerloh et al., 1999, 2001). The effects can be positive, by increasing the abundances of some bird species (Hilgerloh et al., 2001; Caldow et al., 2003; Roycroft et al., 2004; Buschmann et al., 2006) but may be also negative for others species (Kelly et al., 1996). However, with regards to the wide variety of aquaculture practices but also to the diversity of the impacted environment features and of the species concerned, it is difficult to draw general conclusions and case-by-case studies are therefore still required.

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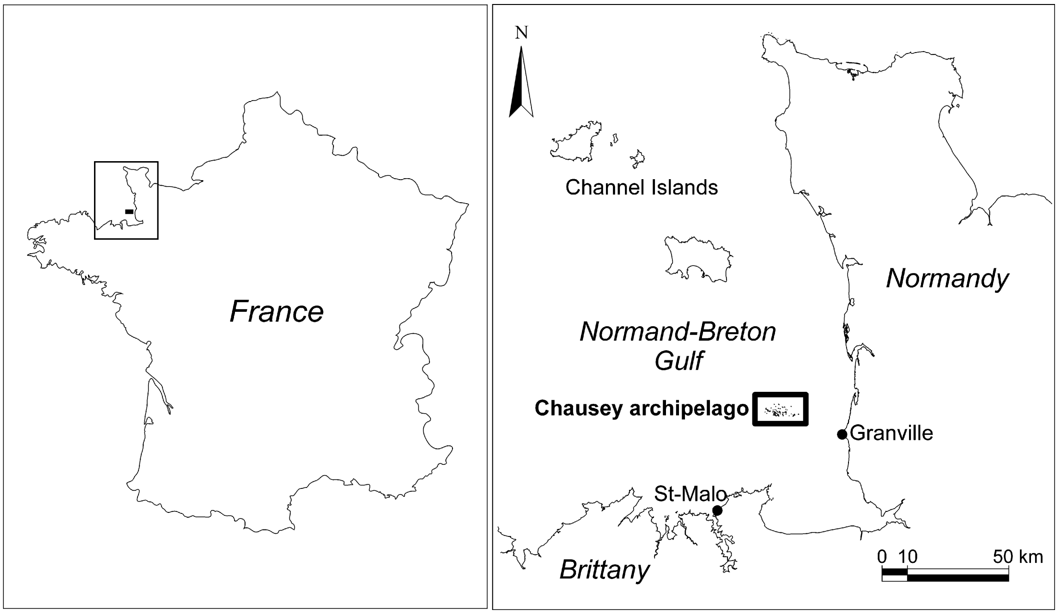

Fig. 1. Study site.

Here, we focus on the impacts of the Manila clam *Ruditapes philippinarum* (Adams and Reeves, 1850) cultivation on an original benthic habitat: the *Lanice conchilega* (Pallas, 1766) beds. Few studies focused on the impacts of human activities on this habitat (but see Rabaut et al. (2008)). However, this habitat is known to be rich, diversified (Zühlke et al., 1998; Zühlke, 2001; Callaway, 2006; Rabaut et al., 2007; Godet et al., 2008) and is an attractive feeding ground for fishes (Braber and De Groot, 1973; Amara et al., 2001; Rijnsdorp and Vingerhoed, 2001) but also for waders and gulls (Goss-Custard and Jones, 1976; Yates et al., 1993; Petersen and Exo, 1999; Godet et al., 2008).

In 2005, we studied the impacts of the Manila clam cultivation on the Chausey's *L. conchilega* beds focusing on the macrobenthic compartment (Toupoint et al., 2008). This study mainly revealed that clam cultivation induced a decrease of both the *L. conchilega* densities and of the abundance and the diversity of the associated macrofauna.

In this paper, we aimed at assessing the impacts of the degradation of Chausey's *L. conchilega* beds by this activity on the spatial distribution of a secondary consumer: the Eurasian Oystercatcher *Haematopus ostralegus* Linnaeus, 1758, for which the Chausey archipelago is one of the most important French breeding sites (Debout et al., 2004). More specifically, we tested if: (1) the Oystercatchers select the *L. conchilega* beds rather than clam concessions or other available habitats when feeding, and (2) the Oystercatchers change their spatial distribution after the regression of the *L. conchilega* beds following the creation of new clam concessions (what we consider as a 'perturbation factor').

2. Materials and methods

2.1. Study site

The Chausey islands are located in the Normand-Breton Gulf (France), which is subject to an extreme megatidal regime (tidal range up to 15.5 m during spring tides) (Fig. 1). This archipelago roughly covers 4500 ha with 1400 ha of sandflats emerged during extreme low water spring tides and 830 ha during mean low water spring tides. The complexity of this archipelago of more than 100 islets, combined with the extreme megatidal regime of the Gulf, provides highly fragmented intertidal benthic landscapes. Among the high numbers of benthic intertidal habitats of the site (Godet, 2008), the *L. conchilega* beds cover 100–120 ha with densities exceeding mostly 400 ind m^{-2}. Within the archipelago, a 130 ha study area was selected because it included Chausey largest *L. conchilega* bed (38 ha), 2/3 of the clam concessions and large sand banks.

2.2. Manila clam cultivation in the study site

The Manila clam has been cultivated in the Chausey archipelago (Normandy, France) since the 1980s, and this activity takes place on the *L. conchilega* beds of the site. The clam production cycle is performed in three years. After spat seeding using a sowing machine, juveniles are immediately covered with plastic nets (5 mm mesh size) to avoid crab and bird predations. Nets are removed just before winter (approximately six months after seeding) when clams have reached a length of 10 mm. In the second year, farmers let the bivalves grow naturally without any interference. The harvesting phase starts during the third year, in spring, and clams are collected by a tractor–towed sifter which samples the first 10 cm of the substratum. Nowadays, clam concessions cover 40 ha of the Chausey sandflats. In August 2006, 16 ha of new clam concessions were created, and we used this as a potential 'perturbation factor'.

2.3. Monitoring the impacts of Manila clam cultivation on *L. conchilega* beds

Toupoint et al. (2008) have already demonstrated that clam culture significantly decrease *L. conchilega* densities. The aim of the present study was to monitor the spatial extent of the concessions in a view to detect any potential regression/progression of *L. conchilega* beds because it can potentially affect the spatial distribution of Oystercatchers.

Initial maps of *L. conchilega* beds in the study area have been created using photo-interpretation of 1982, 1992 and 2002 aerial photograph mosaics. The 2002 photographs, completed by field

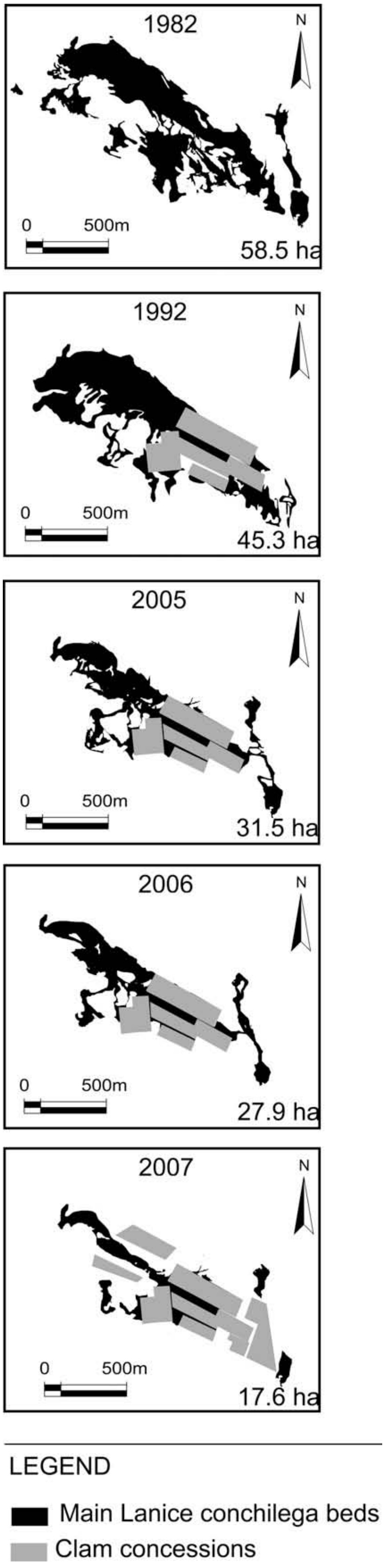

Fig. 2. Spatial evolutions of the *Lanice conchilega* beds of the study area between 1982 and 2007.

observations acquired in April 2005, were used to map the 2005 *L. conchilega* beds. Two additional field surveys conducted in April 2006 and April 2007 were necessary to update this last map by collecting waypoints along the boundaries of the beds using global positioning system (GPS).

2.4. Assessing the impacts of Manila clam cultivation on the spatial distribution of Oystercatchers

Oystercatchers were counted during 11 spring ebb tides from mid-tide to low tide covering the wintering, the migration and the breeding period: two counts in winter 2006 (01/02; 02/02), three in spring 2006 (26/04; 27/04; 28/04), four in summer and in autumn 2006 (25/05; 26/05; 07/10; 08/10) and two in winter 2007 (19/02; 20/02). In order to assess the variations in bird abundances and their spatial distribution along each ebb tide, birds were counted every 20 minutes (9–11 counts per day; total number of counts over the study = 105). In order to assess the bird bathymetric distribution in relation to the decreasing ebb tide, four bathymetric belts were delimited on the seabed using plastic sticks. For each 20 minutes count, we noticed both bathymetric belt and habitat where birds were located (i.e., *L. conchilega* bed, clam concessions or sand banks). We distinguished feeding and non-feeding birds (considered as ‘at rest’). In our data analyses, we defined an ‘attractive bathymetric belt’ which corresponds to the last emerged bathymetric belt. Actually, most of the wader species follow the tide line and always use the just emerged tidal zones.

In the bird data analyses, we have considered two factors: the habitats (*L. conchilega* beds, sand banks or clam concessions) and the perturbation (the state before and the state after new clam concession creation). A theoretical bird density was calculated for each habitat, at each count, assuming that the bird distribution was homogeneous over the attractive belt. In consequence, the theoretical bird number per habitat was equal to the total bird number on the attractive belt divided by the specific habitat surface. For example, if 100 birds were counted on the attractive belt during one observation and if the habitat surfaces on the attractive belt were estimated to 10 ha of *L. conchilega* beds, 20 ha of clam concessions and 70 ha of sand banks, the theoretical bird numbers were therefore: 10 birds on *L. conchilega* beds, 20 birds on clam concessions and 70 birds on sand banks. When birds were overlapping two virtual bathymetric belts, we calculated mean surface areas of the habitats of the two corresponding belts. All the surface areas were calculated with the Geographic Information System (GIS) Software Arcview 3.1 (ESRI).

At each 20 minutes count, and for each habitat, we finally calculated a ‘feeding representation rate’ (‘*y*’) as follow: (observed feeding birds − theoretical feeding birds)/theoretical feeding birds. ‘*y*’ is positive when birds are more present on a habitat than expected, and conversely. *Y*-values were compared by a mixed model analysis of variance (ANOVA) with day count considered as a random factor and habitat and perturbation as fixed factors. When the theoretical number and the observed number of feeding birds were equal to 0, the data were not included in our analyses.

3. Results

3.1. An overall regression of the L. conchilega beds

There was an overall decline of the surfaces colonized by *L. conchilega* between 1982 and 2007 (−69.9%, Fig. 2). Two regressions were particularly important, the first from 1982 to 1992 (−22.5%) and the second, mainly localized within the newly settled clam concessions, between 2006 and 2007 (−36.9%). However, other minor spatial variations also occurred aside from the concessions, especially in the western part of the area.

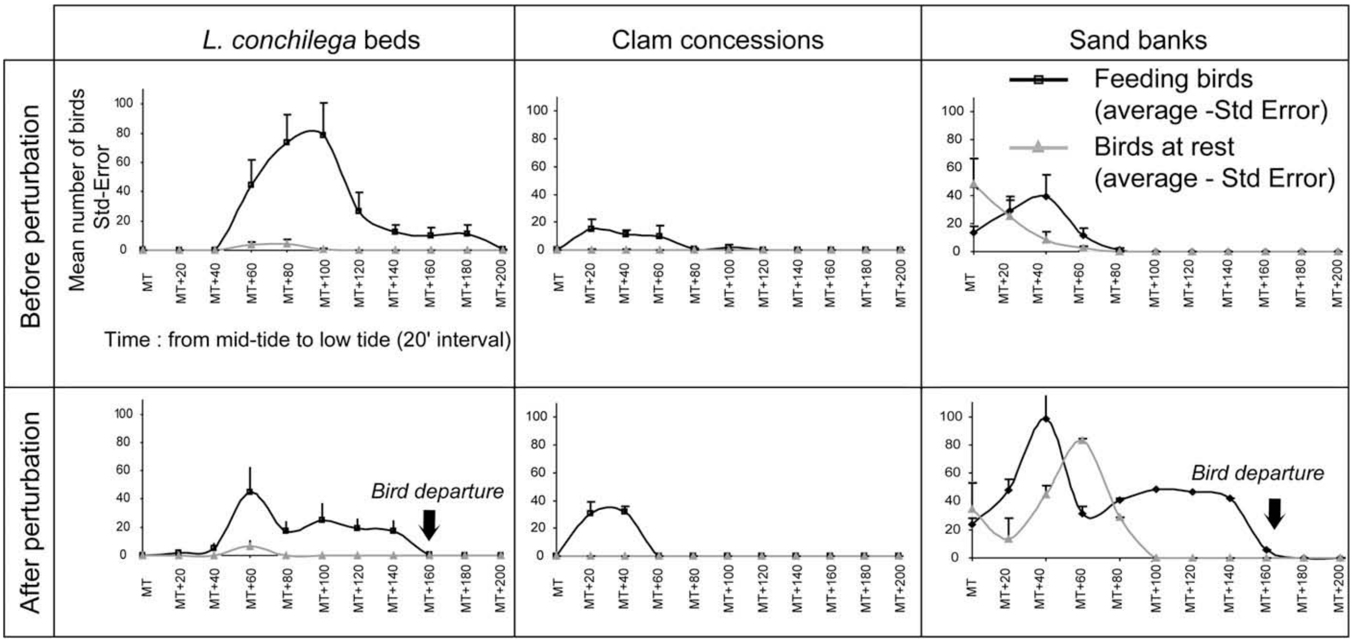

Fig. 3. Number of feeding birds and birds at rest on each habitat between mid-tide and low tide (average – standard error).

3.2. *Impact of clam cultivation on Oystercatchers: birds selected L. conchilega beds before the perturbation, and switched to sand banks after*

Before the perturbation, birds were firstly at rest on sand banks at mid-tide, then they fed on sand banks and on clam concessions. At this stage, a large and increasing number of new birds joined the initial group 1 h after mid-tide and all birds fed massively on the *L. conchilega* bed (Fig. 3). From 100 minutes after mid-tide to the low tide, the bird abundance decreased slowly but all the remaining birds fed on the *L. conchilega* beds. After the perturbation (settling of the new clam concessions), the feeding activity and the spatial distribution of the birds were drastically different. After a roosting phase on sand banks, they fed both on sand banks and on clam concessions, but, contrary to the previous observations, no bird arrival was observed later than 1 h after mid-tide and more birds fed on sand banks rather than on *L. conchilega* beds. Finally, all the birds left the area from 160 minutes after the mid-tide.

Birds significantly selected different habitats for feeding ('*y*' data; $F = 35.5$, $p = 0.0001$) but they switched after the perturbation ($F = 25.6$, $p = 0.0001$) (Table 1) from an over- to and under-representation on the *L. conchilega* beds (mixed model analysis of variance $p < 0.0001$; Fig. 4). They were also under-represented on the sand banks before the perturbation, but over-represented on them after (mixed model analysis of variance $p < 0.0001$; Fig. 4). Finally, they were under-represented on the clam concessions both before and after the perturbation but they were more represented on them after the perturbation (mixed model analysis of variance $p = 0.0004$; Fig. 4).

4. Discussion

4.1. *L. conchilega beds are attractive feeding grounds*…

Before the creation of the new clam concessions, *L. conchilega* beds were significantly selected by Oystercatchers as a major feeding ground. By comparing our data with the Wetland International winter counts on this site (unpublished data from the Groupe Ornithologique Normand), we found that approximately 2/3 of the wintering Oystercatchers of Chausey fed on our study area, and, as we saw, with a majority feeding on *L. conchilega* beds.

The attractiveness of the *L. conchilega* beds is certainly due to the high abundance of macrobenthic invertebrates associated to these beds. Among the seven main soft-sediments intertidal habitats we previously studied (Godet et al., 2008), *L. conchilega* beds, as well as *Zostera marina* beds, hosted the richest and the most diversified benthic macrofauna. Moreover, we highlighted (Godet et al., 2008) the important abundances of large bivalves especially

Table 1
Feeding representation rates (*y*) compared by mixed model analysis of variance (ANOVA) with day count being a random factor and habitat and perturbation considered as fixed factors.

Factors	Df	*F*	*p*
Habitat (1)	217	35.46	<0.0001
Perturbation (2)	9	0.02	0.9026
(1) × (2)	217	25.64	<0.0001

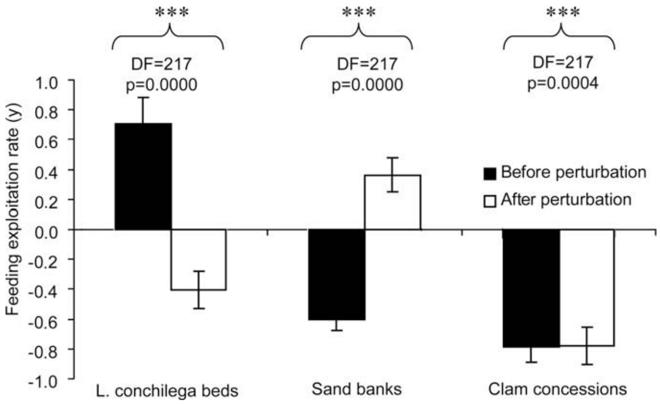

Fig. 4. Feeding representation rate (*y*) per habitat before and after perturbation. Feeding representation rates were compared by mixed model analysis of variance (ANOVA) with day count being a random factor and habitat and perturbation considered as fixed factors (∗∗∗: $p < 0.05$).

the Cockle (*Cerastoderma edule*) (mean number of 10 ind m^{-2} and up to 23 ind m^{-2}), known to be an important prey for the Oystercatcher (Cramp and Simmons, 1983). There are also probably other parameters explaining the attractiveness of the *L. conchilega* beds which have to be explored, such as the presence of mounds and shallow depressions generated by the aggregations of the worm (Carey, 1987) that retain water which should be attractive for feeding birds. The attractiveness of *L. conchilega* beds and of the species *L. conchilega* itself for waders but also for gulls have been already shown by a number of authors (Goss-Custard and Jones, 1976; Yates et al., 1993; Petersen and Exo, 1999; Godet et al., 2008) but not the decline of this attractiveness after a strong perturbation.

4.2. … but without resilience of their functional value, and with a limited accessibility

The previous study of Toupoint et al. (2008) revealed that the decrease of *L. conchilega* densities was coupled with a decrease of the abundance, species richness and species diversity of the associated macrofauna. These results agree with those of Zühlke (2001) who emphasized that the positive effects of this engineer species were ephemeral and disappeared instantaneously with the disappearance of the worm aggregations. The present study revealed that the positive effects of the *L. conchilega* beds for birds are also ephemeral: the regression or the disappearance of *L. conchilega* beds involved directly a loss of attractiveness for the feeding Oystercatchers.

In intertidal areas, the attractiveness of benthic habitats for birds has not to be assessed by their total surface but by the mean emerged surface at one particular time. For example, *Z. marina* beds can be very attractive for feeding birds as Brent Geese (*Branta bernicla*) but they are only attractive when emerged, therefore only accessible for birds during spring tides. By contrast, *Zostera noltii* beds, located at much higher bathymetric levels, would be more exploited by birds. In the present study, we have only conducted our field surveys during spring tides. The *L. conchilega* habitat is located below the mean low water neap level up to subtidal areas and it is thus not emerged during neap tide and so not accessible for birds. Over one year, less than 15% of the 100 ha of *L. conchilega* beds of the archipelago are emerged (Godet, 2008), but this habitat with such a short-term accessibility may have a strong functional value for populations of birds. Further analyses have to be conducted in order to determine the trophic role of such bioherms for bird populations.

4.3. Long-term environmental changes of L. conchilega within natural bed and short-term 'irreversible' changes within shellfish concessions

The variation in the extent of *L. conchilega* beds may be explained both by the setting of new concessions, which altered the initial *L. conchilega* beds, but also by other environmental natural factors. Such factors have been studied by several authors but low-temperature during severe winters is known to have strong negative effects on the *L. conchilega* beds (Buhr and Winter, 1976; Strasser and Pieloth, 2001; Zühlke, 2001). Although, rather low-temperatures during the 2005–2006 winter may explain the natural regression of the beds, we do not have enough observations to detect short-term variations, especially seasonal or year-to-year variations along several decades. We know that these habitats are very dynamic, but surprisingly the most abundant areas remained stable during the last two decades and historical reports revealed that such beds have been present in the Chausey archipelago since 1828 (Audouin and Milne-Edwards, 1828) and the beginning of the 20th century (De Beauchamp, 1923) (Godet, 2008). On the contrary, Manila clam cultivation has strong short-term mechanical effects based on a three years cycle (Toupoint et al., 2008).

4.4. The introduced clams do not replace the original food resource

Before conducting this study, we hypothesized that Manila clam farming should modify the spatial distribution of Oystercatchers by degrading the *L. conchilega* beds. However, we also hypothesized that the introduction of clams should represent a new food resource for the Oystercatchers. Caldow et al. (2007) have recently showed that introduced Manila clam populations can be a new food resource for Oystercatchers and can even reduce their overwinter mortality. Quite surprisingly, we found that Oystercatchers did not select the clam concessions for feeding. Different hypothesis may explain this lack of attractiveness of the clam concessions for the Oystercatchers.

Oystercatchers are bivalve-eaters and are known to prefer cockles (*C. edule*), mussels (*Mytilus edulis*) and baltic tellin (*Macoma balthica*) (Cramp and Simmons, 1983). In Chausey, natural mussel beds and baltic tellin are scarce but cockles are common and are mainly found both in *L. conchilega* beds and in coarse to medium muddy sands of the western part of the site (Godet et al., 2008). Consequently, Oystercatchers have another abundant available food resource in the remaining *L. conchilega* beds of the site and in the western part of the site. Furthermore, Oystercatchers are known to select one sole type of prey on one site (Feare, 1971; Dare and Mercer, 1973; O'Connor and Brown, 1977) and also to adopt one type of feeding technique (Cramp and Simmons, 1983; Goss-Custard, 1996). The switch to another prey may occur but it is rare and it often results from a crash of the preferred prey (Hulscher, 1964; Dare and Mercer, 1973). If the Oystercatchers of Chausey still have abundant available preys like cockles, they do not need to turn to other prey like Manila clam, even if these ones are abundant. Our results are in good accordance with the results of other studies about the 'aggregative responses' (Hassell, 1966) of predatory birds to their prey. For example, Caldow et al. (2003) only found a weak aggregative response of the Oystercatchers when they laid high densities of mussels on experimental plot. The authors explained this result both by the availability of alternative feeding grounds and maybe the size of the mussels used to seed the plot.

Moreover, potential predation of the Oystercatchers on Manila clam depends on the clam sizes and the presence/absence of nets. Plastic nets, placed from April to September/October just after seeding (first year of the production cycle) protect the concessions from any bird predation: birds can neither feed on the clams nor on other benthic species. Moreover, Oystercatchers tend to select bivalves over 10–15 mm: Manila clam from 16 to 50 mm (Caldow et al., 2007); mussels over 10 mm (Drinnan, 1958) and mainly over 40 mm (Cayford and Goss-Custard, 1990; Goss-Custard et al., 1993); cockles over 10–15 mm (Drinnan, 1957; Hulscher, 1964; Goss-Custard et al., 1977) or baltic tellin over 10–15 mm (Hulscher, 1964; Goss-Custard et al., 1977). In Chausey, plastic nets are removed when the clam have reached a length of 10 mm.

Consequently, during the first year of the production cycle, clam concessions are not attractive for Oystercatchers because: (1) during six months nets prevent from any predation, (2) during the following months, clam are hardly large enough to be profitable for the birds, and (3) the associated benthic macrofauna is less abundant in one-year concessions. Actually, clam concessions are potentially the most attractive during the second year of the production cycle until the beginning of the third year, before harvesting. The extent of the concessions of year one, two or three varied. 2006 can be considered as the 'worst-case scenario' with 47% of the total surface area of the clam concession just seeded. This can explain the lack of attractiveness of the concessions during our study. Nevertheless, we did not find any differences between the different concessions of one, two or three years for the attractiveness of the birds.

5. Conclusion

We can consider that *L. conchilega* beds are an attractive habitat for the Oystercatchers of the Chausey archipelago. The alteration of this habitat via clam cultivation induces a significant loss of attractiveness for the feeding Oystercatchers. The issue is even more serious when one considers that if there are natural variations in *L. conchilega* beds over the years, the destruction of these beds via clam cultivation, which is a growing activity, seems to be irreversible, except if the concessions are removed or practices are modified.

Natural variations of benthic habitats may drastically affect the birds. Nevertheless, the rapid growing of the shellfish farming activities along the world's coasts may have irreversible and increasing negative impacts on secondary consumers which have only just begun to be explored by the scientific community.

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