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Influence of intertidal recreational fisheries and 'bouchot' mussel culture on bivalve recruitment

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ABSTRACT

In coastal environments, fishing and aquaculture may be important sources of disturbance to ecosystem functioning, the quantification of which must be assessed to make them more sustainable. In the Chausey Archipelago, France, recreational fishing and commercial shellfish farming are the only two evident anthropogenic activities, dominated by bivalve hand-raking and 'bouchot' mussel culture, respectively. This study evaluates the impact of both activities on bivalve recruitment dynamics by comparing primary recruitment intensity (short-term effect) and recruitment efficiency (medium-term effect) by sampling bivalves in reference (undisturbed) and disturbed (i.e. subjected to hand-raking or in 'bouchot' mussel culture areas) parcels throughout and at the end of the recruitment season, respectively. Specific hypotheses evaluated were that (*H1*) bivalve hand-raking negatively affects bivalve recruitment and that (*H2*) 'bouchot' mussel culture promotes bivalve recruitment.

Patterns in bivalve community structure in reference parcels (i.e. natural pattern) differed between initial and final recruitment, underlining the great importance of early post-settlement processes, particularly secondary dispersal. Primary recruitment intensity was inhibited in hand-raking parcels whereas it was promoted in 'bouchot' mussel culture parcels, but the effect on recruitment efficiency was muted for both activities due to post-settlement processes. Nevertheless, the importance of effects that occur during the first step of recruitment should not be ignored as they may affect bivalve communities and induce immediate consequences on the trophic web through a cascade effect. Finally, it is highlighted that hand-raking damages all life stages of the common cockle *Cerastoderma edule*, one of the major target species, suggesting that this activity should be managed with greater caution than is currently done.

1. Introduction

Coastal systems provide a variety of ecosystem services, each of which has some intrinsic value. However, the degree to which each service is valued is a moving target that follows fickle societal values and the idea of limit of acceptable change is clearly a function of the social carrying capacity of an area (McKindsey et al., 2011). Growing anthropogenic pressures are of major concern for managers since all human activities (recreational and commercial) may lead to ecological disturbance, which may be defined as "any discrete event in time that disrupts ecosystem, community or population structure and changes resources, substrate availability or the physical environment" (Pickett and White, 1985). Fishing and aquaculture represent important anthropogenic disturbances in many coastal environments. Given that both activities rely on healthy ecosystems, understanding how they influence marine ecosystem functioning is not only of general importance to coastal management, but also to their sustainability (Newell, 2004; Holmer et al., 2008; Dumbauld et al., 2009; Smith et al., 2011).

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Over the past few decades, littoral areas have become increasingly used for leisure activities, such as shellfish harvesting, the recent intensification of which has raised questions about its impact (Le Berre and Brigand, 2011). This activity mostly concerns harvesting infaunal bivalves, which is most often done using a garden rake. While the use of mobile bottom fishing gear can have large-scale and long-term impacts on the ecology of benthic systems (Jennings and Kaiser, 1998; Moritz et al., 2015), the negative effects of manual tools, such as hand-raking, are mostly short-lived on benthic macrofauna (Kaiser et al., 2001; MacKenzie and Pikanowski, 2004; McLaughlin et al., 2007), meiofauna (Sherman and Coull, 1980; Mistri et al., 2004), and sediment biogeochemical parameters (Falcão et al., 2003; Fiordelmondo et al., 2003). In addition, impacts due to this activity are considered to be minor as it only affects the surface layer of bottom sediments (Leitao and Gaspar, 2007), with harvesting typically causing less impacts than may storms (Carvalho et al., 2011). Recovery is often rapid, particularly in coarse sediment areas (Collie et al., 2000), with macrofauna recolonizing sediments fairly quickly (Munari et al., 2006) due to the redistribution of adults and juveniles (Hall, 1994). Nevertheless, caution is needed as community responses may vary among sites and dominant species, and with sources of disturbances (Whomersley et al., 2010), their frequency (Jennings and Kaiser, 1998; Séguin et al., 2013) and spatial extent (Kaiser et al., 2001). For example, the effect of cockle hand-raking on benthic habitat was demonstrated to last for a year, with the greatest effect being damage of under-sized cockles (Kaiser et al., 2001).

Extensive mussel farming may affect coastal ecosystems by modifying hydrosedimentary conditions, organic content, sediment biochemistry, biogeochemical fluxes, and infaunal and epifaunal communities (see review of McKindsey et al., 2011). Biodeposition from farmed bivalves may lead to organic enrichment (Cranford et al., 2009), although related impacts are not always observed (Crawford et al., 2003) as effects are to some degree dependent on local hydrosedimentary dynamics (Hartstein and Rowden, 2004). Bivalve farming effects also depend on the type of physical structures used for bivalve grow-out. 'Bouchot' mussel culture was developed in and is restricted to France and has been shown to have specific hydrodynamic effects at various spatial scales, ultimately impacting sedimentation as the grow-out structures (wooden stakes driven into the seafloor in intertidal areas – 'bouchots') reduce current flow, increase turbulence, and dampen wave height (Sornin, 1981). To date, only Grant et al. (2012) have examined the effects of long-established 'bouchot' culture in a highly dynamic intertidal system on endobenthic communities. At a meso-scale (km), finer sediments and more heterogeneous infaunal communities were present in mussel farms. At a small-scale (m), abundances of the dominant bivalve species were greater at the foot of 'bouchots'. As may be predicted for strong hydrodynamic regimes, 'bouchot' culture did not appear to impact sediment organic matter, although some evidence of organic loading was observed over short time scales.

The present study evaluates how anthropogenic activities influence bivalve recruitment (population renewal) – a key benthic community ecosystem function (Menge and Sutherland, 1987) that promotes demographic resilience in marine systems (Winemiller, 2005). The work was done in the Chausey Archipelago (Normandy, France), an highly dynamic system, 17 km from the closest coast. Intertidal soft-sediments are mainly composed of coarse sands characterized by low levels of organic matter – a relatively understudied habitat relative to muddy sandflats. Only two anthropogenic activities are evident in Chausey tidal flats: recreational fishing and commercial shellfish farming, dominated by bivalve hand-raking and 'bouchot' mussel culture, respectively. The present study assessed the influence of both anthropogenic activities on bivalve recruitment by performing two types of observational experiments. The first experiment was done throughout the recruitment season to evaluate the impact of both activities on recruitment intensity (short-term effect). The second was restricted to sampling at the end of the recruitment season to assess recruitment efficiency (medium-term effect). Since both activities affect the bottom surface, which is of primary importance for newly settled post-larvae, we hypothesized that (*H1*) bivalve hand-raking negatively affects bivalve recruitment and that (*H2*) 'bouchot' mussel culture promotes bivalve recruitment.

2. Material and methods

2.1. Study site

This study was done in the Chausey Archipelago, in the 'Normand-Breton' Gulf (English Channel, France; Fig. 1). This 4 500 ha archipelago is subject to an extreme tidal range (up to 14 m during spring tides) and is characterized by extensive, but very fragmented, intertidal areas, with 1 410 and 829 ha of sandflats exposed during extreme and mean low water spring tides, respectively (Godet et al., 2009). Commercial and recreational fishing, as well as shellfish farming (Fig. 1) – including mussels, oysters and Manila clams – are done in the archipelago.

The influence of the two anthropogenic activities (bivalve hand-raking and mussel 'bouchots' culture) on bivalve recruitment was assessed by monitoring bivalve recruitment dynamics in 2 intertidal areas, located at a similar tidal level (2.25–3 m above the zero of the chart datum), and corresponded to the most common habitat in the archipelago i.e., coarse sands dominated by *Cerastoderma edule* and *Glycymeris glycymeris* (Godet et al., 2009).

2.2. Bivalve hand-raking

Typical spring tide recreational shellfish harvests were mimicked by hand-raking several small parcels and harvesting adult bivalves each spring tide from April 9 to September 5, 2013. Experiments were done on a 0.6 ha protected (i.e., fishing is prohibited) tidal flat area between mid- to low-tide levels, where the target species (cockles and clams) are normally found (Fig. 1). Three, 9 m^2 experimental parcels (3 × 3 m), were disturbed during each spring tide using a 19 cm wide garden rake (ten, 6 cm long teeth, spaced by 1.3 cm, Wolf® DSM19), as done locally by recreational fishers. Bivalve recruits were sampled just prior to each simulated harvest, and all harvested adult bivalves in disturbed parcels, principally Cardiidae (*C. edule*) and Veneridae (*Ruditapes philippinarum*, *Ruditapes decussatus*, *Polititapes aurea*), were removed and released far away in the protected area.

2.3. 'Bouchot' mussel culture

In contrast to long-line or raft structures (but see McKindsey et al., 2011 for more details), mussels in the Normand-Breton Gulf are traditionally cultivated on wooden stakes with ca. 3 m exposed (i.e., above the sediments) called 'bouchots', which are spaced by 1 m and arranged in ca. 100 m parallel paired rows separated by ca. 2 m. Experiments were done on a 37 ha tidal flat where blue mussel (*Mytilus edulis*) is cultivated on 'bouchots', in farms organized in series of paired rows, each separated from neighboring rows by ca. 25 m. Four, 12 m^2 disturbed parcels (3 × 4 m), were located in several farms to integrate the natural hydrosedimentary variability due, in part, to both 'bouchot' orientation and exposure (Fig. 1). Bivalve recruits were sampled within 1 m of the paired rows of 'bouchots' as the influence of these culture structures on bivalve abundance has been shown to be restricted to this zone (Grant