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Improvements in the physiological performance of European flat oysters *Ostrea edulis* (Linnaeus, 1758) cultured on elevated reef structures: Implications for oyster restoration☆

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A B S T R A C T

The precarious status of flat oyster *Ostrea edulis* stocks in Europe is widely acknowledged. To build a scientific basis for oyster restoration, an elevated experimental reef stocked with *O. edulis* was established within Poole Bay (Dorset, UK). Oysters were out planted on twenty four oyster reef modules (80 cm above sea bed) and compared with oysters held on the sea bed close to each reef module to test the hypothesis that a reef habitat enhanced physiological performance. Filtration and respiration rates, condition index, haemolymph protein concentration, haemocyte counts and gonad maturation were measured as indicators of physiological performance. During the first 15 months of oyster reef deployment, water samples were collected at regular intervals at the sea bed and at a height of 80 cm from the sea bed to determine chlorophyll *a* concentration, total suspended solids and bacterial abundance. Total suspended solids were significantly higher at the sea bed than at 80 cm above the sea bed at every sampling interval, while bacterial abundance adjacent to the sea bed was significantly higher than 80 cm above the sea bed in August and November 2013 when temperature was 18 °C and 15 °C, respectively. The filtration rates of oysters varied with elevation (reef/sea bed) and months. Filtration rates of 'reef oysters' (oysters on elevated reefs) were significantly higher than 'sea bed oysters' (oysters held on the sea bed). Respiration rates varied among months but were not significantly affected by elevation (reef/sea bed). Elevation and month also affected the total number of haemocytes and the granulocyte population; reef oysters had significantly higher numbers of haemocytes than sea bed oysters. As current stocks of European flat oysters (*O. edulis*) in Europe have declined in both abundance and distribution, the results of this pilot study suggest that the culture of oysters on elevated reef structure represents at least a partial solution to improve *O. edulis* physiology for restoration in Europe.

1. Introduction

The European flat oyster, *Ostrea edulis* (Linnaeus, 1758) occurs throughout the Atlantic and Mediterranean coasts of Europe (Airoldi and Beck, 2007; Lallias et al., 2007). At one time the species was among the most commercially important marine resources in the European waters (Orton, 1937). Today, stocks in France, Spain, Ireland, Croatia, Holland and United Kingdom are exploited commercially (Smith et al., 2006; Kamphausen et al., 2011). However, stocks of *O. edulis* have been in decline since before 1970s, principally as a result of over exploitation (through technological improvements in fishing and a lack of effective management) (Edwards, 1997), low rates of recruitment (Laing et al., 2006), the effects of the extremely cold winters in the 1930s and 1940s (Crisp, 1964), the prevalence of parasitic organism *Bonamia ostreae* (Lallias, 2008) and the destruction of natural oyster beds (Mackenzie et al., 1997). Jackson et al. (2001) stated that destruction of oyster reef habitats resulted to reduce a number of dominant filter-feeding bivalves and consequently influenced degradation of marine environmental ecosystems. Officer et al. (1984) and Jackson et al. (2001) reported that the evidences of hypoxia, anoxia and eutrophication were observed after the over exploited to oyster stock (*Crassostrea virginica*) in Chesapeake Bay. Therefore, the decline of *O. edulis* represents a financial loss to European coastal economies and also reduces the quality status of the marine environment. As filter feeders, oysters are a keystone species that play a major role in dissolved nutrient cycling by removing phytoplankton, suspended solids, and organic particles from the water column and therefore can contribute to the control of eutrophication in marine ecosystems (Newell, 1965; Ward and Shumway, 2004; Fulford et al., 2010). As such, the critical status of *O. edulis* has been recognised by its inclusion in the list of UK

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Biodiversity Action Plan species (BRIG, 2007) as a response to the UN Rio Convention on Biological Diversity.

The restoration of shellfish stocks, especially reef-forming bivalves, using artificial reefs has become a popular management strategy, especially as applied to the restoration of *C. virginica* in USA. Often the common goals have been for habitat restoration, fisheries enhancement and recovery of species diversity (Bartol et al., 1999; Coen and Mark, 2000; Beck, 2011). Lenihan et al. (1999) suggested that *C. virginica* culture above sea bed can increase growth rates, survival rates and resistance to diseases, especially during periods of summer hypoxia. Moreover, Frechette et al. (1989) revealed that complexity and elevation of mussel beds enhanced vertical diffusive turbulent water flow past the mussels (*Mylitus edulis*), which in turn further enriched nutrients and improved growth rates of filtering feeding species. However, there has been no study evaluating the merits of building artificial reefs with which to restore communities of *O. edulis* and explicit evidence that artificial oyster reefs in the European region improve physiological potential is generally lacking. In light of the paucity of available data, it is first necessary to establish the potential benefit of reef culture of *O. edulis* at a pilot-scale before the fishery-scale introduction of this approach as a management strategy. The objective of the research herein was, therefore, to compare the physiological performance between sub-tidal *O. edulis* held off the sea bed on elevated structures and oysters (individuals) held on the sea bed. Indicators of physiological health included filtration and respiration rates, haemolymph protein content, and haemocyte counts.

2. Materials and methods

2.1. Study area and artificial reef construction

The experimental reef was located in Poole Bay, Dorset (50°40′ N 01°55′ W, Fig. 1A) at a depth of ~10 m below chart datum (tidal range = 2 m) (Jensen et al., 2000). Each individual reef module consisted of a breeze block base (40 cm high) with a 'reef box', a 0.064 m^3 cube of cleaned oyster valves encased within a Netlon™ mesh, attached to the top of the base (Fig. 1 B). The total height of the base plus reef box was 80 cm from the sea bed (Fig. 1 C) and reef boxes were held in place on top of the breeze block mount using 150 cm steel pins. Oyster shells, collected from the Solent, 50°46′ N and 1°14′ W, were washed, scrubbed of epibiota, and dried and were used as the material or 'fill' for each reef box. Reef boxes were3/4 filled with oyster shells – comprising approximately 1200 shells each box. Oyster cages (0.4 × 0.4 × 0.2 m), used to hold oysters on the sea bed, were located close to each of the reef box units. Twenty-four reef boxes and twenty-four oyster cages were deployed on the sea bed at Poole Bay in August 2012. Twenty live *O. edulis* (Othniel Oysters Ltd., Poole), 57–99 mm in shell height, were then added as a top layer to each reef box and oyster cage by divers.

2.2. Sampling intervals and oyster samples

After deployment in August 2012, replicate reef boxes were recovered on four occasions during the 15-month field experiment:

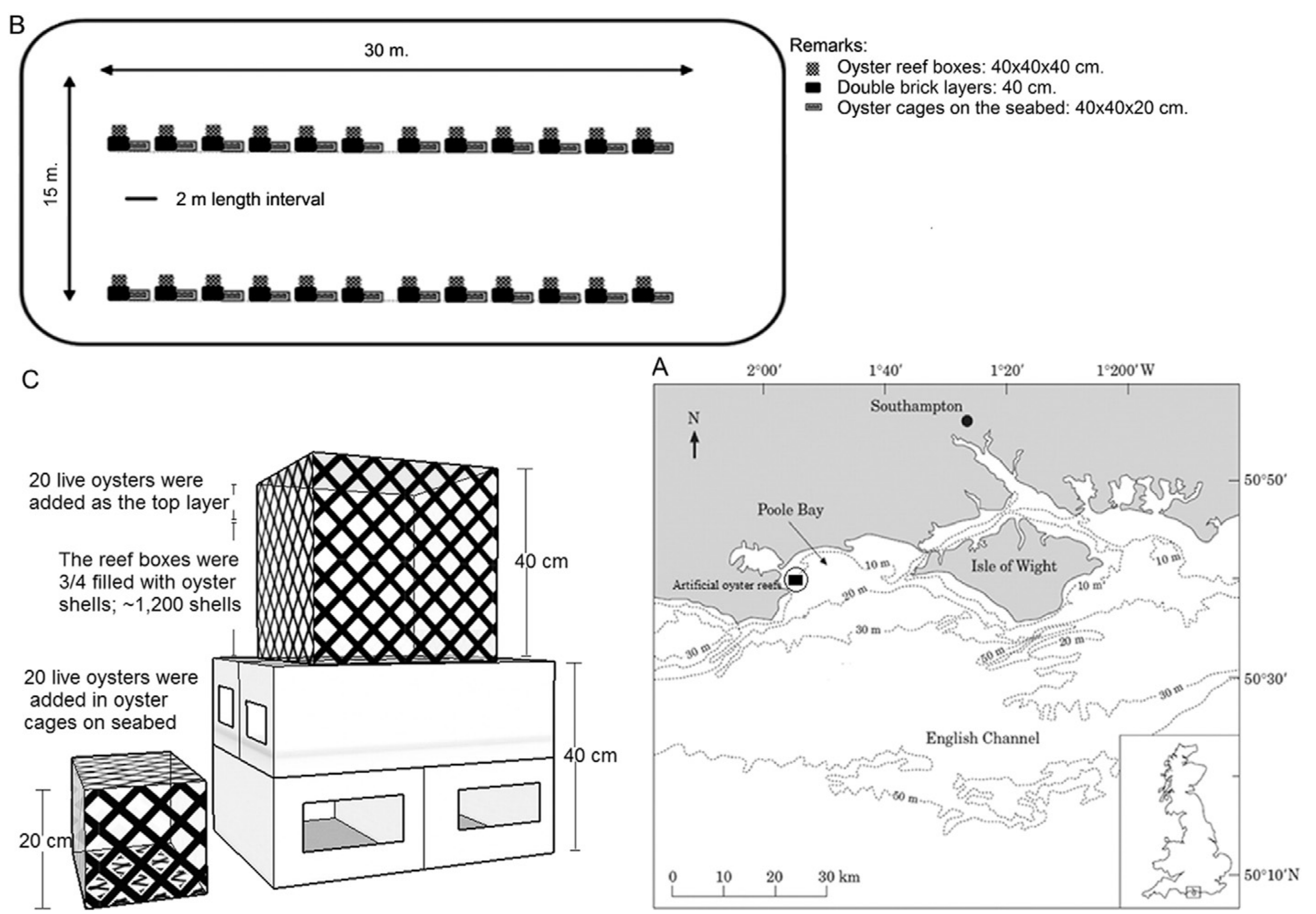

Fig. 1. Study area and artificial oyster reef design: (A); location of Poole Bay on the south coast of the UK, (B); Schematic of the general arrangement of the 24 replicate reef modules, (C); An artificial reef module; breeze block height plus reef box height is 80 cm from the sea bed.