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Community convergence and recruitment of keystone species as performance indicators of artificial reefs

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ABSTRACT

An experimental artificial reef was constructed in Strangford Lough, Northern Ireland as part of trials to regenerate damaged biogenic reefs formed by the horse mussel *Modiolus modiolus*. Experimental reef plots were constructed using *Pecten maximus* shell as cultch. Clumps of live adult *M. modiolus* were translocated from nearby natural reefs into cultch with a high profile (elevated cultch), cultch with a low profile (flattened cultch), as well as directly into the seafloor. The aim of the study was to test the hypothesis that translocated mussel clumps would increase habitat complexity thus accelerating community succession and enhancing natural recruitment of *M. modiolus* spat. These effects were predicted to be greater on elevated cultch due to greater protection from predators and increased accessibility to food resources. Within the artificial reef array the translocated clumps had a significant positive effect on recruitment compared to cultch without mussels with average densities of spat settled on the translocated *M. modiolus* clumps ranging from 100 to 200 individuals m^{-2} compared to 4 to 52 spat m^{-2} on cultch without mussels. Recruitment of *M. modiolus* spat was also significantly higher on translocated horse mussels when compared to natural reefs where densities of 8–36 spat m^{-2} were recorded. Reef elevation appeared to provide some degree of protection from predators but differences in translocated *M. modiolus* survival on the different elevation treatments were not significant. In total, 223 taxa were recorded 12 months after reef construction. The presence of translocated clumps of *M. modiolus* was the main driver of the increases in faunal diversity and species abundance. Application of objective criteria to assess the performance of artificial reefs suggested that translocation of *M. modiolus* clumps alone achieved most of the restoration objectives. Consequently this pilot study demonstrates a straightforward and realistic intervention technique that could be used to kick start the regeneration and expansion of impacted mussel and similar biogenic reefs elsewhere.

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1. Introduction

Biogenic reefs formed by bivalves provide a wide range of ecological services such as seston filtration, benthic-pelagic coupling, provision of feeding and structural habitat for mobile species and attachment surfaces for sessile species (Brumbaugh et al., 2007; Coen et al., 2007; Holt et al., 1998), as well as seabed stabilization (Jones, 1951; Rees, 2009). In addition, the complex three-dimensional structure characteristic of pristine reefs supports high biodiversity (Coen et al., 2007; Mann and Powell, 2007; Powers et al., 2009) which can range from 25 associated taxa to well over 300 (Borthagaray and Carranza, 2007; Cranfield, 2004; Kenchington et al., 2006; Koivisto and Westerbom, 2010; Ojeda and Dearborn, 1989; Rees et al., 2008; Sanderson et al., 2008). When such habitats are compromised these features and services are reduced or lost and may recover slowly or not at all without intervention.

The most widely used shellfish restoration technique involves the construction of artificial reefs as a way to address not only habitat loss and recruitment limitation of the keystone species, but also 'to mimic some characteristics of a natural reef' (Jensen, 1997; OSPAR, 2009). Reefs in bivalve restoration projects usually consist of suitable substrate or 'cultch' used to construct an elevated three-dimensional structure (Nestlerode et al., 2007); brood stock of the keystone reef-forming species is often added to the reef (Brumbaugh and Coen, 2009). The complexity created by the added substrate increases survival of juveniles of the keystone species (Bartol and Mann, 1997; Bartol et al., 1999; Nozawa, 2008) and provides refuge for associated biota (Breitburg, 1999; Tolley and Volety, 2005). The elevation of the cultch is a key element of artificial reef design for oysters, significantly increasing their recruitment and survival (Schulte et al., 2009). Translocation of mature stocks increases the production of larvae to effectively kick-start a declining population by addressing recruitment limitations (Barnabé and Barnabé-Quet, 2000; Caddy and Defeo, 2003).

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Modiolus modiolus is a long-lived mussel of circumboreal distribution (Anwar et al., 1990; Rees, 2009) that also aggregates to form reefs that increase seabed stability (Jones et al., 1997; Meadows and Shand, 1989), biodeposition and habitat heterogeneity. The biodeposits constitute a microhabitat for a rich array of infaunal species that live and feed in them (Navarro and Thompson, 1997; Ojeda and Dearborn, 1989; Rees et al., 2008). Reef forming mussels (*M. modiolus*, *Mytilus edulis*) also offer protection from predators (Koivisto and Westerbom, 2010; Lintas and Seed, 1994; Witman, 1985) and suitable substrata for sessile epifauna which, along with the infauna and crevice fauna, results in a very rich faunal assemblage (Erwin, 1977; Rees et al., 2008; Sanderson et al., 2008; Wildish et al., 1998) with some of the species exclusively linked to the reefs (Ojeda and Dearborn, 1989). Fish species are also known to use *M. modiolus* reefs for food and refuge (Rees, 2009; Roberts et al., 2011).

M. modiolus reefs were historically widespread throughout Strangford Lough, Northern Ireland (Brown and Seed, 1976; Erwin, 1977; Roberts, 1975) and were a major feature in its designation as a candidate Special Area of Conservation (SAC) and proposed Marine Protected Area (MPA). In the 1990s the reefs were reported to be in an 'unfavourable conservation status' because they had experienced a reduction in both condition and extent due to fishing impacts (Magorrian and Service, 1998; Roberts et al., 2011; Service and Magorrian, 1997; Strain et al., 2012).

This study assesses the potential for *M. modiolus* restoration using artificial reefs. The rationale for the reef design was based on (1) the wide use of cultch in restoration of biogenic reefs of the American oyster *Crassostrea virginica* (Barnes et al., 2010; Mann and Evans, 2004; Piazza et al., 2005); (2) reports that *M. modiolus* recruitment occurs primarily amongst the byssal threads of adult conspecifics (Rees et al., 2008); and (3) that recruit survival in reef-forming bivalves such as *C. virginica* increases with reef elevation (Lenihan, 1999; Powers et al., 2009; Schulte et al., 2009). The experimental *M. modiolus* reef system was constructed using a total of 16 tonnes of scallop shell distributed in replicated plots with different elevations. More than 6000 adult *M. modiolus* were collected from impacted patches of mussels close to the artificial reef and translocated into elevated and flattened cultch as well as seafloor plots. The key objective of this experimental reef array was to pilot different reef designs which might subsequently be scaled up in a more extensive restoration exercise.

This paper describes the results of a comprehensive survey carried out 12 months after construction of the artificial reef. The main aim of the survey was to determine whether translocation of the keystone species, *M. modiolus*, into an artificial reef constructed from shell cultch is an effective short-term strategy to stimulate recovery of damaged biogenic reefs. The performance of the reef 12 months after deployment was assessed using criteria developed by Baine (2001) and by testing the following hypotheses: (1) communities would be more diverse in translocated mussels than on cultch or seafloor alone; (2) recruitment of *M. modiolus* spat would be greater on translocated mussel clumps than on cultch alone; (3) survival of *M. modiolus* translocated in clumps would be greater on cultch than directly on seafloor; and (4) recruitment and survival would be higher in mussels translocated onto elevated cultch than on other treatments. It was also predicted that communities associated with the artificial reef would become more diverse and would converge with adjacent natural *M. modiolus* biotopes over time.

2. Methods

2.1. Study area

The experimental reef was located in Strangford Lough, a large sea inlet on the east coast of Northern Ireland (Fig. 1) lying between 54°35′N and 54°20′N and between 5°41′W and 5°34′W. The Lough is 30 km in length and 8 km wide and occupies a total area of 150 km^2 (Service et al., 1996). Strangford Lough is a semi-enclosed sea lough connected to the Irish Sea by a narrow channel where the maximum depths (~60 m) have been recorded and where tidal currents reach 4 m s^{-1}. The waters in the southern basin mix freely with the Irish Sea while the northern part of the lough is characterised by shallower depths and higher water retention times (Boyd, 1973; Ferreira et al., 2007). The markedly different hydrographical regimes found in different parts of the lough together with its glacial origin have created a wide range of habitats supporting a high diversity of marine communities with more than 2000 recorded species (Williams, 1953).

2.2. Ecological importance

Strangford Lough was designated as Northern Ireland's first Marine Nature Reserve and has been identified as a pilot Marine Protected Area (MPA) (Cork et al., 2006).

It is also listed as a NATURA 2000 area [UK0016618] (JNCC, 2012). A key feature in this designation is the presence of biogenic reefs including *M. modiolus* reefs (DOENI, 1994; Roberts et al., 2011).

2.3. Artificial reef site selection

Site selection was carried out following published guidelines on selection of suitable sites for shellfish restoration (Brumbaugh et al., 2006; Caddy and Defeo, 2003; OSPAR, 1999). The reef should ideally be located in an area where: (1) targeted shellfish populations historically existed; (2) bottom conditions are adequate for supporting shell or other materials used; (3) natural recruitment is likely to occur; (4) the current velocity is likely to provide a good influx of nutrients and oxygen; and (5) it is protected from human activities. The artificial reef was established in the western side of Strangford Lough, ca. 1 km south of Brown Rocks (54°25′16″N, 5°37′13″W) and 17 m below chart datum (Fig. 1), an area of *Modiolus* shell and mud (Roberts et al., 2004) within the historical range of *M. modiolus* habitats in Strangford Lough (Erwin, 1977; Roberts et al., 2011). The reef was set up in an area designated to become a sea fisheries exclusion zone which was subsequently established in March 2011 by the Department of Agriculture and Rural Development of Northern Ireland (The Strangford Lough [Sea Fisheries Exclusion Zones] Regulations (Northern Ireland) 2011, SR2011/35). At this site currents are up to 62 cm s^{-1} at spring tides (unpublished data) and salinity was a little over 34 PSU while bottom temperatures ranged from 5 °C in January to 15 °C in July 2010. Average values for chlorophyll-a in the lough's south basin ranged from 0.345 to 5.19 μg l^{-1} for the duration of the monitoring period (data supplied by the Northern Ireland Environment Agency (NIEA)). In addition, *M. modiolus* spatfall has previously been recorded on mussel beds close to the experimental reef (unpublished data). Site assessments were made and licences obtained for the work in line with the relevant legal frameworks (Sayer and Wilding, 2005).

2.4. Artificial reef design and construction

The artificial reef array was constructed using ca. 16 tonnes of flat valves of the king scallop *Pecten maximus*. The shells were locally sourced from a scallop processing plant and weathered onshore for 6 months to avoid the introduction of undesirable invasive species to Strangford Lough (Bushek et al., 2004). The shells were bagged in 0.5 and 1 tonne polypropylene bags prior to deployment.

A lifting crane positioned on a barge was used to lower the bagged cultch onto four random positions around a concrete block previously deployed to mark the centre of the licensed area. Each position contained four tonnes of bagged cultch divided equally into two sets to simulate elevated and flattened reefs. Once the arrangement was completed divers constructed four replicated flattened cultch plots by slashing one set of bags in each position and spreading the cultch to create an artificial reef of ca. 0.5 m elevation above

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