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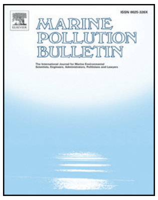

Commercially important species associated with horse mussel (*Modiolus modiolus*) biogenic reefs: A priority habitat for nature conservation and fisheries benefits

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ABSTRACT

Horse mussel reefs (*Modiolus modiolus*) are biodiversity hotspots afforded protection by Marine Protected Areas (MPAs) in the NE Atlantic. In this study, horse mussel reefs, cobble habitats and sandy habitats were assessed using underwater visual census and drop-down video techniques in three UK regions. Megafauna were enumerated, differences in community composition and individual species abundances were analysed. Samples of conspicuous megafauna were also collected from horse mussel reefs in Orkney for stable isotope analysis. Communities of conspicuous megafauna were different between horse mussel habitats and other habitats throughout their range. Three commercially important species: whelks (*Buccinum undatum*), queen scallops (*Aequipecten opercularis*) and spider crabs (*Maja brachydactyla*) were significantly more abundant (by as much as 20 times) on horse mussel reefs than elsewhere. Isotopic analysis provided insights into their trophic relationship with the horse mussel reef. Protection of *M. modiolus* habitat can achieve biodiversity conservation objectives whilst benefiting fisheries also.

1. Introduction

Globally, fish stocks are under threat (Jackson et al., 2001) with the proportion of over-exploited fish stocks at 32% in 2008 (FAO, 2010), leading to calls to halt this trend and restore them (Worm et al., 2009). One method of improving fisheries management has been a shift to 'Ecosystem-Based Management' (EBM) that involves a move from traditional single species based management to a greater understanding of the interactions between habitats and commercially important species. In the NE Atlantic, habitat-forming species such as maerl (a coralline red algae) create a physically complex and biodiverse seabed, which provides a nursery ground for commercially important fish and shellfish (Kamenos et al., 2004a, 2004b). *Modiolus modiolus* (horse mussel) reefs are structurally complex habitats, characterised by high species diversity (Hirst et al., 2012; Rees et al., 2008; Sanderson et al., 2008). The societal benefits of horse mussel reefs for fishermen have been demonstrated in the Irish Sea (Kent et al., 2016); yet the widespread utilisation of horse mussel reefs as a resource for benthic consumers has not been addressed.

In the United States, the Sustainable Fisheries Act (SFA) now requires fisheries managers to identify the 'Essential Fish Habitat' (EFH) for commercially important fish species (Fluharty, 2000), i.e. "those waters and substrate necessary to fish spawning, feeding or growth to maturity" (NOAA, 1966). This concept is not confined to describing finfish habitat associations; it has also been used for invertebrates such as conch (Glazer and Kidney, 2004), octopus (Garofalo et al., 2011) and even bottlenose dolphin (Ingram and Rogan, 2002).

The EBM approach extends the focus of managing resources beyond the target species and includes impacts to non-target species and benthic habitats, supporting ecological processes that are required to sustain harvestable resources (Hughes et al., 2005). With an increasing human population comes an increased demand for ecosystem goods and services, i.e. "the benefits natural ecosystems provide to human society" (de Groot et al., 2002). In the marine environment, there is increasing interest in the relationship between biodiversity and ecosystem services given the wide scale loss of biodiversity in marine ecosystems (Worm et al., 2006). Marine Protected Areas (MPAs) are seen as an important management tool to conserve species and habitats

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(Agardy, 1994) and, over time, well managed MPAs can support ecosystem services to provide ecological and societal benefits (Fox et al., 2012).

Those implementing the Habitats Directive and MPA management measures across Europe have rarely evaluated the ecosystem services or the commercial value of the biodiversity that they seek to maintain (Maes et al., 2012). Marine biodiversity conservation is lagging behind the terrestrial equivalent, and increasing uses and demands on the marine environment have led to the development of policy frameworks that integrate human activities as part of the system (Atkins et al., 2011). Historically, biodiversity management and fisheries management have developed separately, diverging in the 19th Century under impacts of industrialisation and starting to converge from the 1970s due to the development of UN cross-sectoral summits (Garcia et al., 2014). More recently, ecosystem-based management initiatives have been seeking to create synergies and improve the efficiency of marine management (cf. The Marine Strategy Framework Directive, 2008 and the Maritime Spatial Planning Directive, 2014). Genuine integration of fisheries management and biodiversity conservation is yet to be seen, however, the recognition of habitat associations and appropriate management of EFH have the potential to provide benefits for both fisheries and nature conservation.

Identifying a habitat as an EFH is not a simple task, especially for highly mobile species that use a range of habitats throughout their life cycle. With limited resources, conserving or restoring every habitat used by a fish is unrealistic, therefore identifying habitats that are used during sensitive life stages is often a priority (Levin and Stunz, 2005). Relative fish abundance measurements provide an initial insight into which areas are important for fish and shellfish. However, to recognise a habitat as an EFH requires a greater understanding of the functional role of the habitat, i.e. whether it is being used for feeding or reproduction, etc.

Stable isotope analysis has developed as an important technique in food web research (Newton, 2016; Peterson and Fry, 1987; Post, 2002; Schaal et al., 2012). ^{15}N becomes enriched during trophic transfers, with a mean increase (or "trophic enrichment factor", TEF) of 3.4‰ (Caut et al., 2009; Minagawa and Wada, 1984; Post, 2002; Vanderklift and Ponsard, 2003). This is equivalent to approximately one trophic level, though there are variations, with TEF being larger for herbivorous fish (Mill et al., 2007). The δ^{13}C from the tissue of an animal is more conservative with trophic transfer, instead reflecting the source(s) of carbon in the food chain. Analysis of δ^{15}N and δ^{13}C together can therefore be used to determine the feeding relationships on a biogenic habitat (Grall et al., 2006), bentho-pelagic coupling (McIntyre et al., 2006) and habitat associations (Yeager and Layman, 2011).

UK biogenic reefs have been recognised as biodiversity hotspots, e.g. *M. modiolus* reefs; (Mair et al., 2000; Moore et al., 2013; Rees, 2009) and mapped for conservation purposes, e.g. Lindenbaum et al. (2008). However, our understanding of habitat associations and the trophic structure of many biogenic reef communities is limited. Underwater Visual Censuses (UVCs) can be used to measure relative megafauna abundance (Kamenos et al., 2004b) and the benefits of using this technique include it being non-destructive and independent of fishing gear bias. Remotely Operated Vehicles (ROVs) and towed videos have also been used to record the abundance of mobile species associated with coral reefs (Söffker et al., 2011) and gorgonians (De Clippele et al., 2015).

As structurally complex seabed features, *M. modiolus* reefs are expected to provide a 'habitat provision' ecosystem service that has been shown to be the case for other biogenic structures (De Clippele et al., 2015; Kamenos et al., 2004b; Margiotta et al., 2016). However, *M. modiolus* reefs are relatively inaccessible and their ecological function is understudied. The aim of this study is to identify the key megafaunal species (defined as animals >2 cm maximum length) associated with three *M. modiolus* reefs in the UK and to investigate the trophic feeding niche structure of a *M. modiolus* reef megafaunal community.

2. Methods

2.1. Megafauna abundance

Underwater Visual Censuses (UVCs) were carried out using SCUBA at twenty-three sites in Shetland and Orkney (Fig. 1B and C) between 15 and 25 m below chart datum. It was impractical to survey at multiple sites at Pen Llŷn (Fig. 1D) due to strong currents and short slack water periods, therefore a Drop Down Video (DDV) camera system was used. Sites off Pen Llŷn were surveyed between May and June of 2008 and 2010. Sites in Orkney and Shetland were surveyed in May 2013 and September 2012 respectively. In all cases, conspicuous megafauna, including fish and commercially important invertebrates such as shellfish, were quantified.

UVC sites were selected at random using extant video footage and preliminary dive data to stratify sampling to 'horse mussel reef' (8 sites), 'sand' (8 sites) or 'cobble' (7 sites) habitats. Horse mussel reef sites had a density of >20 *M. modiolus* m^{-2}. All observers were trained in species identification during a pilot study in May 2012 in Orkney and all surveys covered a 60 m^2 area, delineated by a transect tape deployed from a shot-line. Surveyors used a 2 m pole to ensure the transect width remained consistent (Fig. 2A). Habitats were verified as cobble, sand or *M. modiolus* reef using photoquadrats and granulometry samples.

The DDV camera system used was a Sony Model DCR-TRV950 camcorder fitted into a tubular aluminium housing with two HID video lamps and lasers (10 cm apart) were used to quantify the seabed area covered. The video surface unit included a labelling system that overlaid GPS position and depth information onto the surface image for recording and viewing. DDV camera tows were approximately 100 m in length, but actual distances were calculated from the GPS start and end points and a section of 4–8 min was edited from the video clip for analysis. Video footage that was too fast (>30 m per minute) or with <1 m visibility was disregarded. Eight *M. modiolus* reef sites were sampled off Pen Llŷn as well as 8 cobble sites and 8 sand sites.

2.2. Food web analysis

Thirty-seven samples were collected for stable isotope analysis from eleven species across three *M. modiolus* reef sites in Orkney (see Supplementary Table S1 for sampling locations) from the 1st-5th December 2013. *Aequipecten opercularis* ($n = 6$), *Leocarcinus depurator* ($n = 5$), *Asterias rubens* ($n = 1$) and *Buccinum undatum* ($n = 5$) were collected using SCUBA by searching the reef from a central location or on a drift dive. *M. modiolus* ($n = 14$) and polychaetes ($n = 3$) were collected using a 'clump sample' technique where a clump of 3–5 *M. modiolus* and associated fauna are placed into a bucket along with the underlying sediment (Mair et al., 2000). *Gadus morhua* ($n = 1$) and *Taurulus bubalis* ($n = 3$) were collected from sites adjacent to the reefs using baited creels.

White muscle was taken from the fish samples and adductor from the bivalves, whilst the foot muscle was dissected from the *B. undatum* samples. Gill tissue was taken from the crustaceans and tube feet from *A. rubens*. Samples were freeze-dried and ground to a fine powder using a pestle and mortar. Approximately 1 mg of tissue from each sample was loaded into a 4 × 6 mm tin capsule and combusted in continuous flow isotope ratio mass spectrometer (CF-IRMS). Results are expressed as parts per thousand (‰) deviations from international standards, in delta (δ) notation.

2.3. Data analysis

Megafauna counts from the Underwater Visual Censuses (UVCs) and those from the Drop Down Video (DDV) transects were analysed separately due to the different methodology used. For the multivariate analysis, all data were log transformed to down-weigh very abundant

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