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Missing native oyster (*Ostrea edulis* L.) beds in a European Marine Protected Area: Should there be widespread restorative management?

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ABSTRACT

Anthropogenic pressures on the marine environment have escalated and shellfish habitats have declined substantially around the world. Recently, Marine Protected Areas (MPAs) have rapidly increased in number, but management baselines rarely account for historical conditions. Marine examples of habitat restoration are therefore unusual.

An interdisciplinary review of management baselines was undertaken for the Dornoch Firth protected area (NE Scotland) as well as three adjacent inlets and 50 km of open coastline. The protected area has low levels of industrial development, is sparsely populated, and previously achieved management objectives.

Here we systematically searched for historical evidence of native oyster (*Ostrea edulis*) beds, a habitat now rare and of conservation importance throughout Atlantic Europe. Archaeological records, navigational charts, historical maps, museum collections, land-use records, fisheries records, public online databases and naturalists' records were searched. We conducted intertidal and subtidal surveys and sample oyster shells were radiocarbon dated.

The combined interdisciplinary sources showed that *O. edulis* occurred in the inlets and open coast areas of NE Scotland, and specifically in the protected area: Probably since the end of the last glaciation to the late 1800s when they were likely over-fished. Present environmental conditions are also suitable for oyster restoration.

Habitat restoration in protected areas is an emerging global theme. However, European oyster restoration effort is currently confined to remnant populations with a clear history of exploitation or dwindling associated fisheries. An interdisciplinary review of baselines will probably show scope for the restoration of *O. edulis*, for nature conservation, in many other European MPAs.

1. Introduction

Human populations have long depended on coastal zones and the ecosystem services they provide; particularly in terms of food provision, transport, recreation and cultural activities (Mehvar et al., 2018; Neumann et al., 2015). As human populations have grown, so too have global pressures on coastal areas such as overfishing, physical damage to benthic habitats, pollution and eutrophication and these pressures are regionally intense in places such as Atlantic Europe (Halpern et al., 2015). Among marine habitats, shellfish reefs are especially sensitive to anthropogenic disturbance (see Cook et al., 2013; Fariñas-Franco et al., 2018) and are one of the most "imperilled" marine ecosystems on Earth (Beck et al., 2009).

In the last 25 years there has been an increasing recognition of the importance of protecting the marine environment through the designation of Marine Protected Areas (MPAs); now a mainstream global management tool applied to 7% of the world's marine environment (UNEP-WCMC and IUCN, 2018). In Atlantic European countries such as the UK, around half of these MPAs are Special Areas of Conservation (SACs) designated under the EU Habitats Directive (Frost et al., 2016).

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The condition and management plans of SACs, as with almost all MPAs, are typically judged against the ecological condition of the site when the legislation was introduced (1992 in the case of the EU Habitats Directive). These 'baselines' thus provide the benchmark against which changes are measured (Piazzi et al., 2016).

Since baselines have usually been defined at the time a protected area was designated, it is plausible that they might not reflect past conditions when certain species and habitats were more common, biodiversity was higher or when locally extinct species were present. Indeed, it has previously been observed that conservation and Marine Spatial Planning usually make no reference to historical conditions, specifically those prior to the influence of large scale anthropogenic changes since the Industrial Revolution (Plumeridge and Roberts, 2017). However, assessing historical conditions can be difficult because impacts often pre-date readily available documentation or any kind of scientific study.

The 'shifting baselines' paradigm was first referred to in the scientific literature to suggest that the concept of 'pristine' in the marine environment evolves across different generations of sea users (Pauly, 1995; Sáenz-Arroyo et al., 2005). As a result, the past-history of the sea can inform management policies (Roberts, 2007) which are otherwise founded on baseline conditions derived from limited historical data or current conditions (Gatti et al., 2015). Although the shifting baselines concept has been commonly applied within a fisheries context (Ferretti et al., 2015), it is also applicable to habitats and whole ecosystems where losses in biodiversity are typically measured against very recent conditions with little regard to the 'millennia of habitat loss' (Airoldi and Beck, 2007; Howarth et al., 2014). Recent initiatives to improve the management of the marine environment call for careful consideration of environmental baseline and reference conditions (see OSPAR Commission, 2011) because, in the context of 'sustainable management', it is logical to consider what *could* be achieved as well as what *is* being achieved in terms of benefits to human society.

Shellfish reefs, and oyster reefs in particular, have been severely impacted by overexploitation, disease and other human induced pressures throughout their global distribution; mostly in the late 1800's and early 1900's (Beck et al., 2011; Gatti et al., 2015; Howarth et al., 2014). In the USA declines of up to 88% of the American oyster (*Crassostrea virginica*) biomass have been documented in some waterbodies (e.g., Chesapeake Bay) with consequent losses in associated ecosystem services such as water filtration (Zu Ermgassen et al., 2012b). In Europe, the native oyster *Ostrea edulis* has been a documented source of food since at least Roman times and in the North Sea over-exploitation has led to the loss of extensive beds (Anon., 1885–1886, 1882).

O. edulis is found in Atlantic Europe and North Africa from Morocco to Norway as well as the Black Sea and in the Mediterranean (Cano et al., 1997; Zaitsev and Alenxandrov, 1998). It usually inhabits relatively shallow sheltered estuaries but has been historically recorded in deeper waters of up to 80 m off the Channel Islands and Grimsby (UK) and the wider North Sea (Laing et al., 2005). Native *O. edulis* beds were also present in Scotland but the advent of industrialised trawling (Roberts, 2007) and the development of the railway system at the end of the 19th century, facilitated a sharp increase in demand by urbanised markets and a corresponding extirpation in the Firth of Forth (Scotland, UK; Fig. 1A) where an oyster (*O. edulis*) bed was reported to cover an area of about 10 × 30 km and to produce up to 30 million oysters in some years (Olsen, 1883; Fulton, 1896; Thurstan et al., 2013). Oyster populations in the UK still exist in remote sheltered sea lochs on the Scottish west coast, most notably Loch Ryan (University Marine Biological Station Millport, 2007), and in a few inlets and coastal waters of southern England and Wales (Woolmer et al., 2011). Overall, *O. edulis* habitats are endangered in Europe, losses and threats have been overlooked and there is scope for restoration (cf Airoldi and Beck, 2007). As a result, in areas with well documented historical *O. edulis* fisheries, as well as remnant fisheries and populations, the concept of localised restoration is gaining traction (Gercken and Schmidt, 2014; Sawusdee et al., 2015; Smaal et al., 2015; Smyth et al., 2018) and *O. edulis* beds are now identified as a priority marine habitat for protection in European MPAs (OSPAR Commission, 2011). However, the European Atlantic MPA network covers a substantial area and *O. edulis* populations may well have been ubiquitous in what is now the MPA network: over and above those places where the recent history of fisheries is apparent in the modern context.

Although a commercial fishery for oysters existed in the past in Scotland (notably the Firth of Forth; Thurstan et al., 2013), there is no mention of *O. edulis* in conservation objectives or management planning documents for any of the marine protected areas of North-East Scotland, including the Dornoch Firth (SNH, 2016).

Through an inter-disciplinary review and novel first-hand field investigation, we aimed to determine the likely historical presence of native *O. edulis* beds in the Dornoch Firth protected area and the three neighbouring inlets and open coast in northeast Scotland. The ultimate goal was to determine if oyster restoration could be relevant to the conservation objectives of the wider European Atlantic MPA network, with its long history of environmental degradation (Gilbert et al., 2014); especially where there are now no remnant populations or contemporary knowledge of historical fisheries.

2. Materials and methods

2.1. Site details

The Dornoch Firth is a little-studied marine protected area located in the remote northeast coast of Scotland with low fishing pressure and a sparse human population. Unlike many areas in the North Sea, the Dornoch Firth (Fig. 1A–C) has been virtually unaffected by industrial development and is considered of high environmental quality (Mackay et al., 2004). The Dornoch Firth is a Special Area of Conservation (SAC) and a Special Protected Area (SPA) under European Directive and, as such, it is also part of the OSPAR network of MPAs. In addition, the intertidal zone bounding the Dornoch Firth is a Site of Special Scientific Interest (SSSI). Two Nature Conservation Orders banning collection of shellfish and other invertebrates (except for mussels) provide statutory protection.

The Dornoch Firth is an estuarine inlet and, along with the Inverness, Beauly and Cromarty Firths, is part of the much larger Moray Firth system (Fig. 1A, B; Hunter and Rendall, 1986). The Firth is a sheltered, semi-enclosed embayment of glacial origin, ca. 23 km long and occupying 12,273 ha (Stapleton and Pethick, 1996). The main freshwater inputs are from relatively small rivers (Balls, 1994; SEPA, 2011). The subtidal zone is shallow, not exceeding 10 m, with the exception of the entrance channel between Gizzen Briggs and Whiteness Sands (Fig. 1C) where 17 m depth has been recorded (UK Hydrographic Office, 1978). Minimum water temperatures are 5 to 6 °C in February and in July to September temperatures range from 12 °C to 14 °C (Balls, 1994; unpublished SEPA Shellfish Growing Waters data 2006 to 2008).

The outer Moray Firth is a fully saline (> 34 psu), open water system with a decreasing salinity gradient towards the inner firths (Balls, 1994). Most of the inner Dornoch Firth can be regarded as brackish, with salinities ranging from < 9 psu in the uppermost section to 25–31 psu in the main channel. The outer sections east of the Dornoch Bridge are less influenced by freshwater inputs and conditions here are regarded as fully marine.

The waters in the Dornoch Firth are well mixed from tidal currents and occasional wave action from easterly winds. According to Balls (1994) oxygen saturation at or exceeding atmospheric levels was found throughout the Dornoch Firth whilst dissolved oxygen levels were consistently above 5 $mg\,l^{-1}$ from 2006 to 2008 (7–12 $mg\,l^{-1}$ in most sampling dates), particularly in the winter months (SEPA, 2009).