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Review

Impact of kelp cultivation on the Ecological Status of benthic habitats and *Zostera marina* seagrass biomass

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ABSTRACT

The Ecological Status of subtidal benthic communities within a commercial kelp farm on the southwest coast of Ireland was not impacted by macroalgal cultivation. Additionally, there was no effect on the biomass of *Zostera marina*, a key habitat under the EU Habitats Directive and OSPAR Commission. However, sediment grain size and total organic matter (TOM) were influenced by abiotic and biotic aspects of the farm. A temporal effect on univariate and multivariate species data, Infaunal Quality Index (IQI) and *Z. marina* biomass was observed. This effect was likely a community response to high storm disturbance in winter 2013/14.

The use of IQI to assess the impact of macroalgal cultivation on benthic communities is a novel approach. This study supports a view that environmental impacts of macroalgal cultivation are relatively benign compared to other forms of aquaculture. Further research must be conducted to understand all interactions between aquaculture activities and the environment.

1. Introduction

World aquaculture production continues to grow year on year with approximately 131.4 million tonnes of fish, aquatic animals and plants produced in 2014 (FAO, 2016). It has long been established that cultivation methods can impact on the benthic environment; these impacts include organic loading of the sediments and associated biogeochemical changes caused by the bio-deposition of faeces and pseudofaeces at culture sites (Crawford et al., 2003; Forde et al., 2015; Kalantzi and Karakassis, 2006; O'Carroll et al., 2016). However, many of these studies have focused on finfish (Kalantzi and Karakassis, 2006; Silvert and Sowles, 1996) and shellfish (Crawford et al., 2003; Dubois et al., 2007; O'Carroll et al., 2016; Stenton-Dozey et al., 1999) aquaculture. Assessments of the impacts of macroalgal cultivation has so far focused on tropical macroalgal species (Eklöf et al., 2005; Johnstone and Olafsson, 1995; Ólafsson et al., 1995) or their impact when combined with shellfish cultivation in integrated multi-trophic aquaculture (IMTA) systems (Ning et al., 2016; Ren et al., 2014; Zhang et al., 2009).

Seaweed aquaculture farms are generally situated in nearshore coastal environments with average water depth ranging from 6 to 20 m. Semi-exposed sites with good current flow and shelter from the open ocean are ideal to provide the nutrients required for biomass growth without damage of the crop and infrastructure during storms. Typical farm set-up consists of a header ropes suspended approx. 1 m below the surface by buoys and kept in position by anchor ropes and weights, vertical ropes called dropper ropes (approx. 3 m in length) are sometimes added to increase the surface area of the farm (Edwards and Watson, 2011; Peteiro et al., 2016; Walls et al., 2016, 2017). Seaweed cultivation is an extractive cultivation method meaning it assimilates nutrients required for growth from the environment with no need for the addition of supplementary feed or nutrients (Chopin and Sawhney, 2009). As a consequence seaweed farms are assumed to have a more benign impact on the benthos when compared to finfish or shellfish aquaculture (Roberts and Upham, 2012; Soto, 2009). However, possible impacts include organic enrichment from loss of kelp biomass to the seabed and surrounding environment (Zhang et al., 2012 and discussed in more detail below) and from faeces and pseudofaeces released from fouling organisms (e.g. bivalves, polychaetes and amphipods) which use kelp as a habitat (Walls et al., 2016, 2017). In addition, the infrastructure of the farm and the biomass could have baffling effects and possible wave attenuation altering local hydrodynamics similar to that of wild kelp forests (Lovas and Torum, 2001; Mork, 1996; Rosman et al., 2007).

Over 33% of the 27.3 million tonnes of global annual aquatic plant production in 2014 came from just 2 kelp species *Laminaria japonica* and *Undaria pinnatifida* (FAO, 2016). Kelps are among the largest sources of primary productivity in marine habitats (Mann, 1973; Reed et al., 2008) and this primary productivity enters the food chain

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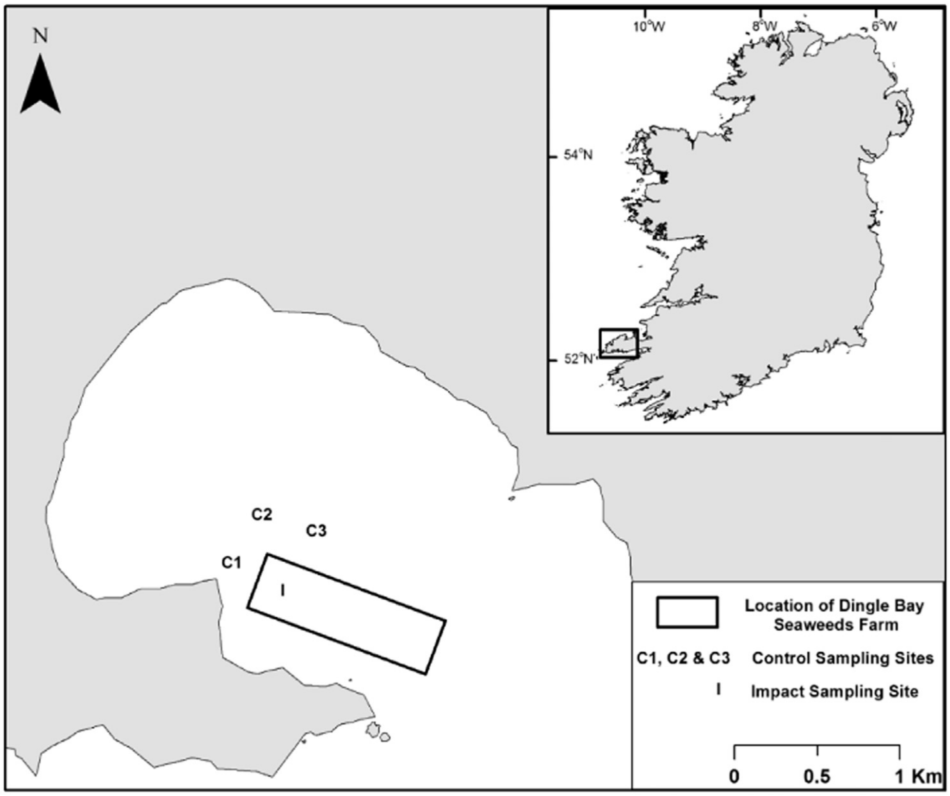

Fig. 1. Dingle Bay Seaweeds farm and sampling sites at Ventry Harbour, County Kerry, Ireland. I = Impacted Treatment Site; C1 = Control Treatment Site 1; C2 = Control Treatment Site 2; C3 = Control Treatment Site 3.

through two routes; direct grazing on kelp tissue or detrital pathways. Much of the standing stock in temperate kelp beds is released either as particulate organic matter (POM) also called detritus or as dissolved organic matter (DOM). Krumhansl and Scheibling (2012) estimate that > 80% of kelp production enters the carbon cycle as POM or DOM. Kelp detritus can range in size from small particles to whole thalli depending on how the biomass was removed. There are three main ways tissue can be lost. 1-Whole thalli are removed from breakage at the stipe or when the holdfast becomes detached from its substratum, either rocks or boulders in wild kelp forests or suspended rope substratum at cultivated sites. 2-Parts of the frond can break off removing large pieces from the frond. 3-Erosion of the distal ends of fronds can occur as tissue is continually lost through decay and natural senescence (Krumhansl and Scheibling, 2012; Zhang et al., 2012). The impacts of detrital deposition from macroalgal cultivation on the benthos could be analogous to the impacts caused by the bio-deposition of faeces and pseudofaeces from finfish and shellfish aquaculture on benthic communities.

Over the last few years, interest in kelp cultivation in Europe has increased, supported by feasibility studies (e.g. Bruton et al., 2009) and experimental farms which are being set up to begin to industrialise the industry and advance the cultivation of kelps native to this region This interest includes Ireland, with the establishment of Dingle Bay Seaweed in Ventry Harbour, County Kerry in 2011 as one of the larger commercial kelp farms (18 ha) in Europe (M.D. Edwards pers. comm.). With an increase in demand for kelp biomass to supply traditional (e.g. food) and expanding uses (e.g. biofuels) of kelp (Guiry, 1989; Walls et al., 2016), the industry is set to expand and investigation into the possible impacts of this cultivation method on the local environment is essential.

2. Aims of this study

The aim of this study was to assess any potential impacts on infaunal community structure at a commercial macroalgal farm at Ventry Harbour, County Kerry on the southwest coast of Ireland over a 2-year period. This was conducted by using an asymmetrical before after control impact (BACI) design to test for differences between control and impact stations in terms of univariate and multivariate faunal distributions and biotic indices including Infaunal Quality Index (IQI). IQI has been used to successfully discriminate the responses of macrobenthic communities to a wide range of natural and anthropogenic environmental impacts including aquaculture, in both coastal and transitional waters. However, many of the studies investigating aquaculture impacts using AMBI (part of IQI) based indicators have only focused on finfish and shellfish aquaculture and not macroalgal cultivation. Additionally, we assessed particle grain size and total organic matter to investigate if the kelp farm had an impact on sediment characteristics. Lastly, the farm site in Ventry Harbour is located above a *Zostera marina* seagrass bed, which is recognised as a very important habitat as they provide ecosystem services such as substratum stabilisation, shelter and substrate for associated organisms, nursery grounds for fish, and are hugely productive (Bertelli and Unsworth, 2014; Davidson and Hughes, 1998; Herkül and Kotta, 2009; OSPAR Commission, 2008). As a result of the supply of these important ecosystem services, *Z. marina* beds are recognised as a characteristic component of five Annex I habitats in the EU habitats Directive (92/43/EEC). Additionally in 2004, OSPAR produced descriptions of habitats on the Initial List of OSPAR Threatened and/or Declining Species and Habitats, which outlined 14 habitat types considered to be a cause for concern and included *Zostera* seagrass beds (OSPAR Commission, 2008). Given the importance of *Zostera* habitats we conducted analyses to test the trends of *Z. marina* biomass at our impacted and control sites over the duration of the study.

3. Materials and methods

3.1. Study site

This study was conducted in the south-west coast of Ireland in Ventry Harbour, County Kerry (52° 06′ 49.45″ N, − 10° 21′20.17″ W; Fig. 1) at the largest operating commercial seaweed farm in Ireland