Marine Pollution Bulletin 98 (2015) 201–209

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Broad-scale impacts of salmon farms on temperate macroalgal assemblages on rocky reefs

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ARTICLE INFO

Article history:
Received 2 February 2015
Revised 25 June 2015
Accepted 27 June 2015
Available online 11 July 2015

Keywords:
Aquaculture
Fishes
Benthic macrofauna
Invertebrates
Organic pollution
Tasmania

ABSTRACT

Intensive fish culture in open sea pens delivers large amounts of nutrients to coastal environments. Relative to particulate waste impacts, the ecological impacts of dissolved wastes are poorly known despite their potential to substantially affect nutrient-assimilating components of surrounding ecosystems. Broad-scale enrichment effects of salmonid farms on Tasmanian reef communities were assessed by comparing macroalgal cover at four fixed distances from active fish farm leases across 44 sites. Macroalgal assemblages differed significantly between sites immediately adjacent (100 m) to fish farms and reference sites at 5 km distance, while sites at 400 m and 1 km exhibited intermediate characteristics. Epiphyte cover varied consistently with fish farm impacts in both sheltered and exposed locations. The green algae *Chaetomorpha* spp. predominated near fish farms at swell-exposed sites, whereas filamentous green algae showed elevated densities near sheltered farms. Cover of canopy-forming perennial algae appeared unaffected by fish farm impacts.

1. Introduction

Nutrient and sediment inputs from anthropogenic activities can cause changes to habitat structure and diversity in temperate reef ecosystems (Airoldi, 2003; Connell et al., 2008; Krause-Jensen et al., 2008; Worm et al., 1999b). These changes may affect delivery of ecosystem services to society, as well as marine conservation objectives for reef areas, which are disproportionately rich in species compared with other habitats. Whilst much attention has been focussed on terrestrial-derived pollution on reef (Arevalo et al., 2007; Connell et al., 2008; Costanzo et al., 2001; Giordani et al., 2009; Littler and Murray, 1975), eutrophication from marine fish farms may also pose a threat. Most previous monitoring and research programs relating to fish farm aquaculture have focused solely on changes to the soft sediments below and adjacent to farm lease areas, in-water nutrients levels, and phytoplankton populations (Edgar et al., 2010a).

Farmed salmon are commonly grown to maturity in net cages, situated in unpolluted sheltered temperate coastal waters. Salmon rely on nutrient-rich compound aquafeeds as an external food source (Tacon and Metian, 2008). Although improved feeding technology has provided a reduction in wasted feed input, Sanderson et al. (2008) suggested that about 70% of the nitrogen and 80% of the phosphorus input to a salmon farm is released to the environment as feed wastage, fish excretion, faeces production and respiration. The majority of these nutrients dissipate in dissolved form. Approximately 87% of nitrogen released from fish farms in the Huon Estuary, Tasmania, is estimated to be in dissolved form and 13% as particulate matter (HEST, 2000b, a). The impact of particulate fish farm waste on sediment communities is variable, according to interactions between depth, current speed, current direction, sediment type, and latitude (Kalantzi and Karakassis, 2006). Commonly impacts are found to be relatively localised (Borja et al., 2009; Grego et al., 2009; Ye, 1991), with meta-analyses reporting benthic community change extending 40–70 m on average (Giles, 2008), although instances of impacts to 145 m have also been recorded (Hamoutene et al., 2015). The extent of impact of dissolved wastes is poorly known, but may extend further (HEST, 2000a).

The effects of fish farm derived nutrients on the diversity and composition of macroalgal-dominated reef communities are likely to be similar to those already observed in eutrophic systems affected by terrestrial derived organic pollution, such as sewage and runoff from fertilised landscapes. A well-documented consequence of excessive nutrients in coastal reef environments is the over-abundant growth of certain types of productive, fast growing macroalgae (Bokn et al., 2003b; Krause-Jensen et al., 2008;

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http://dx.doi.org/10.1016/j.marpolbul.2015.06.049
0025-326X/

Teichberg et al., 2008) at the expense of habitat-forming perennial species (Gorgula and Connell, 2004; Valiela et al., 1997; Worm and Sommer, 2000). These fast growing algae have been termed, 'opportunistic', 'bloom forming' or 'nuisance' macroalgae (Krause-Jensen, 2007a; Littler and Littler, 1980; McGlathery, 2001; Valiela et al., 1997).

In temperate waters, opportunistic green algae in the genera *Ulva* (which now includes the genus *Enteromorpha*), *Cladophora,* and *Chaetomorpha* (Lavery and McComb, 1991) are commonly reported to form blooms (Valiela et al., 1997). These algae are typically ephemeral, with a filamentous or sheet-like form, a relatively undifferentiated thallus, and a high thallus area to volume ratio (Littler and Littler, 1980). Such attributes allow for fast growth and rapid reproduction when environmental conditions are suitable (Littler and Littler, 1980). These algae typically also have a high demand for nitrogen (Barr and Rees, 2003), and their growth is favoured under a variety of pollution types (Guinda et al., 2008), such as sewage pollution (Arevalo et al., 2007; Soltan et al., 2001), sedimentation (Eriksson and Johansson, 2005), and pollution from urbanisation (Gorgula and Connell, 2004; Mangialajo et al., 2007). In eutrophic systems, dense blooms of opportunistic algae can develop, influencing nutrient dynamics beyond their role as nutrient sinks (Lavery and McComb, 1991), and substantially altering biotic community structure and ecological functions (Nelson et al., 2008).

In many but not all cases, increased over-growth by opportunistic algae is associated with a decrease in species richness and cover of canopy-forming perennials (Wells et al., 2007). On South Australian temperate reefs, algal turfs (filamentous assemblages of algae <5 mm in height) have replaced canopy-forming algae along urbanised coastlines, with canopy algae declining up to 70% in cover on reefs (Connell et al., 2008). Experimental tests indicate that algal turf can rapidly colonise and retain space at high rates of sedimentation and nutrient enrichment (Gorgula and Connell, 2004). Benthic communities in the Baltic Sea change along a gradient of eutrophication, with canopy-forming algae replaced by bloom forming algae towards pollution sources (Worm and Lotze, 2006; Worm et al., 1999b).

The possibility of impacts to macroalgal communities is of concern, since some species of bloom forming macroalgae are known to effectively uptake fish farm derived nutrients (Hernández et al., 2008), and many macroalgal species have a preference for ammonia–nitrogen which is released from fish as metabolic waste (Sanderson et al., 2008; Sanderson et al., 2012). In polyculture situations, the production of 92 tons of salmon can potentially yield 385 tons (fresh weight) of *Ulva* or 500 tons of red algae through assimilation of nutrient waste (Neori et al., 2004). Given the likelihood of dissolved nutrient waste from salmon farms dissipating well beyond farm boundaries, broad-scale effects of nutrification on macroalgal communities should be considered within fish-farm management frameworks.

Although of great ecological and economic significance, few studies have addressed the issue of fish farming impacts on nearby reef communities (Ruokolahti, 1988). Most of what is known relates to the Baltic, where Ronnberg (1991), Ronnberg et al. (1992) and Hemmi et al. (2005) observed increased growth and biomass of epiphytes on *Fucus* near fish farms, with a shift from brown and red epiphytes to green epiphytes towards farms. Vadas et al. (2004) found increases in the foliose green alga *Ulva* near fish farms in Maine. Boyra et al. (2004) also found significant differences between intertidal macrobenthic assemblages near fish farms and at control locations. In the Mediterranean, significant losses of seagrass communities have been associated with fish farms (Dolenec et al., 2006; Holmer et al., 2008; Perez et al., 2008). Virtually nothing is known on the overall scale and nature of such influences on subtidal macroalgal assemblages.

In Australia, farmed salmonids are, by gross value, the most valuable fisheries product and now account for the largest quantity of fish produced in Australia, surpassing the Australian sardine in 2011 (ABARE, 2014). Almost all (97%) of Australia's $497 million of salmonid production occurs in Tasmania (ABARE, 2014), and between 1996/97 and 2011/12, Tasmanian salmon production levels increased sixfold from 7647 to 43,989 tonnes (ABARE, 2013). The most concentrated region of fish farming in Tasmania occurs in the D'Entrecasteaux Channel and adjoining Huon Estuary – a 40-km long bifurcated and semi-enclosed water body. Salmon farming is considered the major source of anthropogenic nutrient input to the waters of the region (Macleod and Helidoniotis, 2005). In 2000, The Huon Estuary Study Team estimated that of the nitrogen contained in fish feed, 36% is retained as harvested fish, and the remaining 64% released into the estuary through metabolic waste or uneaten feed. While seasonal variation in biogeochemical attributes of the area are well enough understood to have motivated a voluntary moratorium on increased use of fish feed in the Huon Estuary (Crawford, 2003), significant growth of the industry has continued in the adjacent D'Entrecasteaux Channel, and the relationship between distance from fish farms and the characteristics of reef macroalgae assemblages has not been investigated locally.

In this project, we investigate scale and nature of the ecological impacts of fish farming on temperate macroalgal communities in the D'Entrecasteaux Channel, with the ultimate aim to improve monitoring of reef assemblages in fish farming areas and inform the adaptive management of current and future impacts. We address two specific research hypotheses: (1) macroalgal assemblages are locally influenced by nutrient inputs to fish farms, and as a consequence vary with distance from farms; (2) patterns of variation with distance from farm are also influenced by reef depth and exposure.

2. Methods

2.1. Reef selection

To locate potential study sites, spatial data on the distribution of marine farm lease areas and benthic marine habitats in the Bruny Marine Bioregion were collated in ArcGIS 9.3 (ESRI), and reef sites 0.1, 0.4, 2 or 5+ km from the boundaries of fish farm leases were identified (Fig. 1). These distances were chosen because effects of nutrient drift were likely to decrease exponentially with distance from fish farms. Any reefs close to an onshore source of marine pollution (determined by a spatial dataset for foreshore pollution sources (Migus, 2008)) were then excluded from the set available for selection. Ten spatially well-separated reefs were chosen from those available in each distance class, which varied in their exposure to swell and wind. Alternative site locations were also identified in case some selected sites were not rocky reef.

2.2. Field data collection

Spatial coordinates extracted from ArcGIS were used to locate predetermined field sites. Each site was first scoped with a depth sounder to determine the reef depth and extent. If the site was determined unsuitable, an alternative *a priori* identified site was surveyed or the number of sites investigated was reduced. The final 44 sites were surveyed between 17 November and 17 December, 2008.

As the effect of fish farms on macroalgal composition was expected to vary with depth, reefs were sampled at two depths (2 m and 5 m) where possible. A transect tape of 50 m length