Aquaculture 452 (2016) 88–96

Contents lists available at ScienceDirect

Aquaculture

journal homepage: www.elsevier.com/locate/aqua-online

Efficiency of starfish mopping in reducing predation on cultivated benthic mussels (*Mytilus edulis* Linnaeus)

Julia Calderwood [a,b,*], Nessa E. O'Connor [a,b,c], Dai Roberts [a,b]

[a] Queen's University Marine Laboratory, 12-13 The Strand, Portaferry, Co. Down, Northern Ireland BT22 1PF, UK
[b] School of Biological Sciences, Medical Biology Centre, Queen's University Belfast, 97 Lisburn Road, Belfast BT9 7BL, UK
[c] Institute of Global Food Security, Queen's University Belfast, 18-30 Malone Road, Belfast BT9 5BN, UK

ARTICLE INFO

Article history:
Received 17 June 2015
Received in revised form 10 October 2015
Accepted 18 October 2015
Available online 22 October 2015

Keywords:
Asterias rubens
Mytilus edulis
Predation
Starfish mop
Aquaculture
Fisheries

ABSTRACT

The starfish, *Asterias rubens*, preys on mussels (*Mytilus edulis*), which are relaid during benthic cultivation processes. Starfish mops, a modified dredge used to remove starfish from mussel cultivation beds, are used in several fisheries today but few studies have attempted to quantify the effectiveness of this method in removing starfish. This study tested the effectiveness of starfish mopping to reduce starfish numbers on mussel beds in Belfast Lough, Northern Ireland. Video surveys to determine starfish densities on mussel beds were conducted between October 2013 and December 2014 using a GoPro™ camera attached to starfish mops. This allowed us to firstly test whether starfish density varied among mussel beds and to investigate how fluctuations in starfish numbers may vary in relationship to starfish ecology. We then estimated the efficiency of mops at removing starfish from mussel beds by comparing densities of starfish on beds, as determined using video footage, with densities removed by mops. Starfish abundance was similar among different mussel beds during this study. The efficiency of mops at removing estimated starfish aggregations varied among mussel beds (4–78%) and the mean reduction in starfish abundance was 27% (±SE 3.2). The effectiveness of mops at reducing starfish abundance was shown to decline as the initial density of starfish on mussel beds increased. It can be recommended that the exact deployment technique of mops on mussel beds should vary depending on the density of starfish locally. The area of mussel bed covered by mops during a tow, for example, should be less when starfish densities are high, to maintain efficiencies throughout the full length of tows and to optimise the removal of starfish from mussel beds. This strategy, by reducing abundance of a major predator, could assist in reducing losses in the mussel cultivation industry.

Statement of relevance: Starfish mops are often utilised during benthic mussel cultivation where predation from starfish threatens mussel crops. Although mops appear to remove starfish from mussel beds there is uncertainty as to their exact effectiveness and there is scope to enhance efficiency of this predator removal technique. This research used a novel method of attaching GoPro cameras to starfish mops deployed from mussel dredgers to investigate the effectiveness of starfish mops in removing predatory starfish from commercial mussel beds. This work was the first study conducted to assess the effectiveness of this predator removal technique since the 1940s and the use of underwater video footage gives greater insight into the efficiency of starfish mops as a predator removal technique for use within bivalve aquaculture.

We found that efficiency of starfish mops varied temporally and discovered a density dependent relationship between the efficiency of starfish mops and the density of starfish encountered. These findings have particular relevance to on-growing of mussels in benthic cultivation in addition to the culture of other bivalve species. By providing insight into the ecology of starfish feeding on mussel beds and furthering knowledge on how best to remove predatory starfish species from the seabed in areas where they could affect the output from mussel fisheries this research is highly relevant to mussel cultivators.

1. Introduction

Starfish are frequently described as keystone species, acting as major predators within subtidal and intertidal communities (Aguera et al., 2012; Himmelman et al., 2005; Paine, 1966). *Asterias rubens*, a starfish with a distribution ranging from Arctic to Boreal regions, is an important component of soft bottom benthic communities throughout Europe (Anger et al., 1977; Guillou, 1996; Nichols and Barker, 1984). It is an opportunistic and voracious predator with the ability to feed on a variety of crustaceans, molluscs and echinoderms, utilising chemoreception and chemically mediated prey location to find suitable food sources

* Corresponding author.

http://dx.doi.org/10.1016/j.aquaculture.2015.10.024
0044-8486/

(Hancock, 1955; Sloan, 1980). *A. rubens*, along with several other starfish species within the genus *Asterias*, exhibit large population density fluctuations and are known to form dense aggregations (Sloan, 1980; Uthicke et al., 2009). High densities of *A. rubens* have frequently been reported at numerous locations across Europe and Russia since a dense aggregation was first reported, feeding on oyster beds, in the Firth of Forth, Scotland in 1841 (Dare, 1982, 1973; Forbes, 1841; Guillou, 1996; Hancock, 1955; Saier, 2001; Sloan and Aldridge, 1981; Sloan, 1980). These dense starfish populations are often associated with an abundant prey source and are known to have significant impacts on associated communities (Aguera et al., 2012; Castilla, 1972; Uthicke et al., 2009).

During the benthic cultivation of mussels (*Mytilus edulis*) small seed mussels are collected from high density offshore sites where there is competition for food and space, and are returned to sheltered inshore sites with a good food supply where they are spread at lower densities and grow to a marketable size within approximately two years (McQuaid et al., 2007; Smaal, 2002). Mussel cultivation sites can occupy large areas with mussels often being relaid at densities of between 25 and 75 tonnes per hectare (McQuaid et al., 2007). Mussels, when relaid on the seabed as part of benthic cultivation operations, thus, provide starfish with an abundance of prey in their natural environment (Barbeau et al., 1998; Miron et al., 2005). Consequently marine farming activities may influence the size and dynamics of aggregating starfish populations (Inglis and Gust, 2003). Observations of dense aggregations of starfish moving towards prey sources have noted particularly high densities of individuals within feeding fronts with 47 and 78 starfish m^{-2} being recorded on mussel beds in Morecambe Bay and the Wadden Sea respectively (Aguera et al., 2012; Dare, 1982; Saier, 2001). Starfish within such dense populations act as highly efficient predators, increasing their consumption when they encounter high-density prey patches, with aggregations in Morecambe Bay having been noted to advance up to 200 m a month destroying mussel beds that lay in their path (Dare, 1982; Inglis and Gust, 2003). *A rubens* is thought to be one of the most destructive species feeding on beds of cultivated mussels, as well as on natural populations, in northern Europe (Dare, 1982; Gallagher et al., 2008).

In areas where starfish occur in high densities it is often deemed necessary for these predators to be removed from mussel beds to help reduce losses within the benthic cultivation industry. The use of baited crab pots, as used to remove predatory crabs from mussel beds, have also been shown to attract starfish in some areas (Calderwood et al., 2015a,b). Thus there may be an additional need to tackle and reduce inflated starfish numbers in areas where pots are deployed. Individual starfish typically consume around 0.5 mussel per day although maximum feeding rates of 0.8 mussels per hour have been recorded for larger individuals (Aguera et al., 2012; Calderwood et al., 2015a; Kamermans et al., 2009; Bettina Saier, 2001; Vevers, 1949). In areas, such as Menai Straits, Wales, where benthic mussel cultivation occurs with starfish densities of 4 m^{-2}, it is estimated that starfish are responsible for removing at least 20,000 mussels per hectare per day (Gallagher et al., 2008). American shellfish growers have attempted to control starfish populations since the middle of the 19th century through the adoption of numerous methods (Barkhouse et al., 2007; Galtsoff and Loosanoff, 1939; Lee, 1951). A number of mechanical methods have been used including the use of dredges and suction dredges in areas with particularly high concentrations of starfish (Galtsoff and Loosanoff, 1939). Another common control measure is the use of starfish tangles or mops. Although the exact design can vary, starfish mops generally consist of a modified dredge which has a number of lengths of chain, attached at regular intervals perpendicular to the dredge bar, onto which are attached small sections of knotted and frayed rope (Fig. 1). Mops are slowly dragged across the surface of mussel and oyster beds, starfish become entangled in the ropes and the mops are raised to the surface where starfish are removed from the mops by hand (Galtsoff and Loosanoff, 1939; Lee, 1951; Smith, 1940). Dredgers usually move forwards and backwards over aquaculture plots, deploying mops from alternating sides of the ship, in an attempt to clear areas of starfish. Mopping is thought to result in less damage to shellfish beds compared to dredging and be generally more efficient, depending on substratum type and working conditions, although little work has been done to determine the exact efficiency of such starfish removal techniques (Barkhouse et al., 2007; Galtsoff and Loosanoff, 1939).

Fig. 1. GoPro™ camera on the starfish mop deployed from the starboard side of a mussel dredger in Belfast Lough.

Despite uncertainty of effectiveness these mopping techniques are still widely used in the benthic mussel cultivation industry in an attempt to remove starfish from cultivation beds. Although mops appear to remove starfish from mussel beds, there is scope to enhance efficiency. In addition, there is a need to better understand starfish population dynamics and feeding behaviour in relation to environmental factors and reproductive condition to help determine how mopping efforts could be more cost-effectively focussed both spatially and temporally (Calderwood et al., 2015b; Dare, 1982; Gallagher et al., 2008; Sloan and Aldridge, 1981). By attaching a GoPro™ video camera to starfish mops on a commercial mussel dredger working in Belfast Lough, Northern Ireland, we filmed the mussel bed being swept by the mops. We tested whether the population structure and abundance of starfish on mussel beds differed with: (i) date of mopping; (ii) size of mussels on mussel beds; and (iii) the reproductive condition of starfish on the mussel beds. We also examined whether the efficiency of mops differed with: (i) date of mopping; (ii) size of mussels on mussel beds; (iii) reproductive condition of starfish on mussel beds; and (iv) initial density of starfish on mussel bed being mopped.