Fisheries Research 113 (2012) 45–54

Contents lists available at SciVerse ScienceDirect

Fisheries Research

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

Spatial variation in body size and reproductive condition of subtidal mussels: Considerations for sustainable management

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ARTICLE INFO

Article history:
Received 26 April 2011
Received in revised form
17 September 2011
Accepted 19 September 2011

Keywords:
Subtidal
Mytilus
Spatial structure
Recruitment overfishing
Management

ABSTRACT

Population characteristics such as body size and reproductive condition are widely used by industry and resource managers as criteria for harvesting commercial species. Given the broad-scale approaches commonly adopted by managers to evaluate stocks, any spatial heterogeneity in the structure and functioning of those stocks may result in inaccurate assessments, interpretation and inappropriate management. Spatial heterogeneity in body size and reproductive condition has been shown in intertidal populations of *Mytilus* spp., but no assessment of subtidal structure has been made despite the importance of these populations as a mariculture resource. A spatially stratified sampling programme was used to test hypotheses of differences in bed structure depending on position within the bed. Commercial gears were used to harvest seed mussels and two condition indices were tested to identify a rapid accurate approach to evaluate reproductive condition for resource managers. Differences in the size and condition of mussels were dependent on spatial position within the population, with mussels exhibiting strong seasonal growth patterns. Edge-zone mussels showed both greater reproductive condition and body size than bed centre mussels. Reproductive condition also covaried with body size. Differences in spatial structure and function have the potential to confound stock assessments if appropriate sampling programmes are not utilised. Appropriate survey and reproductive condition assessment methods should be used to support subtidal stock persistence and optimal exploitation practices.

1. Introduction

Throughout Europe, mussels are an important commercial shellfish species (€231 million in 2007; European Commission, http://ec.europa.eu/fisheries/marine_species/farmed_fish_and_shellfish/mussels/index_en.htm). Production has increased dramatically since the 1950s (Caceres-Martinez and Figueras, 1998; Goulletquer and Le Moine, 2002; Smaal, 2002) and cultivation on the Atlantic, North and Mediterranean Sea coasts of France, The Netherlands, Ireland and the United Kingdom contributes over 85% of global production (European Commission, http://ec.europa.eu/fisheries/marine_species/farmed_fish_and_shellfish/mussels/index_en.htm). Cultivation approaches vary widely between countries; raft (Caceres-Martinez and Figueras, 1998; Fuentes et al., 2000), stake (bouchot) (Goulletquer and Le Moine, 2002) and bottom culture (Smaal, 2002) techniques have been developed to utilise favourable site characteristics such as high water flow (flushing) and food availability (Caceres-Martinez and Figueras, 1998; Goulletquer and Le Moine, 2002). Despite differences in culture methods, all of these approaches are entirely dependent on the use of wild seed mussel to prime culture stocks. This requirement coupled with demand for cultivated mussels has led to year-on-year increases in demand for seed mussel at levels which greatly outweigh supply (Maguire et al., 2007).

Despite mussels being ubiquitous throughout Europe dominating both intertidal soft-bottom and rock habitats (Crawford et al., 2006; Lawrie and McQuaid, 2001; Snover and Commito, 1998), seed mussels for cultivation are predominantly harvested from intertidal and subtidal soft-sediment habitats such as the western Wadden Sea and the Irish Sea although water column spat collection is becoming more common. Mussels can form extensive beds covering 100 s m^2 (Dudgeon and Petraitis, 2001; Metaxas, 2001) but differential recruitment rates and post-settlement mortality lead to fragmented populations and beds variable in size and shape (e.g. Knights and Walters, 2010; Menge, 1978; Paine, 1976). In soft-bottom subtidal habitats, populations are subjected to several environmental stressors (e.g. currents, substrate resuspension), and the lack of suitable substrate for attachment may result in highly transient populations (Pulfrich, 1995). Increased shear and pronounced turbulence from currents (Metaxas, 2001) may also redistribute and disperse aggregations of mussels and as a result, subtidal populations are assumed to be prone to

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doi:10.1016/j.fishres.2011.09.002

rapid extinction over potentially large spatial and temporal scales.

There has been very little regulation of seed harvesting in Ireland, in large part due to the assumptions of fisheries managers that (1) subtidal populations are unable to persist for long periods, and (2) the primary source of larvae is derived from intertidal sources (Bord Iascaigh Mhara; John Dennis, pers. comm). As such, subtidal stocks are heavily exploited to the point of localised extinction with little consideration of their contribution toward the maintenance of local and regional populations (Maguire et al., 2007). However, self-recruitment from subtidal sources is likely to make an important contribution to the persistence of both local and regional populations (James et al., 2002). Mussels display a highly adaptive metabolism and can vary both their somatic growth and sexual maturation in response to their surrounding environment. In rocky intertidal habitats, individuals tend to be small to reduce shear from waves and currents and reproduce earlier in the year (Hunt and Scheibling, 2001), whereas soft-sediment subtidal habitat individuals tend to grow larger and reproduce later in the year (Kautsky, 1982b). Individuals become sexually mature after settlement (Kautsky, 1982b; Seed, 1969) and intertidal and subtidal populations produce similarly large numbers of eggs (7×10^8 m^{-2}), despite potentially large differences in body size (Honkoop and van der Meer, 1998; Sprung, 1983). Therefore, removal of large numbers of seed mussel prior to maturation and spawning has the potential to greatly affect the ability of regional populations to self-recruit (Maguire et al., 2007).

In commercial fisheries management, a primary goal is economic and environmentally sustainable exploitation. In order to fully utilise the economic potential of the living resource and to ensure the resource is not exploited beyond its ability to regenerate, several metrics including stock size, reproduction and the level of pressure (i.e. catch size) should be evaluated. These metrics allow resource managers to estimate the limits of pressure (exploitation) a stock can withstand without collapse (Gotelli, 2001). Spawning stock biomass, fishing mortality, catch/landings (e.g. CPUE) and abundance are all common measures in finfish fisheries (see ICES Advice for stock specific information, http://www.ices.dk/products/icesadvice.asp) and precautionary (pa) and maximum limits (lim) are defined to indicate the level of sustainable exploitation. In European mussel fisheries, no such limits are defined despite calls to do so (e.g. Caceres-Martinez and Figueras, 1998; Maguire et al., 2007) although some simple metrics are routinely evaluated. Shell thickness (a measure of robustness to reduce damage during harvesting), relative abundance and reproductive condition are all measured (BIM; John Dennis, pers. comm), however, these metrics are generally evaluated to support exploitation by producers rather than for stock protection purposes.

Considerable annual investment is made by fisheries managers to (1) identify and assess subtidal populations using simple metrics, (2) map the location of subtidal seed beds, and (3) publicise the location of those seed beds. In the Irish Sea, attempts to quantitatively assess subtidal populations have been problematic. The location of subtidal beds is variable year-on-year, although some common geographic areas of settlement are apparent. Variable supply and settlement success of larvae and post-settlement mortality from competition (e.g. Connell, 1961; Knights and Walters, 2010) and predation (starfish, *Asterias rubens* and gastropod, *Nucella lapillus*) (Gaymer et al., 2001, 2004; Gaymer and Himmelman, 2002) can greatly affect recruitment and decimate populations in the short term resulting in highly fragmented populations over large spatial scales.

Our limited understanding of the basic ecology of subtidal populations e.g. where patches form and why, and rates of growth and reproductive development within a patch, are yet to be described, making management of the resource difficult. Using studies of populations in more widely accessible habitats (e.g. intertidal) may provide some insights of the ecology of subtidal populations and help guide their management. For example, in intertidal habitats, structural differences in body size and development in relation to position within a patch have been described. Larger individuals are generally spatially distributed near to, or at the edge of patches and smaller individuals with lower reproductive condition located toward the centre of a patch (Alvarado and Castilla, 1996; Kautsky, 1982a; Newell, 1990; Svane and Ompi, 1993). Heterogeneity in body size (shell thickness) and reproductive condition at the within-bed scale has the potential to greatly confound interpretation of population condition. If subtidal populations display similar heterogeneity to intertidal populations and without knowledge of where in a patch you are extracting samples from, condition metrics such as gonad development/maturity, may indicate spawning is complete if the sampled individuals were from the edge of the bed. Should harvesting ensue based on this estimate, large numbers of individuals from the centre of the bed may be removed prior to spawning and possibly greatly limiting self-recruitment.

With this limitation in mind, the aim of this study was three-fold. Firstly, to evaluate approaches to rapidly estimate reproductive condition. A rapid and accurate technique of assessing reproductive condition would allow managers to identify the period when spawning is complete and allow management options to be implemented to enhance the likelihood of self-recruitment. Secondly, to determine whether subtidal *Mytilus* beds exhibit a differential size and reproductive structure in relation to position within the bed, and third, can differences in bed structure be detected using commercial dredging gears?

2. Materials and methods

2.1. Study system

The study was carried out in the Blackwater region of the Irish Sea off the coast of County Wexford, Ireland (Fig. 1). The area is a flat plateau composed of slightly gravely-sand (Source: Bord Iascaigh Mhara and Geological Survey Ireland) at a depth of approximately 25 m. BIM identified a large subtidal bed in early October 2004 following spawning in late July 2004 (Maguire et al., 2007). A preliminary survey using a Baird grab (sampling area = 0.5 m^2) and underwater video was used to estimate the spatial extent of the bed indicating an approximate area of 1.6 km^2 (3600 m × 450 m) (Fig. 1). Severe weather conditions between July and October 2004 prevented any commercial fishing of this population prior to the closure of the fishing season in late September 2004 and sampling of the population was undertaken in February, April and June 2005. Sampling beyond June 2005 was not possible as the commercial fishing fleet was granted access and the bed was exhaustively harvested in July 2005.

2.2. Survey design

A stratified sampling design was used to test the hypotheses that both shell length and reproductive condition vary with position within the bed. The bed was spatially stratified into three distinct zones; Edge-west (EW), Middle (M), and Edge-east (EE), with each zone stratified in a north–south direction. Each zone was arbitrarily defined, based upon the initial population size estimation by BIM, as one-third of the bed area resulting in zones 150 m wide (east–west) by 2600 m long (north–south) (Fig. 1). The full north–south extent of the bed (3600 m) was not used to allow a 500 m buffer zone at each end of the Middle (M) zone to allow for 'edge effects' that were predicted to surround the entire bed. Within each zone, three sites were randomly selected from a series of pre-defined point