# The Ecology of Seed Mussel Beds

# Literature Review

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# 1 Summary

- Mussel (*Mytilus edulis*) cultivation is the main form of molluscan shellfish production in the UK, worth ~£4.7 million in 2001, about two thirds of which came from Wales.
- The commercial mussel industry is dependent on harvesting wild seed mussel beds. Important areas for seed mussel harvest are Caernarfon Bay, Morecambe Bay, South Wales and the Wash.
- The main period of mussel larval settlement (spatfall) in the UK is spring. The main determinants of settlement rates are i) substratum availability, ii) climatic and hydrodynamic factors and iii) adult abundance where the system is relatively closed (e.g. the Wash, the Wadden Sea). Spat settle preferentially on to hard substrata, or on to filamentous substrata such as algae, with a secondary dispersal phase on to hard substrata. Summer growth is rapid but mortality rates are also high and increase as the year goes on. Main sources of mortality are smothering due to the biodeposition of sediment by the mussel bed ("mussel mud"), wave or tidal scouring and predation. Seed mussel beds are frequently dispersed and lost in autumn or winter.
- Important predators on seed mussel beds are i) starfish, (*Asterias rubens*), ii) crabs (*Cancer pagarus* and *Carcinus maenas*) and iii) fish (plaice *Pleuronectes platessa*, flounder *Platichthys flesus*, dab *Limanda limanda*), with crabs and starfish likely to have the greatest impact on mortality. Birds are not likely to be important predators on seed mussel beds. Predation on seed mussel beds may have secondary ecological effects since crabs and starfish are important as predators and prey or other species.
- Seed mussel beds are likely to have strong effects on benthic community structure due to competition for space and by changing the nature of the sediment through biodeposition. Mussels enhance some species (particularly mobile epifauna) by providing structure and food. Generally, however, both number of individuals and species richness of benthic communities declines in mussel beds compared to control sites, with edge effects extending a few metres outside the bed.
- Seed mussels probably have an important effect on local nutrient fluxes since active filter feeders such as mussels promote the cycling of nutrients between the water column and the sediment. This may in turn enhance local phytoplankton production and hence food availability to the system.
- The main direct impact of seed mussel exploitation is through dredging, which releases sediment into the water column. However the accumulation of mussel mud in seed beds detaches the bed from the substratum, meaning that dredging can often leave the underlying (pre-settlement) substratum relatively undisturbed. The main impacts of seed mussel exploitation are likely to be indirect ecological effects.
- The main proposed alternative to natural seed mussel bed exploitation is spat collection using water column rope collectors. These have worked well in trials in the Wadden Sea, but are not economically viable for large scale bottom culture, such as in the Menai Strait.
- Exploited seed mussel beds in the area of interest for this project (Morecambe Bay, Caernarfon Bay) are generally in sites which are relatively predictable from year to year, although the magnitude of settlement is highly variable. In Morecambe Bay, settlement is concentrated on patches of hard substratum in the intertidal, while in Caernarfon Bay, settlement is in the subtidal.
- In intertidal seed beds in Morecambe Bay there are two main mechanisms of natural mortality and dissipation of the beds: loss due to physical damage from storms and mass mortality of mussels for reasons which remain unexplained. Mechanisms involved in the dissipation of subtidal beds are unknown, although starfish predation is sometimes important and storm damage is probably also a factor.

# 2 General Introduction

The seabed cultivation of mussels generates the greatest revenue of any molluscan shellfish cultivation in the UK. Production in 2001 was 14,900 tonnes, worth £4,736,000 (data from DEFRA and the Scottish Executive). About two thirds of UK production of mussels comes from Wales; much of which is from lays in the Menai Strait (Fig. 1).

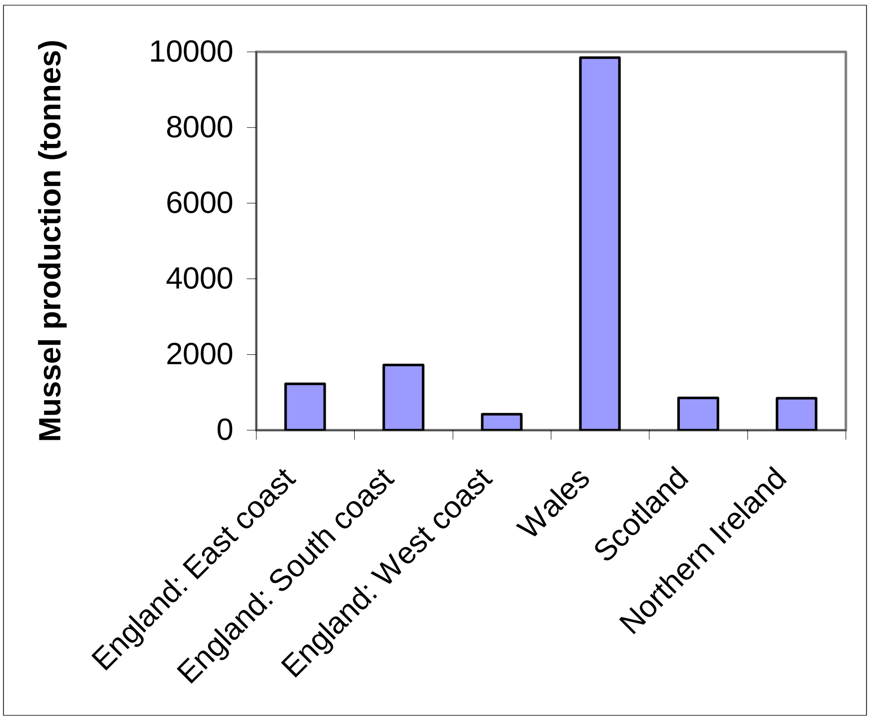


**Fig. 1.** Wales is the most important mussel producing area in the UK (2001: Data from DEFRA and the Scottish Executive).

The industry is dependent on the irregular supply of seed mussels harvested from wild subtidal stocks. Wild seed mussels are harvested using dredges and relaid on commercial beds in sites leased from the Crown Estate via the Sea Fisheries Committees in England and Wales and via the Scottish Executive in Scotland. At present, little is known about the ecological importance of seed mussel beds or the ecological consequences of harvesting them. Most existing knowledge of mussel ecology comes from research on intertidal seed beds or adult mussel beds.

North Wales is the main mussel farming region in the UK. Production from lays in the Menai Strait was c. 11,000 metric tonnes in 2003 (Kim Mould, Myti Mussels, pers. comm.), representing more than half of the current production in the UK. Other areas where the is bottom culture of mussels include Poole Harbour, Morecambe Bay, the Wash, the River Exe and the Dornoch Firth, Scotland.

In the Menai Strait-based industry, seed mussels are collected by dredging seed beds elsewhere (e.g. Morecambe Bay, Caernarfon Bay). They are re-laid on the muddy substrata in the Menai Strait for on-growing. Mussels are laid first in the intertidal zone for c. 18 months, until they grow large enough to reach a partial predation refuge. The mussels are then moved into subtidal lays for a final period of rapid growth. Mussels are marketable when they reach a shell length >45 mm, a process that takes approximately 2½ years from the settlement of spat to the harvesting of marketable mussels (Pillay, 1993, Kim Mould, Myti Mussels, pers. comm.).

The dynamics of seed mussel beds are driven by recruitment (spatfall) and mortality from food limitation, predation and interaction with the physical environment. The commonly held belief is that seed mussel beds (like mussel beds in general) are vulnerable to storm damage or tidal scouring and are often dispersed during the winter (Nehls and Thiel, 1993; Reusch and Chapman, 1995; Hilgerloh *et al.*, 1997). Predation could also be responsible for the decline of the beds (Herlyn and Millat, 2000; Hilgerloh *et al.*, 1997). Even if the beds are ephemeral, however, harvesting during the summer may cause impacts on other species that may depend on mussel seed resource at that time.

In this review, we bring together the available information on seed mussel biology, ecology and the potential impacts of harvesting. In Section 3, we briefly review mussel reproductive, larval and post-larval biology. In Section 4, we examine the interaction of seed beds with physical processes. In Section 5, we consider the ecological role of mussel seed beds as i) a food source of predators, ii) consumers of phytoplankton, iii) dominant members of the benthic community and iv) mediators of carbon and nutrient fluxes. Section 6 sets out the limiting factors for seed mussel production. In Section 7, we examine the potential impacts of the process of dredging seed. Section 8 looks at proposed alternatives to seed mussel collection and bottom culture, while Section 9 reviews the information available on specific seed mussel beds in the main areas of interest (Caernarfon Bay, Conwy Bay and Morecambe Bay).

# 3 Mussel Reproductive and Larval Biology

## 3.1 *General mussel biology*

The blue mussel, *Mytilus edulis* (Bivalvia: Mytilidae) is a sessile bivalve. Adults generally occur in the intertidal zone, in temperate latitudes. Mussels can withstand wide variation in salinity, desiccation, temperature and oxygen concentration, resulting in the ability to occupy a large variety of microhabitats (Seed and Suchanek, 1992). Mussels can be found on any substratum providing a secure anchorage (Seed, 1976) such as rocks, stones, gravel, shingle, dead shells, and even mud and sand, where they attach to each others or to debris. Mussel beds are often dominant in terms of biomass, and form a key component of many marine communities (Herman, 1993; Seed, 1976). These beds support their own diverse communities as the mussel matrix, composed of layers of mussels with accumulated sediments and debris, provides numerous microhabitats and an organically enriched environment (Ragnarsson and Raffaelli, 1999).

## 3.2 *Distribution*

*M. edulis* has a broad global distribution (Gosling, 1992), which is principally influenced by seawater temperature (Seed, 1976). On a smaller scale, mussels (and communities of filter feeding bivalves in general) tend to do best in areas, such as open water or estuaries, where the energy of the water flow is sufficient to provide food and remove waste (faeces and pseudofaeces) and inorganic material (Seed, 1976; Dame and Prins, 1998). Generally, mussels are highly dependent on water column dynamics (Dame and Prins, 1998). In the intertidal, the upper distributional limit of *M. edulis* is determined by physiological intolerance to extreme temperature and desiccation, whereas the lower limit is strongly influenced by predation (Paine, 1974; Seed and Suchanek, 1992).

## 3.3 *Mussel reproductive biology*

*M. edulis* is gonochoristic (has separate sexes) and usually has a 1:1 sex ratio (Seed, 1976). The reproductive tissue is creamy-white for males and orange for females (Seed, 1976; Seed and Suchanek, 1992). Mussels can be sexually mature after one year (Seed, 1976), although growth and time to maturity varies with temperature and the physical environment. Gametes are released into the water column where fertilisation occurs.

Mussels follow a reproductive strategy of producing a very large number of gametes and hence planktonic larvae, of which a small proportion survive to settle and establish in the seabed (McGrorty *et al.*, 1990). Mussels can adapt their reproductive strategy depending on environmental conditions, hence the reproductive cycle depends on the population's geographical situation (Seed and Suchanek, 1992). In the Irish Sea, the development of the gonad generally starts during October and November and is followed by gametogenesis during the winter months. A partial spawning occurs in spring, followed by rapid gametogenesis until early summer. Less intensive spawning takes place throughout the summer (Dare, 1976). From late August to November, the mantle tissue thickens with nutrients to prepare for winter gametogenesis (Seed and Suchanek, 1992). An extended period of reproduction with repeated spawning in spring and summer is sometimes seen in mussels growing under favourable nutrients conditions (Rodhouse *et al.*, 1984).

After fertilisation occurs, the fertilised zygotes undergo several metamorphoses before settlement (Fig. 2). Mussels settle after the sixth larval stage (postlarval or plantigrade; Fig. ), at a size of 250-350µm (Bayne, 1964). The planktonic life of *M. edulis* varies from 2-4 weeks depending on temperature, food supply and availability of suitable settlement substratum; hence it can take 10 and more weeks between the fertilisation and the settlement of the mussel (Seed and Suchanek, 1992). Mussel larvae are present in the plankton throughout the year, although most numerous from April – July in the Irish Sea (Seed, 1969a, Dare, 1976).

Peak settlement (spatfall) occurs in spring. Newly settled *M. edulis* postlarvae attach themselves to a suitable surface with secreted byssus threads and start to develop a shell. At this stage they are still highly mobile and may release their byssal threads and return to the water column if their settlement site proves unfavourable. This process of secondary migration peaks in May in Morecambe Bay (Dare 1976). When they reach a size of ~20mm length, they are called seed mussels and can be harvested for cultivation.

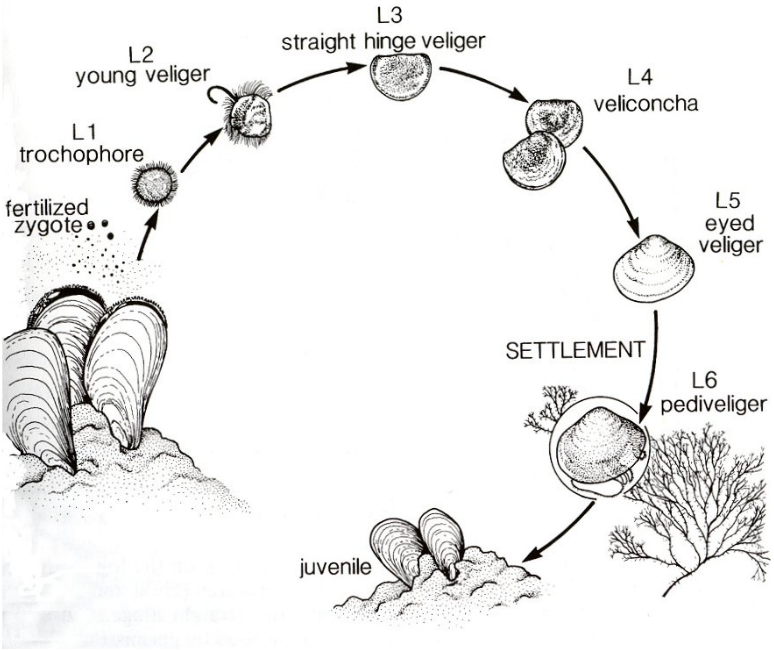


**Fig. 2.** Larval and postlarval life history of *M. edulis*. The postlarval plantigrade is not shown. From Wildish and Kristmanson, 1997, based on photomicrographs and figures in Bayne, 1976.

### 3.4 Factors influencing larval settlement

The settlement pattern of most marine invertebrate larvae is influenced by both biological and physical processes (Pernet *et al.*, 2003). On reaching a critical size, larvae search for a substratum to attach to (Brinkman *et al.*, 2002). Hydrodynamics play an important role in encountering substrata, and to some extent larvae can be regarded as inert particles deposited passively to settlement sites (Hannan, 1984). The surface complexity of the seafloor also plays an important role in formation of seed mussel beds (Commito and Rusignuolo, 2000), and larval settlement is affected by the interaction between flow and substratum heterogeneity (Lapointe and Bourget, 1999; Hills *et al.*, 1999). Various artificial substrata have been tried for seed mussel collection, and this is discussed further in Section 8.

In order to attach, the spat has to move across the surface until it encounters a solid and large enough substratum (pebble, shell debris, gravel, other mussels etc.; Young, 1983). Rough surfaces with niches, crevices or grooves are most favoured (Dare and Edwards, 1976; Seed, 1976;Young, 1983). In Morecambe Bay, it was found that settlement succeeded only on ground devoid of mud and loose accumulation of shell Dare, 1976). Once a wide range of small mussels are attached to a clump, their movement declines rapidly and the stabilisation of the bed begins (Young, 1983).

Thus larvae do not act solely as passive particles, and biological factors are also important in mussel settlement. Primary settlement is influenced by nearby biota which presumably exude chemical cues (Dobretsov and Wahl, 2001). Mussel larvae are attracted to conspecifics, causing aggregation in dense mussel beds (Seed, 1969a; Young, 1983). In the intertidal, spat frequently settle on established adult mussel beds (McGrorty *et al.*, 1990). Settlement also occurs on other biological substrata such as algae and hydroids (Seed, 1969a; Verwey, 1952). This may be due to chemical cues or to the structure of their surface (De Blok and Geelen, 1958), although larvae may be trapped passively by mucus threads rather than actively choosing these substrata (Caceres-Martinez *et al.*, 1994).

Spat often settle consistently on the same area every year. In small estuaries, they rarely settle elsewhere than on established beds (McGrorty *et al.*, 1990). In other intertidal areas, such as Morecambe Bay (Dare, 1976) and in the Wadden Sea, spat settle onto stony “skears” or sand to form new beds (McGrorty *et al.*, 1990). These seed mussel beds develop regularly in the same place, but unlike a mature bed, their survival rate is low due to their instability (Dankers *et al.*, 2001; see below).

Older seed mussels do well in the crevices formed by mussels on mussel banks, but these sites can be unfavourable for young spat (Maas Geesteranus, 1942; McGrath *et al.*, 1988). There are thus large secondary migrations of young mussel spat to seek out favourable conditions, which may chance as they grow (De Blok and Geelen, 1958). It is possible that further migrations can take place even when the mussels are fairly large. In extremely dense mussel beds, mussels are often observed to have byssal threads which are very loose or completely missing. Possibly this is an adaptation for transport to a better environment, or it may simply be a reaction to stress (Bill Cook, North Western and North Wales Sea Fisheries Committee (NW&NWSFC) pers. comm., authors pers. obs.).

## 4 Physical Factors in Seed Mussel Beds

Even after settlement, the dynamics of seed mussel beds, as with all filter feeding organisms, are controlled by a feedback between biotic and physical processes (Dankers *et al.*, 2001). Mussels depend on water column movement for food, as well as to transport the mussel larvae which settle to form the seed bed. Mussel beds often form in highly energetic areas with high flow rates and turbulent near bed mixing. Mussels play an important role in "benthic-pelagic coupling" in these areas, by transferring material from the water column to the sea bed.

A multivariate analysis of physical factors in seed mussel beds in the Wadden Sea predicted the distribution of spatfall in two years (1994 and 1996) quite successfully, suggesting that physical factors play an important role in determining the formation of seed mussel beds, although it is not clear whether physics impacts most upon the settlement process or survival after settlement (or both). Seed mussel beds in this area formed preferentially in the low intertidal zone, in areas of low wave orbital velocity and medium overall flow (not very high or very low) and not in areas of coarse sand or silt (Brinkman *et al.*, 2002).

Mussels are active filter feeders, capable of processing large volumes of water through their gills (Jørgensen, 1990). This results in a continuous flux of particulate matter from the water column to the bivalve beds (Smaal and Prins, 1993). The rate of particle sedimentation in cultivated mussel beds can be 2 to 3 times higher than comparable locations without mussels (Inglis *et al.*, 2000). Mussels thus have a large impact on the seston flux in the water column (Dame *et al.*, 1991). Filtered inorganic material is either ingested, resulting ultimately in faeces production, or rejected prior to ingestion as pseudofaeces (Bayne *et al.*, 1976; Smaal, 1991). The deposited material is enriched in organic content.

Only a fraction of the suspended particulate matter (SPM) filtered by the mussel population is stored as deposits in the sediments (Dame *et al.*, 1991). The majority of filtered and biodeposited material is resuspended immediately (Smaal *et al.*, 1986). Mussel faecal material is easily resuspended relative to non-biogenic sediment due to its low density and high water content (Stuart *et al.*, 1982), particularly in the energetic environments in which mussels are found (Dame *et al.*, 1991). Furthermore, resuspended mussel biodeposits have been found to settle extremely slowly compared to inorganic sedimentary material (Kautsky and Evans, 1987). Hence mussel beds increase sediment flux both from water column to bed and from the bed back to water column, and mussel biodeposits may contribute significantly to the total suspended load in estuarine and coastal environments (Kautsky and Evans, 1987).

As the seed beds mature, they initially stabilise the sediment matrix by increasing the sedimentation rate from the water column (Dankers *et al.*, 2001). However, mussel faeces and pseudofaeces production together with accumulated shells and silt eventually result in a build up of "mussel mud" beneath seed mussel beds (McGrorty *et al.*, 1990). This "mussel mud" layer can create an elevation of 30-40 cm above the surrounding bed (Higerloch *et al.*, 1997), and may cause the whole bed to detach from the underlying substratum and become unstable (Nehls and Thiel, 1993; Reusch and Chapman, 1995). The most likely hypothesis to explain the ephemeral nature of seed mussel beds is that they are dispersed each winter with the onset of autumn storms, although density dependent secondary migration (see above) or predation (see below) may also be important (Nehls and Thiel, 1993; Reusch and Chapman, 1995; Hilgerloh *et al.*, 1997). It is important to bear in mind that many of the seed beds studied are also those which are fished, and dredging is likely to destabilise seed beds (although there is some as yet unpublished data that indicates that the opposite may be the case). Studies in the German Wadden Sea show that most of the seed mussel beds which were partially fished disappeared after fishing activity occurred, whereas the non-fished beds and bed areas remained (Herlyn and Millat, 2000). On the other hand, mussel farmers who dredge in Caernarfon Bay suggest that dredging may prolong the life of a bed such that it lasts through the winter. This is possible if a reduction in density due to dredging means that the mussels do not loosen their byssus as happens in more dense beds (K. Mould, Myti Mussels, J. Wilson, Deep Dock Mussels pers. comm.).

Even if physical forces do not cause the destruction of the entire seed mussel bed, it is likely that physical factors are responsible for a high proportion of the mortality of individual mussels within the bed. Smothering by biodeposits is a major cause of mortality in seed beds, and tidal scour or wave action can remove clumps of mussels within a bed (Dare, 1976).

# 5 Seed Mussel Ecology

## *5.1 Predators*

Mussels have many predators that significantly determine their local distribution (Seed, 1969b). The main predators of bottom-grown cultivated mussel and natural mussel beds in the Northern Europe are starfish (*Asterias rubens*), crabs (*Cancer pagarus* and *Carcinus maenas*) and birds (oystercatcher *Haematopus ostralegus* and eider duck *Somateria mollissima*) (Dare, 1976; Dare, 1980). Oystercatchers are important in the intertidal zone, starfish in the subtidal and crabs in both. Other predators include gastropods (*Nucella lapillus*), lobsters (*Panulirus interruptus* and *Homarus americanus*), flatfish (*Platichthys flesus*, *Pleuronectes platessa*, *Limanda limanda*) and seals (see Seed, 1969b; Seed and Suchanek, 1992 and references therein). The magnitude of predation pressure and the identity of the main predators depend on mussel size, season and height relative to the shore and location (Hamilton *et al.*, 1999).

*Birds*

Oystercatchers predate on mussels mainly in winter during the migration of large flocks (Craeymeersch *et al.*, 1986; Seed and Suchanek, 1992); they do not occur in any numbers during the period of seed production. Oystercatchers target larger size classes, from 25 to 55 mm mussel shell length in the intertidal (Goss-Custard *et al.*, 2004; Meire, 1993). It therefore seems unlikely that oystercatchers are significant predators on seed mussels. Eider duck are subtidal predators on mussels (Nehls *et al.*, 1997), but again, they usually feed on larger mussel size classes (Meire, 1993; Goss-Custard *et al.*, 2004). Oystercatcher and redshank population have been increasing in the Menai Strait, possibly as a consequence of mussel cultivation, and the loss of the mud flat to mussel cultivation has not had a detrimental effect on other bird species in the area (Caldow *et al.*, 2003).

*Fish*

Various species of flatfish are known to take mussels in flat sandy areas (Seed, 1969b). A stomach content analysis of flounder (*Platichthys flesus*) and plaice (*Pleuronectes platessa*) from Morecambe Bay showed that seed mussels were an important component of the diet, with flounder stomachs containing an average of 150 seed mussels and plaice stomachs an average of 105, from 1-15 mm long (Dare, 1976). Dab (*Limanda limanda*) are also reported to feed on mussel spat (Seed and Suchanek, 1992). In New England, fish such as the cunner (*Tautogolabrus* sp.) may play a significant role in controlling the vertical distribution of *M. edulis* (Edwards *et al.*, 1982).

*Starfish*

Starfish are mainly present in the subtidal and lower intertidal (Seed, 1976), and are attracted to mussel beds through their well developed olfactory sense. They generally feed on mussels <35 mm (O'Neill *et al.*, 1983). They constitute a potential major predator for mussel seed, particularly in subtidal areas, and can alter community structure (Buschbaum, 2002). Mussels are known to respond phenotypically to the presence of starfish even in areas where they are not normally exposed to them (Reimer, 1999, Reimer and Harms-Ringdahl, 2001). Starfish (*Asterias vulgaris* in this case) pose a major problem for mussel cultivation in Newfoundland, where peak starfish settlement occurs a few weeks after peak mussel spatfall, and may be timed to take advantage of this food source (Pryor *et al.*, 1999). In the Pacific Northwest, starfish (*Pisaster ochraceus*) predation on small mussels (*M. californianus*) excludes mussels from the low intertidal and subtidal (Yamada *et al.*, 1992).

In Morecambe Bay, swarms of starfish (*A. rubens*) have been observed to invade seed mussel beds in the subtidal and low intertidal in some summers (Sloan and Aldridge, 1981, Dare, 1982). These swarms can be as large as 2 x 5 hectares and contain up to several million starfish, with maximum concentrations of 300 – 400 starfish per $m^3$. Fronts of starfish can advance 150 – 200 m per month and clear several thousand tonnes of seed mussels at a time. Anecdotal evidence from mussel growers and the North Western and North Wales Sea Fisheries Committee suggests that seed mussel beds in Conwy Bay periodically have been eliminated by starfish predation (Bill Cook, NW&NWSFC, pers. comm.). Video footage of seed mussel beds in Caernarfon Bay in spring 2003 showed that *A. rubens* was present on the beds in very high densities (Bill Cook, NW&NWSFC, pers. comm.). Thus starfish can cause very high mortality in seed mussel beds, but this source of mass mortality is sporadic in space and time.

*Crabs*

Crab predation occurs in both the intertidal and subtidal zone, since crabs migrate into the intertidal zone on the rising tide. Crabs are most active in spring and summer, corresponding to the main period of spat settlement and seed mussel growth (Hunter and Naylor, 1993, Aagaard *et al.*, 1995). All size ranges of crabs can crush small mussels with a reduced handling time compared with that required for larger mussels (Elner and Hughes, 1978). Hence crab predation is a major restriction on the yield of mussels in size classes < 40-45 mm, and particularly those <25 mm (Seed, 1976; Dare and Edwards, 1976; Mascaro and Seed, 2001) and crabs are probably the main predators of seed mussels (Dare and Edwards, 1976). Nevertheless, crabs do not feed exclusively on mussels and much of their diet is composed of brown algae (Reid *et al.*, 1997). In the Exe estuary, the density-dependent mortality of the 0-yr class of the mussel beds was found to be probably mainly due to juvenile crabs *Carcinus maenas* (McGrorty *et al.*, 1990). Video footage of seed mussel beds in Caernarfon Bay showed that *C. maenas* was present on the beds in very high densities (Bill Cook, NW&NWSFC, pers. comm.). Above 40mm in length, mussels attain a relative size refuge from crabs (Davies, 1966). Additionally, mussel beds are often used as nurseries for shore crabs since they provide refuge from predation (Mosknes *et al.*, 1998; Mosknes, 2002). The formation of seed mussel beds could be an opportunistic shelter and food supply for migratory crabs.

Davies *et al.*, 1980 demonstrated that the number of seed mussel collected could be reduced by preventing seed mussel predation by crabs using crab fences. They estimated that the reduction in mortality of seed inside fences should lead to a six-fold increase in yield and thus a saving of 75-80% in the weight of seed needing to be dredged and transported to the cultivation ground. However, they found that the fences altered the hydrodynamics regime of the bed such that the rapid build-up of mussel-mud deposits and their slow clearance within the fence posed significant problems.

The impact on crab and starfish populations of changes in food supply due to cultivated mussel beds and seed mussel harvesting has not been specifically addressed, although increases in *Carcinus maenas* numbers were thought to occur in Swansea Bay following the introduction of a mussel bed (Smith, 2002).

*Secondary effects of predation*

If there is a change in the number of starfish and crabs as the result of harvesting seed mussel beds, there is also the potential to affect other species which are either predators or other prey species of starfish and crabs. Starfish may have an impact on populations of gastropods such as *Hydrobia ulvae*, and other bivalve species such as *Abra alba*, *Spisula subtruncata*, *Macoma balthica* and the more commercially important scallop species *Pecten maximus* and *Aequipecten opercularis* (Anger *et al.*, 1977; Allen, 1983; Veale *et al.*, 2000). *Carcinus maenas* has been shown to have an impact on mollusc population including the gastropods *Nucella lapillus, Littorina littorea* and *Littorina obtusata* (Rangeley and Thomas, 1987), and the bivalves *Macoma baltica, Cerastoderma edule* and *Mya arenaria* (Jensen and Jensen, 1985; van der Veer *et al.*, 1998; Richards *et al.*, 1999). *Carcinus maenas* can also impact juvenile population of flatfish (Kuipers *et al.*, 1986; Ansell *et al.*, 1999). Crabs are also an food source for bird species such as the herring gull *Larus argentatus* (Dare, 1976; Dumas and Witman, 1993).

## 5.2 Phytoplankton

Mussel beds can process large volume of water (Jørgensen, 1990) and consequently affect the abundance and structure of phytoplankton communities due to their filter feeding activities. This is also likely to be true of seed mussel beds, particularly since they show rapid initial growth rates and usually have high densities of mussels. However, there is little information available on feeding specifically in seed mussels. Seed mussels may also impact upon different size-classes or species of phytoplankton and thereby have different ecological effects compared with adult mussels. General information on mussel feeding is likely to be broadly applicable and is briefly reviewed.

The uptake of phytoplankton by large bivalve beds tends to exceed the primary production per $m^2$ of bottom area in shallow water (Smaal and Prins, 1993). Mussels feed on seston from the water, composed of phytoplankton, detritus and other organic particles. The food quality of the seston for suspension feeders depends on the fraction which is living material and labile detritus (Smaal and Haas, 1997). Food availability is limited or diluted by the large inorganic fraction (Widdows *et al.*, 1979). The size range of these particles varies from 3 – 200 µm and most bivalve retain particles from 3 – 4 µm diameter with very high efficiency (Shumway *et al.*, 1985). *M. edulis* has a very fine filter with a mesh size of ~2.5 x 0.5 µm which also allows the efficient retention of 1 – 2 µm particles (Møhlenberg and Riisgård, 1979).

Mussel food consists of different types of suspended particles such as bacteria, phytoplankton, microzooplankton, detritus and dissolved organic material (DOM such as amino acids and sugars). Mussels can also capture and ingest benthic animal such as crustacean and bivalve larvae (10 – 1000 µm size range) (Davenport *et al.*, 2000). Mussels can retain flagellates ~1 – 2 µm and bacteria 0.3 – 1.0 µm from suspension (Gosling, 2003). Particle retention efficiency may depend not only on the particle size but also on shape, mobility, density and chemical cues such as ectocrines (Hawkins and Bayne, 1992; Gosling, 2002).

Reduction of phytoplankton biomass in the water column, as result of mussel populations, has been demonstrated in numerous studies with depletion in phytoplankton biomass ranging from 10% to 74% (e.g. the Oostercheekde Estuary, Netherland (Prins *et al.*, 1996), Rokilde Fjord, Denmark (Møhlenberg, 1995); Limfjordenm Denmark (Dolmer, 2000); Oeresund Strait , Sweden (Noren *et al.*, 1999); Wadden Sea, Germany (Asmus and Asmus, 1991)). Phytoplankton depletion due to filter feeding depends on mussel density (Prins *et al.*, 1995) and water column mixing. Vertically declining profiles of phytoplankton biomass are produced in the water column (Dolmer, 2000), and food limitation of mussel growth immediately above mussel beds has been observed (Fréchette and Bourget, 1985a; Fréchette and Bourget, 1985b, Bertness and Grosholz, 1985; Okamura, 1986; Fréchette *et al.*, 1992, Newell, 1990, Svane and Ompi, 1993, Haamer and Rohde, 2000;Smaal *et al.*, 2001. Cropping of phytoplankton population by bivalve filter feeders has been suggested as a natural control of eutrophication (Officer *et al.*, 1982, Alpine and Cloern, 1992, Thompson, 2000). The necessary conditions under which this is likely to occur are shallow water, abundant nutrients, no light, temperature or turbidity limitations and a calm or stratified water column (Dame, 1993).

Mussel filter feeding can also affect the plankton community structure, skewing the community structure towards smaller faster growing species (Furnas, 1990; Prins *et al.*, 1995;

Noren *et al.*, 1999). This can cause a shift in the population to higher proportions of diatoms (high growth rate species) and declines in relatively slow growing dinoflagellates (Prins *et al.*, 1995). In certain circumstances, this could therefore result in fewer toxic algal blooms due to dinoflagellate species such as *Diophysis* (main factor in the distribution of Diarrhetic Shellfish Toxic DST) and *Alexandrium* (main factor in the distribution of paralytic Shellfish Toxin PST) (Noren *et al.*, 1999). Mussel filter feeding may not be completely unselective, however, since some species may be unpalatable, including many toxic or noxious species. The precise food requirements of many filter-feeding organisms, including mussels, are not well understood.

Although mussels consume phytoplankton, they may also help regenerate phytoplankton populations by increasing nutrient availability through nutrient regeneration (Prins *et al.*, 1995). Filtered material is remineralised through the direct excretion by filter feeders or via bacterial processing in the underlying sediments. When phytoplankton growth is nutrient limited, this release of nutrients may promote phytoplankton growth (Asmus and Asmus, 1993). In a mesocosm study, phytoplankton growth rates were greatest at the highest mussel densities are attributed to increased nutrient availability (Prins *et al.*, 1995). A study in the Wadden Sea indicated that induced phytoplankton production by ammonium released from a mussel bed could be higher than the actual phytoplankton uptake (Asmus and Asmus, 1991). However, the effect of nutrient release on phytoplankton productivity will be dependent on various environmental conditions, and the nutrients will also be available to other primary producers such as benthic algae and microalgae (Asmus and Asmus, 1993).

## 5.3 Benthic communities

Mussel beds, presumably including seed mussel beds, support a benthic community which develops in the mussel and mussel mud matrix. Mussels affect the benthic faunal community of the sediment onto which they are laid in terms of both the number of individuals and species present (e.g. Commito, 1987; Dittmann, 1990; Guenther, 1996; Ragnarsson and Raffaelli, 1999; Beadman *et al.*, 2004). The diversity of the associated invertebrate communities increases with the size and age of the mussel beds, as the latter is proportionally linked to the structural complexity and thickness of the bed (Tsuchiya and Nishihira, 1985; Tsuchiya and Nishihira, 1986; Tsuchiya, 2002).

Mussels provide complex physical habitat structure capable of harbouring diverse assemblages of associated epiflora and epifauna (Seed and Suchanek, 1992, but see Beadman *et al.*, 2004). Mussels also provide an input of sediment and organic matter in the form of faeces and pseudofaeces (Kautsky and Evans, 1987) and remove fine particulate matter and some larvae of benthic invertebrate through their filter-feeding activities (Cowden *et al.*, 1984; Morgan, 1992; Wahl, 2001). Consequently, mussel communities have the capacity to either enhance or degrade the associated benthic community. Enhancement can occur through the provision of a more complex habitat substratum (on the surface of the shell matrix) and the production of organically enriched sediment microhabitat. Degradation can occur through competition, smothering, anoxia, destabilisation of the sediment due to the increased flux between the bed and the water column and removal of larvae in the water column through filter-feeding. *A priori* therefore, we might predict that seed mussels would, in the long-term, enhance epifauna but suppress infauna. However, a mussel seed bed is by definition relatively young and hence may not develop a particularly rich associated epifauna as in adult mussel beds.

In adult mussel beds, there are differences in epifauna between beds in the low intertidal and beds in the subtidal (Saier, 2002) so care needs to be taken in assuming that the information below (from the intertidal) applies directly to seed beds in the subtidal.

*Effects on numbers and species richness*

Ditman (1990) and Beadman *et al.* (2004) demonstrated a reduced abundance of individuals within a mussel bed compared to the surrounding sediment, but the opposite trend was observed by Commito (1987). Beadman *et al.* (2004) also found a decline in species richness within the mussel bed compared to control areas contrary to Ditman (1990). Mussel density and spatial scale are key variables in this analysis, however. Beadman *et al.* (2004) found a strongly significant and negative relationship between mussel surface area per unit bed area (the proportion of the bed taken up by mussels) and both the number of infaunal individuals and the number of infaunal species. In addition, they found that the effect of the mussel bed is visible in controls 10 m away from the edge of the bed, but not in those taken 100 m away. Clearly mussel density and size and experimental design are key to detecting changes in benthic communities due to mussels. Given the high density at which spat settle to form seed mussel beds, it seems likely that the main effect on the infaunal community of mussel seed beds would be suppression, but that this effect would most likely be localised to the immediate vicinity of the seed mussel bed.

*Effect on individual taxa*

The presence of mussels has a large positive impact on the abundance of small epibenthic crustaceans (e.g. juvenile *Carcinus maena* and *Melita palmata*) due to the refuge that the mussel matrix provides from water movement, dessication and predation (Dittmann, 1990; Mosknes *et al.*, 1998; Ragnarsson and Raffaelli, 1999; Mosknes, 2002; Beadman *et al.*, 2004), and well as the increased food supply. The presence of mussels also enhances numbers of barnacles by providing a hard substratum on which to settle. In addition, barnacles seem to settle preferentially on live mussels, near the siphonal aperture, and barnacles on live mussels have higher fitness than those on dead shells; they are presumably taking advantage of the mussel inhalant current for their own feeding (Buschbaum, 2001).

Commito and Boncavage (1989) suggested that the presence of mussels causes an increase in oligochaete abundance and other workers have also found a shift in the community from one dominated by polychaetes to one dominated by oligochaetes (Commito, 1987; Commito and Boncavage, 1989; Dittmann, 1990), or at least a decline in polychaetes but not in oligochaetes in the presence of mussels (Beadman *et al.*, 2004). In particular the abundance of *Tubificoides benedii* in mussel beds has been attributed to their tolerance of organically rich deoxygenated sediment (Commito and Boncavage, 1989). Their reproductive strategy also overcomes the problem of ingestion by mussel filtration due to the production of non-larval benthic offspring from cocoons (Hunter and Arthur, 1978).

It has been hypothesised that larvae of certain species in the infaunal community are susceptible to removal through bivalve filtration. Woodin (1976) suggested that suspension-feeding bivalves would have negative effect on the recruitment of infaunal species due to predation by filter feeding, although this hypothesis was refined by Commito and Boncovage (1989) to preclude organisms that do not have a pelagic development stage (*e.g. T. benedii*). Filtration by the mussel bed is likely to have an effect not only on the benthic infaunal community within a mussel bed (Cowden *et al.*, 1984; Morgan, 1992) but also the communities associated with areas in close proximity to it (Wahl, 2001).

Some infaunal species are strongly suppressed by mussels. Numbers of tube dwelling species such as the polychaete *Pygospio elegans* and amphipods in the genus *Corophium* are greatly reduced by mussels due to tube destruction by increased sediment flux and movement of the mussels themselves, and possibly because of competition for space with mussels (Kautsky and Evans, 1987; Guenther, 1996; Ragnarsson and Raffaelli, 1999; Beadman *et al.*, 2004). Other species can be suppressed by the increased mud content of the sediment (the capitellid amphipod *Notomastus latericeus*) or by a reduction in prey (the polychate *Nephtys hombergii*) (Beadman *et al.*, 2004). Spencer et al. (1996) reported a linear decrease in the number of cirratulids with increasing bivalve density in plots of cultivated Manila clams (*Tapes philippinarum*).

## 5.4 Nutrient fluxes

*Carbon*

Bivalve filter feeders are important nutrient processors in estuaries and shallow coastal waters (Dame *et al.*, 1991; Kautsky and Evans, 1987). Mussel beds speed up the cycle of production and breakdown of organic matter through the ecosystem (Dankers *et al.*, 2001). Mussel beds process nutrients in two main ways, through their own metabolism and through bacterial decomposition of organic material within the mussel bed. Hence, the mussels and mussel beds act as a sink for carbon. Dissolved organic carbon can also be released from broken cells during feeding, and as a by-product metabolism (Dame *et al.*, 1991).

*Nitrogen*

Mussels produce nitrogen in the form of ammonia, urea and amino acids from the metabolic decomposition of organic nitrogen, proteins and their by-product (Bayne, 1976). Ammonia release from the mussels themselves is significantly higher than the net remineralisation in the sediment (Kaspar *et al.*, 1985; Dame *et al.*, 1991). Bacteria in the sediments can mineralise organic nitrogen into ammonia, which may then undergo nitrification into nitrate. Under anaerobic conditions denitrification may also occur, reducing nitrate to nitrite and eventually to nitrogen gas (Dame *et al.*, 1991). Where bivalves rather than zooplankton are the dominant grazers, this increase in nitrogen cycling via the sediment may enhance primary production (Smaal *et al.*, 2001).

*Other nutrients*

Mussel beds are also thought to be a major component in the recycling of phosphorus, which is released from the sediments as a result of bacterial decomposition (Prins and Smaal, 1990). Silicon release in mussel beds is probably the result of the break down of phytoplankton cells during metabolism. Regeneration of silicon is of particular importance since in many estuaries it is a limiting factor for diatom blooms (Officer and Ryther, 1980). In seasonal phytoplankton succession cycles microflagellate blooms generally follow diatom blooms after silicon depletion (Smaal, 1991); this is the case in the Menai Strait, for example. These blooms have a lower food quality for mussels and may even be toxic for human mussel consumers; therefore silicon release provides a feedback mechanism which has beneficial consequences for the ecosystem (Doering *et al.*, 1989).

Generally, nutrient cycling in mussel beds seems to result in significant uptake of total organic carbon (uptake of nitrate and nitrite varies), and significant release of ammonium, phosphate and silicon. Mineralisation rates on biodeposits also seem to be higher than in non-enriched sediments (Smaal *et al.*, 1986). Hence the cultivated mussel beds in the Menai Strait and surrounding area will function as processors and accelerators of the remineralisation of estuarine materials (Dame and Dankers, 1988).

Biodeposition from mussel beds can result in large differences in the quality of sediment below (in longline and raft cultivation) and within mussel cultivation areas compared to surrounding sediments (Dahlback and Gunnarsson, 1981; Kaspar *et al.*, 1985; Kautsky and Evans, 1987; see above). Enrichment with organic material leads to increased bacterial respiration rates and oxygen consumption, which can lead to anoxic conditions and sulphate reduction (Dahlback and Gunnarsson, 1981; Kaspar *et al.*, 1985). The sediment becomes black due to chemoautrophic sulphur bacteria (e.g. *Beggiatoa*) (Grant *et al.*, 1995). The by-products of the anaerobic metabolism such as $H_2S$ and ammonium will then accumulate in the upper layers of sediment.

# 6 Limiting Factors in Seed Mussel Production

In this section we briefly summarise the key points from above to assess what are likely to be the main limiting factors for seed mussel production.

## 6.1 Larval production

Size and proximity of adult mussel beds can be an important limitation on larval production where the system is relatively closed and hence there is a high water retention time. The loss of adults in mussel beds results in the production of fewer gametes, hence, as the density of adults falls, larval production declines (McGrorty *et al.*, 1990). In broadcast spawners such as mussels, density is also an important factor since fertilisation efficiency in the water column declines exponentially with nearest neighbour distance (Gascoigne and Lipcius, 2004). The effect of reduced density is particularly marked in small populations (Levitan and Young, 1995). The creation of large, dense cultivated mussel beds (e.g. in the Menai Strait) should in theory enhance larval availability to downstream settlement sites (e.g. Caernarfon Bay), but the high flow, low retention time environment of the Menai Strait probably precludes this from happening in practice.

Mussel reproduction and larval survival is also affected by climatic conditions. Individual mussel reproduction is highest after a cold winter, but conversely larval survival is highest when water is relatively warm (because of the faster development rate and lower cumulative mortality) (Dare *et al.*, 2004). A cold winter also reduces predator populations (particularly shore crabs) so can result in higher survival of seed mussel. It will be interesting to see whether climate change has an impact on the reproductive success and distribution of *M. edulis.*

Problems associated with the collection of seed and the reliance of fisheries on natural spatfall have arisen in other mussel fisheries where adult mussel beds have been reduced in size and density by harvesting. In the Wadden Sea during the late 1980s and in the Wash in the 1990s, intertidal mussel beds almost disappeared due to low spatfall (Dankers *et al.*, 1999; Dare *et al.*, 2004). It is likely, in the Wash at least, that the low spatfall is associated with the fishing of adult mussel beds, since generally, climatic conditions which suppress mussel recruitment enhance cockle recruitment and vice versa, but in the 1990s, recruitment of both species has been very low (Dare *et al.*, 2004).

## 6.2 Larval settlement or spatfall

The factors that determine the number of mussel larvae that settle on to seed mussel beds and the location and size of the newly formed seed mussel beds largely remain a mystery. Presumably they are linked to physical transport processes which in turn are linked to weather and tidal patterns. However, many areas in which seed mussels settle frequently are determined by their substratum type. In Morecambe Bay, seed mussel beds form on patches of hard or cobble substratum resulting from remnant glacial deposits, but do not form on the surrounding sand. None the less, settlement on these sites cannot be guaranteed from one year to the next (Bill Cook, NW&NWSFC, pers. comm.; see below).

## 6.3 Mussel seed bed survival and growth

Again, the factors that determine the survival of mussels in seed beds are not clear. Physical factors (the destabilisation of the bed through the build-up of mussel mud) are clearly important (see Section 4). Likewise predation may decimate seed beds, particularly in the subtidal (see Section 5). In intertidal beds, very high mortality for unexplained reasons has also been reported (Bill Cook, NW&NWSFC, pers. comm.; see Section 8). Possibly this is a function of overcrowding resulting in a two layer structure, where mussels in the bottom layer die and then are revealed by the loss of the upper layer when those mussels reduce their byssus attachment. It is not known whether this also happens in subtidal beds.

# 7 Seed Bed Exploitation

In north Wales, UK, the culture of *M. edulis* is dependent on natural variation in spatfall and also on the destruction of seedbeds by predators and tidal forces in autumn (Dare, 1980; Dare *et al.*, 1983). After collection from subtidal seedbeds, mussel seeds are laid by farmers on bottom culture plots until they reach a marketable size. In the Menai Strait (North Wales), one tonne of unprotected 20-25 mm length seed mussels usually produces about 1 tonne of marketable >45 mm mussels (2 – 2½  years), indicating a 85% mortality (Dare, 1976). The high rate of mortality is mainly due to shore crab (*Carcinus maenas*) predation (Davies *et al.*, 1980). The mussel seed target is not always reached (Kamermans and Smaal, 2002) due to high variability of spatfall and the small time window for collection.

The north Wales mussel industry collects seed by dredging natural seed beds. The Sea Fisheries Committees issues a licence to the farmer for the collection of seed, which are dredged once a layer of “mussel mud” has built-up under the mussel beds. This means that farmers can dredge the targeted bed and collect seeds leaving the substratum relatively unaffected (Kaiser *et al.*, 1998). There can be short term impacts of mussel dredging on associated benthic communities, however. In a Danish sound, recently dredged areas had significantly lower density and number of species compared to control and boundary areas. They also found that shrimps invaded dredged areas and preyed on small invertebrates (Dolmer *et al.*, 2001).

Dredging the mussel seed beds releases sediment into the water column and may increase the settlement of mussel mud in other areas. Increased sedimentation of organically rich particles in these areas could lead to similar effects to those found in the mussel beds; anoxia and increased sulphate production (Kaspar *et al.*, 1985; Dahlback and Gunnarsson, 1981) and a change in infaunal community (Dame, 1993). This is less of a problem in high energy environments such as the Menai Strait and Morecambe Bay, where the dredge plume is dispersed very rapidly. In cultivated areas, if the mussel mud is not dredged post harvest to break up the mussel mud and avoid raising of the bed higher into the intertidal zone, it will persist in excess of 18 months after the mussels have been removed.

# 8 Alternatives to Exploiting Natural Seed Beds

The reliance of the mussel industry on wild collected seed has been a concern for some years, (Asmus and Asmus, 2002), and attempts have been made to find alternatives. These mainly centre around the use of artificial collection substrata to enhance spat settlement and to reduce predation on seed mussels.

Generally, mussels seem to target filamentous or pitted structures for primary settlement (Pulrich, 1996) so rope and gauze work well as substrata for collection, while mussel shell and plastic netting do not (Kamermans *et al.*, 2001). The position of the collector in the water column is also important, with settlement and survival being higher on collectors which are placed off the bottom relative to those near the bottom (Dare *et al.*, 1983, Pulrich, 1996, Kamermans *et al.*, 2001). Spat could in theory be grown on rope collectors until they reach a size (15 – 20 mm) suitable for relaying as seed mussels onto the ground. This alternative to dredging and relaying seed would avoid relying upon irregular seed mussel beds, and avoid competition with seed mussel predators for this resource. Offshore long-line culture also reduces the exploitation of seed mussels from wild beds by providing a settlement substratum for larvae in the water column and by reducing mortality from bottom living predators

(Asmus and Asmus, 2002). However, for large scale bottom culture of mussels, such as in the Menai Strait, rope seed collection would have to be on a massive scale. The strong currents around much of the UK coast also make this method difficult.

A key problem in relation to mussel fisheries has been the perceived conflict with the conservation of bird populations. In the Wadden Sea, fishing for mussel seed in subtidal areas is starting to become an issue, as these stocks also provide food for eider ducks (Kamermans and Smaal, 2002). One of the major concerns by fishermen and environmentalists has been the question of calculating the amount of food needed by the birds (Kamermans and Smaal, 2002). A recent study by Goss-Custard *et al.* (2003) demonstrated that even by leaving enough shellfish to meet 100% of the birds' demand might not ensure that birds will survive in good condition. However, there is not much evidence that mussel seed beds (as opposed to more mature mussel beds) are an important food source for birds, either in the intertidal or subtidal, so this is not likely to be an important issue in the harvesting of seed beds separate from adult beds.

# 9 Seed Mussel Beds in the Northwest and North Wales

The mussel culture industry in the Menai Straits harvests seed from three main areas: Caernarfon Bay, Morecambe Bay and South Wales. Seed beds have also developed periodically in Conwy Bay. Seed beds in Caernarfon Bay are subtidal, on gravel or cobble substratum. In Morecambe Bay the beds are mainly intertidal, often concentrated on areas of harder substratum (e.g. glacial moraine deposits), although they can also be on sand. The information on mussel seed beds presented in this section of the report comes mainly from unpublished monitoring data from the North Western and North Wales Sea Fisheries Committee (NW&NWSFC).

## *9.1 Morecambe Bay seed beds*

Morecambe Bay seed beds tend to form in fairly predictable areas, although the extent of settlement is highly variable from year to year. In recent years, settlement has been high around Morecambe, with a possible change in settlement patterns related to coastal defence works which have altered the flow regime.

Monitoring work by NW&NWSFC in Morecambe Bay has concentrated on two intertidal seed beds; Heysham Flats, near Morecambe, and the so-called South America bed, which is 4-5 km offshore and only accessible by helicopter or small boat. Both beds have been harvested by Bangor-based boats in the past.

The settlement in the Fleetwood area (south Morecambe Bay) is on 5 main beds, or "scars". These were periodically monitored in 2002 and 2003, and this data shows the variability in % mussel cover at these sites (Fig. 3), as well as the changes in underlying substratum as a consequence of the interaction between mussels and scouring by tides and waves (Fig. 4).

**Fig. 3.** Estimated percent cover of mussels at five seed mussel beds near Fleetwood, Lancashire. Data from NW&NWSFC.

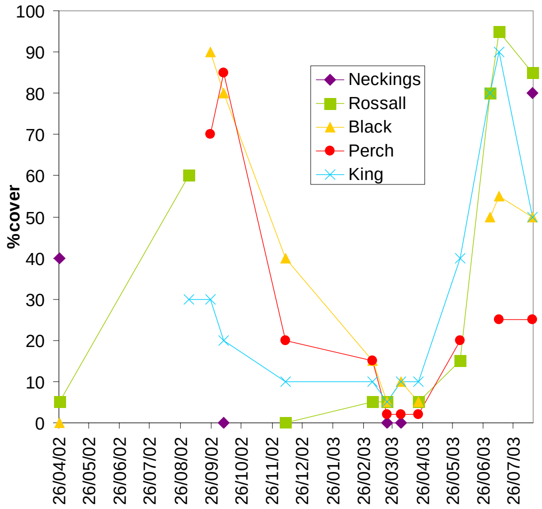
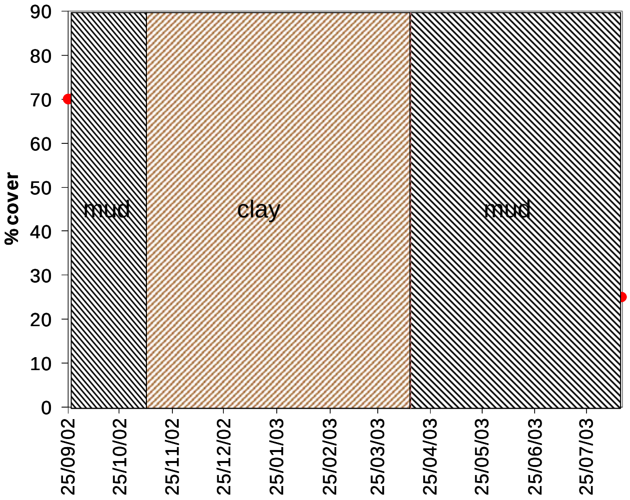


**Fig. 4.** Data from Perch Scar, showing the interaction between mussel cover and the underlying substratum. Data from NW&NWSFC.



Anecdotal evidence suggests that cover is lost in these Heysham Beds by two different mechanisms. Firstly, the accumulation of mussel mud (pseudofaeces deposition) lifts the bed away from the underlying substratum, rendering it vulnerable to removal by scouring.

Secondly, mussels may suffer very high (almost total) mortality on these beds, after an initial period of quick growth. This was observed on Neckings, Perch Scar and King Scar in October 2002. As a final response to stress, the mussel may detach their byssal threads, so highly stressed mussels are also often removed by scouring. Thus frequent monitoring is required to distinguish between the two mechanisms of loss.

The South America bed is more difficult to monitor frequently, being inaccessible from shore. However there is anecdotal evidence that mussel cover is very patchy over the course of a season at this bed as well. In 1999, there was dense settlement over an area of ~10 ha, but this was gone by the time seed harvesting vessels arrived. Likewise in May 2001, dense mussels of about 9mm mean length were observed, but in July, there were no mussels and the area, normally a cobble substratum, had been covered by a layer of sand. Settlement in the South America bed is also very patchy from year to year.

| **Year** | **Tonnes harvested** |
|---|---|
| 2001 | 4975 |
| 2000 | 0 |
| 1999 | ? |
| 1998 | 0 |
| 1997 | 0 |
| 1996 | 2700 |
| 1995 | 0 |

## 9.2 Caernarfon Bay seed beds

The mussel seed beds in Caernarfon Bay are mainly subtidal, and are the main source of seed for the lays in the Menai Straits. The distribution, growth rates and mortality of mussels at these sites are not well known, although they are known to be patchy in space and time. Some video footage of these beds from June 2003 shows very dense settlement of small mussels in places (100% cover with several layers), and high densities of invertebrate predators (starfish, crabs, whelks).

## 9.3 Conwy seed beds

There is annual settlement on a permanent adult mussel bed in the Conwy estuary, and spat from the top of the bed is generally removed by NW&NWSFC to lays in the low intertidal or subtidal. This site is very different to the other seed beds in the area because it is sheltered, with settlement on to live adult mussels. Settlement is much less patchy, both within and between seasons. In 1997, subtidal mussel seed beds developed in Conwy Bay. Two were harvested and one left for monitoring purposes, but was subsequently decimated by starfish. Since then, subtidal spatfall has not been observed in Conwy Bay.

## 9.4 Other seed beds in North Wales

Mussel seed beds develop in the high intertidal in Rhos-on-Sea and Llanddulas, near Colwyn Bay. In 2001, the beds at Llanddulas had high settlement of mussels, which then suffered very high mortality. Some mussels have been harvested by hand from these sites and relaid in the Wash.

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