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Seed mussel ecology

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Executive summary

Introduction

The commercial seabed cultivation of mussels is dependent on the supply of seed mussels from naturally occurring mussel seed beds. Seed mussel beds can form in predictable places from year to year although often they do not survive due to consumption by predators or erosion by winter storms. Where they occur, mussel seed beds can provide a source of food for predators such as diving and wading seabirds, fish, starfish and crabs. However, naturally occurring mussel seed beds also provide the seed upon which the mussel industry depends for relaying on commercial on-growing beds. This creates a potential conflict between conservation and commercial stakeholders. The current study was designed to increase understanding of the ecology of mussel seed beds under a potential regime of commercial harvest.

The present study focussed on the mussel seedbeds that tend to form at Caernarfon Bar, North Wales and Morecambe Bay, Lancashire. Ideally, a third site would have been studied, however due to the late settlement of seed at Swansea, and total seed settlement failure at Conwy, it was not possible to sample these areas. Therefore effort was focussed at Caernarfon and Morecambe. Both Caernarfon Bar and the South America skear at Morecambe Bay are characterised by a cobble/gravel substratum in contrast to surrounding sandy sediments. This hard substratum provides the anchor point to which mussel spat initially settle and develop into mussel seed. Poor settlement of mussel seed throughout the study period (as exemplified by the greater use of mussel seed collected from other areas e.g. English Channel) created logistical problems in generating consistent sampling strategies. In addition to these two sites a third mussel seed bed at Heysham was sampled opportunistically. This seed bed is intertidal in contrast to the other two sites which are only rarely exposed at low water. Sampling at this site enabled us to develop an experimental approach to examining the effects of partial harvesting of mussel seedbeds.

Fate of mussel seed

Acoustic techniques to differentiate and quantify mussel seed proved ineffective in this study due to the strong acoustic signal generated by the underlying substratum on which the mussel seed settle and due the lack of formation of distinctive bed forms by the mussel seed. Nevertheless, such acoustic techniques are useful for mapping suitable substrata upon which mussel seed may settle.

Predators such as crabs and starfish were found to aggregate over mussel seed beds, and there was some evidence of competitive exclusion (or avoidance) of small starfish from mussel seed beds. Fish that were large enough to consume mussel spat occurred in low abundance over the mussel seed beds and only a small proportion of the fish sampled consumed mussel seed. Fish smaller < 8 cm in length dominated the fish fauna. Plaice, gobies, scaldfish and solenettes were dominant (in terms of abundance) at different times of the year. The low numbers of predatory fish may reflect the extremely impoverished fauna associated with the mussel seed beds.

The question remains whether mussel seed beds are likely to be ecologically important for the taxa that might depend upon them as either a habitat or a prey resource. In this context mussel seed beds should be thought of as an *energy subsidy*. However, for energy subsidies to have population level effects they must occur in sufficient quantity, frequency and on a predictable basis (Polis et al. 1996). However, it is clear from the logbook data and also the experience in the present study that mussel seed beds are ephemeral and occur erratically such that it would not be possible for predators to adapt annual migration patterns that depended upon them. Thus they provide an opportunistic prey resource at best.

It is important to note that the numbers of fish sampled in the present study are low. While this may indicate that fish do not depend upon the mussel seed beds, further sampling would be required to increase the power of this inference. It is also important to note that bird

predators were not included in our considerations. Thus mussel seed may be more important for avian predators that seek food resources at a different spatial scale than crabs, starfish and fishes.

Mussel seed harvesting – Heysham experiment

Replicated harvested plots showed initially depressed growth rates compared with unharvested control plots. However the mussels in the harvested plots showed a more rapid growth rate after an initial delay such that the endpoint biomass of both plots was statistically the same. There was no sign of the mussel seed bed breaking up over the winter as a result of the experimental harvesting, indeed the bed remained in situ into the early spring. A secondary settlement of mussel seed occurred into the harvested patches within the harvested plots. These results are important as they indicate that light harvesting (50%) of a recently settled mussel bed may be sustainable and may even enhance its probability of survival over-winter. Such findings mirror those found in the Wadden Sea in as yet unpublished results from Alterra (Royal Netherlands Institute for Sea Research).

The mechanism of mussel seed bed break up may be partly linked to density dependent competition. It was observed that in the late autumn, the surface mussels had developed into loose patches that were only lightly attached by byssus threads to the underlying mussel bed. These patches would be particularly prone to wave erosion. The reason such patches may occur could be explained by increased movement of individuals within the bed to gain the best position for feeding (i.e. at the surface of the mussel bed). This is supported by our own in situ observations of mussels laid subtidally in another related project (funded by BBSRC). Increasing competition for food and hence increased numbers of individual movements could lead to the weakening of the mussel bed as individual mussels continually detach and reattach to each other. This hypothesis could only be tested in another specific study but if true would suggest that dense beds of seed mussels are almost certain to break up due to competitive interactions under certain environmental conditions (e.g in areas exposed to storm waves).

We tested the effect of experimental harvesting on mussel growth and mortality and infaunal and epifaunal diversity in summer/autumn 2004 using six replicate plots on a mussel bed at Heysham, UK. The experiment was set up such that three 10 x 10 m plots had 30-50% of their mussels removed manually. Samples of mussel seed and the associated benthic community assemblage were collected periodically between July – November 2004 from the three harvested plots and three adjacent control areas (each 10 x 10 m).

We found an initial negative impact of harvesting on mussel growth and a positive impact on mussel recruitment, however these impacts were transient, only lasting 6-8 weeks, after which there were no longer any differences between plots. There was no effect of harvesting on diversity or abundance on the associated faunal community, which was depauperate. Transient effects of harvesting on mussel growth are likely to be due to a number of factors that include: post-harvest stress, release of sediment by harvesting, or loss of byssal attachments. Transient increases in recruitment were probably due to increased space in the harvested plots, although survival of recruits was apparently low – however, this effect could be of importance for beds harvested earlier in the year. Overall, any effect of harvesting in the treatment plots was rapidly cancelled out by erosion caused by autumn storms acting on the unharvested control plots.

The knowledge gained from the Heysham experiment was instrumental in the joint decision by the North Western North Wales SFC and English Nature (Natural England) to open this bed to limited levels of hand harvesting of mussels. Formerly this bed was closed to harvesting, in part due to its close proximity to a *Sabellaria* worm reef.

Original project objectives

1. **Literature review.** Undertake a literature review of peer reviewed and ‘grey’ literature pertaining to mussel seed beds and their exploitation. This review would cover both issues of use of seedbeds by birds as a food source and by other potential fish and invertebrate predators. The review would establish the current state of knowledge of ecological issues that relate to mussel seed.

Review complete by March 31st 2004

2. **Temporal changes in the extent of seed beds and quantity of seed.** Undertake an acoustic survey at two of the following three areas to ascertain the extent of mussel seedbeds if present: Morecambe Bay, Conwy Bay and Caernarfon. All three areas are currently exploited by the mussel industry. Other seed beds may be sampled if the opportunity arises.

Complete analysis on 1st May 2006.

3. **Population structure of mussel seed banks and associated fauna.** Repeated sampling will establish to what extent mussel seed beds are composed of a unimodal cohort of mussels. Although the majority of mussels may have settled during one season, they may have settled on a smaller population of adult mussels that have been present for many years. Dredging may affect the viability of any resident ‘older’ mussels.

Complete analysis on 1st May 2006.

4. **Fate and importance of mussel seed.** Repeat sampling will establish the composition of those predators most likely to feed on mussel beds (e.g. starfishes, crabs and flatfishes). Samples will be collected for dietary analyses so that the relative importance of mussel seed in the diet can be compared to other components of the diet. While literature on potential avian predators will be extracted in (1), there is insufficient budget to make direct observations on diving birds.

Complete analysis on 1st May 2006.

5. **Final report and recommendations.** A final report and synthesis of results will include a clear statement on the ecological implications of harvesting mussel seed beds.

Complete draft 30th October 2006, Final report 31st December 2006.

1. Seed mussel harvesting, settlement and development

1.1. Logbook records of mussel seabed harvesting

1.1.1 Introduction and methods

In order to ascertain the demand for mussel seed for cultivation in the Menai Strait it is necessary to obtain historical information regarding the cultivation practices, and quantify of seed mussels harvested and relaid. This information was ascertained by approaching the owners of the principle operators in the Menai Strait with a request to access their logged records of mussel harvesting and movements from outwith and within the Menai Strait.

1.1.2. Results

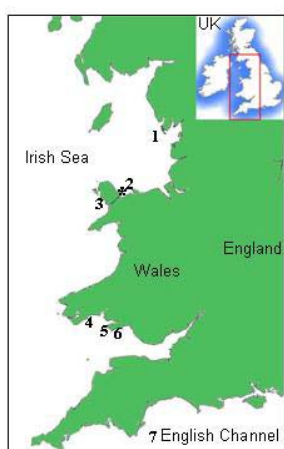


Fig. 1.1 The location of the seed beds used by the fishermen in the Menai Strait. For the “Extensive list of sublittoral ephemeral seed resources of the UK”, see Seafish report NO. SR554 March 2004 by M. Syvret.

* Menai Strait site with seed bed relaying

- 1 – Morecambe: South America
- 2 – Conwy
- 3 – Caernarfon Bar
- 5 – Caldey Island
- 4 – Port Fynon
- 6 – Swansea Bay
- 7 – English Channel

There are five principle companies that cultivate mussels in the Menai Strait, North Wales (Table 1). Of these companies, the largest users of seabed cultivation, harvesting and mussel seed transport are Myti Mussel Ltd. and Deep Dock Ltd. Data on the harvesting, relaying and movement of mussels for recent years were extracted from the logbooks of these company’s (Table 2). From the company logbooks it appears that the peak of mussel seed harvesting from areas outside the Menai Strait occurred in 2000 and 2001. In this combined period, 6000 t and 9290 t of mussel seed were relaid into the Menai Strait by Deep Dock Ltd. and Myti Mussel Ltd. respectively. The amount of seed relaid has declined for each company to 1147 – 1400 t per annum in 2005. Despite a reduction of mussel seed imports of approximately 80 – 85% this is not reflected in the tonnes of mussels harvested which has declined relatively little (25 – 30% as calculated from the difference between the harvest in 2003 and 2005) (Tables 3 and 4). This may reflect better husbandry of diminishing mussel seed, or perhaps reflects a better proportional return from fewer seed mussels due to the effects of competition for food at high densities (Gascoigne et al. 2005). Both Deep Dock Ltd. and Myti Mussel Ltd. prosecute local and distant mussel seed resources. Local mussel seed are harvested primarily from Caernarfon Bar. However, Morecambe Bay has consistently yielded the highest harvests although in recent years both companies have sought mussel seed from areas as distant as South Wales and the English Channel. The time series of data available is too limited to be able to draw any inferences as to whether this is a temporary change in

harvesting patterns or whether this represents a longer-term decline in local mussel seed resources.

Table 1.1 List of the companies involved (currently or recently) in mussel cultivation practices in the Menai Strait, North Wales.

Company	Owner	Strait Area	Notes
Menai Oyster	Mr. S. Krijnen	West	Mainly oysters and natural beds of oysters at the end of the western part of the Menai Strait.
Extramussel	Mr. T. Jones	West + East	Merged /in collaboration with Kim Mould
Myti mussels	Mr. K. Mould	East	Main operator
Ogwen Mussel Partners	Mr. B. Tipton	East	Not active currently
Deepdock	Mr. A. Wilson	East	Main operator

Table 1.2 Information ascertained from Myti Mussel Ltd. and Deep Dock Ltd. regarding mussel cultivation operation and strategy employed in the Menai Strait.

		Myti Mussel Ltd.	Deep Dock Ltd.
No. of dredging operations/ year for movements	Intertidal to subtidal (day/year)	~ 30 days / year	15-20Apr/June
	Harvesting (weeks/y & d/wk)	35 weeks 5d/week	16 weeks 5d/week
Density of mussels (tonnes/ hectares)	Seed (/ha)	50t	25t
	Intertidal (/ha)	100t	50t
	Subtidal (/ha)	100t	150t
Number of ha exploited	intertidal	90	Area 4: 7-8ha Area 6: 4ha
	subtidal	50	Area 4:2-3 Area 6: 10-11
Order area of the company		Area 1 Area 2	Area 4 (10ha total)+ Area 6 (57ha total)+
Total ha exploited		90 ha intertidal 50 ha subtidal	12 ha intertidal 13 ha subtidal
Approx. area of seed beds (ha)		40 ha intertidal	No data
Size class of the mussels		Seed mussels ~15 mm 1y ~ 25 mm 2y ~ 35-40 mm 3y ~ 55 mm	Seed mussels ~15 mm 1y ~ 25 mm 2y ~ 35-40 mm 3y ~ 55 mm
Cultivation strategy		3 y cycle	2 y cycle, with future shift to 3 y cycle
Capacity of vessel		No data	Max ~100t (to 2003) ~ 250t (from 2003)
Boats owned		BS1, Lolly Pop	Mare Gratia (2003) Ostrea still

	BS8 Valente	
Log book of dredging	Copy of SMR from 2001 – 2005	No copy

Table 1.3 Direct movements of mussels into and within the Menai Strait by Myti Mussel Ltd. See Fig. 1 for a map of locations.

Year	Total seed deposit (tonnes/year)	Mean size (in mm)	Source (kg)	Weight (t) + Trips numbers	Means of transport	Mussel harvested (tonnes/year)	Mussels moved intertidal to subtidal (t/year)
Period						Sept - April	April-May-June
2005	1147	10 10 10	English Channel Port Fynon Caldey	237 – 9 560 – 3 350 – 3	Road Valente Valente	5000t	5000t
2004	1850	10 10	South America Caernarfon	1660 – 8 190 – 2	Valente Valente	5500t	4600t
2003	1590 + (Adults 450 = 2040)	10 30 40	South America Caernarfon Walney	200 – 2 1390 – 10 450 – 2	Valente Valente (+2Mytilus*) Valente	6700t	5000t
2002	2680 + (Adults 210 = 3270)	20 to 25 20 to 30 35	Caernarfon Morecambe Walney	830 – 9 2230 – 17 210 – 4	Mytilus Mytilus Mytilus	5300t	5500t
2001	1610 (SMR) or 3260 (KM)	20 40	Morecambe Caernarfon	1610 – 13 200 – 2	Mytilus Mytilus	2000t	5000t
2000	4300 (KM)					600t	5000t
1999	700 (KM)						

Note: The numbers with a line passing through them and their origin denote adult mussels i.e. not seed mussels

Table 1.4 Direct movements of mussels into and within the Menai Strait by Deep Dock Ltd. Fig. 1 for a map of locations. HS = Horse shoe, GP = Gallows Point.

Year	Total seed deposit (tonnes/year)	Mean size (in mm)	Source (kg)	Weight (t)	Means of transport	Mussel harvested (tonnes/year)	Mussels moved intertidal to subtidal (t/year)
Period						Sept - April	April-May-June
2005	1400	10-25	South Wales		Mare Gratia (B932)	1600t	Hope to move 2000t to HS 350t to GP

2004	1500	25-30	Morecambe		Mare Gratia(B932) Still Ostrea (LR111)	1750t	1500t to HS 400t to GP
2003	2150	25-30-35	Morecambe South Wales Conwy	1500 500 150	Mare Gartia (B932) Still Ostrea (LR111)	2340t	2500t to HS 200t to GP
2002	1900 (1200 E – 700 W)		Caernarfon		Still Ostrea (LR111) Drie Gebroeders (B57)	1980t	2200t to HS
2001	3100		South Wales Caernarfon Morecambe	600 500 1000	Still Ostrea (LR111)	2260t	2000t to HS
2000	2900	30-35	South Wales Conwy Caernarfon	500 700 1700	Still Ostrea (LR111)	2400t	2300t to HS
1999	900				Still Ostrea (LR111)	1520t	2300t to HS
1998	Poor spat				Still Ostrea (LR111)	1400t	1750t to HS
1997	2000		Morecambe (only 200t to Menai Strait) Caernarfon Bar	1200 800		2200t	1500t to HS

1.2 Growth of mussel seed on natural seed beds

1.2.1 Introduction and methods

In order to ascertain the growth rate of mussels on mussel seed beds, we undertook repeated surveys in 2004 and 2005. Sampling was carried out from the boats of either Deep Dock Ltd. or Myti Mussel Ltd. on either Caernarfon Bar or in Morecambe Bay. We were unable to sample Conwy for mussels as spatfalls did not occur during the sampling years in sufficient quantities for the mussel companies to attempt harvesting of the seed. On each occasion, mussels were sampled haphazardly from mussel dredges which had been hauled across the seabed, the number of tows varied according to the commitments of the mussel dredging company at the time of sampling. Frequency length histograms were plotted and the daily growth increment calculated when mussel seed were sampled on separate occasions. The sample sizes (number of mussels) are small and this reflected in the locations used to collect mussel seed in 2005.

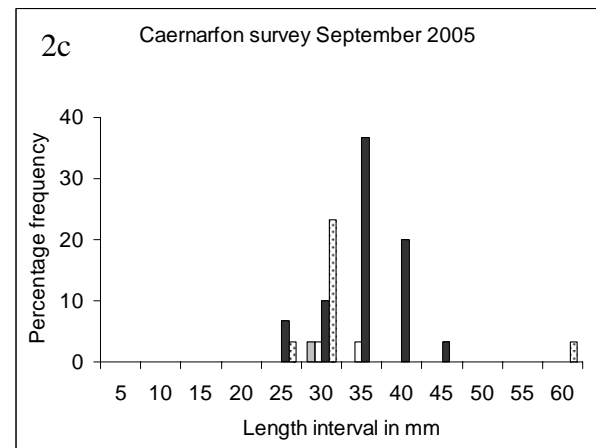
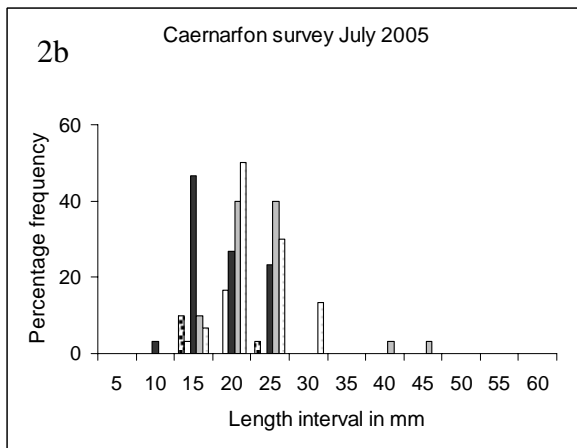
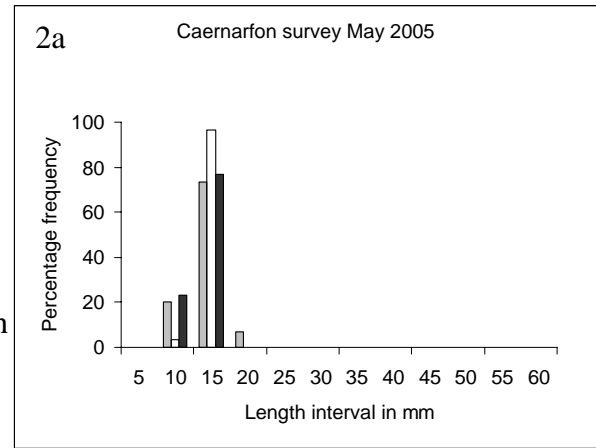
1.2.2 Caernarfon survey

Surveys showed that there was an increase in mussel size from a mean shell length of 11.8 mm (May) to 31.0 mm in September, with mussels almost tripling their shell length over the summer (Table 5, Figure 2). The growth increment was calculated and is shown in Table 5. Only one seed cohort was found in the area although there is some evidence of the previous years settlement in July and September.

Table 1.5 Caernarfon survey information:

Date	No. tows	N	Mean size \pm 2SE (mm)	Daily increment
May	3	30	11.8 \pm 0.4	-
July	5	99	18.6 \pm 1.0	0.13 mm
Sept.	4	35	31.0 \pm 1.7	0.19 mm

Fig. 1.2 Percentage frequency for 5 mm length intervals for a May; b July and c September 2005 for seed mussels sampled on Caernarfon Bar. The different hatched bars relate to the data from each separate tow.



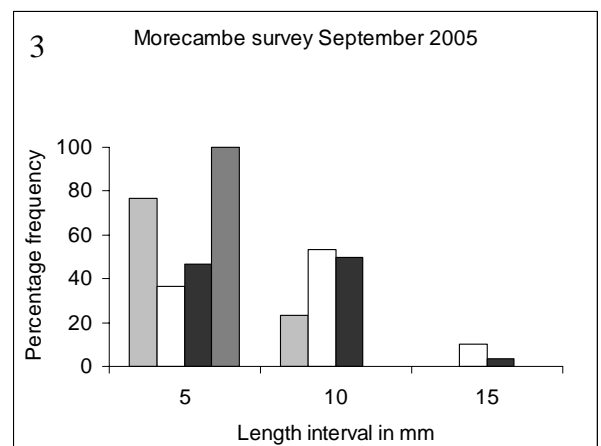
1.2.3 Morecambe survey

Surveys were undertaken in May, July and September 2005, no seed was found in May and July. In September 2005, seed was only present at a site adjacent to the usual naturally occurring seedbed; there was no seed on the sampling site where seed are usually present. Due to the lack of seed on two of the sampling dates it was impossible to calculate growth increment using these data.

Table 1.6 Morecambe survey information:

Date	Tows	N	Mean size \pm 2SE (mm)	Daily increment
May	4	0	-	-
July	4	0	-	-
Sept.	4	150	31.0 \pm 1.7	-

Fig. 1.3 Percentage frequency for length intervals for September 2005 in Morecambe Bay. The different hatched bars relate to the data from each separate tow.



1.3. Direct observations of mussels in disintegrating seed beds.

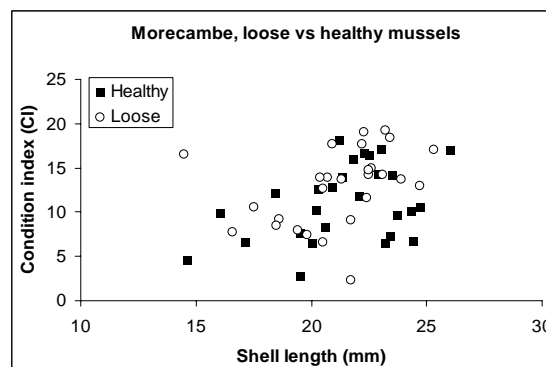
1.3.1. Introduction and methods

In ephemeral mussel seed beds, at high density, mussels tend to “loosen up” such that two layers of mussel appear. Of these, the lower layer of mussels is anchored to the substratum and neighbouring mussels by byssus threads, while an upper layer is composed of mussels that are loosely attached to each other. This gives the mussel bed the appearance that it is breaking up with patches of loose mussel clumps overlying a more firmly attached bed (Mr W Cook, NWNWSFC pers. comm.). These loose mussels are more vulnerable to being washed away by tidal and wave action. This phenomenon may be an adaptation of mussels to conditions of high density that results in intense competition for food, or it may be a mechanical result of mussels reorientating their position more frequently within the mussel bed to gain better feeding conditions (Saurel et al. in press). We wanted to ascertain if the quality of the mussels that have become detached from the main mussel bed differs from that of the mussels that remain attached within the mussel bed. During a survey in Morecambe Bay at the South America site, mussels from the two different layers were collected at the same station: loose (not attached to main bed with byssus) and healthy (attached together with byssus). Biomass and condition index (CI = dry flesh weight/shell length) were measured for the two populations.

1.3.2. Results

After checking that the data met the assumptions of normality and heterogeneity of variance, a two sample t-test to test for differences in the condition indices for the mussels collected from the ‘loose’ and ‘healthy’ part of the mussel seed bed revealed that there was no significant difference between these two categories of seed mussels ($T = -1.4$; $p = 0.51$; $N = 51$) (Fig. 4).

Figure 1.4: Condition index for each mussel size, loose and healthy samples collected in Morecambe Bay (4/07/2004).



1.4 Discussion

It is clear that two main operators dominate the mussel cultivation industry in the Menai Strait, North Wales. Both of these operators harvest mussel seed from Caernarfon Bar and Morecambe Bay. Both operators have harvested mussel seed from other areas in the past, but this practice is becoming more common in recent years. Nevertheless, despite a lower overall tonnage of harvested mussel seed in

recent years, the tonnage of harvested marketable product has declined far less. This suggests either better husbandry of the limited resource or reduced density-dependent mortality as a result of lower initial stocking density (Gascoigne et al. 2005). The increasing tendency to harvest mussel seed from distant locations is perhaps reflected by our inability to sample satisfactorily mussel seed settlement in either Morecambe Bay, Caernarfon Bar or Conwy. Although samples were collected in 2004, these were too haphazard for meaningful analysis. Samples collected in 2005 provided a time-series of growth data which indicated that the mussels at Caernarfon Bar are composed primarily of one cohort of the current settlement. The first samples collected in May indicated that initial settlement probably occurred sometime in April. Shell length increased 3 fold up until September when sampling ceased after the mussel bed began to break up. The mussel settlement was so poor that neither Deep Dock Ltd. nor Myti Mussel Ltd. reported landings from this location. Spat settlement occurred very late that year in September 2005 which provided us with no opportunity to measure further the growth and fate of this mussel bed. Our observations add further support that settlement of mussel spat is highly unpredictable and ephemeral at some locations. Nevertheless it is impossible to determine the cause of the intermittent nature of mussel settlement in the absence of a long-term time series of data.

Mussel settlement in 2005 occurred in different months at Caernarfon and Morecambe Bay. Only one sampling trip was accomplished at Morecambe due to the very late settlement of mussels in September 2005. The earlier settlement and development of mussel seed on Caernarfon bar indicates that the mussel seed probably settled sometime in March 2005. Only a single cohort of mussels was present and growth rate was rapid with the mussels tripling their length between May and September. Thereafter the mussel bed broke up rapidly according to the observations made by Deep Dock Ltd.

The development of loose 'mats' of mussels on the mussel seed bed in Morecambe Bay on South America skear was of interest as this phenomenon has been reported anecdotally but not in a formal manner. The mechanism by which such mats develop may occur as a result of competition for food and oxygenated water which results in reorientation by individual mussels within the bed as they detach their byssus and move to the surface of the bed. This behaviour has been observed by deploying underwater video cameras directly over a mussel bed in the Menai Strait and recording their behaviour over several tidal cycles (Saurel et al. in press).

2. Partial harvesting of intertidal seed mussel beds: consequences for mussel growth and mussel bed biodiversity

Gill Osborn (Blackpool & Fylde College) and Bill Cook (NWNWSFC) contributed to this research.

2.1 Introduction

Morecambe Bay, in northwestern England (Fig. 2.1), is a macrotidal inlet composed of a dynamic mosaic of sandbanks and cobble hard bottom (areas known by the Norse word 'skears'). Skears provide an excellent settlement substratum for mussels (*Mytilus edulis*) and are frequently densely colonised in spring and summer. On some skears, (mainly intertidal) the mussel bed is more or less permanent, although it changes greatly in density and extent from year to year, while in other areas (subtidal), the mussel settlement is highly unstable and can be lost unpredictably via wave erosion or sand smothering.

Mussels in these beds are harvested for two different purposes: i) newly settled mussels (seed) are harvested for ongrowing in bottom culture and ii) more mature mussels in intertidal beds are harvested for direct consumption. Both these activities support an expanding market for seafood perceived as sustainable and environmentally benign. In both cases, the beds are generally only partially harvested, with mussels being left, albeit at lower density.

There has been some concern over the impacts of this partial harvesting on these mussel beds and their associated ecosystem, focussed around various questions:

- i) Does the disturbance caused by harvesting damage the integrity of the bed and make erosion and loss of remaining mussels more likely?
- ii) Does harvesting disturbance damage the mussel bed, reducing mussel growth, increasing mussel mortality and reducing associated biodiversity?
- iii) Alternatively, does partial harvesting reduce competition in the mussel bed and thus increase growth and survival of remaining mussels and the integrity of the bed?

We designed an experiment to test the effect of partial harvesting on an extensive mussel seed bed at Heysham, Lancashire.

2.2 Methods

We carried out the research on a seed mussel bed on Heysham Flat, Morecambe Bay, Northwest England (Fig. 2.1). The mussel bed has dense settlement of mussel seed during spring and/or summer in most years. In some years mussels persist through the winter, while in other years the bed is completely cleared of mussels by winter storms (Northwestern and North Wales Sea Fisheries Committee, unpublished data). At the time we did our work (2004) the bed consisted of a mosaic of seed mussel and adult mussels from the previous year.

We set out six replicate 10m x 10m plots on the mussel bed, separated by at least 10m (Fig. 2.1). The plots were marked with small, flexible plastic markers at each corner. Three of the plots (Plots 1, 3 and 6) were partially 'harvested' by hand at low water on

July 21 2004, using rakes and shovels. The other three plots (Plots 2, 4 and 5) were left as controls. The harvested mussels were removed to other areas of the mussel bed.

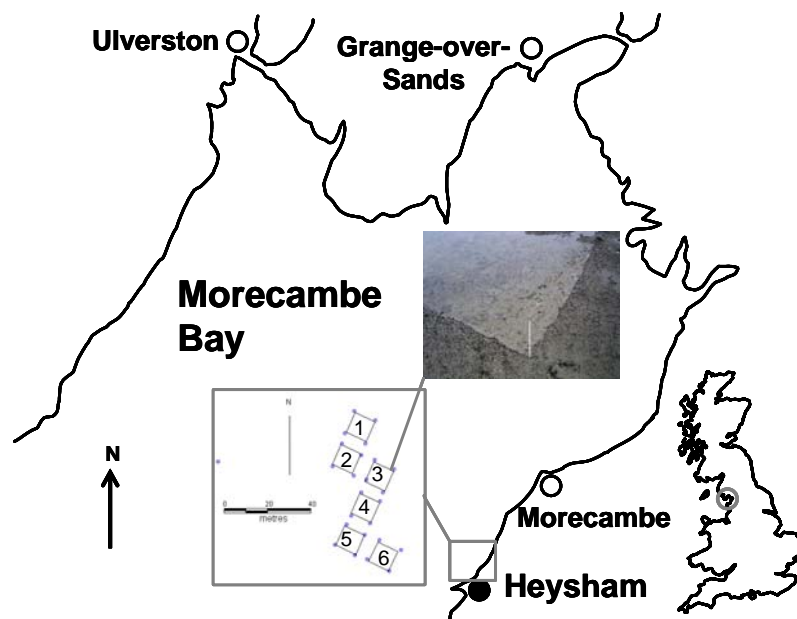


Fig. 2.1. Location of experiment, plot layout and corner of a harvested plot showing effect of harvesting.

Plots were sampled on 20 July (pre-harvesting), 3 August, 3 September, 21 September and 18 November 2004. We measured mussels density in each plot using six replicate photographic quadrats of 0.1 m^2 . We sampled mussels and associated fauna using five replicate 15cm diameter cores per plot. Mussels in each sample were grouped into three categories: ‘seed’ mussels of 10-25mm shell length, which were from settlement in spring 2004, ‘adult’ mussels of $>30\text{mm}$ shell length, which were from previous years’ settlement, and ‘recruits’ of $<5\text{mm}$ shell length which were from low levels of settlement which occurred during the experiment. Seed and adult mussels could be distinguished visually by size (Fig. 2.2), and also because the adults had thicker, rougher and darker shells. Adults were excluded from the analysis since their growth rates are different to those of seed mussels, and the proportion of adults in the core would otherwise have confounded the results. The number of recruits was analysed separately.

Shell length measurement was immediately carried out on a random subsample of 20 of the seed mussels (‘Sample 1’). Subsequently, another random subsample of 20 seed mussels were selected for measurement of shell length (‘Sample 2’), shell weight and meat dry weight. Dry weight samples were prepared in a drying oven for a minimum of 12 hours at 90° (Beadman 2003). Epifauna in the cores were preserved in 10% formalin solution. The sediment down to 5cm below the cores was removed and sieved on a 1mm sieve and infauna also preserved in formalin.

Mussel data (density, shell length (Samples 1 and 2), shell weight, meat dry weight, number of recruits) and univariate data on infauna and epifauna (number of species and number of individuals per core) were analysed for each date separately using a nested analysis of variance with two factors, treatment (harvested vs. control) and plot, nested within treatment. In all cases except the recruit data for November, Levene’s test showed that variances were homogenous and no data transformation was required.

Recruit data for November contained a high proportion of zero values and was considered to have too small a sample size to be appropriate for statistical analysis.

All multivariate analyses were conducted with the statistical package PRIMER v6 (Clarke & Gorley 2006). Infaunal abundances were generally low throughout treatments and dates (Table 1); therefore we applied the mildest possible transformation to the data. Square root transformed data were visually explored with non-metric multidimensional scaling (nMDS) ordination and were also subject to hierarchical agglomerative clustering with group average linking undertaken using the CLUSTER routine. Differences in the assemblage structure between treatments and dates were firstly evaluated with two-way crossed ANOSIM. Pair-wise comparisons were performed on all tests that returned significant results to determine which groups of samples were responsible for the observed differences. Bonferroni-type corrections on the pairwise significance levels were not implemented because, as Clark & Gorley (2006) point out, *R* is largely not a function of the number of replicates (i.e. possible permutations) but an absolute measure of differences between groups in the high-dimensional space of the data (whereas *p* is always affected by sample size). The species that were instrumental in distinguishing between dates and treatments of the data set were extracted using the SIMPER routine.

To investigate likely erosion events on the mussel bed, hourly wind data was obtained from the nearest weather station on Walney Island from the British Atmospheric Data Centre (<http://badc.nerc.ac.uk/>). The data was used to calculate daily mean and daily maximum wind speeds for July – November 2004.

Results

Pre-harvesting sampling

The sampling on 20 July, before harvesting, showed no significant differences between the plots in any of the variables measured.

Mussel density

This data is currently held by Gill Osborn (Blackpool & Fylde College) and as yet we have not received a copy despite requests.

Mussel growth

Shell length samples from sample 1 showed a significant effect of harvesting on the first post-sampling date (3 August 2004), with mussels in harvested plots smaller than mussels in control plots ($p = 0.001$, Fig. 2.2). For the next date (3 Sept. 2004) there was a significant effect of plot ($p < 0.0005$) but not treatment. The three harvested plots had on average smaller mussels, but control plot 4 also had smaller mussels. For subsequent sampling dates there were no significant effects of plot or of harvesting.

Mussels from sample 2 showed no significant effect of plot or treatment on shell length, shell weight or meat dry weight for 3 August sampling. For the 3rd September sampling, there was a significant effect of harvesting on shell length ($p = 0.004$ Fig. 2.3), shell weight ($p = 0.009$ Fig. 2.4) and meat dry weight ($p = 0.001$, Fig. 2.5), with mussels from harvested plots being smaller on average than those from control plots. For shell length, there was also a significant effect of plot ($p = 0.035$) with plots 1 and

2 being smaller than the other four plots (Fig. 2.3). For subsequent sampling dates there were no significant effects of plot or harvesting.

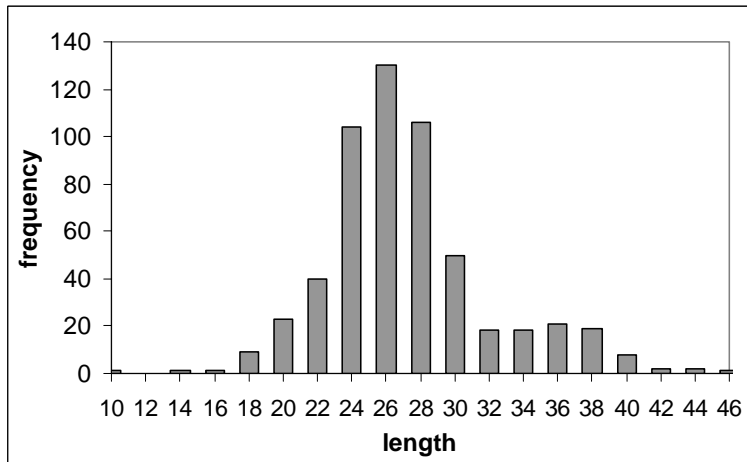


Fig. 2.2. A shell length-frequency histogram from October samples, showing the bimodal distribution of adult / seed mussels (in the other samples, adults were removed before any measurements were taken).

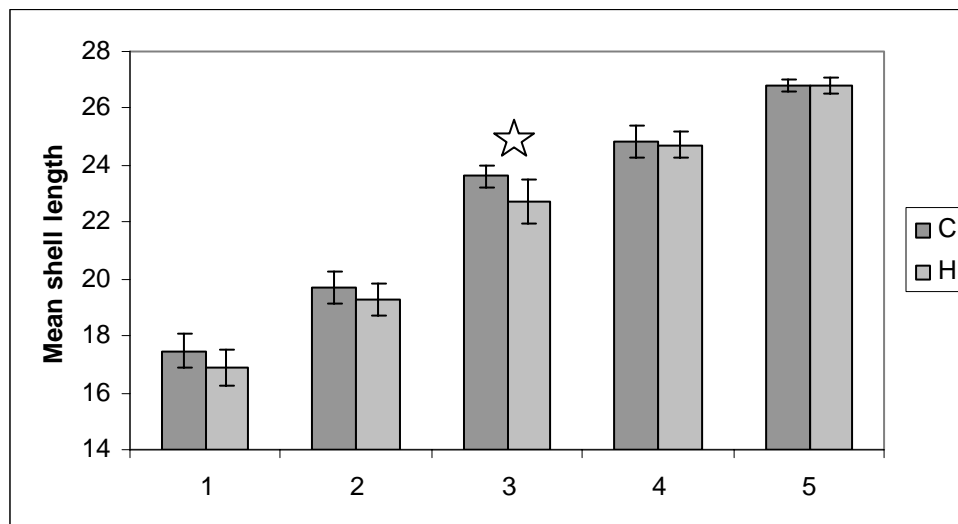


Fig. 2.3. Mussel shell length from sample 2 from control (C) and harvested (H) plots for the five sampling periods: 1 = pre-harvesting (20 July 2004), 2-5 = post-harvesting (3 August, 3 Sept., 21 Sept., 18 Nov. 2004). The star indicates a significant treatment effect.

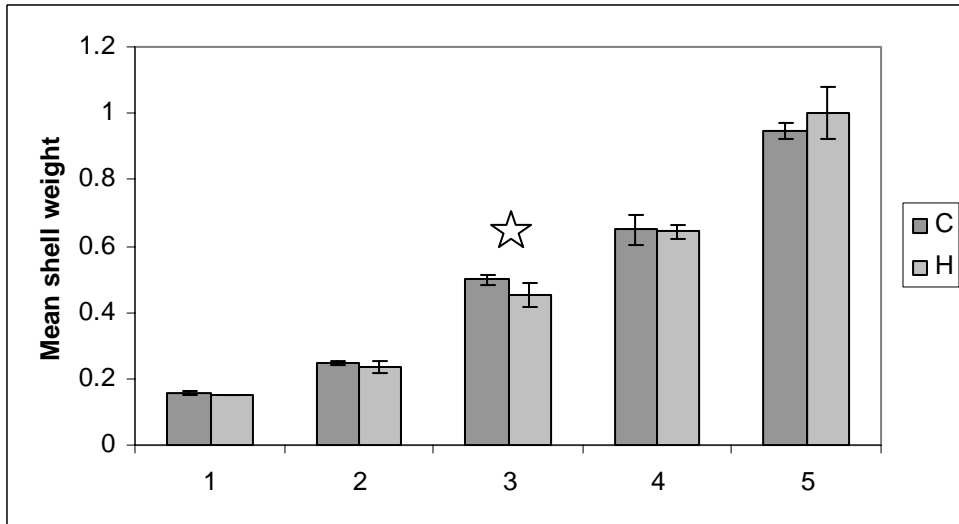


Fig. 2.4. Mussel shell weight from control (C) and harvested (H) plots for the five sampling periods: 1 = pre-harvesting (20 July 2004), 2-5 = post-harvesting (3 August, 3 Sept., 21 Sept., 18 Nov. 2004). The star indicates a significant treatment effect.

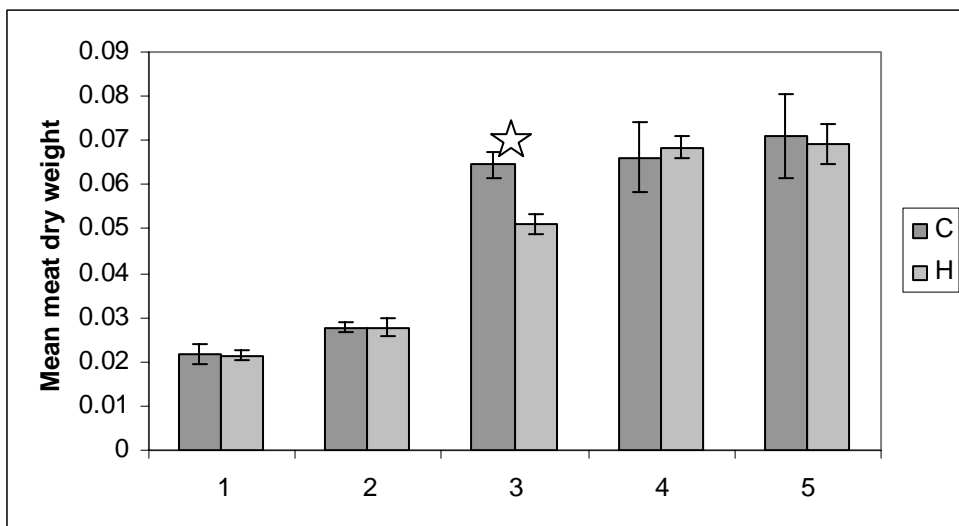


Fig. 2.5. Mussel meat dry weight from control (C) and harvested (H) plots for the five sampling periods: 1 = pre-harvesting (20 July 2004), 2-5 = post-harvesting (3 August, 3 Sept., 21 Sept., 18 Nov. 2004). The star indicates a significant treatment effect.

Recruits

Samples taken on 3 Sept. showed a significant effect of harvesting on the settlement of new recruits, with significantly more new recruits found in harvested than control plots ($p = 0.017$, Fig. 2.7). Samples from the other dates show no significant effects.

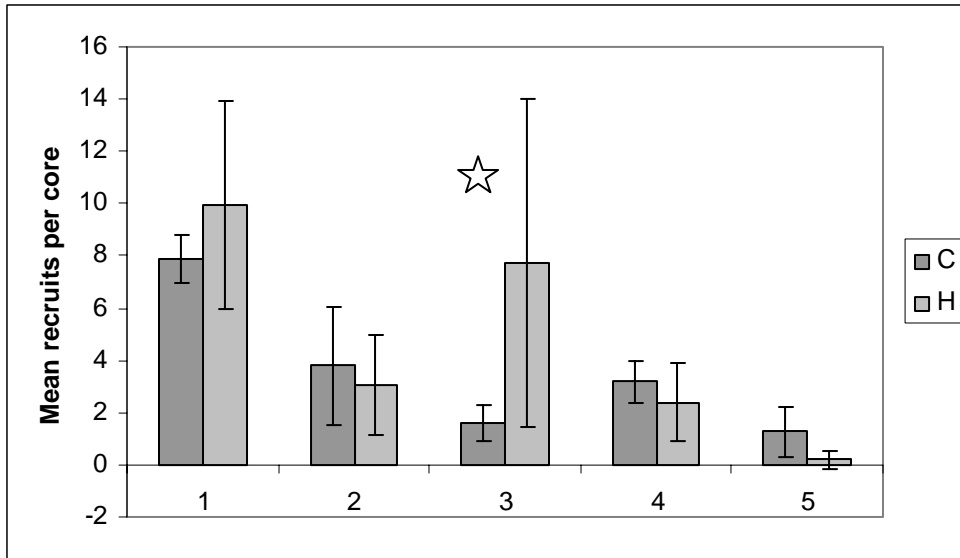


Fig. 2.6. Mean number of new recruits to control [C] and harvested [H] plots for each of the different sampling dates. 1 = pre-harvesting (20 July 2004), 2-5 = post-harvesting (3 August, 3 Sept., 21 Sept., 18 Nov. 2004).

Infaunal and epifaunal samples

The infauna and epifauna associated with the mussel bed was depauperate in species and low in individuals. Univariate analysis of the number of species and individuals (excluding *M. edulis*) by plot and treatment gave some idiosyncratic results, probably related to the small samples sizes. Samples from 3rd August showed a significant effect of plot on the number of species present ($p = 0.005$), but no effect of treatment and no effect on the number of individuals present. Samples from 3rd September showed a marginally significant effect of treatment on the number of individuals ($p = 0.049$), such that harvested plots had a higher number of individuals than control plots, but there was no effect on the number of species present in either treatment or control plots. Samples from 21st September showed a significant effect of plot on both species and individuals ($p = 0.005$ in both cases), with plots 1, 3 and 4 higher than plots 2, 5 and 6. Overall it is difficult to link these significant results meaningfully to the harvesting treatment.

Heysham Infauna plot means

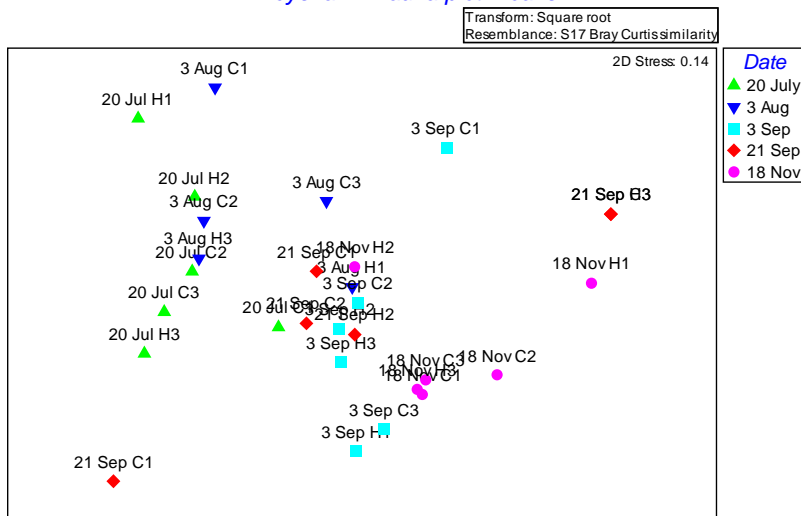


Figure 2.7. nMDS clustering of square root transformed infaunal data from harvested (H1-H3) and control (C1-C3) replicate plots at 5 dates on the Heysham mussel seed bed.

Likewise, the MDS configuration revealed no real separation of samples from harvested and control plots (Fig. 2.7). If anything, infaunal communities displayed higher similarities according to sampling date (Fig. 2.7), with the first two sampling dates having more diverse communities including species such as *Nephtys hombergii*, *Lagis koreni*, *Lanice conchilega*, *Abra alba* and *Pinnotheres pissum* and quite high densities of the bivalve *Macoma balthica*. Subsequent samples, whether treatment or control, were characterised by the presence of the juvenile *Carcinus maenas* and the two common amphipods *Gammarus salinus* and *Melita palmata* (and very little else).

Table 2.1: Abundances of infaunal species collected in the cores from harvested (Harv) and control (Con) plots in Heysham. Numbers are averaged over 15 cores (5 cores x 3 plots for each treatment). The maximum total number of individuals recorded was 56 from 15 cores in the harvested treatment on 3rd September.

	20 Jul Harv	20 Jul Con	3 Aug Harv	3 Aug Con	3 Sep Harv	3 Sep Con	21 Sep Harv	21 Sep Con	18 Nov Harv	18 Nov Con
<i>Glycera tridactyla</i>	0.13	0.13	0	0	0.07	0.07	0	0	0.07	0
<i>Carcinus maenas</i> (juv)	0.27	0.53	0.4	0.13	0.67	0.2	0.2	0.33	0.2	0.2
<i>Gammarus salinus</i>	0	0.2	0	0	0.4	0.07	0.33	0.33	0.13	0.53
<i>Melita palmata</i>	0	0.07	0.47	0.13	2.13	0.73	0.4	0.2	0.87	0.87
<i>Crangon crangon</i>	0.07	0.07	0	0	0.07	0	0	0	0	0
<i>Abra alba</i>	0	0.07	0	0	0	0	0	0	0	0
<i>Pinnotheres pissum</i>	0	0.07	0	0	0	0	0	0	0	0
<i>Nephtys hombergii</i>	0.07	0	0	0	0	0	0	0	0	0
<i>Lanice conchilega</i>	0	0	0	0.07	0	0	0	0	0	0
<i>Lagis koreni</i>	0	0	0	0.07	0	0	0	0	0	0
<i>Macoma balthica</i>	0.87	0.53	0.33	0.87	0.4	0.27	0.33	0.27	0.13	0
No of species	5	8	3	5	6	5	4	4	5	3
No of individuals	1.40	1.67	1.20	1.27	3.73	1.33	1.27	1.13	1.40	1.60

Wind speed

Highest wind speeds (mean daily mean and mean daily maximum), varied significant between months (Fig. 2.8, ANOVA; daily mean: $p = 0.016$; daily max. $p = 0.013$). Highest wind speeds were in September and lowest in August, and these two months were significantly different in daily mean but not in daily maximum (Tukey's pairwise comparisons $p = 0.024$). September had two storm events that both occurred between the two September sampling periods (Fig. 2.9).

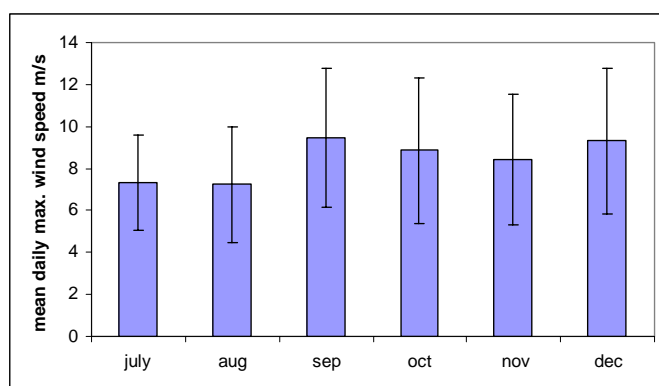


Fig. 2.8 Mean daily wind speed for 2004.

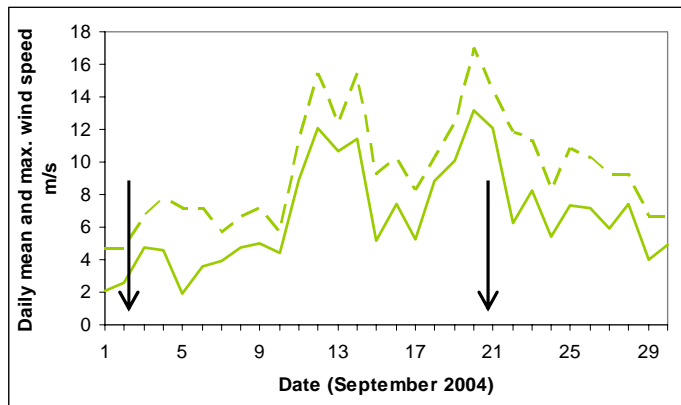


Fig. 2.9 Daily mean (-) and maximum (---) wind speed in September 2004.

Discussion

We found that the effect of partial harvesting on mussel density was short-lived, with no effect of treatment after late autumn. This was due to a marked decline in mussel densities across the whole bed over the course of the experiment, due to erosion by autumn storms. We can therefore reject the hypothesis for this bed that harvesting disturbance damaged the integrity of the bed, which indicates that wave erosion is the most likely cause of loss of bed integrity.

We found that partial harvesting reduced mussel growth, but again the effect was only measurable for a fairly short period (~6-8 weeks) after which no differences were apparent. Partial harvesting also seemed to cause a temporary increase in mussel recruitment, but again the effect was short lived. Partial harvesting had no effect on the biodiversity associated with the mussel bed, which generally decreased over time from summer into autumn regardless of treatment. Our data thus support the hypothesis that harvesting causes some disturbance to the remaining mussels, resulting in a limited, temporary reduction in growth, and do not support the hypothesis of competitive release.

The effect of harvesting on mussel growth could be linked to a variety of factors. It may be directly associated with trauma from the harvesting itself (damage to shells caused by harvesting implements). This is possible, although signs of damage were not observable on most of the mussels collected in subsequent samples. In our opinion, indirect effects of harvesting are thus a more likely explanation.

Firstly, harvesting causes disturbance of the sediment and creates bare patches in the mussel bed. This may result in locally high suspended sediment concentrations generated by friction as the seabed. High suspended sediment concentrations are generally harmful to suspension feeding bivalves, although mussels are regarded as relatively resistant to high particle loads. Energy expenditure is required to sort inorganic from organic particles, food quality and ingestion rates are reduced and at high concentrations there can be direct damage to the gills (Jørgensen 1996, Ellis et al. 2002). Decreases in bivalve growth can be correlated with storm events which increase suspended sediment by an order of magnitude and therefore reduce food quality, although increasing food concentrations (Bock and Miller 1994).

Alternatively (or additionally), harvesting may result in remaining mussels losing some of their byssal attachments to neighbours, either via physical disturbance or because of reduced density and increased patchiness. Byssus threads make up a significant proportion of the carbon allocation for *Mytilus edulis* during growth (8% of carbon and nitrogen allocation - Hawkins and Bayne 1985), and there is evidence of a trade-off between byssus production during periods of strong wave stress and gonad production for autumn spawning (Rhode Island, Carrington 2002) or spring spawning (S. Wales, Price 1982). Mussels track wave stress closely in the strength of their byssal attachment, which can vary by a factor of 2.5 between summer and winter (Carrington 2002; Hunt and Schiebling 2001), and solitary mussels require stronger byssal attachments than mussels in large beds (Bell and Gosline 1997, van de Koppel and Gascoigne unpublished data). Thus if harvesting is followed by a period of rough weather, mussels may be obliged to expend energy reserves on byssus production rather than growth. A wind event occurred almost immediately after harvesting. High density has been shown to benefit mussels in soft sediment environments during periods of high wave stress, probably via this mechanism (Gascoigne et al. 2005).

In this study we found no apparent benefit of harvesting via release from competition. Firstly, this is probably because initial mussel densities on the bed were not dramatically high. In other harvested skears in Morecambe Bay (e.g. South America skear in the northwestern part of the Bay), settlement densities can be much greater than at Heysham, and seed mussels may be in poor condition and have loose byssal attachments – interpreted as a response to high competition for food. In these areas, partial harvesting is more likely to be of benefit to remaining mussels for two reasons: i) strong competition and ii) reduced stress from harvesting because of loose byssal attachments. Secondly, the balance between competition and facilitation in mussel beds prone to erosion depends on food availability (driving competition) and physical stress (driving facilitation) (Gascoigne et al. 2005). In the Heysham bed, tidal currents are likely to be strong, and this will increase both physical stress and food available, driving the balance towards facilitation. They are also strong on South America skear but the dramatic difference in density is likely nonetheless to swing the balance in favour of competition.

The effect on increased recruitment is likely to arise because of increased space available for settlement in the partially harvested beds. This is a potential benefit of harvesting, except that the increase was only observed during one sampling period, suggesting high mortality of recruits in the bed in autumn. It is unlikely in any case that recruits settling on the bed so late in the year would be able to survive stressful winter conditions (high erosion, low food availability). However, partial harvesting of the bed earlier in the year, when there is a larger pool of potential recruits with a higher survival probability, might result in a flush of settlement.

We were not surprised to find no effect of harvesting on associated fauna and the overall diversity of the mussel bed, because the bed was generally very depauperate in both infauna and epifauna. Studies of diversity associated with mussel beds in other areas have found many more species and higher abundances (Beadman et al. 2004 – see also references therein). This is probably a question of sediment type – many mussel beds accumulate soft muddy sediment ('mussel mud') via the filtration activity of the mussels. This mussel mud provides an excellent habitat for infaunal species such as polychaete worms and some amphipod species (Beadman et al. 2004).

However, mussel mud did not accumulate to any great extent in our plots, probably because the high energy environment, so that such species were absent. The sediment type in the plots (cobbles over compacted sand) is not a habitat associated with a highly diverse macrofauna.

In conclusion, experimental partial harvesting of this bed appears to have a negative impact on mussel growth, a positive impact on mussel recruitment and no impact on associated fauna. It is striking that all the observed effects are very transient, and that partial harvesting did not result in any long term changes either to the mussels themselves or to the long term structure of the bed. It seems likely that changes in the bed associated with the arrival of autumn storms overwhelmed any effect of the harvesting experiment relatively quickly.

3. Fate of mussel seed

3.1. Introduction

In 2005, effort was specifically focussed on ascertaining the utilisation of mussel beds by predators at both Caernarfon Bar and Morecambe Bay. The predators at the two seed mussel beds and adjacent control areas were sampled in May and July 2005 using a 2m beam trawl.

The Caernarfon Bar sampling sites (mussel seedbed and adjacent control area) were characterised by a veneer of sandy sediment overlying a cobble/gravel substratum beneath. The area of the control and seedbed site each measured approximately 300 m by 500 m. At Morecambe Bay, both the mussel seed site (South America skear) and the control site were exposed at extreme low water spring tides. The skear measured approximately 200 m x 400 m. The nearby control site was approximately 300 m x 400 m in dimension.

3.2 Methods

The bottom topography at each of the above sites was surveyed using a CMAX C800 side-scan sonar towed behind a vessel at a speed of 4 knots. It was hoped that the acoustic signature of the mussel bed would be distinguishable from the underlying substratum type such that the mussel bed could be quantified in terms of its extent. A swath range of 50 m for each channel was chosen, thereby mapping a 200 m strip of seabed on each tow of the side-scan fish. An image of the entire area surveyed was compiled using a mosaic grid system.

At Caernarfon and Morecambe Bay, a 2 m beam trawl (Jennings *et al.* 1999) was used to sample the epibenthic fauna on the mussel seed beds and in the nearby control area (at least 4 replicate tows on each area). The trawl had a mesh size of 2 mm and was towed at a speed of c. 5 knots. The longitude and latitude were recorded at the start and at the end of the tow to quantify the area of seabed swept by the trawl. Tow duration over the seed mussel beds was 300 s but was doubled to 600 s in the control areas due to the impoverished nature of the fauna in these areas. At the end of each tow, the species in catch were identified and counted. The total length of all flatfish was measured (nearest mm). Those flatfish over 80 mm total length were preserved in alcohol so that their stomach contents could be examined later in the laboratory.

In many of the trawls the number of green crabs *Carcinus maenas* and common starfish *Asterias rubens* were high. In these cases a sub-sample of 30 individuals from each sample of each species was measured so that the population size-structure could be ascertained. The carapace width of *Carcinus maenas* was measured at its widest point to the nearest mm. The length of *Asterias rubens* was measured as the distance from the tip of the one arm to the tip of the opposite arm.

3.3. Results

Side-scan sonar images of the substrata showed well defined sand ripples at the Caernarfon Bar seed mussel site which indicated that this site is subject to physical forcing and sediment movement. This is entirely expected given the shallow depth at the site (< 5 m at low tide). Van Veen grab samples of this area revealed that there was an underlying cobble substratum. The images from the Morecambe Bay area indicated that the substratum of the two sites is more stony with some large boulders visible on the seabed. However, more importantly it was not possible to distinguish areas that were covered in seed mussels as discrete patches of the seabed. Therefore no further effort was placed into this part of the project as the use of side-scan sonar as a tool to delineate seed mussel beds was not considered to be useful in the context of the current study.

Multivariate statistical analysis was undertaken for the benthic community data to determine if differences occurred in the species composition sampled by the beam trawl (i.e. epifauna) at Morecambe Bay and Caernarfon Bar. This analysis also used to examine the benthic community data for differences between seed mussel and control sites at each location. An Analysis of Similarities (ANOSIM) test revealed that there was a significant difference between the community composition found at the seed mussel sites and the control sites both in May ($R=0.6$ $p=0.001$) and July ($R=0.19$ $p=0.046$) at both Caernarfon and Morecambe Bay. A Kruskal-Wallis test revealed that there was a significantly greater abundance of epifaunal organisms at the seed mussel sites than at the control sites in both May (K-W, $H=9.94$ $p=0.002$) and July (K-W, $H=5.83$ $p=0.016$). A Kruskal-Wallis test also showed that Peilou's evenness index was higher at the control sites for both May ($H=7.48$ $p=0.006$) and July ($H=5.91$ $p=0.015$), this indicated that certain fauna were particularly dominant on the mussel seed beds, and these tended to be predatory species (i.e. *Carcinus maenas* and *Asterias rubens*).

Figure 3.1 shows the abundance of *Carcinus maenas* sampled at each of the control and mussel seedbed areas at each site in May 2005. The median abundance of *Carcinus maenas* had no interaction with site, which means that their abundance was significantly higher at the seed mussel sites at both Caernarfon and Morecambe Bay. The results indicated the same pattern for both of the months which suggests that season has no effect on the distribution of the predators over the sites although the actual abundances differed among time periods. For other species, no significant differences were found between the control and mussel seedbed plots at both locations.

Starfish found on the mussel seed beds were consistently larger than those found in control areas (Fig. 3.2). It is possible that only starfish above a certain minimum size are able to consume the seed mussels present during the summer months, such that

smaller starfish focus on other prey found off the seedbeds where they also avoid competition with larger conspecifics. No such size-related differences were found for other predatory species sampled by the beam trawl.

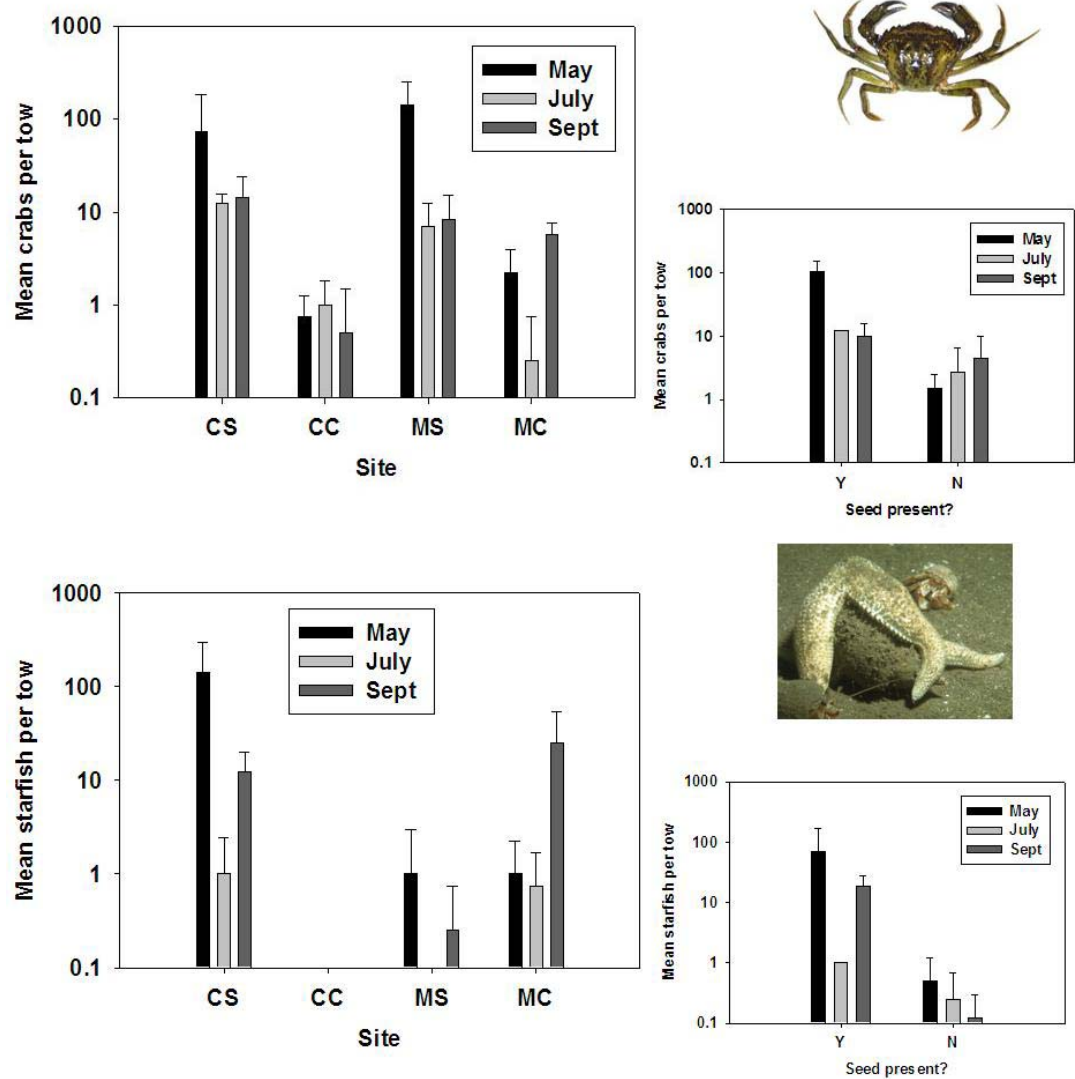


Fig. 3.1 The mean abundance (\pm 95% C.I.) of green crabs *Carcinus maenas* and starfish found at Caernarfon Bar and Morecambe Bay within the mussel seed beds and in nearby control areas. In the smaller inset panel, an analysis was undertaken comparing those locations that had seed vs those with no seed. The reason for this analysis is that in Morecambe Bay, a late settlement of seed occurred on the original control plot. There were significantly more crabs present on plots with mussel seed than those with no mussel seed (ANOVA, $F_{1,4} = 4.66$, $P = 0.05$). Patterns of occurrence of starfish were irregular between sites, although there is a suggestion that plots with seed mussels attracted more starfish this was not significant ($F_{1,4} = 2.63$, $P = 0.14$). Note the Y axis scale is a log scale.

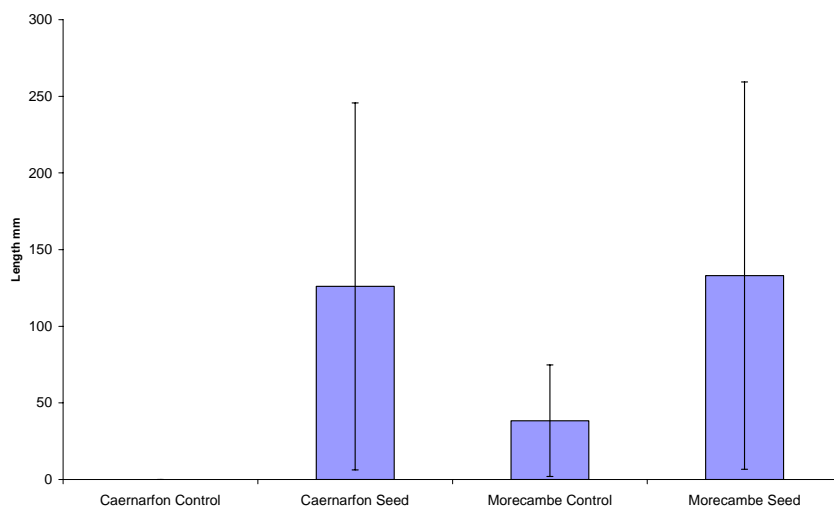


Fig. 3.2 The median size (\pm 95%) of common starfish *Asterias rubens* found on seed mussel sites and control sites within mussel seed beds and nearby control areas at Morecambe Bay and Caernarfon Bar in May and July.

Fish smaller < 8 cm in length dominated the fish fauna. Plaice, gobies, scaldfish and solenettes were dominant (in terms of abundance) at different times of the year (Fig. 3.3). Fish of this size would not be able to ingest mussel seed that occurred on the mussel seed bed at that time. Solenettes, gobies and scaldfish are all relatively small species that each primarily small crustacean and copepods. Stomach contents analysis was undertaken for only plaice that were the only species to occur in sufficient numbers for meaningful analysis ($n = 13$). Only two out of 13 plaice caught had seed mussels in their stomach contents. However, the number of mussels consumed was high (10 and 50). However, the mussels in the stomach contents were much smaller (mean \pm SE shell length 4.7 ± 1.6 mm) than the mean length of mussels in the seedbed (17.7 ± 4.9 mm). This indicates that the small plaice (111 and 198 mm total length) sampled in our survey fed highly selectively on the smallest size-classes of mussels. Mussels were only found in the stomach contents of fish sampled from Morecambe Bay, where they were the most important prey type in terms of their percentage contribution to the diet (Figure 3.4).



	No. Spp.	No. Indiv	Dominant sp.
May	11	388	plaice
July	9	42	solenette
Sept	22	246	gobies/scaldfish

Fig. 3.3 Number of species and total number of fish caught on three dates (total $n = 24$, 5 or 10 min tows with 2 m beam trawl).

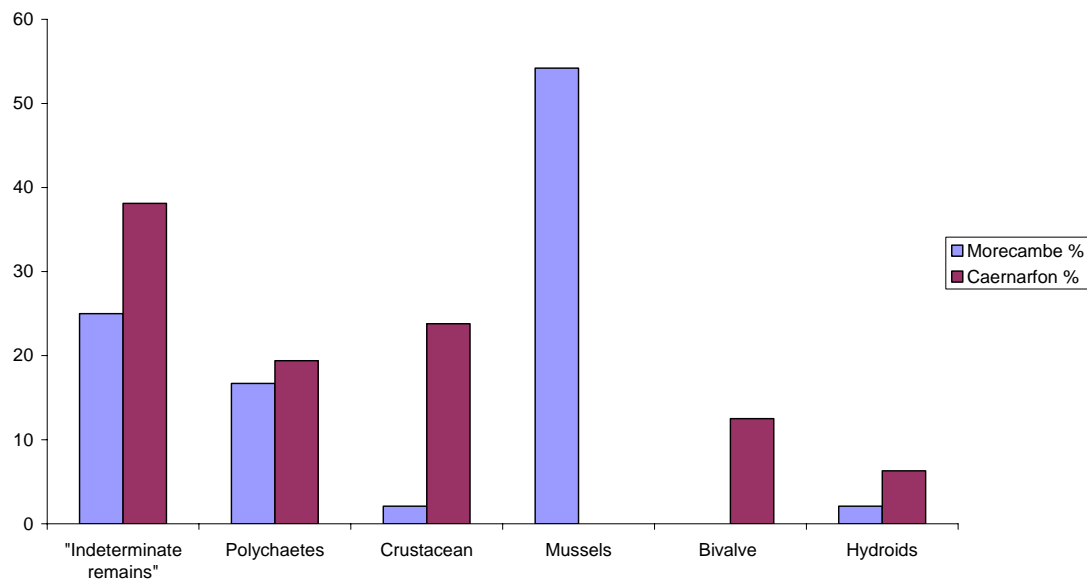


Fig. 3.4. The percentage composition (y-axis) of different prey types found in the stomach contents of plaice (n = 13) sampled from seed mussel and control sites in Morecambe Bay and Caernarfon Bar in May and July. Mussels occurred in the stomachs of only 2 individuals, but were highly abundant in the diet of these fish.

3.4 Discussion

The use of remote acoustic techniques to delineate the extent of mussel seed beds did not prove a useful tool in the present study. This may be because the mussel seed did not develop sufficiently into a seabed feature that could be differentiated from the surrounding sediments. In other situations (e.g. the Menai Strait) it is possible to differentiate mussel seed beds primarily because they differ from the surrounding substratum. However in the present study, the underlying cobble substratum has greater acoustic reflectivity than the overlying mussel seed which made it impossible to differentiate mussels from the underlying substratum. Nevertheless, such acoustic methods would undoubtedly be useful for mapping areas that might provide suitable substratum for mussel seed settlement.

From the samples collected in this study, it is clear that where mussel seed occurs it is utilised by crab and starfish predators and that aggregations of these predators are greater (in abundance) over the mussel seed beds than in surrounding areas. Mussel seed appear to be more important for larger starfish which may be related to their physical capability to handle mussel seed of a particular size or could be related to avoidance behaviour by smaller starfish which are occasionally predated by larger conspecifics. Overall, the number of predatory fish species sampled on the mussel beds was low. This is perhaps not surprising given the extremely impoverished nature of the fauna associated with the mussel seed bed in Morecambe Bay (Table 2.1). Thus, from the results of the present study, it would appear that only a proportion of a relatively small number of fish utilise mussel seed in their diet. However further sampling would be required to confirm this finding.

The question remains whether mussel seed beds are likely to be ecologically important for the taxa that might depend upon them as either a habitat or a prey resource. In this context mussel seed beds should be thought of as an *energy subsidy*. However, for energy subsidies to have population level effects they must occur in sufficient quantity, frequency and on a predictable basis (Polis et al. 1996). However, it is clear from the logbook data and also the experience in the present study that mussel seed beds are ephemeral and occur erratically such that it would not be possible for predators to adapt annual migration patterns that depended upon them. Thus they provide an opportunistic prey resource at best.

It is important to note that the numbers of fish sampled in the present study are low. While this may indicate that fish do not depend upon the mussel seed beds, further sampling would be required to increase the power of this inference. It is also important to note that bird predators were not included in our considerations. Thus mussel seed may be more important for avian predators that seek food resources at a different spatial scale than crabs, starfish and fishes.

4. References

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van de Koppel J. and Gascoigne J. in prep. Measuring self-organised patterning in mussel beds.

Appendix I – Mussel seed literature review

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) adult abundance, ii) substratum availability and iii) climatic and hydrodynamic factors. 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) birds (oystercatchers *Haematopus ostralegus* in the intertidal, eider duck *Somateria mollissima* in the subtidal), ii) fish (plaice *Pleuronectes platessa*, flounder *Platichthys flesus*, dab *Limanda limanda*), starfish (*Asterias rubens*) and crabs (*Cancer pagarus* and *Carcinus maenas*), with crabs and starfish likely to have the greatest impact on mortality. Predation on seed mussel beds may have secondary ecological effects since crabs and starfish are important as predators and prey of 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 nature seed mussel bed exploitation is spat collection using water column rope collectors. These have worked well in trials in the Wadden Sea, where they have been proposed as a means of reducing the impact of mussel harvesting on bird populations.
- 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).

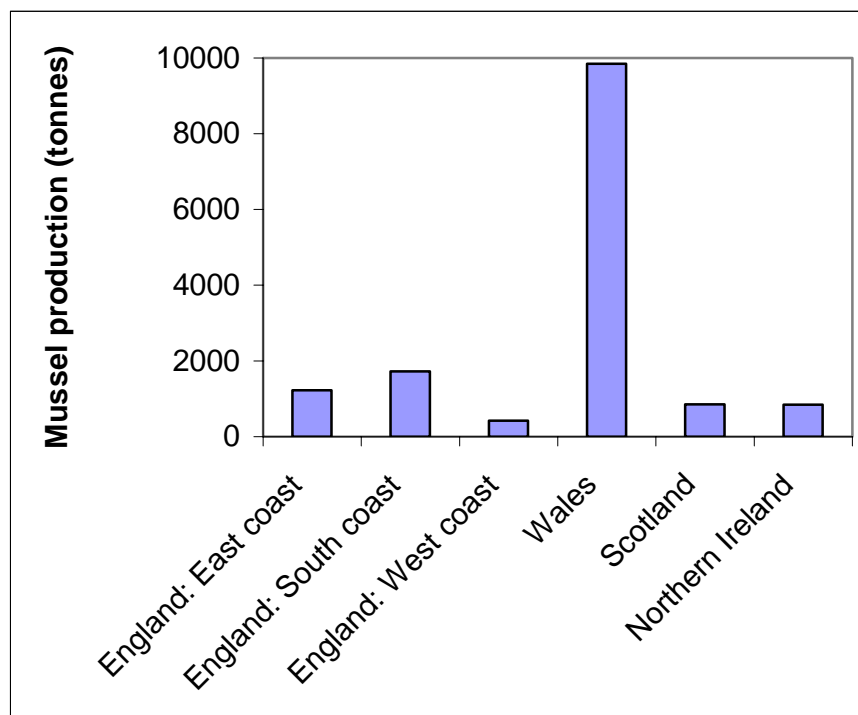


Fig. 1. Wales is the most important mussel producing area in the UK (2001: Data from DEFRA and the Scottish Executive).

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 and are often dispersed during the winter (Nehls and Thiel, 1993; Reusch and Chapman, 1995; Hilgerloh *et al.*, 1997). Predation by vertebrates and invertebrates 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.

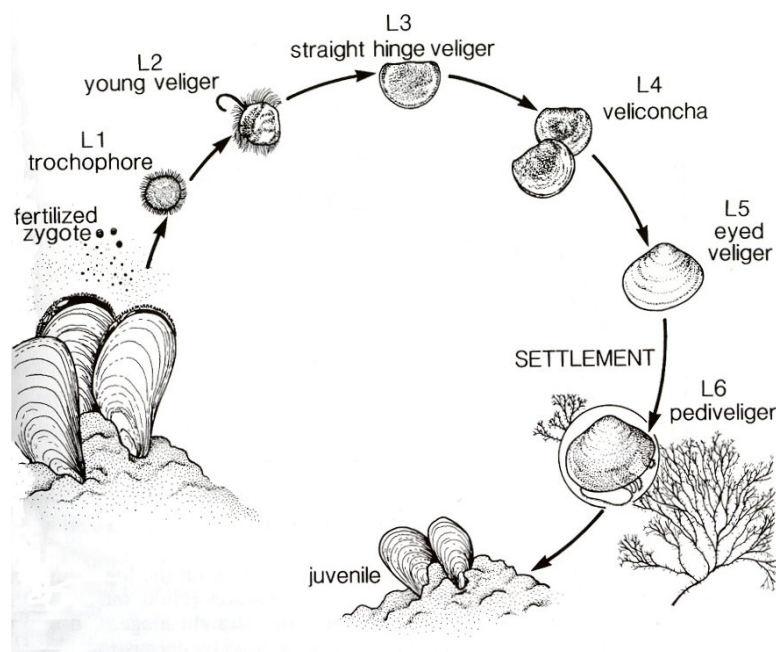


Fig. 2. Larval and postlarval life history of *M. edulis*. The postlarval plantigrade is not shown. From Wildish and Kristmanson, 1997, based on photomicrographs and figures in Bayne, 1976.

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 change 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 (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 (Hilgerloch *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; Hilgerloch *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).

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 Ecological role of seed mussel beds

Mussel beds provide a unique habitat on sedimentary coasts in terms of species richness, biomass, productivity, trophic transfer and material cycling (Asmus and Asmus, 2002). Seed mussels act as the basis for an ecosystem through their role in the creation of a physical structure and by transferring organic matter from the water column to the bed. They also provide a food source for a variety of species higher up the food chain.

5.2 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).

Conflicts have occurred between commercial interests and bird conservation interests since the birds compete for mussels of a harvestable size-class. In the Wadden Sea, intertidal mussel beds almost disappeared in the late 1980s due to low spatfall (Dankers *et al.*, 1999) resulting in an important impact on bird populations and the subsequent creation of management strategies to protect bird populations (Kaiser *et al.*, 1998). However, 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 (*Tautoglabrus* 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 m³. 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. Other predators probably cause more constant levels of mortality.

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 the cultivated 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 important food source for bird species such as the herring gull *Larus argentatus* (Dare, 1976; Dumas and Witman, 1993).

5.3 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 m² 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 *Diophysia* (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).

5.4 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 Boncavage (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 polychaete *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*).

5.5 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 chemoautotrophic sulphur bacteria (e.g. *Beggiatoa*) (Grant *et al.*, 1995). The by-products of the anaerobic metabolism such as H₂S 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 is an important limitation on larval production. 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). Thus the creation of large, dense cultivated mussel beds (e.g. in the Menai Strait) should enhance larval availability to downstream settlement sites (e.g. Caernarfon Bay).

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). 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). 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 predated 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). 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).

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 calculated amount 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.

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).

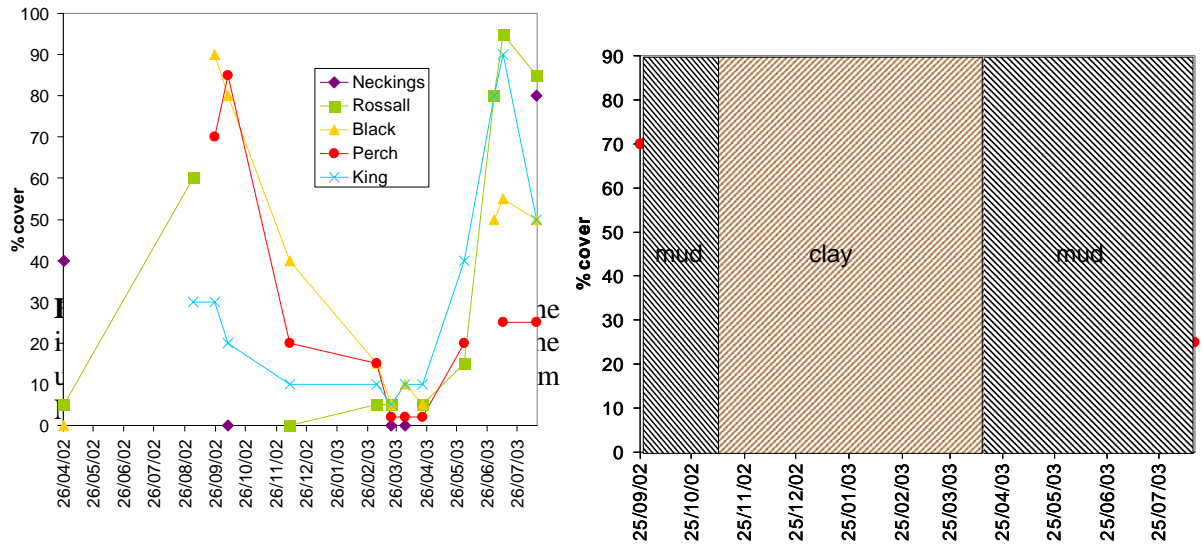
9.1 Morecambe Bay seed beds

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 Heysham Flats area 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 on Heysham Flats, Lancashire. 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 from these sites and relaid in the Wash.

10 References

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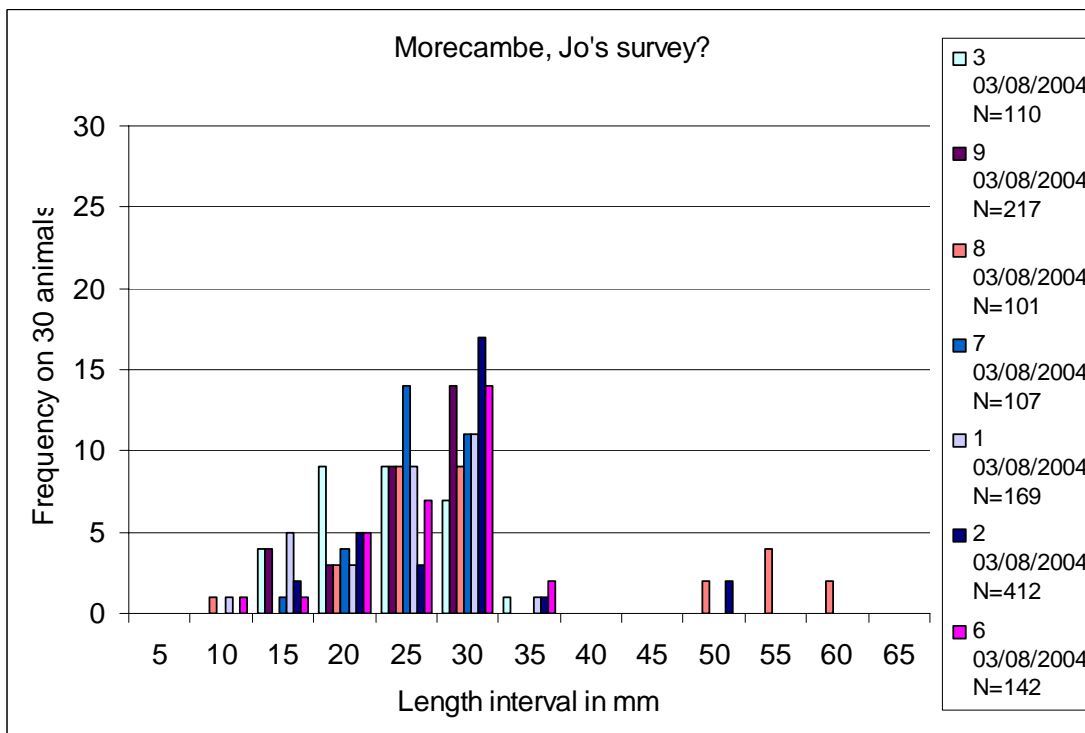
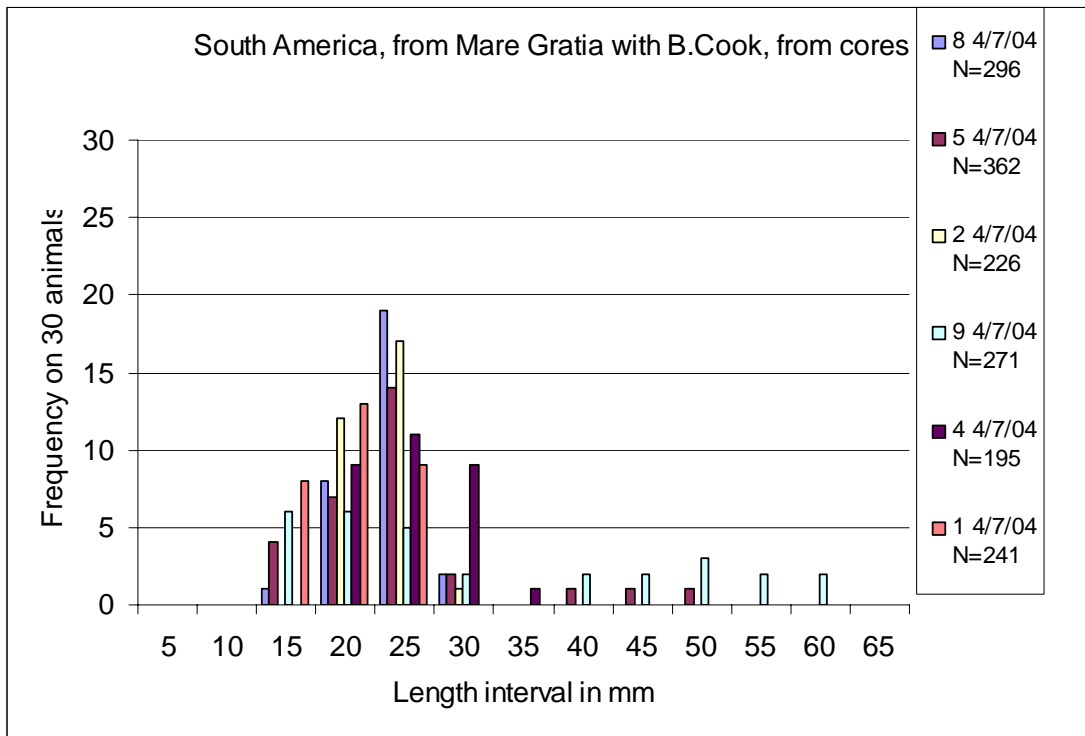
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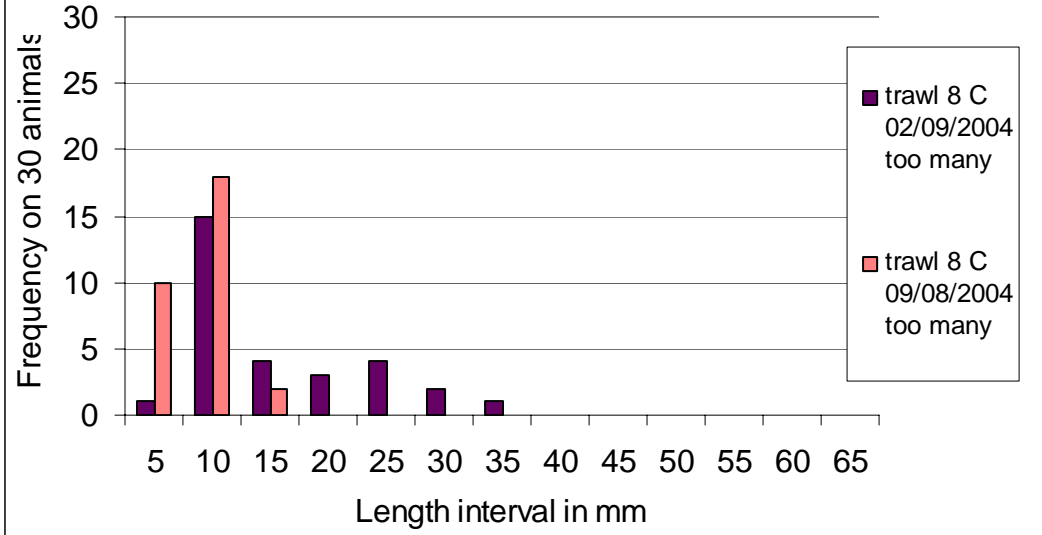
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Appendix 2

Extra data: mussel size class in Morecambe and Caernarfon Bar



02/09/2004 Survey from Wilson boat,
 Note: 4 taws and one with Camera - Marika Camille on
 board, just checking on seed site



Caernarfon Bar survey 8/10/04 From Wilson boat

