Mussel Stock Assessment

2004

Annual Stock Assessment of the Littoral Mussel (Mytilus edulis) Stocks in the Solway Firth

November 2004

Undertaken by:

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Summary

The annual stock assessment of mussel beds in the Cumbrian Upper Solway Firth was undertaken during July 2004. All large mussel beds from Dubmill Point northwards were surveyed.

The total biomass of all the beds surveyed was 9774 tonnes, of which 3754 tonnes were of commercial size (45mm or above) at the time of the survey.

There has been a slight decline in total biomass since the 2003 survey when it was estimated that there was a total biomass of 14,528 tonnes of mussels. The 2003 survey included one extra bed, however even when this was excluded from the total (giving a total biomass of 14,305) the total biomass has still declined overall by 32%. Conversely, commercial biomass has increased slightly since 2003 when there was an estimated 3,287 tonnes (3,399 including the extra bed surveyed in 2003).

The increase in commercial biomass was expected as the exceptionally high spatfalls of 2001 and 2002 have now reached minimum landing size (MLS), hence increasing commercial biomass. Mussels from the 2001 and 2002 year classes have only survived on stable beds, particularly at Ellison’s Scar, and eroded from open coast locations (Lowhagstock and Beckfoot Flats).

It is recommended that 3 beds are opened to fishing this year, Ellison’s Inner, Mid and Outer beds. The TAC should not exceed 836 tonnes.
1. **Introduction**

The edible mussel (*Mytilus edulis*) is the most common type of bivalve to be found on the English side of the Solway Firth (Solway Firth Review, 1996). Mussels can be found on almost every shore along the Cumbrian coast where there is some hard substrate to which they can attach. Mussels also form dense beds in suitable areas and these mussel beds are a common feature of the Cumbrian coast. The mussel beds of the intertidal flats in the Upper Solway north Cumbrian coast are sufficiently large to support commercial exploitation.

Monitoring of the Upper Solway mussel stocks by Cumbria Sea Fisheries Committee began in 1994. The objective of the appraisal was to perform a stock assessment to allow the fishery to be managed in a sustainable way.

Prior to 1999 only beds that were thought to be commercially viable for harvesting were surveyed. From 1999 all large beds were surveyed in an attempt to consider the impact of harvesting on the wider environment, in particular the bird populations. The Solway supports nationally and internationally significant numbers of migrating and wintering waterfowl, regularly supporting peak counts of 110,000 birds (Solway Firth Review, 1996). Mussels are important in the diet of oystercatchers, sandpipers and turnstones (Hulscher, 1982). The management of the mussel fishery, therefore, must take into account the needs of birds, ensuring that their feeding requirements are not adversely affected by the fishing.

The mussel beds of the North Cumbrian coast are notoriously unstable and their population dynamics are not well understood. Mussel beds which form on soft sediment on open coasts are usually short lived. Winter gales, strong tidal currents and ice can cause catastrophic mortalities to mussel populations on open coasts, especially when the mussels are on soft sediment (Dare, 1976; Sousa, 1985).

Very little fishing effort occurred in the 2003-2004 season and less than 50 tonnes were removed from the Ellison's Scar area (Cumbria Sea Fisheries Committee per. com.). This was considerably lower than the previous season, when 450 tonnes harvested between August 2002 and June 2003.

This report has included comparisons with previous surveys in an attempt to understand the dynamics of the mussel populations and the impact of fishing and natural changes on the Solway mussel beds. Comparisons with previous years can be difficult when looking at the Solway mussel beds. Areas that are present one year may be swept away the following year and new areas of spat often settle on scar ground that was not previously a mussel bed. Nevertheless over the past seven years several beds have been repeatedly sampled allowing some analysis of the trends in the mussel population of the north Cumbrian coast.
2. Method

The annual mussel stock assessment of the Cumbrian Upper Solway Firth was undertaken between 2nd and 6th July 2004. All large mussel beds from Dubmill Point northwards were surveyed. The mussel beds surveyed this year were: Dubmill Scar, Ellison’s Scar (containing Ellison’s Inner bed, Ellison’s Mid bed and Ellison’s Outer bed), Lowhagstock Scar, Beckfoot Flats, Lees Scar and Skinburness. The additional bed, Salt Pans, surveyed in 2003 was not included in the 2004 survey.

Each mussel bed was visited at low water on a spring tide. The outer edges of the beds (the area occupied by mussels) were mapped out using the tracking facility on a portable GPS. This information was then downloaded onto a PC and the area (m²) of each bed calculated using GPS Utility software. All maps in this report are reproduced by permission of Ordnance Survey on behalf of the Controller of Her Majesty’s Stationary Office, Crown Copyright 2000, all rights reserved, licence Number 100037042.

The percentage cover of mussels on each bed (i.e. the proportion of the bed covered by patches of mussels) was estimated using the method developed by DEFRA (Walker and Nicholson, 1986). Percentage cover was determined by pacing over the beds in zigzag lines and recording the proportion of footsteps that landed on mussels or bare sediment. The length of each line was determined by the size of the bed and varied from 50m on smaller beds to 200m on the largest beds. The direction of each transect was chosen in the field to satisfy three criteria: so that the transect should remain within the constraints of the bed, the zigzag pattern should effectively cover all of the bed and within these two constraints the direction should be random.

At the end of each transect a 0.1m² sampling quadrat was placed at random on the nearest patch of mussels (Figure 1). All material within this tenth of a meter patch was gathered and sieved through 5mm mesh to remove sediment (Figure 2). After sieving and the removal of stones and debris, the contents of each quadrat was transferred to a bag and taken back to the office lab for measurement and further analysis. On each bed between 5 and 16 quadrats were taken depending on the size and heterogeneity of the mussel bed.

Figure 1
The sampling quadrat used to collect samples
The samples taken were processed back at the office lab as soon as practical after collection to ensure as little weight loss from the mussel shells as possible. The samples were first sorted to separate any stones, debris or dead shells from the living mussels. The total weight of mussels in each sample was recorded. A sub-sample of 100 mussels from each sample was taken and their length recorded to the nearest millimetre. The weight of this sub-sample was also recorded in order to raise the length frequencies to the total sample weight (equal to the number per quadrat). Mussels above minimum landing size (MLS), defined as mussels of 45mm and above, were separated and weighed in each sample to obtain the weight of commercially sized mussels.

The density (number/m$^2$) and biomass per square meter (biomass/m$^2$ as it will be referred to from hereafter or g/m$^2$) of both all and commercial sized mussels was calculated by raising the number and weight of mussels in the sample by 10 and then by the mean percentage cover of the bed they were taken from. The total biomass and commercial biomass (in tonnes) was then calculated by multiplying the biomass/m$^2$ by the areas covered by the mussel bed.

The maximum sustainable yield (maximum tonnage of mussels that should be removed from each bed) was also calculated for each viable mussel bed. The maximum sustainable yield chosen was 33% of the exploitable stock (45mm and above) which is the typical proportion used in most UK bivalve fisheries (CEFAS per. com.).
3.1 Results

This year the largest mussel beds were found at Ellison’s Inner bed and Dubmill Scar (Table 1; Figure 3). The majority of beds surveyed this year have experienced a reduction in area occupied by mussels and there has been a small decline (6%) in the overall area occupied by mussel beds on the North Cumbrian coast (excluding the Salt Pans bed that was surveyed in 2003). The exceptions to this were Beckfoot Flats and Dubmill Scar (which have both experienced a growth in the area due to colonisation of new areas by spat mussels) and Ellison’s Inner bed (which has remained almost the same). Ellison’s Outer bed has suffered the greatest loss in area (49%) closely followed by Ellison’s Mid bed (43%). Lees Scar and Skinburness continue to erode; at Skinburness the mussel bed now occupies an area of only 1.8 hectares.

Table 1

<table>
<thead>
<tr>
<th>Mussel bed</th>
<th>Area (Ha)</th>
<th>Mean percentage cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dubmill - spat bed</td>
<td>40.403</td>
<td>59.1</td>
</tr>
<tr>
<td>- adult bed (total area of Dubmill)</td>
<td>28.417 (68.82)</td>
<td>59.3</td>
</tr>
<tr>
<td>Ellison’s Inner bed</td>
<td>58.105</td>
<td>52.4</td>
</tr>
<tr>
<td>Ellison’s Mid bed</td>
<td>22.171</td>
<td>42.4</td>
</tr>
<tr>
<td>Ellison’s Outer bed</td>
<td>8.896</td>
<td>46.2</td>
</tr>
<tr>
<td>Lowhagstock</td>
<td>15.117</td>
<td>61.5</td>
</tr>
<tr>
<td>Beckfoot</td>
<td>9.436</td>
<td>68.3</td>
</tr>
<tr>
<td>Lees Scar</td>
<td>14.167</td>
<td>39.8</td>
</tr>
<tr>
<td>Skinburness</td>
<td>1.815</td>
<td>11.5</td>
</tr>
<tr>
<td>Total</td>
<td>198.527</td>
<td>-</td>
</tr>
</tbody>
</table>

Spatfall (the settlement of young, newly attached mussels of less than 20mm in length) has been very patchy this year, with some beds receiving a high spatfall and other receiving very little (Table 2). Most beds have experienced a decline in spat density, however huge amounts of spat have settled on Beckfoot Flats, Lowhagstock and on the landward side of Dubmill scar. On these beds spat has settled in vast numbers occupying previously uncolonised areas. Virtually no spat was found on the three beds at Ellison’s Scar, at Lees Scar and at Skinburness.

Table 2

<table>
<thead>
<tr>
<th>Mussel bed</th>
<th>Percentage spat mussels (&lt;20mm)</th>
<th>Percentage commercial sized mussels (45mm and above)</th>
<th>Mean length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dubmill - spat bed</td>
<td>30.9 0.2</td>
<td>0.2 48.0</td>
<td>22.4 44.6</td>
</tr>
<tr>
<td>- adult bed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ellison’s Inner bed</td>
<td>3.3 28.8</td>
<td></td>
<td>39.3</td>
</tr>
<tr>
<td>Ellison’s Mid bed</td>
<td>0.3 51.3</td>
<td></td>
<td>43.8</td>
</tr>
<tr>
<td>Ellison’s Outer bed</td>
<td>0 88.5</td>
<td></td>
<td>50.8</td>
</tr>
<tr>
<td>Lowhagstock</td>
<td>89.4 1.3</td>
<td></td>
<td>14.0</td>
</tr>
<tr>
<td>Beckfoot</td>
<td>54.7 10.9</td>
<td></td>
<td>25.5</td>
</tr>
<tr>
<td>Lees Scar</td>
<td>7.0 9.9</td>
<td></td>
<td>30.9</td>
</tr>
<tr>
<td>Skinburness</td>
<td>2.3 40.3</td>
<td></td>
<td>39.2</td>
</tr>
</tbody>
</table>
As a result of the poor spat settlement and the continued growth of the established mussels the mean length has increased on most beds this year (Table 2), with the exception of Lowhagstock and Beckfoot Flats where spatfall was higher. As a result of the continued growth of older mussels the percentage of commercially sized mussel has increased on all the beds surveyed, most markedly at Ellison’s Mid bed, where there has been an increase of over 5000%.

Density was found to be highest on the three beds where large amounts of spat had settled; namely Lowhagstock, Beckfoot and Dubmill spat bed (Table 3). Biomass/m² was highest at Ellison’s Outer bed, Ellison’s Inner bed and the adult bed at Dubmill, where the mussel populations are made up of large mature adults.
Table 3
The density (mussels/m²) and biomass per square meter (g/m²) of total mussels and commercial sized mussels on each bed sampled

<table>
<thead>
<tr>
<th>Mussel bed</th>
<th>Density (mussels/m²)</th>
<th>Biomass per square meter (g/m²)</th>
<th>Density of commercial sized mussels (g/m²)</th>
<th>Commercial Biomass per square meter (g/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dubmill - spat bed</td>
<td>2289.2</td>
<td>3981.0</td>
<td>4.6</td>
<td>52.2</td>
</tr>
<tr>
<td>- Adult bed</td>
<td>467.3</td>
<td>5736.0</td>
<td>213.4</td>
<td>3548.0</td>
</tr>
<tr>
<td>Ellison’s Inner bed</td>
<td>709.7</td>
<td>5618.4</td>
<td>155.4</td>
<td>2465.3</td>
</tr>
<tr>
<td>Ellison’s Mid bed</td>
<td>505.3</td>
<td>4189.1</td>
<td>183.7</td>
<td>2355.7</td>
</tr>
<tr>
<td>Ellison’s Outer bed</td>
<td>500.8</td>
<td>7044.0</td>
<td>447.6</td>
<td>6233.9</td>
</tr>
<tr>
<td>Lowhagstock</td>
<td>8769.1</td>
<td>3742.6</td>
<td>16.8</td>
<td>233.3</td>
</tr>
<tr>
<td>Beckfoot</td>
<td>6666.9</td>
<td>5229.7</td>
<td>75.6</td>
<td>1160.8</td>
</tr>
<tr>
<td>Lees Scar</td>
<td>1330.4</td>
<td>4534.0</td>
<td>34.6</td>
<td>458.0</td>
</tr>
<tr>
<td>Skinburness</td>
<td>121.8</td>
<td>755.7</td>
<td>21.0</td>
<td>330.5</td>
</tr>
</tbody>
</table>

The majority of beds surveyed experienced a decline in total density this year, as a result of the poor spat settlement, with the exception of Lowhagstock and Beckfoot. Conversely, commercial density had increased on all the beds surveyed due to the continued growth of older established mussels. This year Ellison’s Outer bed had the highest commercial density and biomass/m². Biomass/m² has remained stable at Dubmill, Ellison’s Inner bed and Ellison’s Outer bed, but declined at all the other beds surveyed with the exception of Lowhagstock, where the massive spatfall had resulted in an increase in biomass of over 100%. Commercial biomass/m² had improved on the majority of beds surveyed with the exception of Skinburness and Ellison’s Outer bed.

This year at the time of the survey there was an estimated 9773.71 tonnes of mussels on the Cumbrian mussel beds surveyed, of which 3754.32 tonnes were above MLS (Table 4). Overall there has been a 32% decline in the total biomass (tonnage) of the beds surveyed compared with the 2003 survey (excluding the extra bed surveyed in 2003). Conversely the overall commercial biomass in the Upper Solway has increased by 14%, with increases on all beds surveyed with the exception of Lees Scar, Ellison’s Outer bed and Beckfoot.

Table 4
Total biomass, commercial biomass and recommended TAC (tonnes)

<table>
<thead>
<tr>
<th>Mussel bed</th>
<th>Total biomass (tonnes)</th>
<th>Tonnage of commercial sized mussels</th>
<th>Recommended TAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dubmill - Spat bed</td>
<td>1608.44</td>
<td>21.09</td>
<td>0</td>
</tr>
<tr>
<td>- Adult bed</td>
<td>1630.00</td>
<td>1008.24</td>
<td>0</td>
</tr>
<tr>
<td>Ellison’s Inner bed</td>
<td>3264.57</td>
<td>1432.46</td>
<td>477.44</td>
</tr>
<tr>
<td>Ellison’s Mid bed</td>
<td>928.77</td>
<td>522.28</td>
<td>174.08</td>
</tr>
<tr>
<td>Ellison’s Outer bed</td>
<td>626.63</td>
<td>554.57</td>
<td>184.84</td>
</tr>
<tr>
<td>Lowhagstock</td>
<td>565.77</td>
<td>35.27</td>
<td>0</td>
</tr>
<tr>
<td>Beckfoot</td>
<td>493.47</td>
<td>109.53</td>
<td>0</td>
</tr>
<tr>
<td>Lees Scar</td>
<td>642.33</td>
<td>64.88</td>
<td>0</td>
</tr>
<tr>
<td>Skinburness</td>
<td>13.72</td>
<td>6.00</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>9773.71</strong></td>
<td><strong>3754.32</strong></td>
<td><strong>836.36</strong></td>
</tr>
</tbody>
</table>
It is worth noting here that the estimates of the total biomass or tonnage of mussels given here only refer to the weight at the time of sampling. The mussels will continue to grow and their weight will increase throughout the autumn as their meat content increases. For a given shell length it has been estimated that the weight is 21% greater in October than August. The total tonnage will increase by a similar magnitude, however the effect of winter mortality and bird predation will reduce the tonnage of mussels throughout the year.

3.2 There follows a detailed description of each site.

3.2.1 Dubmill Scar

The topography of this area has remained very similar since it was first surveyed in 2002 and can be summarised as follows: The shoreward side of this scar is dominated by spat (or seed) mussels while the outer part of the scar is dominated by large mussels and in the southern part by *Sabellaria* mounds (Figure 4). Mussels do not extend down into the sublittoral at Dubmill and the area from the mean low water mark into the sublittoral is occupied by breadcrumb sponge and kelp.

![Figure 4](image_url)

*The distribution of mussels on Dubmill Scar*

Several changes have occurred at this bed since the 2003 survey. There has been a reduction in the size of the adult mussel bed of 16%, principally due to erosion on the northern side of the scar and increase in *Sabellaria* cover on the south side. The area dominated by *Sabellaria* has increased, completely taking over the southern section of the adult bed (Figure 5). In addition *Sabellaria* cover has also increased throughout the main adult mussel bed, with *Sabellaria* mounds growing over the mussels (Figure 6). At the time of the survey *Sabellaria* mounds accounted for approximately 15% of the
ground cover of the adult mussel bed. Conversely there has been an increase in the area of spat mussels by 65% as a result of new spat settlement on the eastern and southern edges of the spat bed. Hence, despite the reduction of the adult bed, the overall area occupied by mussels on Dubmill Scar has increased by 12%.

Figure 5
Sabellaria cover on the southern section of the Adult bed

Mussel density has declined by 50% and the principal reason appears to be a smaller spatfall in 2004 compared to 2003, combined with a gradual thinning of older year classes. From Figure 7 it is clear that the spat settlement in 2004 was much smaller than in 2003. Since the inclusion of Dubmill Scar in the mussel stock assessment in 2002 there has
been virtually no spat settlement onto the adult bed and there has been a decline in density of 20%. The lack of recruitment combined with the gradual thinning of older mussels as they succumb to natural mortality may have contributed to the increase in the *Sabellaria* cover on Dubmill Scar.

**Figure 7**

Length distribution of mussels on Dubmill Scar (both adult and spat bed), August 2003

Overall the total and commercial biomass have increased slightly at Dubmill, despite the reduction in mussel density. This has arisen primarily due to the continued growth of older mussels on the adult bed. The mean length on the adult bed has increased from 37mm to 45mm and this has been accompanied by an increase in biomass and commercial biomass/m² of 33% and 46% respectively.

From this survey it was estimated that there was 1,029 tonnes of commercially sized mussels on Dubmill Scar, out of a total biomass of 3238 tonnes. This commercial biomass was, however, made up of old barnacle clad mussels which occurred in an area becoming increasingly dominated by *Sabellaria*. Due to the conservation importance of this *Sabellaria* and the low value of barnacled mussels it is recommend that this bed be closed to fishing.
3.2.2 Ellison’s Scar

Ellison’s Scar is the name given to a large area of scar ground on the southern edge of Beckfoot Flats. Within this area there are three main mussel beds namely the Inner, Mid and Outer beds (Figure 8), the size and shape of which continually change.

Figure 8
The distribution of mussels at Ellison’s Scar

3.2.2.i Ellison’s Inner bed

This bed contained the largest amount of total and commercial biomass of all the beds surveyed in the 2004 survey. Both the total biomass and commercial biomass of this bed has remained virtually unchanged since the 2003 survey. The overall area occupied by this bed has also remained almost the same, although there has been some erosion at the north end of the bed.

The majority of this bed was dominated by old, heavily barnacled mussels, with many other year classes present (Figure 9 and Figure 10). The year classes tended to be spatially separate, with patches of older or younger mussels randomly distributed around the bed. The mean length of mussels on this bed has increased from 33mm to 39mm and there has been an increase of 20% in the proportion of mussels over 45mm. In short, the mussel population on this bed is aging and a greater proportion of them are reaching MLS. Despite this, total biomass and commercial biomass have remained virtually unchanged. The reason being that the natural mortality of older mussels has been compensated for by the continued growth of surviving mussels. There has been very little spat settlement on this bed and the percentage of spat has fallen by 52%. 
There is an estimated 1,433 tonnes of commercial sized mussels out of a total biomass of 3,265 tonnes. As the majority of the commercial biomass is made up of old mussels that are subject to ongoing natural mortality it is recommended that this bed is opened for fishing with the TAC set at 477 tonnes.

Figure 9
The mussels present on Ellison’s inner bed

Figure 10
Length distribution of mussels on Ellison’s Inner bed, August 2003
3.2.2.ii Ellison’s Mid bed

This bed was mainly comprised of large, clean mussels which were most likely to be 2 year olds from the 2002 year class (see Figure 1 and 2 in the method). There was a huge spat settlement on this bed in 2002 and these mussels have now reached maturity and MLS (Figure 11). This is evident from the huge increase in commercial biomass and density and percentage of the population over MLS. These mussels have naturally thinned out as they have grown which accounts for the decline in total density and percentage cover. Erosion also appears to have occurred on this bed, particularly on the northern edge and in the area between the Mid and Inner beds. This has resulted in a reduction in the size of the bed by 43%, which accounts for the reduction in overall biomass.

Ellison’s Mid bed was estimated this year to contain 929 tonnes of mussels, of which 522 tonnes were above MLS. As over 50% of these mussels are of commercial size and this bed has been subject to ongoing erosion and natural thinning of the mussel population, it is recommended that this bed should be opened to fishing, with a TAC of 174 tonnes.

Figure 11
Length distribution of mussels on Ellison’s Mid bed, August 2003

3.2.2.iii Ellison’s Outer bed

This bed comprised of large, clean mussels with no spat present. These mussels were most probably 2 and 3 year olds from the 2001 and 2002 settlements (this bed was subject to a huge spatfall in 2001 and again, but to a lesser degree, in 2002). These mussels have now matured (the mean length has increased from 41mm to 51mm) and the majority (89%) have reached the MLS (Figure 12). As these mussels have grown they have thinned out leading to a decline in density (down 53%) and also in percentage cover (8%). Erosion of the bed has taken place resulting in a loss of area of 43%. The overall biomass has declined by 19% as the mussels have thinned out and as a result commercial biomass had fallen by 31%.
From this year’s survey it was estimated that there was 627 tonnes of mussels on Ellison’s Outer bed, 555 tonnes of which were above MLS. As the majority of the mussels on this bed were of commercial size it is recommended that this bed be opened to fishing and no more than 185 tonnes be removed.

3.2.3 Lowhagstock bed

This bed has been in decline for many years and in 2003 survey it was suggested that Lowhagstock could no longer be described as a mussel bed as the percentage cover of mussels and biomass had fallen so low. However there has been a large spat settlement on this bed since the 2003 survey resulting in a large change in the topography of this mussel bed. This spat has settled on the lower shore and in isolated pockets further up the scar (Figures 13 - 16). Where no spat settlement occurred the bed had become narrower and was found to consist primarily of old, barnacled mussels which were thin on the ground.

This year’s spatfall appears to have occurred very late in 2004 as no spat was found in this area as late as May 2004. In many places the spat cover was 100% and had completely grown over the Sabellaria mounds which formed in 2003 on the lower shore (Figure 15). One other interesting observation was that high density spat settlement had occurred on the areas of the scar previously occupied by dead shells (Figure 16).

The settlement of these young mussels has resulted in a huge increase in density and biomass on this bed. Dense settlements of spat are not uncommon on this scar, however there is no guarantee that they will survive. For example the 2002 survey found a density of over 11,000 mussels/m² (mainly spat), however this declined to only 120 mussels/m² by
the 2003 survey. The spat settlement this year is not as great as in 2002 (only 8,769 mussels/m²), however it is hoped that these mussels will survive the winter and a proportion of them go on to reach MLS in a couple of years time.

Figure 13
The distribution of mussels at Lowhagstock Scar
This year it was estimated that there were 566 tonnes of mussels on this bed, of which only 35 tonnes were above MLS. As the majority of the mussels on this bed are newly settled spat this bed should remain closed to fishing.
3.2.4 Beckfoot Flats

There has been a large spat settlement at Beckfoot Flats mussel bed this year, which has resulted a huge increase in density and the area occupied by the mussel bed (Figures 17 and 18). These young mussels appear to have settled late in the year as no spat mussels were present on this bed in May.
Vast amounts of spat also settled this bed in 2002, however the majority of these had washed away by 2003 with only isolated patches remaining. Some of the mussels from the 2002 year class have survived and these have now reached MLS, resulting in an
increase in commercial density and biomass. These commercial sized mussels were found to be surviving in only small patches and surrounded by newly settled spat.

The 2004 spat settlement has covered an area slightly to the north and further inshore of the 2002 settlement (Figure 17). The 2004 spat settlement is not as large as in 2002 (only 6667 mussels/m², compared to 13,675 mussels/m² in 2002) but it is hoped that these mussels will survive the winter and a proportion of them go on to reach MLS in a couple of years time.

As the majority of the mussels on this bed are below MLS (Figure 19) it is recommended that this bed be closed to fishing.

3.2.5 Lees Scar

The area occupied by mussels on this scar has declined by 18% since the 2003 survey (Figure 20). In previous years this scar has been easily divided into zones of different age groups of mussels, however since 2003 survey this zonation has largely disappeared and the bed is now made up of patches of different age class mussels (Figure 21), distributed randomly throughout Lees Scar.

There was a large spatfall on this bed in 2001 and 2002, however as these mussels have grown they have thinned out leaving patches of bare ground or mussel mud (Figure 22), this has lead to a decline in density. The area of this bed is also eroding which has lead to decline in total biomass. There was very little spatfall on this bed this year.

Although there are 643 tonnes of mussels on this bed, commercial biomass has declined by 10% to only 65 tonnes; it is therefore recommended that this bed be closed to fishing.
Figure 20
The distribution of mussels at Lees Scar

Figure 15
Length distribution of mussels at Lees Scar, August 2003

Error bars = standard error
Above minimum landing size of 45mm
3.2.6 Skinburness

The mussel bed at Skinburness has declined so much that it cannot really be referred to as a mussel bed. This bed was surveyed purely for historical scientific reasons (to continue the data set). The value of continuing to survey mussel beds, even when they have greatly diminished has been shown with Lowhagstock bed this year. This has shown that Solway mussel beds can exhibit huge fluctuation in population numbers and recover after several years of decline. Skinburness has experienced a further decline (of 13%) in the overall area occupied by mussels since the 2003 survey. The Southern bed has almost completely disappeared leaving only a small patch of mussels (Figures 24).

Figure 23
The mussel bed at Skinburness
Percentage cover, density and biomass per square meter had also declined at Skinburness leading to a reduction in total biomass from 83 tonnes in 2002 to only 14 tonnes this year. Although there has been a small increase in the density and biomass of commercial sized mussels this has not been sufficient to compensate for the loss in area and this year it was estimated that there was only 6 tonnes of commercial size mussels. It is therefore recommended that Skinburness be closed to fishing.
4. Discussion

Over the past few years there have been several events that have greatly assisted in understanding the population dynamics of the north Cumbrian mussel beds. Firstly, in 2000 there was a very poor spat settlement, accompanied by erosion of many of the established mussel beds. This left many areas which were previously colonised by mussels almost barren (back to bare rocks or sand in some areas). This was then followed by two years of exceptionally high spatfall in 2001 and 2002. These young mussels settled in the highest densities on areas of mussel beds that had been severely eroded the previous year (e.g. Beckfoot Flats, Lowhagstock and Ellison’s Outer bed) or on previously uncolonised areas adjacent to established mussel beds (e.g. the north edge of Ellison’s Inner and Mid beds, and the shoreward side of Dubmill and Lees Scar). In addition young mussels from the 2001 and 2002 spatfalls tended to settle in spatially distinct areas (not on top of each other).

The erosion of these older year classes and re-colonisation by distinct homogenous patches of 2001 and 2002 mussels enabled the calculation of growth rates for different location on the north Cumbrian sand flats. Prior to 2001, the majority of mussel beds present on the north Cumbrian contained a wide range of mussel size classes. It was not known when these mussels had first settled and as mussel age cannot simply be estimated from shell length, growth rate could not be established. The 2003 Mussel Stock Assessment (Lancaster, 2003) contained a detailed section on how these growth rates were estimated and concluded mussels on the north Cumbrian coast take 2 to 3 years to grow from newly settled spat to commercial sized mussel depending on the vertical location on the beach (i.e. submersion time).

In addition to the calculation of growth rates the events of 2000-2002 have allowed the fate of the 2001 and 2002 year classes to be tracked. The results of the 2004 survey have been used to investigate under what circumstances large spatfalls can go on to form stable adult beds, or simply short lived ephemeral beds. Conclusions have also been drawn on the population dynamics of the beds surveyed, depending on their age and location.

The beds surveyed this year can be broadly classified into 4 distinct groups, depending on their age and general stability:

- The first group composes of mussel beds that were not significantly eroded in 2000 namely, Ellison’s Inner bed and Dubmill adult bed. These beds are comprised of old barnacled mussels and have received little spatfall in the past four years (with the exception of the northern edge of Ellison’s Inner bed). Over the past 2 years density has declined on these beds, although biomass has remained relatively stable due to the continued growth of older mussels.

- The second group is composed of mussel beds that were settled in enormous numbers by the dense spatfalls of 2001 and 2002, and survived, with many of the mussels now reaching and exceeding MLS. This refers specifically to Ellison’s Mid and Outer beds. Biomass and commercial biomass initially increased dramatically, although this may have peaked as these beds have begun to erode slightly. As the mussels on these beds have grown they have naturally thinned out, leading to a fall in density. On these beds there has been very little spatfall since 2002, hence the population is made up almost entirely of 2001 and 2002 recruits, the majority of which have now reached maturity.
• The third group is made up of mussel beds that received high spat settlements in 2001 and 2002, but experienced considerable erosion and the mussel populations are now in decline. The mussel beds at Lees Scar and Skinburness fall into this category. These beds have also received very little spatfall since 2002. Unlike the previous group, the increase in biomass as the mussels have grown has not been sufficient to compensate for the reduction in density as they have thinned out and eroded.

• The final group encompasses beds that experienced high spat settlements in 2001 and 2002, but the majority of these mussels eroded within the first 12 months. Beckfoot Flats and Lowhagstock beds fall into this category and the 2003 surveyed revealed that these areas had been so heavily eroded that they were almost barren, except for patches of mussel mud. In 2004 these beds were the only mussel beds surveyed that had received a significant spatfall and large numbers of young mussels have settled onto bare rock and sand.

It is clear from these findings that the heavy spat settlements of 2001 and 2002 have in some places grown on stable beds, while in other locations have formed short lived ephemeral beds. Whether the beds are stable or ephemeral appears to depend primarily on their location and whether they formed on rocky scar ground on open sand.

According to the scientific literature mussel beds which form on soft sediment on open coasts are usually short lived (Dare, 1976; Sousa, 1985). This would certainly appear to be the case at Beckfoot, Lowhagstock (the Lowhagstock scar area has sanded over a great deal over the past 5 years) and Skinburness. Ironically one of the contributing reasons for this instability is the high density at which young mussels settle and their increased growth rate. On a denuded bed there is less competition for space and food which tends to result in higher growth rates than on established beds, with many year classes present (Dare, 1976). The high density of young mussels present and their fast growth rate results in the production of large amounts of mussel mud (faeces, pseudofaeces and washed sand) which develop around the mussels (see Figure 22). Consequently the young mussels end up carpeting a thick layer of soft mud which is liable to erosion by strong tidal movement or wave action (Korringa, 1976). Eventually the entire mussel bed becomes unstable and is liable to be destroyed by storms (Korringa, 1976).

Mussels lost in this way are not necessarily lost from the Solway and it has been speculated that mussels lost from Lowhagstock and Beckfoot Flats may have resettled in the channel and grown on as sublittoral stock to provide the mussels for the dredging fishery.

Where dense spatfalls occurred on more stable scar ground such as Ellison’s scar area and Lees Scar the thick layer of mussel mud also develops, however it appears that somehow these beds are more sheltered and less liable to mass erosion. Hence the young mussels have a greater chance of survival. This could be due to the topography of the scar grounds themselves, with larger boulder offering more stable attachment for mussels than open sand. The topography of the coast and direction of storms will also affect the survival of a mussel bed. This would appear to be the only reason why Ellison’s Mid and Inner beds have survived, yet many of the mussels at Lees Scar have been eroded.
The spat bed on the inshore edge of Dubmill Scar did not fall into any of the above four categories. This bed appears to exhibit much slower growth rates as it is high up the shore (hence reduced submersion and feeding time). The combination of the slower growth rate (and therefore less mussel mud) and shelter of the adult beds mean that this bed is much more stable than other spat beds on the north Cumbrian coast.

One interesting observation, consistently revealed by the annual surveys, is that there is less spat settlement on adult beds. It appears that presence of older mussels inhibits the spat settlement. It is an established fact that adult bivalves can harm young mussels by inhaling the very small ones (Balwin et. al. 1995). In this year's survey the only beds to receive significant spatfalls were the beds where the majority of adults had washed away (Beckfoot and Lowhagstock). Denuded beds are the perfect place for young mussels to settle as the presence of adult shells can facilitate spat settlement by providing a sheltered habitat for settlement and protection from predators (McGorty et. al. 1990), but without the competition.

The population dynamics of the older established beds, Ellison’s Inner bed and Dubmill Scar are very different from the rest of the beds on the North Cumbrian coast. These beds have received very little spat fall over the past few years and the density of the mussels is declining. The lack of recruitment combined with the gradual thinning of older mussels as they succumb to natural mortality may have contributed to the increase in the *Sabellaria* cover on Dubmill Scar. The decline of the mussel population may continue to such a point where there are insufficient adults remaining to inhibit spat settlement. Future surveys will be needed to determine the fates of these older beds.

**Prospect for the fishery**

This year there has been an overall reduction in the total biomass, but an increase in the commercial biomass of the Solway Firth mussel beds since the previous survey (Table 5). This was expected as the 2001 and 2002 year classes have now matured and reached MLS, hence commercial biomass has increased as they have grown, while total biomass has declined as they have gradually thinned out and eroded.

<table>
<thead>
<tr>
<th>Year</th>
<th>Total biomass (tonnes)</th>
<th>Commercial biomass (tonnes)</th>
<th>Number of mussel beds surveyed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>19,212</td>
<td>6,152</td>
<td>8</td>
</tr>
<tr>
<td>2002</td>
<td>14,794</td>
<td>4,421</td>
<td>7</td>
</tr>
<tr>
<td>2001</td>
<td>8,049</td>
<td>4,923</td>
<td>7</td>
</tr>
<tr>
<td>2002</td>
<td>16,218</td>
<td>6,036</td>
<td>8</td>
</tr>
<tr>
<td>2003</td>
<td>14,528</td>
<td>3,499</td>
<td>9</td>
</tr>
<tr>
<td>2004</td>
<td>9773.71</td>
<td>3754.32</td>
<td>8</td>
</tr>
</tbody>
</table>

**Conclusion**

In 2001 and 2002 there was an extraordinary spat settlement which increased the overall area, the percentage cover, the density, and biomass of most of the beds surveyed. These mussels have only survived on stable beds, particularly at all the Ellison’s Scar, and eroded from open coast locations (Lowhagstock and Beckfoot flats). Of the mussels from these year classes that have survived the majority have reached MLS.
References


Dare, P. J. (1976) Settlement growth and production of the mussel, Mytilus edulis L., in Morecambe Bay, England. MAFF Fisheries Investigations, Series II, Volume 28, Number 1; 1-25


