1. Introduction

In 2001 the Committee received applications to use tractor-towed "wet dredges" on the Ribble Estuary. These were considered by the Mollusc Development Group, which recommended the issuing of authorisations for the use of wet dredges for a limited period on the Ribble Estuary only. Any fishing was to be regarded as experimental and careful monitoring of the activity should take place.

Agreement was reached with English Nature for the wet dredge trials to take place in the Ribble Estuary Special Protection Area (SPA), providing that suitable monitoring was carried out. The trials began in mid December 2001 and ceased at the end of April 2002.

The wet dredge is a simple device towed in shallow water behind a tractor. A diagram of the basic design for a wet dredge is shown at Figure 1.1 and a photograph of the sorting grid is shown in Fig 1.2. It must be kept in mind that many modifications were made to the dredge throughout the trials. The dredge has an adjustable blade, which helps to minimise the damage to the cockles. The blade removes the top layer of sediment, which contains the cockles. The sediment moves up the blade and onto a sorting grid. Here the sediment is sprayed with water from a pump, which separates out the cockles, sediment and other infauna. The harvestable cockles are retained on the grid, where they can be collected and bagged, whilst the undersized cockles, sediment and other infauna are washed through and are deposited on the bed below. Cockles are of a harvestable size when they cannot fit through a square gauge 20mm x 20mm, as stated under Byelaw 13.

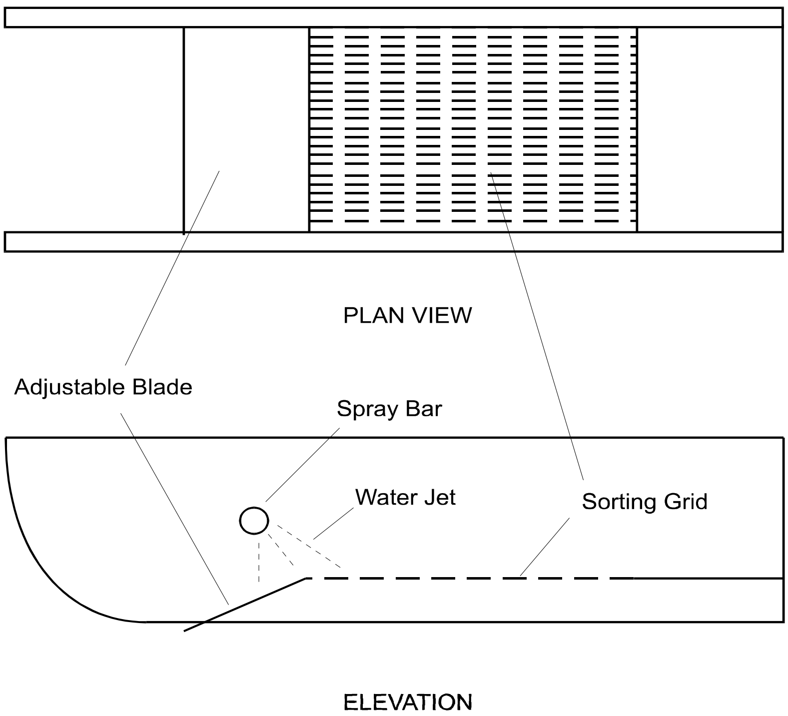


Figure 1.1. The basic design of the "wet" dredge.

Fig 1.2 The sorting grid of the wet dredge.

Wet dredges have possible advantages for fisheries management, as a few easily identifiable dredging units would be easier to police than mobile gangs of hand gatherers. Due to the presence of the pump, the wet dredge is restricted to shallow water. This reduces the efficiency of the wet dredge, as it cannot traverse systematically over the bed, as is the case with the "dry" dredge where the operator can see his previous tracks. Consequently, with the dry dredge, there may be very little area of the bed where the dredge hasn't fished. Therefore fishing can reduce the stock to such a level that it could take a very long time to recover.

Wet dredge trials were performed in the Ribble Estuary in early 1988. The dredge appeared to be capable of 100% efficiency as all the larger cockles were retained whilst all the smaller cockles were deposited back onto the bed. Damage caused by the dredge, either by the blade or the wheels, was around 10% for the larger cockles and around 1% for the smaller cockles. Smaller cockles were collected for survival analysis from the dredge path, tyre tracks and from the unfished area. Survival was very good when retained in aerated seawater for 7 days as virtually no mortalities were seen in any of the three samples. The dredge used in the present study was of generally similar pattern and therefore similar results were expected.

2. Fishing Activity

Five authorisations were issued. Of these, only three operators have used a wet dredge in the Ribble Estuary and only one has fished to an appreciable extent. Consequently, most of the data is from the one operator.

The lack of fishing activity is a consequence of the low density of the harvestable cockles in the area. Figures 2.1 and 2.2 shows the relative catch per unit effort (CPUE) data, calculated from the information provided on the return sheets.

It can be seen that fishing took place periodically throughout the trials. Fishing was not continuous as the activities were constrained due to tides and weather.

Fishing initially took place on the lower Penfold bed, an area of approximately seven hectares. The approximate bed area and two of the dredge paths can be seen on figure 2.3. From the 21st February 2002 onwards, fishing took place in the channel in the upper Penfold.

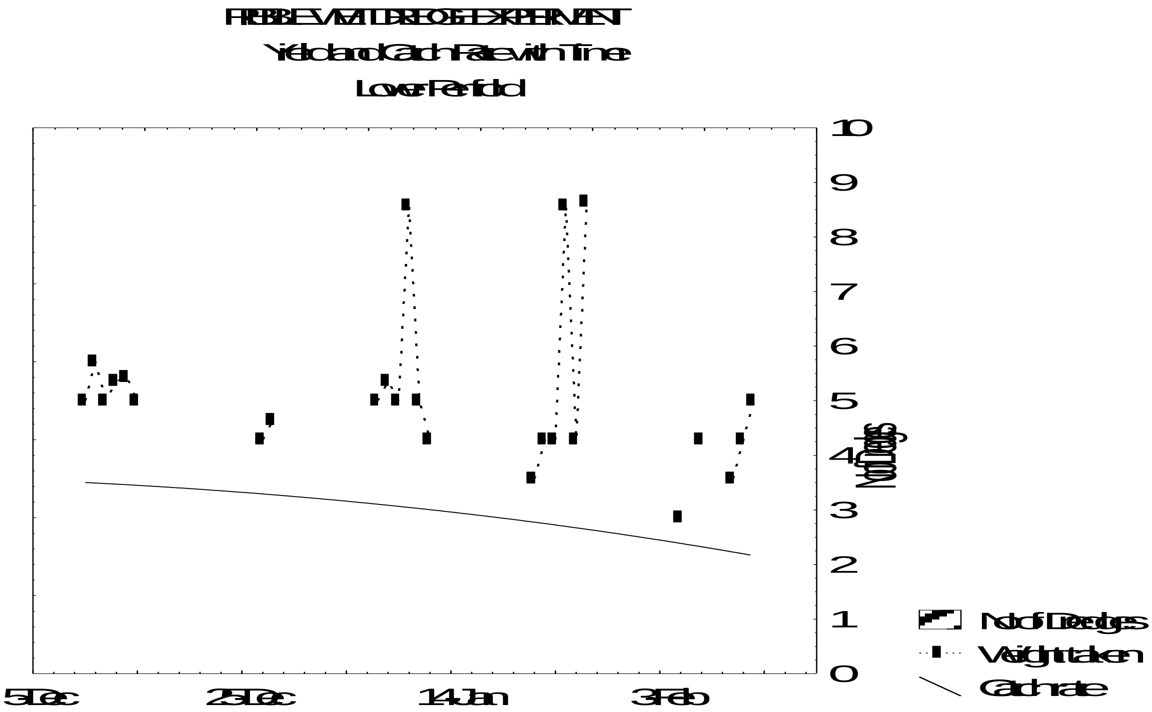


Figure 2.1. Yield and catch rate from the Ribble Estuary wet dredge trials – lower Penfold. The number of dredges operating on each day is shown, either as a 0, 1 or 2. Note that there are no scale values for the weight taken or catch rate, as these are treated as commercially confidential information.

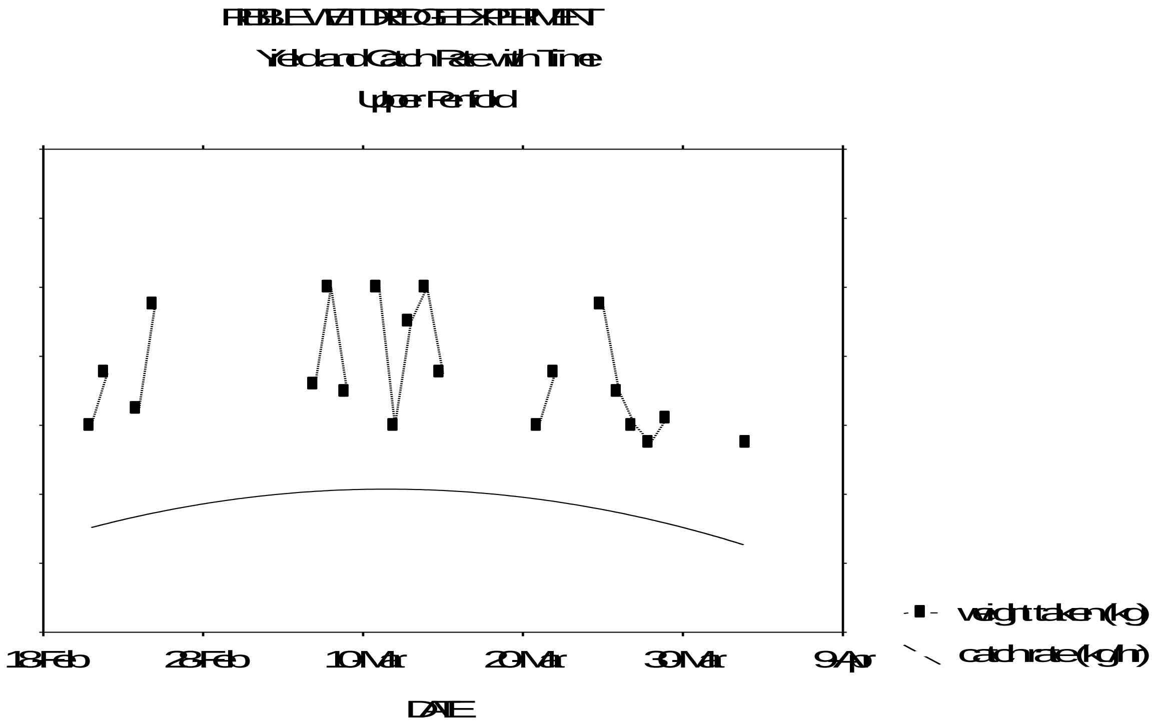


Figure 2.2. Yield and catch rate from the Ribble Estuary wet dredge trials – upper Penfold. Only the one operator was active during this time. Note that there are no scale values for the weight taken or catch rate, as these are treated as commercially confidential information.

Catch rate steadily diminished whilst fishing took place on the lower Penfold bed. Since the density of the harvestable cockles was low at the start of the trials, this decrease in catch rate in not surprising. Catch rate on the upper Penfold was more variable. This is possibly due to the mobile nature of the channel. Since the dredge was restricted to the shallow waters within the channel for most of the available fishing time and the channel was constantly moving, it meant that dredging took place over different areas of the bed. As cockle densities are often patchy within a bed, the erratic nature of the catch rate for this area is not surprising.

3. Monitoring

Nine monitoring occasions took place over low water. Video footage was taken at the beginning of the trials to aid any observations made. Table 3.1 below shows the date, bed area and which operator data was collected from on each monitoring occasion.

Table 3.1. Monitoring information.

Monitoring Occasion	Date	Bed Area	Operator
1	10-12-01	Lower Penfold	A
2	11-12-01	Lower Penfold	A
3	09-01-02	Lower Penfold	A
4	23-01-02	Upper Penfold	B
5	07-02-02	Lower Penfold	A
6	21-02-02	Upper Penfold	A
7	08-03-02	Upper Penfold	A
8	03-04-02	Upper Penfold	A
9	25-04-02	Upper Penfold	A

3.1 Speed of Tow and Rate of Dredge

The speed of tow for the dredge was estimated from the length of the dredge path and the total fishing time. This data was collected by a Global Positioning System (GPS) being placed onboard the tractor towing the dredge. Alternatively, the data was collected by following the dredge path on an ATV quadbike once the tide had ebbed off and using an estimation of fishing time from the fishermen. The rate of dredge was estimated from the area dredged and the total fishing time. The area dredged was calculated from the length of the dredge path and the blade width, which was fixed at 675mm, as stated in the authorisations issued. The three data sets from operator A were taken from the lower Penfold bed. The data set from operator B was taken from the upper Penfold bed.

3.2 Harvestable Cockles

3.2.1 Efficiency and Density

The fishing efficiency of the dredge was estimated by comparing the density of harvestable cockles from the dredge path, tyre tracks and unfished areas. To estimate the densities $0{\cdot}1m^2$ quadrats were used. Sampling locations were chosen at random from the higher and lower areas of the lower Penfold bed. At each sampling location, a quadrat was taken from the dredge path, tyre tracks and from the unfished area. The quadrat from the unfished area was taken from a good distance away from the dredge path to minimise any influence the dredging activity may have upon it.

When fishing moved to upper Penfold bed, 10·3cm diameter cores were used instead of quadrats to collect the quantitative samples. This is because it was decided to also monitor the density of *Macoma balthica*, a small, pink bivalve, as they exploit a similar niche to cockles. As the purpose of these density measurements was to more closely monitor the effect of dredging activity upon the cockle stocks and *M. balthica* populations, only samples from the unfished areas were taken. The location for each sampling location was recorded on the GPS so repeated sampling could be undertaken.

3.2.2 Damage Rates and Survival

Samples of the catch were taken from high shore and low shore when fishing was taking place on the lower bed. The incidence and type of damage was recorded and analysed. Those cockles that were not damaged, were placed in aerated seawater for 15 days and their mortalities were noted.

3.3 Undersized Cockles

3.3.1 Sorting Efficiency of the Dredge

The sorting efficiency of the dredge was established from the catch samples described in 3.2.2. The age class and length frequencies for the cockles were recorded.

3.3.2 Density

The density of the undersized cockles was estimated from the quadrats and cores described in 3.2.1.

3.3.3 Damage Rates and Survival

3.3.3.1 Dredging Effect

Undersized cockles were carefully hand-gathered from the dredge path, tyre tracks and from unfished areas. The incidence and types of damage were recorded and analysed. Those cockles that were not damaged were placed in aerated seawater and their mortalities were noted.

Two samples were also taken from the grid of the dredge to monitor more closely the effect of the blade and water pump. One of these samples came onto the sorting grid in a consolidated mass of sediment apparently undisturbed by the water jet. It was thought that this sample would be affected less by the water pump and not subjected to the sorting processes, etc.

3.3.3.2 Density Effect

It was thought that density might have an effect upon the survival of the undersized cockles. Samples were taken the dredge path, tyre tracks and from unfished areas at both high shore and from the low shore. The cockles from the high shore were found in a lower density. The samples were kept in aerated seawater and their mortalities were noted.

3.3.3.3 Jumbo and Raking Effect

For comparisons with other fishing methods, samples were also collected by jumboing and raking, and just raking. There were six sampling locations, three from each of the two beds, one each at high shore, mid shore and low shore. At each sampling location, four samples were taken, jumbo and raked, just raked, carefully hand gathered and a $0{\cdot}1m^2$ quadrat to establish the density in that area. The incidence and type of damage were noted. The undamaged cockles were kept in aerated seawater and their mortalities were noted.

3.3.3.4 Sediment Effect

The fluidity of the sediment was thought to have an effect on the damage rates and survival for the cockles. The more fluid the substrate, the easier the cockles can move through it when being knocked by the blade or squashed against other cockles by the tyres. If the cockles can move with greater ease through the sediment, the less damage they were likely to receive. Two samples were raked from within the channel on the upper Penfold bed. Their damage rates and mortalities were compared to hand-gathered cockles from outside of the channel, where the sediment was more compacted.

3.3.3.5 Effects of Aerial Exposure

Three samples of surface cockles were hand-gathered from the dredge path. One of the samples had not had any aerial exposure, as that part of the dredge path was in a dip in the bed and so was still underwater. Another of the samples had been exposed for approximately half an hour. The last samples had been exposed for approximately one and a half hours. The occurrences and types of damage were noted. The undamaged cockles were placed in aerated seawater and their mortalities were recorded.

3.3.3.6 Shaking Effect

To ascertain whether the mortalities observed were due to physical disturbance from the dredge, or if they were due to another factor, carefully hand-gathered cockles were shaken for various lengths of time and then kept in aerated seawater. The first set of shaking samples were shaken more gently and in a circular fashion. The second set of shaking samples was shaken in a more vigorous manor with an up and down motion.

It was unknown whether the cockles from the Ribble Estuary were in a poorer or healthier state than cockles found elsewhere. To try to establish this, cockle samples were carefully hand-gathered from Red Bank in Morecambe Bay and were subjected to the same vigorous shaking as those from the Ribble Estuary. A $0{\cdot}1m^2$ quadrat was used to estimate the cockle density at Red Bank where the hand-gathered cockles were taken from.

3.4 Infauna

The infaunal communities were examined by taking 10·3cm diameter cores from random places on the cockle bed. Each sampling location consisted of a sample from the dredge path, tyre track and from the unfished area. Each core sample was washed through a 1mm mesh. All taxa were identified to genus or species level. The abundance of each taxon was compared for dredge path, tyre track and the unfished area.

3.5 Sediment Analysis

Sediment samples were taken using the same method as described in 3.3. A sample was taken from the tyre track and from the unfished area. Each sample was washed through a series of sieves, each one decreasing in mesh size. The percentage of the sample found in each sieve was measured and recorded.

3.6 Birds

The feeding activity and behaviour of the birds was noted during the fishing activity and immediately proceeding. Video footage was taken to aid in the assessment.

4. Results

4.1 Speed of Tow and Rate of Dredge

Table 4.1.1 below describes the data for the speed of tow and rate of dredge. As the dredge was modified throughout the trials, it became more efficient. The blade width was fixed at 675mm as it was stated in the design specification as part of the conditions of the authorisations issued.

Table 4.1.1. Operational parameters for the wet dredges.

Date	Operator A or B	Length of Dredge Path (m)	Approx. Time for Tow (hrs)	Speed of Tow (m/hr)	Area Dredged (m^2)	Rate of Dredge (m^2/hr)
10-12-01	A	1606	2·25	713·78	1084·05	481·80
11-12-01	A	1806	2·25	802·67	1219·05	541·80
23-01-02	B	2094	2	1047·00	1413·45	706·73
07-02-02	A	4082	2	2041·00	2755·35	1377·68

Note that there is no data for monitoring occasion 3 as no dredge data was collected on this occasion.

It can be seen from operator A that the modifications to the dredge made it more efficient in terms of ground covered. For the fifth monitoring occasions, a chute had been added which enclosed the blade and spray bar. This meant that the sediment arrived onto the sorting grid more fluidised which was theoretically gentler on the cockles. It also meant that collecting the cockles at the end of the grid would be more efficient and so would speed the whole process up. The presence of the chute also meant that none of the sediment or the harvestable cockles within it would be lost over the side of the blade and therefore increase the efficiency of the dredge and the catch rates. It is this variant of the dredge that is shown in photograph 1.1.

4.2 Harvestable Cockles

4.2.1 *Efficiency and Density*

Table 4.2.1.1 shows the average density for the harvestable cockles on the lower Penfold bed. Samples were taken from the dredge path, tyre tracks and from the unfished areas using 0·1m^2 quadrats.

Table 4.2.1.1. Average density for the harvestable cockles on the lower Penfold bed (nos per m²).

Date	Dredge Path	Tyre Tracks	Unfished
10-12-01	0	-	43
11-12-01	0	28	30
09-01-02	0	93	10
07-02-02	0	0	17

Note that there is no data for monitoring occasion 4 as the data collected is from the dredge of a different operator and fishing had taken place on the upper Penfold. No data for the tyre tracks on the first monitoring occasion.

No harvestable cockles were found in the dredge path, which suggests that the dredge had a 100% fishing efficiency.

The density for the harvestable cockles in the tyre tracks was more erratic, ranging from none found up to 93 per m². As briefly mentioned in section 4.1, some of the sediment that would still have cockles within it, fell off the sides of the blade as it was being passed up to the sorting grid. This meant that some of the cockles found in the tyre tracks had been brought up by the dredge as well as already being within the substrate. Some of the cockles brought up by the dredge and fallen off the blade, would have been washed down the shore by the wave action as the tide ebbed off, hence the very variable nature of the data.

This suggests that the dredge is not 100% efficient. However, the introduction of the chute for the fifth monitoring occasion (as mentioned in section 4.1) meant that this problem would have been overcome and the efficiency of the dredge would have been increased.

In the unfished areas, the general trend was for a decrease in harvestable cockle density. This is not surprising, as regular fishing has taken place in a relatively small area over a period of ten weeks.

A decrease in harvestable cockle density was also seen on the upper Penfold. The data can been seen in table 4.2.1.2 and figure 4.2.1.1. In figure 4.2.1.1, 1999 year class cockles are displayed, as they were by far the most abundant year class for cockles of a harvestable size.

Table 4.2.1.2. Average harvestable cockle density for the upper Penfold bed (nos per m²).

Date	Average Density (m²)
08-03-02	31
03-04-02	13
25-04-02	4

As the GPS sets are generally accurate to 3m, given good satellite coverage, returning to the same location using a GPS can on most occasions be expected to be within a 3m radius of the original sampling location. Where some of the samples appear to increase in density, this is likely to be due to the patchy and mobile nature of the bed, although positional errors when returning to the same area twice are also possible.
Kolmogorov-Smirnov, Lilliefors and Shapiro-Wilks normality tests were performed on the data from the upper Penfold bed. All three tests suggested that the data was not normal, so

the Kruskal-Wallis one way ANOVA non-parametric significance test was applied to the data. The results from this test suggested that there were significant differences at the 95% confidence limit between the three monitoring occasions (H value = 6·77, P value = 0·03). A Chi squared median test was included, which also suggests that there were significant differences at the 95% confidence limit ($\chi^2 = 9{\cdot}45$, P value = 0·01). This suggests that there is a real decline in the population of the 1999 year class cockles. However, it must be highlighted that neither the Kruskal-Wallis one way ANOVA test nor the Chi squared median tests take into account the fact the data is a time series.

4.2.2 *Damage Rates and Survival*

Table 4.2.2.1 shows the damage rates for the samples taken from the catch. The damage rates ranged between 1% and 9%. This seems reasonable, especially as most of the damage was minor damage. The occurrences for each type of damage are shown in figure 4.2.2.1 below.

Table 4.2.2.1. Damage rates for cockles retained by the wet dredges and harvested

Date	Operator	Shore Height	% Damaged
11-12-01	A	Low	3·1
11-12-01	A	High	1·9
09-01-02	A	Low	8·1
09-03-02	A	High	8·2
23-01-02	B	Only sample	4·7
07-02-02	A	Low	8·3
07-02-02	A	High	2·9
		4 Average	**5·3**

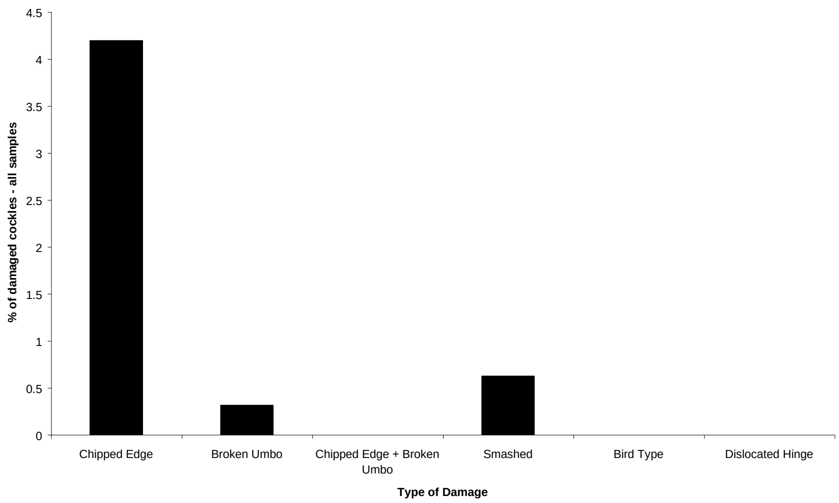


Figure 4.2.2.1. Types of damage and their occurrences for the harvested cockles.

Chipped edge was the most common type of damage, although some of the cockles had a broken umbo or were smashed. All of these types of damage suggest blade edge damage. Most of the cockles that would have been subjected to blade edge damage were likely to be left in the substrate, just being damaged as the blade clips them on its way past. This could be an explanation as to why the damage rates for the second monitoring occasion were lower than for other monitoring occasions

The results from the survival analysis are shown in table 4.2.2.2 below.

Table 4.2.2.2 Mortality of cockles collected on the third monitoring occasion. Only undamaged cockles are included. 57 cockles were used from the low shore and 80 were used from the high shore.

Shore Height	Number Dead After 15 Days	% of Sample Dead After 15 Days
Low	0	0
High	1	1.3

The results suggest that the harvestable cockles were not adversely affected by the dredging activity. Only one mortality was observed and it is quite possible that this cockle died from natural causes.

4.3 Undersized Cockles

4.3.1 *Sorting Efficiency of the Dredge*

In all the catch samples analysed, only two undersized cockles were found, and they were stuck in an empty shell of a much larger cockle. This equates to 0·3% of all the catch samples analysed. In terms of rejecting the undersized cockles, the dredge appears to be nearly 100% efficient.

4.3.2 *Density*

At the beginning of the trials, the density for the undersized cockles (2001 year class) on the lower Penfold bed was outstandingly high, with over 10,000 undersized cockles per m² were found in one of the samples from the unfished area. Table 4.3.2.1 shows the average densities of undersized cockles for the unfished areas on the lower Penfold bed.

Table 4.3.2.1. Average densities. Densities are shown in cockles per m².

Date	High Shore	Low Shore
10-12-01	2235	1140
11-12-01	9483	690
09-01-02	8183	-
07-02-02	202	-
Average	5026	915

The results suggest that the cockles were denser on the higher parts of the bed.

During this period, density samples were gathered from the upper Penfold bed on monitoring occasion 4. The densities were similar, 8480 cockles per m² on the high shore and 4555 cockles per m² on the low shore, which suggests a similar pattern for the whole area.
It seems that the population crashed by the fifth monitoring occasion in February, probably due to the harsh weather conditions over the winter period.

A return visit was made during the ninth monitoring occasion at the end of April. Samples were taken from the lower areas of the bed. The average 2001 year class cockles density was 804 per m². Outside of the bed, it could be seen where the undersized cockles were still

relatively dense as the cockles were beginning to create small golf ball like bumps in the substrate as they were beginning to grow with the start of the spring plankton bloom.
Figure 4.3.2.1 below shows the average densities for samples taken from the unfished areas, dredge path and tyre track from the high shore of the lower bed.

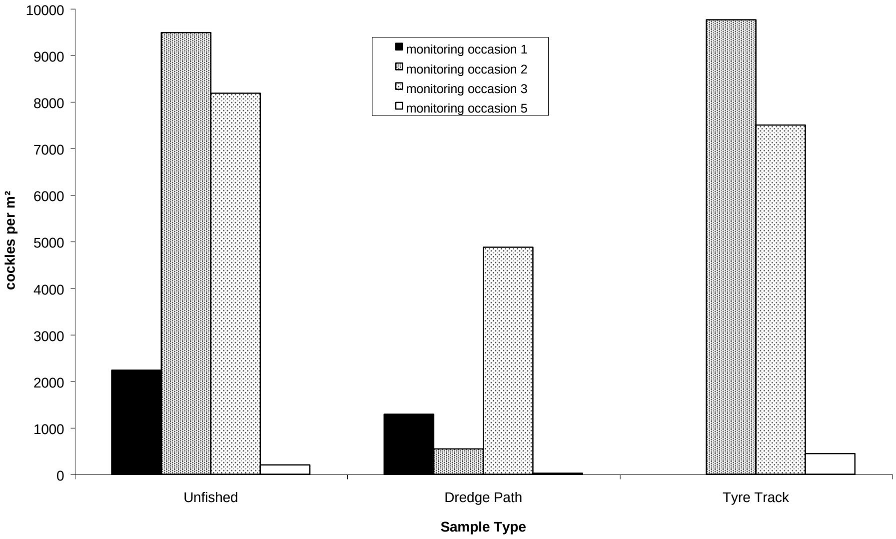


Figure 4.3.2.1. Average densities for the unfished areas, dredge paths and tyre track. Data taken from the high shore of the lower Penfold bed. There is no tyre track data for the first monitoring occasion.

The densities of the undersized cockles for the unfished areas and for the tyre tracks were relatively similar. The density for the dredge path was always lower than for the tyre tracks or unfished areas. This is probably because as the cockles were brought to the surface and redeposited by the dredge, wave and tide action could have moved them a considerable distance. It was observed that the undersized cockles were being subjected to much movement by the wave action, much more so than the harvestable cockles. Some of these cockles would have been kept in the dredge path by the edge of it as the dredge blade left a slight trench, a few centimetres deep, in the substrate. This can be seen in photograph 4.3.2.1 below, where there are also surface cockles in the tyre tracks outside of the dredge path.

Photograph 4.3.2.1. The re-deposited surface cockles in the dredge path and tyre tracks.

Photograph 4.3.2.1 highlights the very high density of the undersized cockles. The surface cockles look dense in the dredge path, but they were much less dense than the cockles still untouched in the unfished areas and the tyre tracks. It was noticed that the surface cockles did not immediately try to rebury themselves in the substrate. When monitoring for that day had finished, the undersized cockles that were brought up by the dredge were still on the surface.

The density changes for the undersized cockles and for *Macoma balthica* are shown in figure 4.3.2.2 and figure 4.3.2.3 respectively.

Kolmogorov-Smirnov, Lilliefors and Shapiro-Wilks normality tests were performed on the both the undersized cockle and *Macoma* sp data from the upper Penfold bed. All three tests suggested that the data was not normal, so the Kruskal-Wallis one way ANOVA non-parametric significance test was applied to the data. A Chi squared median test was also included. Neither of the tests suggest that there are significant differences in the data for the undersized cockles at the 95% confidence limit (Kruskal-Wallis: H value = 3·50, P value = 0·17. Chi squared: χ^2 = 4·15, P value = 0·13). For the *Macoma* results, Kruskal-Wallis suggests that there is a difference at the 95% confidence limit (H value = 10·39, P value = 0·01). Conversely, Chi squared suggests that there is no significant difference at the 95% confidence limit (χ^2 = 3·11, P value = 0·21). Although figures 4.3.2.2 and 4.3.2.3 suggest that the cockle and *Macoma* populations are decreasing, the significance tests suggest otherwise. However, it must be highlighted that neither the Kruskal-Wallis one way ANOVA test nor the Chi squared median tests take into account the fact the data is a time series.

4.3.3 *Damage Rates and Survival*

It was noticed that the survival rates for the carefully hand-gathered cockles decreased throughout the trials. This suggests that the cockles were becoming weaker with time. This is probably due to less food being available to them in the plankton and the harsh weather conditions during the winter period.

4.3.3.1 Dredging Effect

The cockles were collected on the third monitoring occasion, which was before the chute was added. The damage rates for the undersized cockles varied between dredge path, tyre track and unfished areas. 5% of the undersized cockles from the dredge path were damaged, 9% in the tyre track and 1% in the unfished area. As most of the damaged cockles were found in the tyre track, it suggests that many of the cockles were damaged by the blade. Some of these cockles were then lost off the edge of the blade before being passed up to the sorting grid. The high density of the cockles could provide another explanation for the damaged cockles. Due to the high density, the cockles would be squashed together by the dredging operations. This may occur on the sorting grid or, more likely, as the tyres pass over the redeposited cockles, squashing them onto the cockles just beneath the surface of the substrate. Some of these cockles, both damaged and unharmed, would have been washed down shore by the receding tide. This could provide an explanation for the damaged cockles found in the unfished area. The occurrences for each type of damage are shown in figure 4.3.3.1.1 below.

Also shown in figure 4.3.3.1.1 are the types of damage for the two samples taken from the grid of the dredge. 17% of the undersized cockles were damaged in the sample that came up in a mass of consolidated sediment. 6% were damaged in the other grid sample. It must be highlighted that these two samples were taken from the upper Penfold bed in the channel at a later date. Some these damaged cockles could have been damaged by dredging activity higher up on the bed and then washed down the shore and into the channel on the ebbing tide. Even so, the results do suggest a significant blade edge damage effect, although not conclusive.

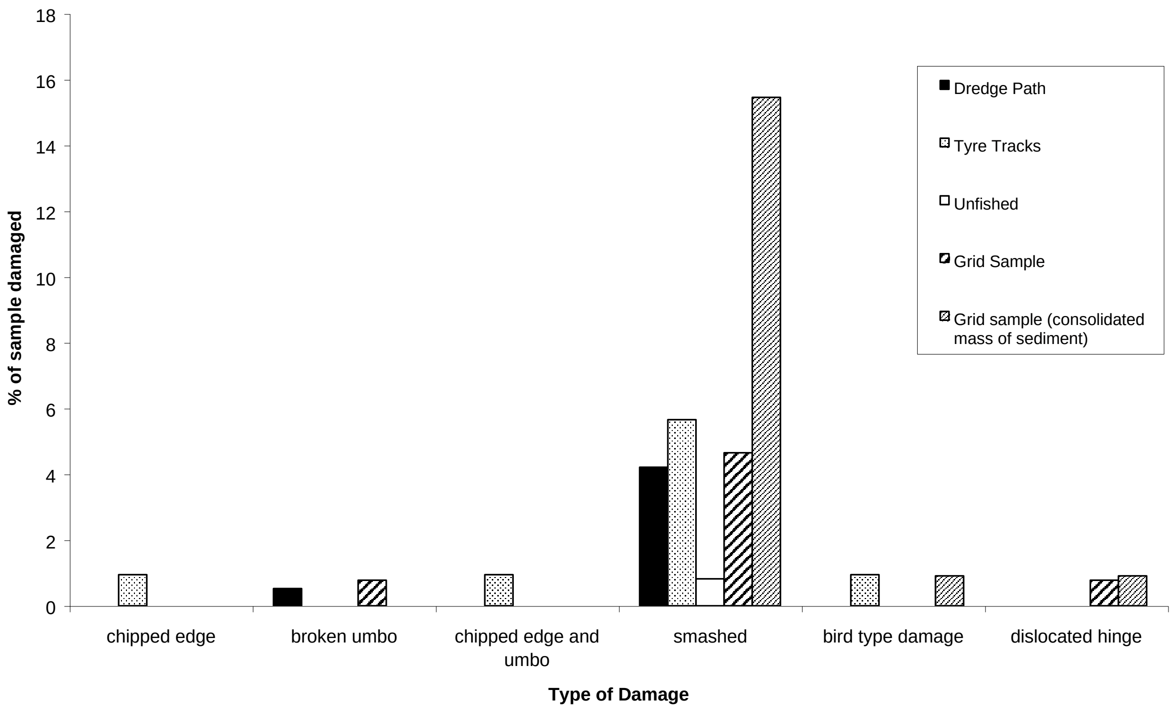


Figure 4.3.3.1.1. The occurrences for the different types of shell damage for the undersized cockles from the dredge path, tyre track, unfished area and the grid of the dredge.

Unlike the harvestable cockles, there were more undersized cockles with major damage. A greater proportion of the damaged cockles was smashed. A smaller proportion had minor shell damage, such as chipped edge or a broken umbo. A likely cause of this damage was the blade edge, as with the harvestable cockles. The undersized cockles have much thinner shells and so a knock from the blade would have caused more damage to the smaller cockles than the larger cockles. Another possible cause of this damage could be the tyres squashing the redeposited cockles, as discussed earlier.

The undamaged cockles from the dredge path, tyre tracks and the unfished area, were kept in aerated seawater for 30 days and their mortalities were recorded. The results from this are shown in figure 4.3.3.1.2 below. By the end of the trials, 37% of the cockles from the dredge path were dead, 62% from the tyre track and 9% from the unfished area.

Kolmogorov-Smirnov, Lilliefors and Shapiro-Wilks normality tests were performed on the data. All three sets suggested that the data were not normal, so the Kruskal-Wallis one way ANOVA non-parametric significance test was applied to the data. A Chi squared median test was also included. The data were not normally distributed, so the Kruskal-Wallis one way ANOVA non-parametric test was applied to the data. The results from all the data suggested that there was a significant difference in the data at the 95% confidence limit (Kruskal-Wallis: H value = 10·43, P value = 0·01. Chi squared: χ^2 = 11·31, P value = 0·00). The tests were then applied to just the data from the dredge path and tyre tracks. There was no significant differences in the data at the 95% confidence limit (Kruskal-Wallis: H value = 2·57, P value = 0·11. Chi squared: χ^2 = 0·94, P value = 0·33) which concludes that the cockles from the unfished area were the outliers in the data. This suggests that the dredge was having an adverse effect on the survival of the smaller cockles.

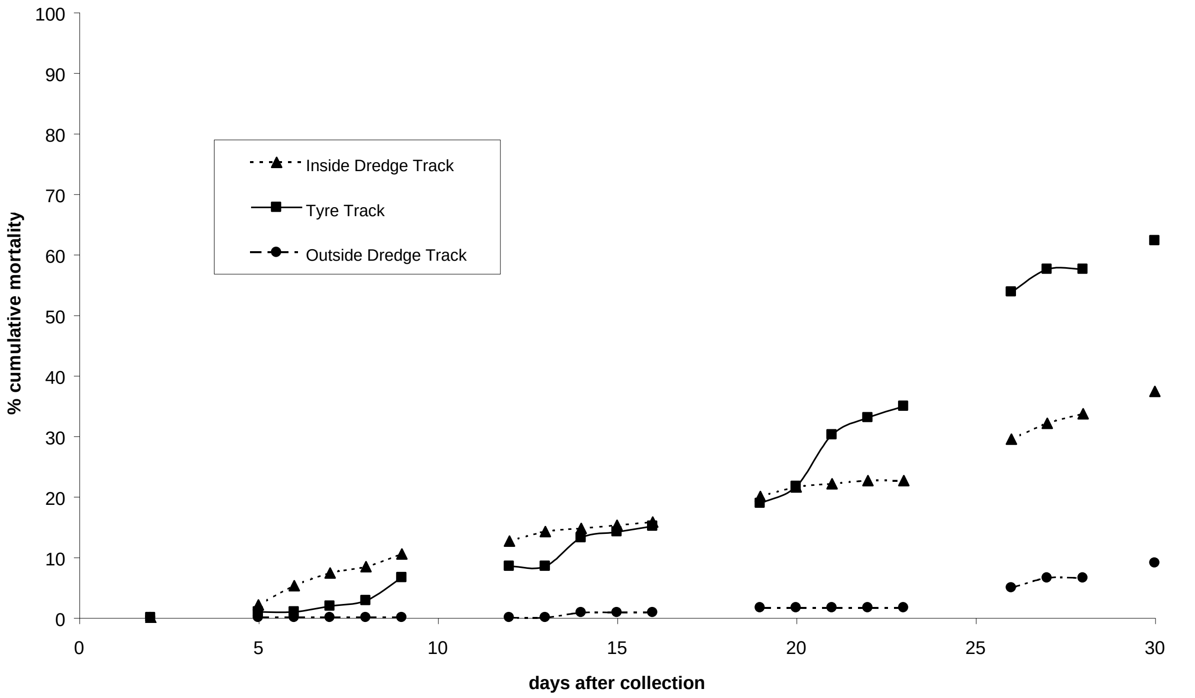


Figure 4.3.3.1.2. The cumulative mortalities for the undersized cockles, collected from the dredge path, tyre track and from the unfished area.

The undamaged undersized cockles from the two grid samples were kept in aerated seawater for 14 days. After 14 days, 42% of the sample in the consolidated mass of sediment were dead. 40% of the other grid sample were dead. This is much higher than for the dredge path, tyre tracks and unfished area after the same length of time. As the grid samples were taken at a later date, the cockles were possibly in a poorer state due to the time of year. There would have been less food in the plankton for the cockles at this time. Consequently, the grid samples cannot conclusively confirm the effect of the blade edge as they cannot be compared to the other samples in this section.

4.3.3.2 Density Effect

The cockles were collected from the fifth monitoring occasion, which was the first time the dredge with the chute enclosing the blade and spray bar had been monitored. Table 4.3.3.2.1 below shows the damage rates for the undersized cockles.

Table 4.3.3.2.1. The percentage of undersized cockles damaged in each sample.

Density	Dredge Path	Tyre Track	Unfished
High	13	10	1
Low	37	16	3

Damage rates are much higher for both high density and low density than for the cockles for the samples from the third monitoring occasion, discussed in section 4.3.3.1. This may be due to the introduction of the chute. The edge of the chute would provide an extra edge for more blade edge damage. However, there is also an increase in bird-type damage so the increased damage rates may also be due to the birds feeding on the cockles before sampling could take place. The feeding activity of the birds are explained further in section 4.6. The fact that a greater proportion of damaged cockles were seen in the dredge path than the tyre tracks was probably due to the presence of the chute, which meant that fewer cockles damaged by the blade would have fallen off into the tyre tracks.

The occurrences for each type of damage can be seen in figure 4.3.3.2.1 below. Again, most of the damage to the undersized cockles is major damage. However, there is also an increase in bird type damage, as discussed above.

The undamaged cockles were placed in aerated seas water for 14 days and their mortalities were recorded. The results from this can be seen in figure 4.3.3.2.2 below.

It appears that the cockles from the low density area were in a poorer condition than those from the high density area. This was not expected. It was expected that the cockles from the high density area would be in a poorer condition as competition for food would be greater. However, as mentioned in section 3.3.3.2, the high density area sampled was on the low shore and the low density area sampled was from the high shore. The emersion time for the high shore cockles would be greater than for the low shore cockles. Although the difference in emersion times may not be a lot greater, it may be a contributing factor towards the poorer condition of the high shore cockles, which were less dense. In addition to this, the sediment on the higher parts of the bed dried out a lot quicker than the lower areas of the bed, thus contributing towards the physical stresses of emersion. If a repetition of the trials were to take place, the density samples should be taken from the same height on the shore.

Only a limited amount can be deduced about the density effect on survival for the undersized cockles. However, the results continue to highlight the effect of the dredging operations on the survival of undersized cockles.

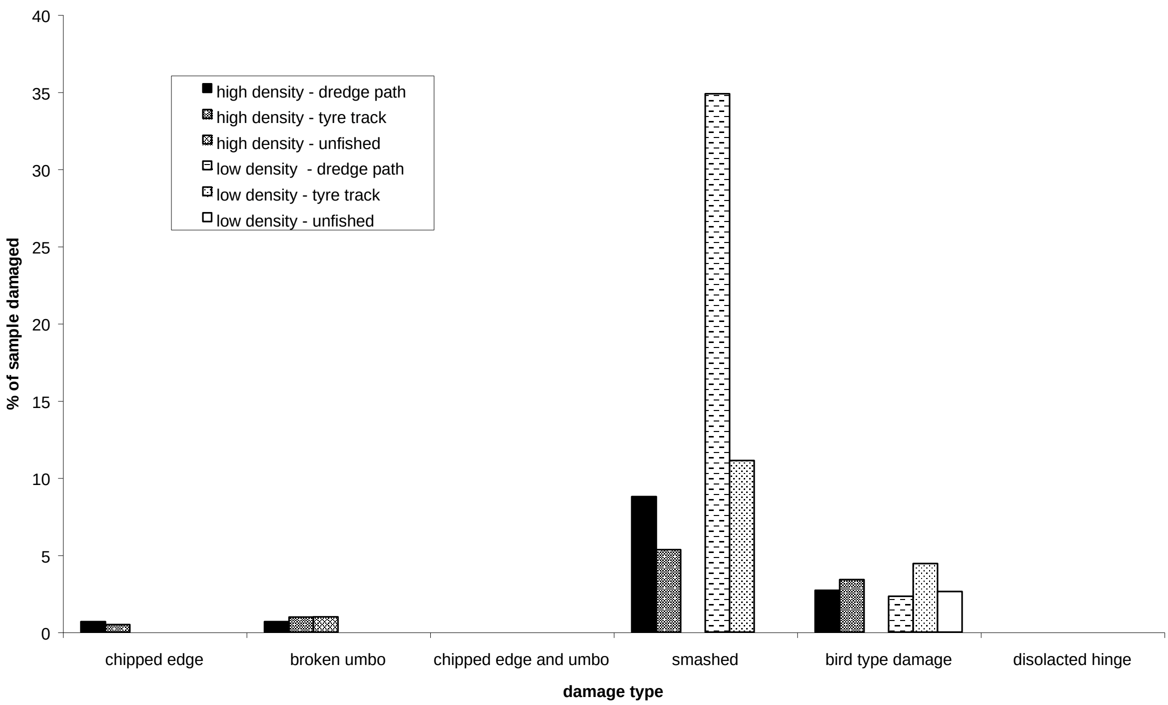


Figure 4.3.3.2.1. The occurrences and types for each type of shell damage for both the high density and low density samples.

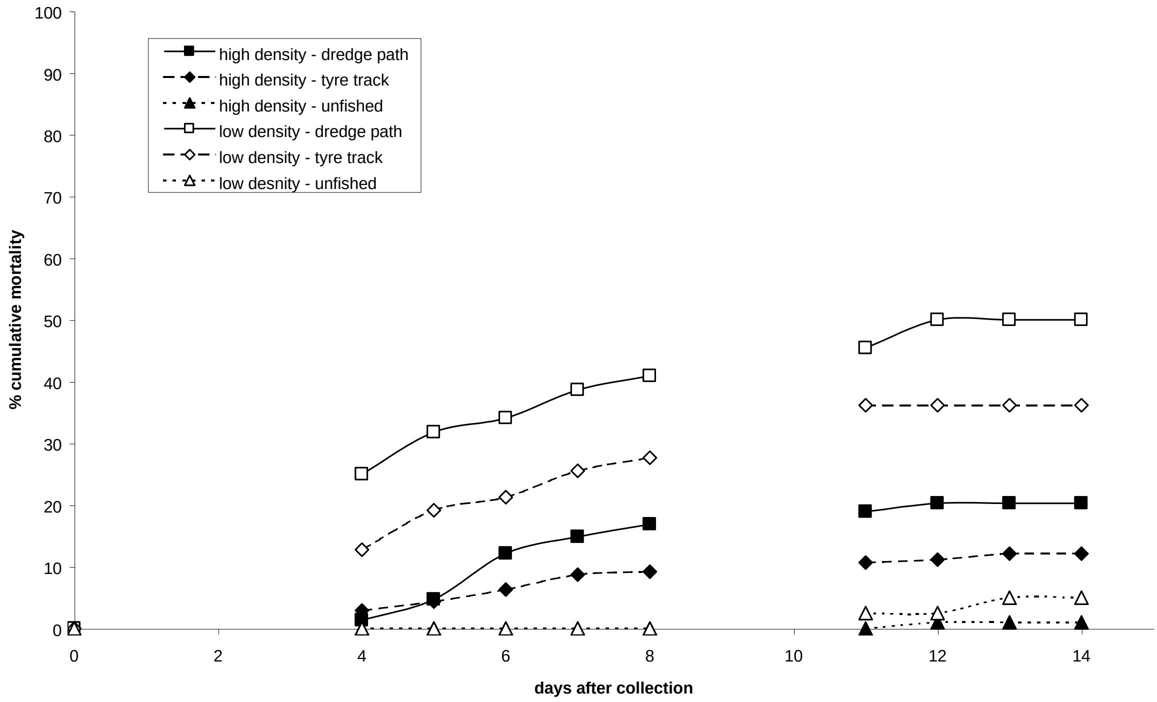


Figure 4.3.3.2.2. The cumulative mortalities of undersized cockles found at both high density and low density areas.

4.3.3.3 Jumbo and Raking Effect

The damage rates for jumbo and raking can been see in table 4.3.3.3.1 below.

Table 4.3.3.3.1. The percentage of undersized cockles in each sample that were damaged.

Bed	Shore Height	Jumbo and Raked (% damaged)	Raked (% damaged)	Hand-gathered (% damaged)	Quadrat (cockles per m²)
Upper	High	3	14	3	710
Upper	Mid	3	0	0	1970
Upper	Low	1	1	0	4570
Lower	High	5	14	2	380
Lower	Mid	4	5	2	570
Lower	Low	0	0	0	240

It can be seen from the hand-gathered cockles, that there were already damaged cockles on the two beds, probably from recent dredging activities. Consequently, the realistic damage rates for the traditional cockle fishing methods are probably not as high as are shown in table 4.3.3.3.1. The fact that some of the cockles were already damaged before sampling took place is demonstrated by the presence of cockles that had bird type damage, as shown in figure 4.3.3.3.1 below.

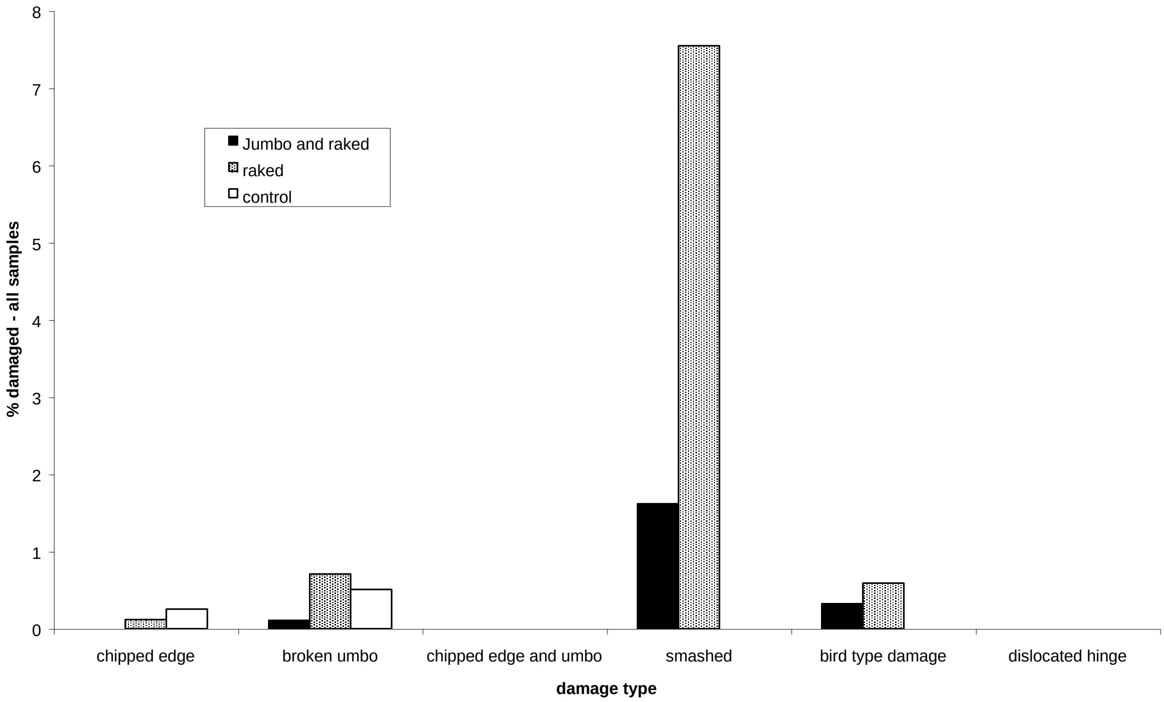


Figure 4.3.3.3.1. The occurrences and types of damage for the traditional methods of cockle fishing.

There was a wide range of damage rates for the raking samples, as seen in table 4.3.3.3.1. This could be due to the fluidity of the substrate. It was noted that for the high shore samples, the substrate was beginning to dry out. This meant that the cockles wouldn't have been able to move through the substrate with as much ease as the cockles in the more fluid substrate further down the shore. Consequently, when the prongs of the rake came into contact with the cockles, they were more likely to get damaged.

The undamaged cockles from the two low shore samples were placed in aerated seawater for 14 days for survival analysis. The results of this can be seen in figure 4.3.3.3.2.

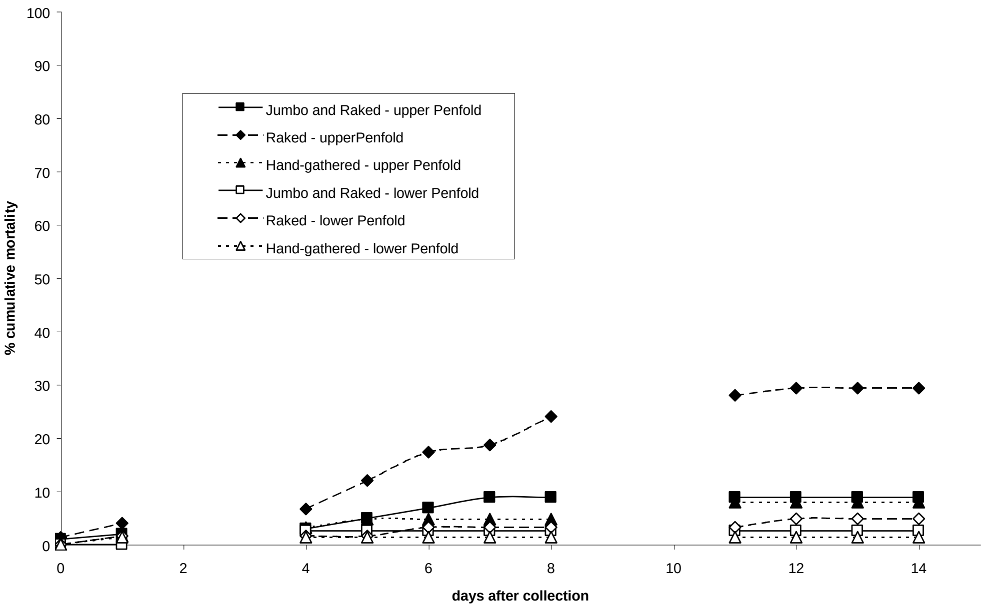


Figure 4.3.3.3.2. The survival rates for the cockles collected using traditional cockle fishing methods.

Generally, all samples had a low mortality rate. Only one of the raked samples had a pattern of mortality similar to those from the dredged samples. It was noted that in the area where this sample was taken from (low shore of the upper Penfold) there was already a great deal of mortality evident. There were many empty cockle shells that were still hinged, which suggests recent mortality. It was believed that just 24hours before sampling took place, a sand bank was covering this area. This might be the cause of the high mortality seen in the raked sample from this area. However, neither the jumbo and raked nor the hand-gathered samples from the same location showed the same mortality pattern. After 14 days, 29% of the cockles from the raked sample of the low shore, upper Penfold, were dead.

4.3.3.4 Sediment Effect

The damage rates for the two samples that were collected by raking in the channel were 6% and 5%. This is lower than the damage rates for the dredge path cockles collected on the same monitoring occasion. However, it is approximately the same as one of the samples collected from the grid of the dredge collected during the same monitoring occasion, as discussed in section 4.3.3.1. The occurrences for the different types of damage are shown in figure 4.3.3.4.1. Again, the majority of the damage is major. There is also an increase in the incidence of cockles with a dislocated hinge.

The undamaged cockles were placed in aerated seawater, alongside cockles that were hand-gathered from just outside of the channel, and were monitored for 14 days. By the end of the 14 days, 16% and 14% of the cockles were dead from the two raked samples. 14% of the cockles from the hand-gathered sample were dead. This suggests that raking in sediment that was more fluid did not adversely effect the cockles' survival.

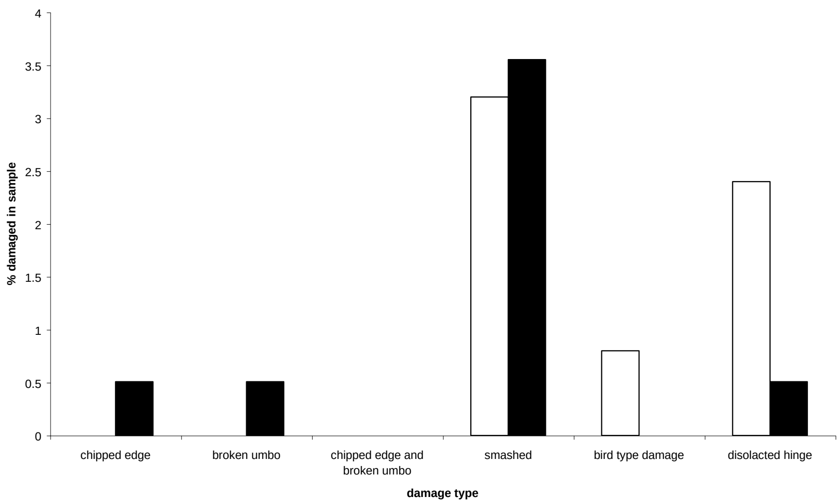


Figure 4.3.3.4.1. The occurrences for the different types of damage for the two channel samples collected by raking.

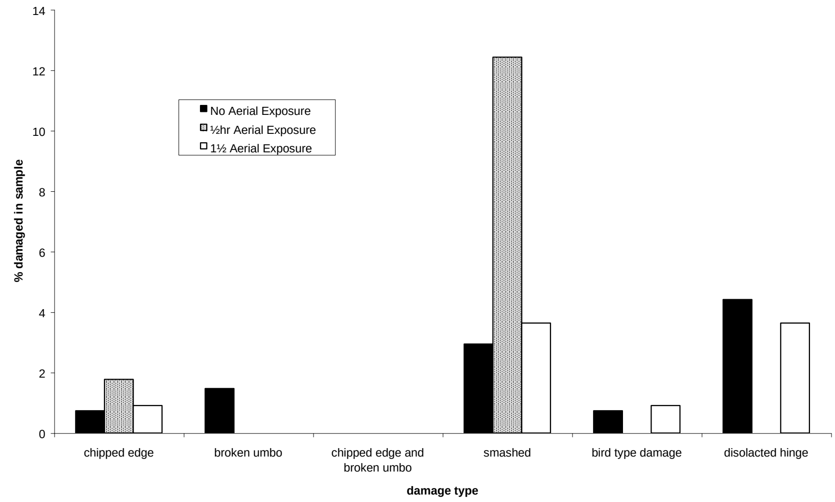


Figure 4.3.3.5.1. The occurrences for each type of damage for the dredge path samples of different aerial exposure times.

4.3.3.5 Effects of Aerial Exposure

The damage rates for the cockles with no aerial exposure was 10%, ½ hour aerial exposure was 14% and for 1½hour aerial exposure was 9%. This suggests that the amount of aerial exposure that the cockles were subjected to did not affect their damage rates, as might be expected. The only type of damage that might be expected to increase with aerial exposure would be bird type damage. However, as figure 4.3.3.5.1 shows, this wasn't the case. However, this is not surprising as no birds were seen in the area on this monitoring occasion.

Once again, most of the damage is major damage. There were not many cockles with bird type damage. More cockles were found with a dislocated hinge.

The undamaged cockles were placed in aerated seawater for 14 days alongside hand-gathered cockles from the unfished area. The results can be seen in figure 4.3.3.5.2 below.

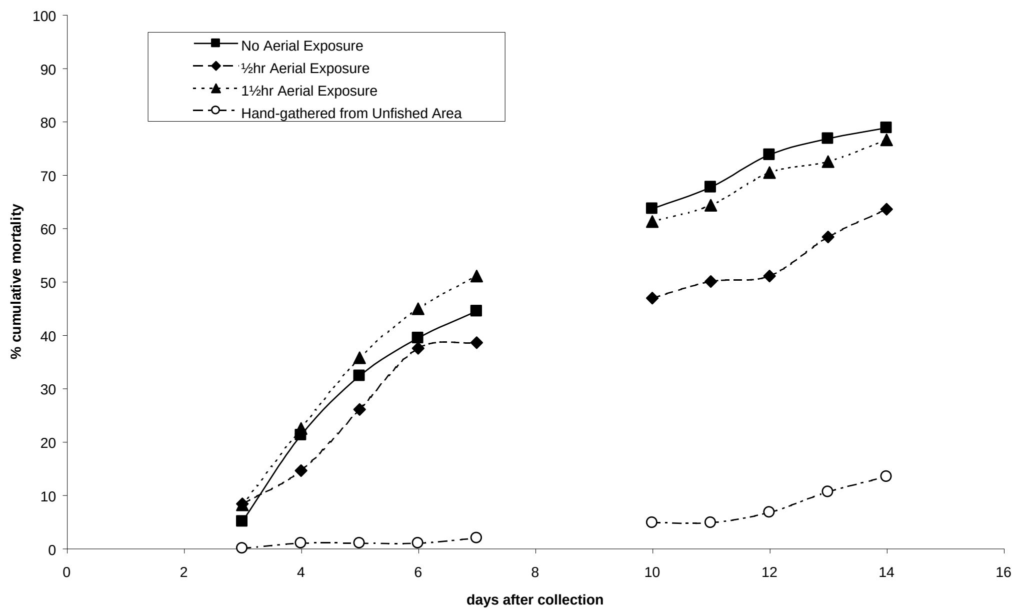


Figure 4.3.3.5.2. The survival rates for the cockles with varying degrees of aerial exposure.

Clearly the amount of aerial exposure the cockles had been subjected to did not affect their survival rates. Those cockles with no aerial exposure showed the greatest mortality rates, whereas those that had only ½ hour aerial exposure time showed the lowest mortality rate of all the samples, except for the hand-gathered cockles. All the cockles from the dredge path showed a much higher much mortality rate than those from the unfished area, again suggesting that the dredging activity is adversely affecting the survival of the undersized cockles.

4.3.3.6 Shaking Effect

Three shaking trials took place. For the first trial, cockles from the Ribble Estuary were shaken in a circular fashion and not very violently. Samples were shaken for 10 seconds, 30 seconds and for 2 minutes. No cockles were damaged. A sample was also left unshaken. The mortality rate was very low for all of the samples and none were different from the unshaken sample.

For the second trial, cockles from the Ribble Estuary were shaken in an up-and-down motion and in a much more violent manner. Samples were shaken for ½min, 1½mins and 3mins. A sample was also left unshaken. Many cockles were damaged by the shaking. After three days, all the cockles from the 1½mins and 3mins were all dead. After six days, all the cockles in the ½min sample were dead. On day six, less than 1% of the unshaken cockles were dead.

For the third shaking trial, cockles were collected from Red Bank in Morecambe Bay, and were subjected to the same degree of shaking as the Ribble Estuary cockles in the second trial, but only for ½min and 1½mins. After three days, the shaken cockles were looking stressed. If they were not dead, they were gaping, but when disturbed, they would close up. After eight days, all of the 1½mins cockles were dead. When the trials terminated after 14 days, 94% of cockles in the ½min sample were dead and 1% of the unshaken cockles were dead. The undersized cockle density of the sampling location at Red Bank, was 2350 per m^2.

Physical disturbance obviously has an adverse effect on the survival for the undersized cockles. These results also suggest that the cockles in the Ribble Estuary are in a poorer condition than cockles in Red Bank as the Red Bank cockles took longer to die when shaken for the same lengths of time.

4.4 Infauna

Invertebrate cores taken from the unfished areas of the bed on the 3 sampling occasions showed that the fauna within the sediment was of very low diversity, and was dominated by first-year cockles and the bivalve *Macoma balthica* (see Table 4.4.1 below). Worms of the genus *Nephtys* were also common in the samples. It can be seen that the density of first-year cockles decreased sharply between early January and February, a similar result to that obtained by quadrat sampling. However the sampling was designed to reflect differences between unfished and dredged areas, rather than density variation with time. Only 5 unfished cores were taken from a very small area, and the sample site was different on each sampling occasion.

Table 4.4.1 Mean infaunal densities from unfished areas of the lower Penfold Channel bed on the 3 sampling occasions.

	No per m²		
	10/12/01	9/1/02	7/2/02
0 grp Cockles	2160	7993	960
1 grp Cockles	0	0	0
2 grp Cockles	24	48	0
Nephtys sp	96	192	48
M. balthica	528	1392	696
Nematoda sp	0	0	0
Hediste diversicolor	0	0	24
Bathyporeia sp	0	0	24
Mya arenaria	0	0	0
Total All Taxa	2808	9625	1752

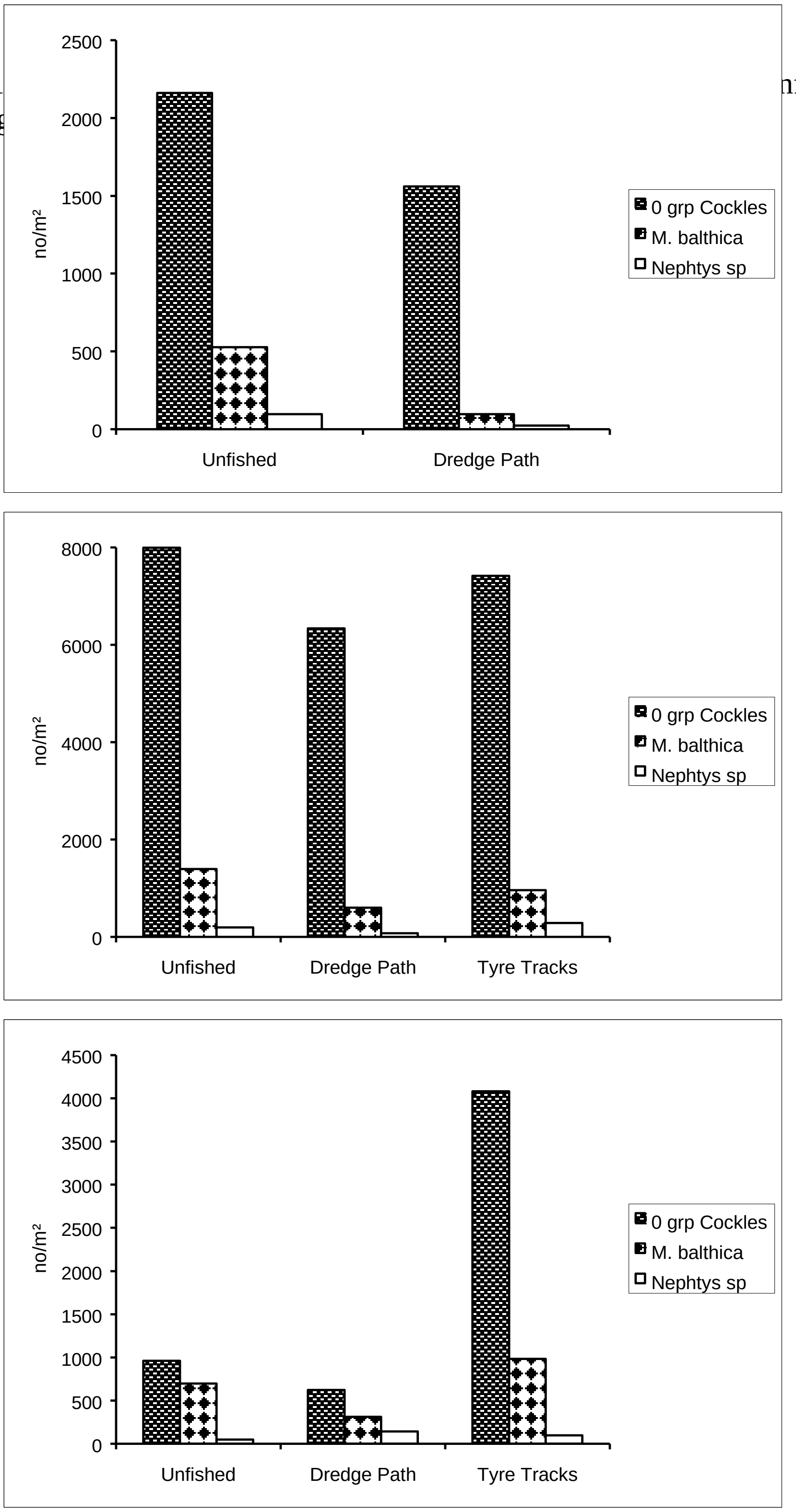
It should be noted that "unfished" refers to areas of the bed that were not fished on that particular sampling occasion, and showed no signs of previous dredge tracks. The December 2001 samples were taken on the first day of the dredging trial and so definitely came from unfished areas. However, the dredge tracks did not persist for more than a few days so that some of the later samples may have come from areas over which the dredge had operated. The taxa *Nematoda sp* and *Mya arenaria* are listed in the table because a few individuals were present in some of the dredge path or tyre track samples, although none were taken from unfished areas.

The relative densities of the 3 most dominant organisms in unfished areas, the dredge path and the tyre tracks are shown in Figure 4.4.1. In December 2001 samples were only taken from the unfished bed and the dredge path. It can be seen that densities of 0-group cockles, *Macoma balthica* and *Nephtys sp* were all lower in the dredge path as might be expected. In January this observation was repeated, but it can be seen that in the tyre tracks densities of cockles and *Macoma* were intermediate between the unfished area and the dredge path, and *Nephtys* densities were higher than in the unfished area. Some of the February results were unexpected. Numbers of cockles and *Macoma* were again somewhat reduced in the dredge path compared to the unfished area, although *Nephtys* densities were higher in the dredge path than in the unfished samples. What was not anticipated was the comparatively high

densities of cockles and *Macoma* found in the tyre tracks. The samples from the tyre tracks contained over 4 times the number of first-year cockles found in the adjacent unfished area. The effect did not seem to be due to sample variability as 4 of the 5 tyre track cores contained more cockles than any of the 5 cores from the unfished area. On this occasion the dredge was of a different design to previous months, and incorporated a chute containing the water-jets. However, it is difficult to see why any aspects of the dredge design should result in cockle accumulation in the tyre tracks.

Figures 4.4.2 and 4.4.3 show the relationship between the sample groups for January and February. The Figures are ordination plots by multi-dimensional scaling using the Bray-Curtis coefficient of similarity. The closer together points appear on these plots, the greater the similarity between the samples. Figure 4.4.2 includes all invertebrates found in the samples, including cockles, whereas Figure 4.4.3 shows an ordination for non-target species only.

Figure 4.4.1 … nfished areas, the
dredg…



In January there was great similarity between the unfished and tyre-track samples. The dredge path samples showed a reduction in numbers of cockles, and a greater drop in *Macoma balthica* and *Nephtys sp* numbers resulting in the greater separation of the January dredge path samples on Figure 4.4.3.

In February there was great dissimilarity between all sample groups, with or without cockles. Like first-year cockles, *Macoma* numbers were reduced in the dredge tracks, but were elevated in the tyre tracks. By contrast, the highest numbers of *Nephtys* were taken from the dredge tracks.

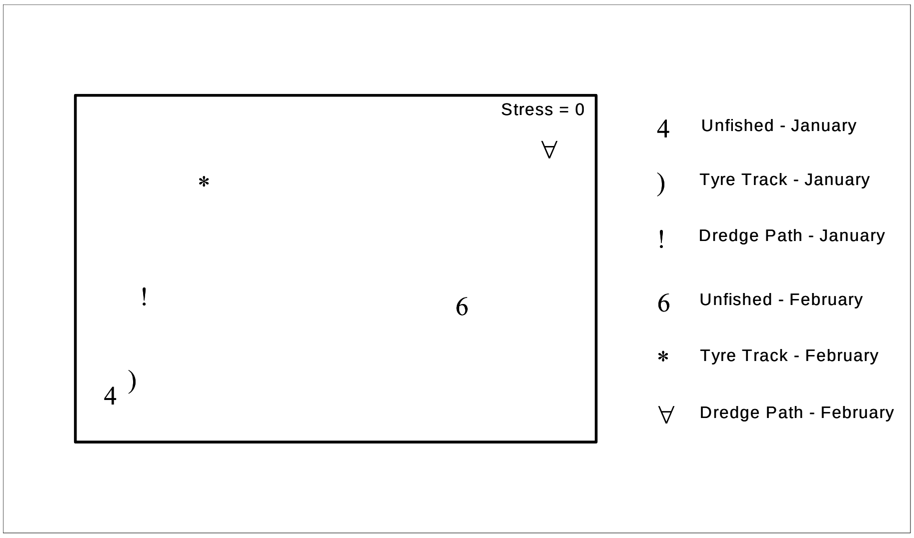


Figure 4.4.2. MDS ordination of invertebrate core samples from the dredge path, tyre tracks and unfished areas in January and February 2002 (including cockles).

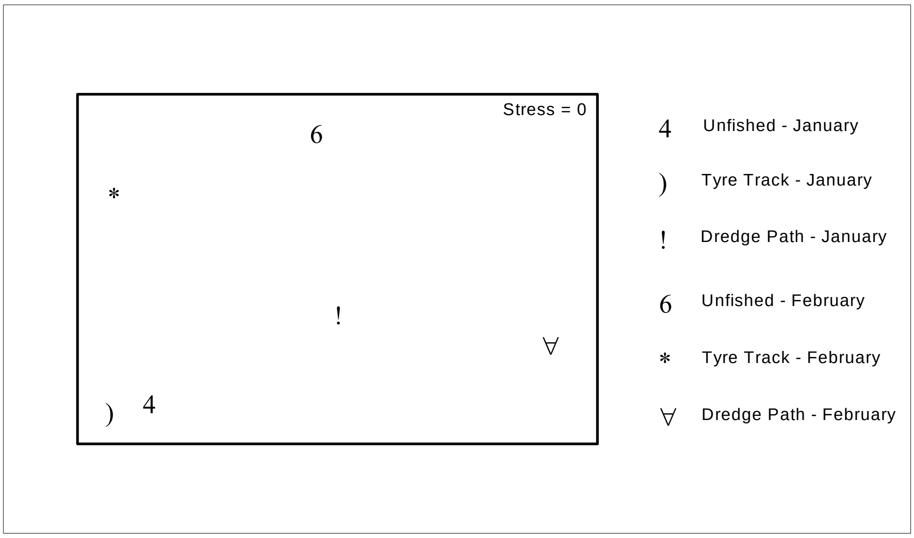


Figure 4.4.3. MDS ordination of invertebrate core samples from the dredge path, tyre tracks and unfished areas in January and February 2002 (non-target species only, cockles excluded).

4.5 Sediment Analysis

The sediment was very well sorted, as can be seen on figure 4.5.1 below. Most of the sediment had a mean phi of 2·5. This is described as fine sand on the Wentworth scale. The sediment from the tyre track and unfished area had similar profiles, which suggests that the tyres on the tractor and dredge had no immediate effect on the sediment composition. It is unfortunate that the sediment sample from the dredge path had to be discarded due to a problem separating the size fractions.

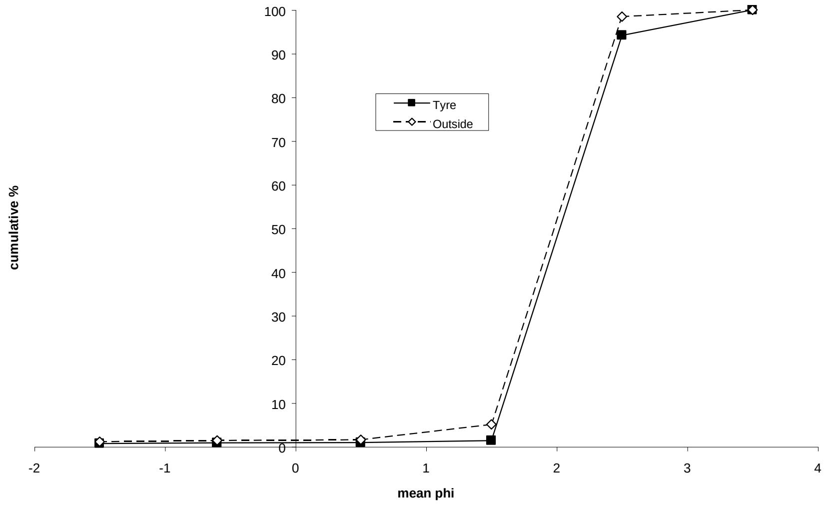


Figure 4.5.1. The sediment profile for the Ribble Estuary.

These samples were collected from a representative area of the lower Penfold bed. However, it was noticed that there were patches of the bed where the sediment was finer and a lot stickier. This proved to be problematic on occasions as the dredge found it harder to move through these patches.

4.6 Birds

On the lower Penfold bed, the main area fished from December to February, considerable bird activity was noted. The cockle dredging appeared to attract birds, especially waders, although it was noted that other large bird groups were present in the vicinity but were not attracted to the dredged area. The most common birds seen feeding in or near the dredge tracks were knot or dunlin. Feeding occurred shortly after dredging commenced, either on exposed tracks or along the receding tidal edge. The knot or dunlin did not seem particularly sensitive to disturbance by the tractor and dredge, which was estimated to approach to within 50m of feeding groups before they flew a few hundred metres along the tideline. At higher tidal levels, where the sediment was drier, feeding seemed to be concentrated on the dredge track and tractor tyre marks. Further down the shore the sediment was wetter, and although birds were observed to feed predominantly in the tracks significant feeding also took place on undisturbed sediment between the tracks. This is illustrated in photograph 4.6.1 below. Observations of the dredge discards suggested that the receding tide distributed some animals well away from the tracks, and the birds may have been feeding on cockles or other invertebrates washed down from the dredge path. It was not possible to directly observe what prey were being taken.

Photograph 4.6.1. Knot or dunlin feeding in the dredge path, tyre tracks and unfished areas.

On the upper Penfold bed very little bird activity was observed. Substantial flocks were observed to be still present in the lower channel, but these were not attracted up the channel to feed in the dredged area.

5. Conclusions

- This basic design of wet dredge is very efficient at retaining the harvestable cockles, whilst depositing the undersized cockles back onto the bed.
- The population of the Ribble Estuary cockles consisted of mainly 2001 year class cockles, at exceptionally high densities, which were undersized. The 1999 year class cockles were the most abundant year class for the harvestable cockles.
- The damage rates for the harvestable cockles were low, which suggests that the wet dredge is an effective method of fishing for a high quality catch.
- The damage rates for the undersized cockles were variable, but mostly high. The very high density that these cockles were found in may be a contributing factor to the high damage rates. It would be worth repeating these trials when the cockles are less dense on the bed.
- The density for both the harvestable and undersized cockles decreased throughout the trials. This may be due to the dredging activities, or it might be due to natural mortality because of the harsh weather conditions over the winter period.
- The survival rates for the harvestable cockles were not adversely effected by the dredging activity.
- The survival rates for the undersized cockles were adversely effected by the dredging activity. However, it is not known which part of the dredging activity is harming the undersized cockles.
- The effect of density on the survival of the undersized cockles was not clearly understood. If the trials were to be repeated, samples with different densities should be collected from the same shore height.
- It appears that traditional cockle gathering methods, such as raking and jumboing, do not have the same effect on survival as the wet dredge. However, more rigorous results could be obtained if samples were collected at the beginning of the trials or in an area where there does not appear to be any damaged cockles or natural mortality evident.
- Collecting cockles from an area where the sediment is more fluid appears to result in lower damage rates.
- The amount of aerial exposure that the undersized cockles are exposed to after being brought up by the dredge does not seem to have any effect on the survival of the undersized cockles.
- Undersized cockles appear to be very vulnerable to extreme physical disturbance. Minor physical disturbance appears to have very little effect.
- The undersized cockles from the Ribble Estuary appear to be in a worse physical condition than the Red Bank cockles. If the shaking trials were to be repeated, it would be worth standardising the method of shaking.
- The invertebrate population had very low diversity, with first-year cockles heavily dominant. Overall, some reduction in the density of most species was noticed in the dredge tracks, but it is unlikely that wet dredging would have a significant effect on community structure in this location.
- The tyres of the tractor and dredge do not appear to affect the topography or sediment composition. However, samples need to be analysed from the dredge path before any real effect of the dredging activities on the sediment composition can be assessed.
- On the lower Penfold bed, birds have not been driven away from the area by the dredging activities. After the dredge and tractor has left the area, the birds actively feed on the cockles and other infauna brought up by the dredge.
- On the upper Penfold bed, birds did not seem to be attracted to feed by the dredging activity.

6. Recommendations

Before any decisions were to be made about the use of wet dredges in our District, further trials should be carried out in the same area in future years. This coming autumn would provide a suitable opportunity for monitoring of the 2001 year class cockles that would then be just under the minimum landing size. It would be important to note the effects of the wet dredge on these cockles once they have grown, as well as further observations on any cockles that settle in 2002.

A more rigorous, planned approach to future monitoring should now be possible, whereas the 2001/2 monitoring needed to react to the uncertainties and changes inherent in a novel method of fishing. It would be particularly important to further investigate the causes of damage to and subsequent mortality of first-year cockles, and to establish whether the dredging may have contributed to the population decline of these cockles between January and February. It Should be noted, however, that the 2001 year class was found at unprecedented high densities, and a drastic reduction in numbers would have to have occurred over the winter period as densities were very much higher than have been observed to impair both growth and survival.

It is suggested that it might be useful if trials of the same type were to be carried out in an area where the cockles would not be so dense and where they may not be exposed to the same stresses as those found in the Ribble Estuary.

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11th June 2002