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Trial of a tractor dredger for cockles in Burry Inlet, South Wales

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The effects on cockle (*Cerastoderma edule* L.) populations in Burry Inlet, South Wales of mechanical harvesting using a tractor dredger were investigated with an experimental trial conducted on 29 October 1992. Previously, only hand gathering methods were used, and the trial was intended to assist a licensing decision for mechanical dredging. Six blocks of dredged and undredged (control) plots were set out in each of two areas, one having a low density of cockles, the other high. Approximately 82% of the dredged areas was lifted by the blade of the dredger. The catch consisted almost exclusively of adult cockles ($\geq$2 years old) over 25 mm in length. Appreciable losses of spat and one-year-olds from the dredged plots were also observed even though they were not taken in the catch. Possible reasons are discussed. Counts of damaged individuals remaining on the plots on the day after dredging were generally low for all age groups. During the year following the trial, none of the year-classes showed further mortalities attributable to dredging, and changes to shell growth were either minor or absent. Spatfall success in 1993 was depressed by 11% on dredged plots compared to that on control plots in the low density area, but was increased slightly (not significant $p>0.05$) in the high density area. It is concluded that delayed effects of the dredging on cockle stocks were negligible.

Key words: *Cerastoderma edule*, cockle, tractor dredging, Burry Inlet, South Wales.

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Introduction

This paper reports an experimental trial of mechanical harvesting of cockles (*Cerastoderma edule*) in Burry Inlet, South Wales (Fig. 1) using a tractor dredger, conducted on 29 October 1992. The Inlet supported a traditional hand-gathering fishery (Hancock and Urquhart, 1966), taking approximately 3000 t per year in the 1990s, as well as being an important site for the conservation of wildlife. The trial was intended to assist a decision on whether or not to license tractor dredging locally. At the time of the trial, tractor dredgers had only operated in the United Kingdom for a few years, and no other studies of effects were known. Being many times faster and more vigorous than hand-gathering methods, the main concerns were that it might cause excessive stock depletion, impair future spatfall, and be damaging ecologically for both the benthos and birdlife on the sandflats. Investigation of the first two topics is reported here; the ecological results have been reported separately (Ferns and Siman, 1993; Rostron, 1993). Studies of earlier hydraulic dredging methods used from boats (Allen, 1995) are of related interest. They differ in the type of mechanical treatment suffered by the cockles, in less systematic ground coverage, in the timing with respect to tidal exposure, and in the lack of sedimentary compaction under heavy vehicles.

Tractor dredgers for cockles are constructed like potato harvesters. An inclined horizontal blade held at a preset depth skims sand and cockles onto a conveyor belt and thence upwards into a revolving riddle. Sand and small cockles are ejected to the side of the dredger, while large individuals are trapped and rolled towards a take-off hatch for bagging. The detailed objectives of the present study were to describe performance of the dredger shown in Figure 2, to estimate the numbers of

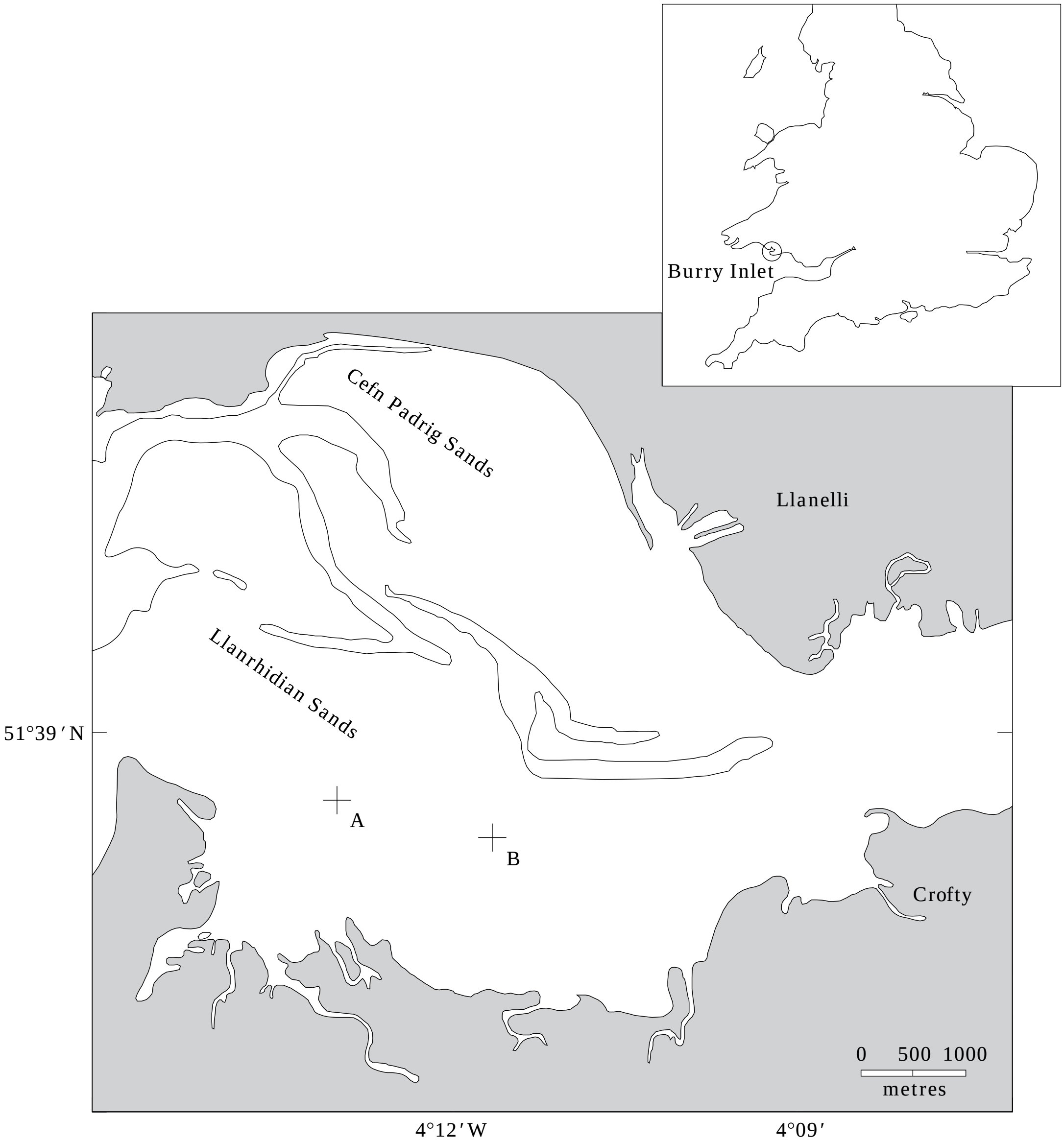

Figure 1. Burry Inlet showing approximate positions of experimental areas A and B. Inset is a map of England and Wales showing location of Burry Inlet.

cockles removed or lost in different age classes, to assess selectivity by length or age as well as damage to undersized cockles, and to look for post-dredging effects on recruitment.

Method

Locality

Two areas of the sands near Llanrhidian in Burry Inlet were chosen for investigation on the basis of their accessibility, suitability for dredging, relative flatness, apparent homogeneity, and distance from hand-gathering and nature conservation areas. They were called areas A and B (Fig. 1); preliminary observations found relatively dense and sparse populations, respectively. Area A was sited near conservation interests; but area B, being of less value to hand-gatherers, was considered more typical of areas that might be licensed for tractor dredging.

Experimental design

The experimental trial had to be planned without detailed knowledge of how the dredger would perform on the Llanrhidian sands since this was to be the first

Figure 2. Photograph of the tractor and dredger at work during the trial at Llanrhidian Sands, Burry Inlet.

visit by such a machine. A "randomised blocks" design was chosen because it required no special manoeuvring by the dredger, making completion of the trial in the limited time available between tides more certain. The design was intended to reduce the amount of uncontrolled environmental variability confounded with treatment effects by confining each replication of dredged and control plots within a block of small area.

In each area, six posts were set out to mark a hexagon (Fig. 3) of radius 60 m, using a compass, pedometer and tape measure for geometric accuracy. The tractor driver was instructed to dredge around the posts, moving outwards on each circuit until a 20 m wide band had been uniformly dredged; this was calculated to require 28 circuits. Six experimental blocks, each 30 m long, were then designated, one per side between the corner posts, taking into account the fact that the dredger had to slightly overshoot each post before it could turn, as shown in Figure 3. Each block consisted of two adjacent plots, one within the dredged band, the other a control. The control plots, also 20 m wide, were randomly situated either inside or outside the hexagon, so that on average over all blocks, any environmental trends affecting the comparisons between experimental and control plots should have been cancelled by the diverse orientations of the blocks. The plots were marked with nylon whip aerials coded with inscribed rings around the top to indicate block number, and attached to a wooden plate buried in the sand. The aerials were designed to resist storm damage and to be inconspicuous to vandals.

Dredged and control plots were sampled on either the day, or the morning before dredging. Both are denoted as day 0. It was assumed that counts on the control plots would not vary overnight so that only the experimental plots were sampled on the day after dredging, denoted day 1. On days 14 (12 November 1992), 85 (22 January

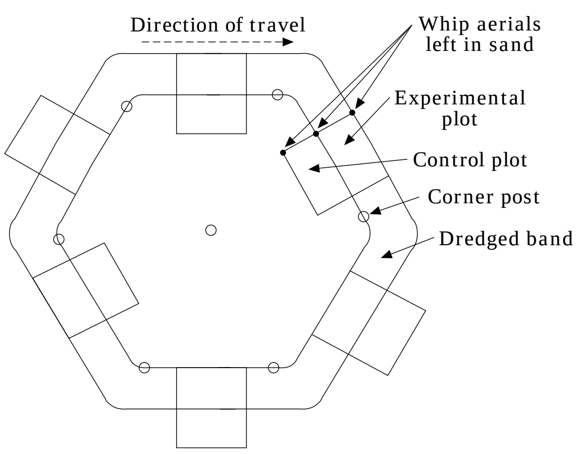

Figure 3. Schematic diagram of an arrangement of dredged and control plots around the hexagonal dredged band in each of areas A and B. The control plots were sited randomly either inside or outside of the dredged band.

1993), and 373 (6 November 1993), experimental and control plots were both sampled.

Cockle numbers

Cockle numbers were estimated within each plot by sieving (4 mm mesh) the sediment enclosed by 0.1 m^2 quadrats raked out to about 5 cm depth, and then counting the undamaged, presumably living cockles by age group. Damaged cockles, i.e. shell fragments with flesh still adhering, were also looked for and counted on the first day after dredging. Quadrats were located using random numbers to choose co-ordinates within the lengths of the two sides of each plot, and pacing approximately one metre strides to the selected point. Field staff were instructed to drop the quadrat without looking whether it fell on or between dredged tracks if gaps were identifiable. This was only a consideration on the first day after dredging; thereafter, dredger tracks were not clearly visible. Ten quadrat samples were taken from each plot on each occasion, making a total of 240 samples to be collected between the outgoing and incoming tides, with darkness further restricting work in the winter months. The sampling rate proved to be an achievable maximum for the 6 to 8 sampling staff available.

Whenever possible, the age of cockles was determined at the time of sampling on the beach, but on some occasions it was necessary to remove samples in labelled bags for counting and ageing later. The year classes identified were: 1990+ (cockles settling in 1990 or before), 1991, 1992, and, on the last visit to the site, 1993.

Cockle lengths

Approximately 50 to 100 cockles from one or more quadrat samples were removed from each plot in labelled bags for length measurement by age group. (No samples were collected from the control plots on days 0 or 1.) Similar numbers of cockles were taken as a grab-sample from the dredger's catch, and from rejects, the latter being obtained when the machine was operating on two areas just to the north and south of area A after the main experiment. These samples were intended to indicate size selectivity.

Statistical methods

Standard errors (S.E.) for tabulated plot mean counts were derived from the between-quadrat variances (s^2) averaged over all plots on all observation days, since reasonable homogeneity of these variances was observed; the formula is $S.E.=\sqrt{(\text{mean } s^2)/n}$ where $n=10$. Given that estimated plot means are approximately normally distributed (by the Central Limit Theorem), there is a 95% probability that the true plot mean fell within ± 2 S.E. of the estimated value. Linear models were fitted separately to the mean numbers of each year class on each plot as a function of time using the SAS GLM least squares procedure.

The preliminary model tested for each year class, except 1993, was

$$N=\beta_b . B+\beta_d . D+\beta_t . T+\beta_{dt} . DT+e$$

where N is the mean quadrat count for the plot, B is the mean count for each block within the area, D is either 1 or 0 depending on whether the plot had been dredged or not, T represents the effects of time in days after dredging which are common to both dredged and undredged plots, DT represents the effects of time on the dredged plots only, e is the error term, and the β are the least squares regression coefficients. This a standard linear model for a randomised blocks design (Hicks, 1973) but with the addition of linear time effects to provide a simple, if approximate, way of allowing for the repeated measures on the same set of plots. Terms were eliminated from the model by the usual F test at 5% significance. In contrast to estimation, this requires normally distributed, homoscedastic data, so, as a test of the robustness of the finally selected models, the analysis was repeated with ln N in place of N. Improved homogeneity of variance was achieved by analysing results from areas A and B separately. Linear models for each area were also fitted to the mean shell lengths of each year class for each plot.

Results

Observations on the tractor dredger

The dredger proved to be sufficiently manoeuvrable to cover the hexagonal course at a fast walking speed. Much of the material rejected by the riddle fell under the wheels of the dredger where appreciable compression of the sand was observed. No loss of cockles or substrate occurred from the sides of the conveyor belt during dredging. Measurement of the riddle on the dredger found two sizes of metal mesh, the front three quarters having apertures of 22 × 22 mm, the rear quarter having 14 × 90 mm. The blade of the dredger was 71 cm wide.

Changes in cockle numbers on the plots

Table 1 shows mean numbers of undamaged cockles per quadrat by age group, treatment, block, and time before and after dredging, together with area means and standard errors. The 1990 year class was poorly represented in the stock before dredging. About 49% of the 1990+ group of cockles (i.e. mostly 1989 and older) were lost

Table 1. Mean numbers of cockles (*C. edule*) per 0.1 m^2 as estimated from 10 quadrats randomly located in control and dredged plots in six experimental blocks in areas A and B, Llanrhidian Sands before (day=0) and after (day>0) dredging, together with estimated standard errors, and block means; 1990+, 1991, 1992 and 1993 year classes.

	Block 1		Block 2		Block 3		Block 4		Block 5		Block 6		Average all blocks	
Days	Control	Dredged	Control	Dredged	Control	Dredged	Control	Dredged	Control	Dredged	Control	Dredged	Control	Dredged
Area A														
1990 and older (estimated standard error ± 2.50):														
0	22.22	21.00	21.30	12.40	14.70	18.50	19.70	23.60	32.90	32.10	27.30	30.90	23.03	23.12
1	—	11.00	—	5.80	—	6.90	—	17.00	—	18.50	—	12.10	—	11.88
14	16.40	10.80	19.00	8.30	10.30	6.80	18.90	12.40	31.10	13.00	34.80	8.60	21.75	9.98
85	19.00	8.40	17.20	12.70	13.90	8.00	22.40	14.10	27.80	13.00	27.40	12.70	21.28	11.48
373	13.50	7.70	9.30	8.90	5.70	5.40	14.10	11.80	9.50	11.30	13.50	11.70	10.93	9.47
1991 (estimated standard error ± 3.10):														
0	23.33	23.44	23.80	23.80	17.50	22.20	32.80	32.20	33.80	37.60	34.20	32.60	27.64	28.73
1	—	18.90	—	21.40	—	18.30	—	29.70	—	32.00	—	20.10	—	23.40
14	18.90	15.20	24.00	18.30	13.60	14.10	40.20	26.80	25.00	30.40	34.60	16.70	26.05	20.25
85	16.20	14.30	26.20	17.70	22.30	14.40	33.60	28.90	28.50	19.90	29.90	16.80	26.12	18.67
373	17.40	17.80	17.80	17.40	16.90	15.10	28.10	25.00	16.50	20.90	22.90	16.80	19.93	18.83
1992 (estimated standard error ± 4.78):														
0	69.33	63.00	91.30	82.80	40.20	44.80	30.10	26.60	24.20	18.00	38.90	50.30	48.66	47.32
1	—	44.30	—	54.50	—	32.40	—	25.80	—	13.60	—	19.50	—	31.68
14	66.90	24.90	80.70	37.40	50.00	19.80	35.10	16.80	17.60	8.00	58.20	13.70	51.42	20.10
85	45.60	27.90	76.40	42.30	48.10	30.60	40.30	30.10	24.20	19.60	45.30	32.70	46.65	30.53
373	40.80	32.70	55.70	38.40	33.90	34.10	41.10	28.00	25.30	25.60	50.20	40.10	41.17	33.15
1993 (estimated standard error ± 6.73):														
373	98.90	112.70	112.20	140.70	51.50	70.90	42.10	40.50	53.70	38.70	61.90	81.60	70.05	80.85
Area B														
1990 and older (estimated standard error ± 0.50):														
0	2.60	2.90	1.40	2.90	1.30	1.00	1.60	1.30	2.00	1.40	2.20	2.10	1.85	1.93
1	—	1.50	—	1.90	—	1.10	—	0.70	—	0.70	—	2.10	—	1.33
14	4.30	1.00	1.50	1.30	1.90	1.10	1.70	1.00	1.90	1.20	2.00	1.80	2.22	1.23
85	3.90	1.80	1.40	1.30	1.40	1.30	1.20	1.10	1.10	1.10	1.50	1.00	1.75	1.27
373	2.60	2.00	0.30	0.90	1.10	1.20	1.30	0.30	1.00	0.70	1.80	1.50	1.35	1.10
1991 (estimated standard error ± 0.63):														
0	5.00	3.10	2.60	2.50	3.20	2.50	3.30	2.80	1.40	2.10	2.90	3.10	3.07	2.68
1	—	2.80	—	2.80	—	2.60	—	1.80	—	2.20	—	2.40	—	2.43
14	6.00	2.00	1.90	2.50	1.30	2.20	3.50	1.20	1.80	2.10	2.20	2.60	2.78	2.10
85	5.10	2.10	1.70	1.40	2.50	2.40	1.60	1.40	1.50	1.80	2.20	1.60	2.43	1.78
373	3.10	2.30	0.80	1.10	1.10	1.00	1.20	0.60	1.00	2.00	2.40	1.70	1.60	1.45
1992 (estimated standard error ± 0.75):														
0	2.30	2.10	2.20	1.60	2.00	2.70	3.90	4.40	3.80	4.60	2.80	3.80	2.83	3.20
1	—	1.60	—	2.00	—	1.70	—	2.60	—	3.00	—	2.60	—	2.25
14	1.50	1.00	3.10	1.60	1.40	1.10	5.30	2.90	4.20	2.30	3.20	3.30	3.12	2.03
85	3.40	1.60	1.80	1.40	2.70	2.50	2.00	2.40	2.40	2.60	3.10	2.20	2.57	2.12
373	2.30	1.50	0.80	0.90	1.70	1.40	1.60	1.50	1.00	1.10	2.00	1.80	1.57	1.37
1993 (estimated standard error ± 0.58):														
373	3.00	2.90	2.60	2.40	3.10	2.50	1.50	1.50	2.50	2.10	3.60	3.20	2.72	2.43

Table 2. Cockle densities: regression coefficients and their standard errors for effects of dredging (β_d), time in days (β_t), and dredging × time (β_{dt}) on numbers of cockles (*C. edule*) per 0.1 m^2 by area and year class. Also shown are the coefficients of determination (R^2) for the models (which include block means, not tabulated). n.s. = not significant ($p>0.05$).

Year class	Area A				Area B			
	β_d	β_t	β_{dt}	R^2	β_d	β_t	β_{dt}	R^2
1990 and older	− 11.8 ± 1.2	− 0.0044 ± 0.005	− 0.027 ± 0.007	0.82	− 0.56 ± 0.14	− 0.0012 ± 0.0005	n.s.	0.60
1991	− 5.03 ± 1.1	− 0.014 ± 0.004	n.s.	0.73	− 0.51 ± 0.20	− 0.0028 ± 0.0007	n.s.	0.56
1992	− 18.3 ± 2.7	n.s.	n.s.	0.76	− 0.64 ± 0.19	− 0.0031 ± 0.0006	n.s.	0.58
1993	n.s.	—	—	0.92	− 0.28 ± 0.09	—	—	0.97

on average over all experimental plots in area A between days 0 and 1, and 31% in area B. There were also appreciable losses of younger cockles in both areas: one-year-olds (1991 class) lost 19 and 9% respectively, while spat (1992 class) lost 33 and 30% respectively.

Regression statistics for the linear models fitted to untransformed data are given in Table 2. Significant block effects were found, but since they merely expressed local spatial variability, they are not tabulated. Using a log transform somewhat improved homogeneity of variances but did not alter the terms found to be significant, and, for simplicity, only the estimates based on the untransformed data are presented. For all year classes (excluding the spatfall in 1993) in both areas, the preliminary drop in numbers directly attributable to the dredger ($\beta_d + \beta_{dt}$ in Table 2, for T = 1 in the model) was significant ($p<0.05$).

The estimated losses due to dredging in the 0.1 m^2 quadrats were converted to absolute numbers using the area of each hexagon, approximately 8600 m^2, and β_d from Table 2. 1 014 800 (= 11.8 × 8600 × 10) individuals of the 1990+ group were lost from area A, and 48 160 individuals of this group were lost from area B.

Changes in numbers in the following year varied for the different year classes. The 1990+ year class in area A showed gradually declining numbers on the dredged plots, but markedly greater losses on the undredged plots (Fig. 4a), until on day 373 the mean numbers on each plot type were comparable; the time × dredge factor, was significant at p = 0.001 (Table 2). In area B, where initial numbers were much lower, both plot types showed a gradual decline in numbers with time (β_t in Table 2), and the time × dredge factor was not significant. The 1991 year class showed gradually reducing numbers over time in both areas, without a significant time × dredge factor (Fig. 4b). The 1992 year class showed a slight decline in area B, but not in area A (Fig. 4c).

Settlement of spat in 1993 in area B was 11% lower on the plots dredged in the previous year than on the control plots (p = 0.026, Tables 1 and 2). By contrast, an increase was observed in area A amounting to 15% (Table 1), but this was not statistically significant (p = 0.161).

Analysis of cockle lengths

Figure 5a and b present histograms of the lengths of cockles on days 0 and 1 in (a) area A and (b) area B. The ordinates are given as percentages because the factors to adjust numbers for the total size of the areas were not estimated. A depression of the proportions of cockles over 25 mm is not clearly visible. This is consistent with the findings (Table 1) that cockles were lost in all age groups even though the catch consisted almost entirely of mature individuals. There is an indication from the histograms that the 1991 year class fared less badly than the older and younger groups in both areas, a findng which was consistent with the initial losses from the groups indicated by β_d (Table 2).

Linear modelling of plot mean lengths found that dredging only affected the 1990+ year class, and then only in area A (Table 3). The effect of dredging was a slight drop in mean shell length of 0.47 ± 0.15 mm. The dredge factor was not significant ($p>0.05$) for any other group, and the time × dredge factor (omitted from Table 3) was not significant for any group. A day × day factor was found significant for the two younger year classes, reflecting slower growth in the winter months.

Cockles caught

223 bags of cockles were taken from area A, and 16 from area B. Given that bags weighed approximately 40 kg each, and the average weight of an individual 1990+ group cockle was 10.5 g (as estimated from a routine survey of cockle stocks made during the same week as the dredger trial, Walker, 1992), we calculated that 849 524 and 60 952 individuals were caught from areas A and B respectively. These estimates are of

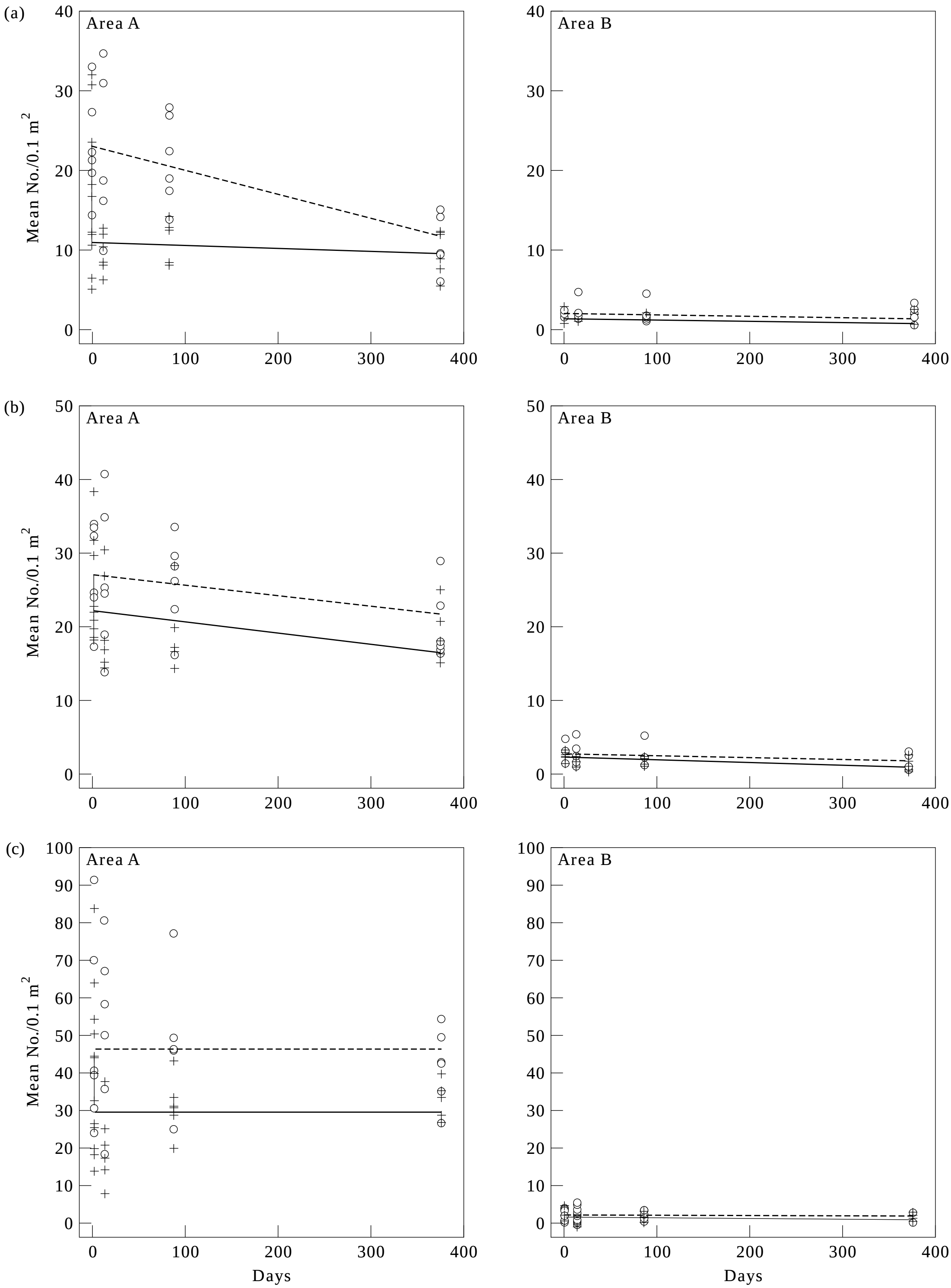

Figure 4. *C. edule*. Changes in densities as mean numbers per 0.1 m^2 quadrat in areas A and B on day 0, and over the days after dredging. ○– – –○ = control plots; +——+ = dredged plots. (a) 1990+, (b) 1991, (c) 1992 year classes.

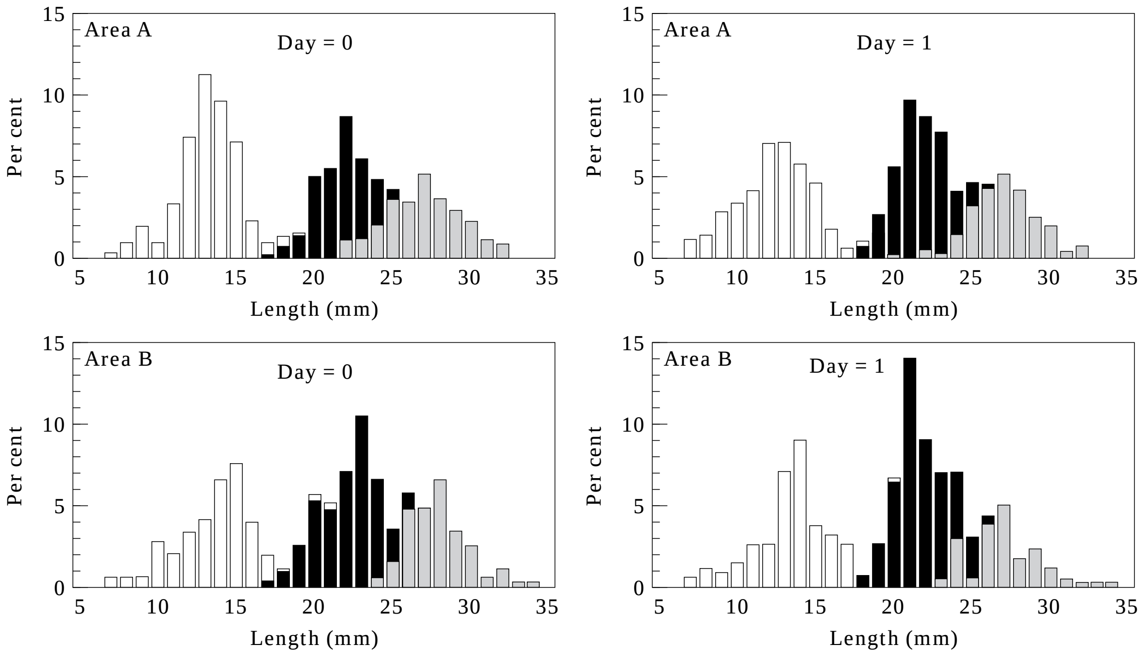

Figure 5. *C. edule*. Histograms of shell lengths by year class before (day=0) and after (day=1) dredging at areas A and B. Year class: ▨=1990+, ■=1991, □ 1992 year class.

Table 3. Shell growth: regression coefficients and their standard errors for effects of dredging (β_d), time in days (β_t), and time × time (β_{tt}) on lengths of cockles (*C. edule*) in mm by area and year class. Also shown are the coefficients of determination (R^2) for the models (which include block means, not tabulated. n.s.=not significant ($p>0.05$).

	Area A				Area B			
Year class	β_d	β_t	β_{tt}	R^2	β_d	β_t	β_{tt}	R^2
1990 and older	0.47 ± 0.15	0.0046 ± 0.0005	n.s.	0.81	n.s.	0.0055 ± 0.0010	n.s.	0.48
1991	n.s.	n.s.	0.00003 ± 0.000001	0.98	n.s.	n.s.	0.00003 ± 0.000002	0.93
1992	n.s.	− 0.0066 ± 0.0028	0.000087 ± 0.000007	0.99	n.s.	− 0.012 ± 0.0037	0.00011 ± 0.000009	0.98

approximately the same magnitude as those made from the quadrat counts, given above. A histogram of the size composition of cockles sampled from the catch, together with observed types of shell damage and their respective rates is given in Figure 6. The catch consisted almost entirely of the 1990+ age group.

Cockles damaged and rejected

Table 4 shows numbers and percentages of damaged cockles, aged if possible, found on the dredged plots on day 1. Most of the observed damage rates fell between 5 and 15% of the total of damaged plus undamaged individuals. Only a small proportion of cockles was so badly damaged that their age could not be determined. The estimated damage rates for all ages are probably below the true rates because some damaged cockle fragments would have lost the scraps of flesh which distinguished them from the ubiquitous, natural shell debris. Damaged cockles were found only rarely in other plots and at other times.

Histograms showing the size and age compositions of the measurable cockles rejected by the dredger are given in Figure 7. Although these were sampled after the main trial, comparison with the histogram for cockles taken during the trial (Fig. 6) indicates that the dredger accurately selected cockles of shell length greater than 25 to 26 mm.

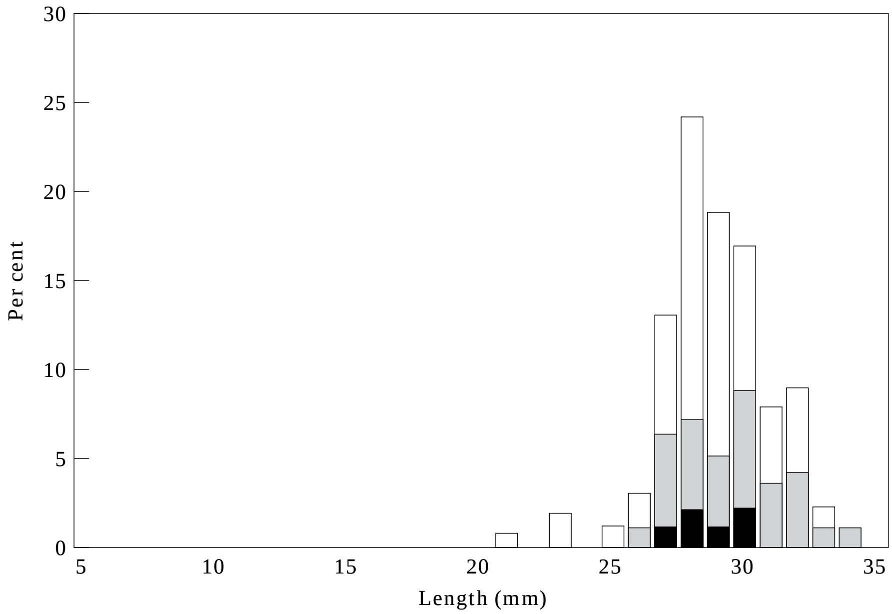

Figure 6. *C. edule*. Histograms of shell lengths in a sample taken from the catch of the tractor dredger during operations on area A. The incidence of shell damage at the beak, or elsewhere: □ = none, ▩ = chip, ■ = beak.

Dredging efficiency

The finding that cockles over about 25 mm length were efficiently removed by the dredger while mortality rates observed for that length group were well below 100% implied that the dredger did not succeed in dredging 100% of the areas of the treated plots. This conclusion was supported by graphic plots (not illustrated) of quadrat counts for the 1990+ year class against distance from the inside boundary of the dredged plots; high counts were more common towards the outer boundaries. Study of a video film of the dredging, and discussions with the driver, indicated that approximately 23 revolutions around the hexagons were made in each area before the outer boundary was reached, instead of the intended 28. This means that approximately 5/28ths (=18%) of each plot was not dredged.

Discussion

This study served to estimate the mortalities caused by a tractor dredger. Stocks of adult cockles (1990+) were cut by about 31 and 49% in low and high density areas respectively. Younger individuals were lost at somewhat lower rates, with the spat (1992) being slightly more vulnerable than the one-year-olds (1991). Losses depended upon the proportions of the experimental plots actually touched by the dredger's blade during the trial, estimated at about 82%. The driver could not easily abutt the tracks because rejected material tended to obscure the divisions between the dredged track and the wheel marks of the previous circuit. Usual commercial practice is to put tracks close to each other but without attempting to abutt them. Mortalities resulting per unit area would then be appreciably lower than were observed in our experiment.

Comparing the estimates of numbers in the catch, and numbers of the 1990+ age group lost from the plots immediately after dredging, it can be calculated that the catch accounted for 84% and 127% of the cockles lost from areas A and B respectively, given that the catch consisted almost exclusively of the 1990+ age group, as found in a sample. The divergences from 100% probably reflect variability arising from sampling both the catch and the plots. Adding the damaged cockles left on the plots after dredging (Table 4) to the numbers caught only marginally increases the percentages of lost cockles accounted for.

Losses of the two younger age groups from the dredged plots are harder to explain since they were scarcely represented in the catch, and did not show high damage rates (Table 4). One possibility is that rejected cockles were buried so deeply by the dredger that they were not found and raked up in the 5 cm deep quadrat samples. Our own experiences of emptying quadrats did not support this idea. Richardson *et al.* (1993) reported that *C. edule* can tolerate unstable sedimentary environments and actively emerges when smothered by 2 cm of sediment, particularly in darkness.

An alternative explanation is that rejected cockles were left on the surface or buried loosely, and then taken by predators such as birds, or washed away by the tide.

Table 4. Mean numbers by year class (if possible) of damaged cockles (*C. edule*) per 0.1 m^2 quadrat on dredged plots within the 6 blocks of areas A and B on Llanrhidian Sands on the day after dredging (day 1). The numbers damaged are also shown as percentages of (undamaged+damaged) individuals.

		Area A						Area B					
		Block 1	Block 2	Block 3	Block 4	Block 5	Block 6	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6
1990 and older	N damaged	1.2	0.5	1.3	1.4	1.3	1.1	0.1	0	0.1	0.2	0	0.3
	%	10	8	16	8	7	8	6	0	8	22	0	13
1991	N damaged	1.9	1.6	1.5	1.6	2.3	2.4	0.2	0.1	0	0.1	0.1	0.1
	%	9	7	8	5	7	11	7	3	0	5	4	4
1992	N damaged	4.0	5.0	5.5	2.9	2.8	1.9	0.2	0.1	0.2	0	0.2	0.1
	%	8	8	15	10	17	9	11	5	11	0	6	4
Unaged	N damaged	0.1	0.4	0	0	0	0.1	0	0	0	0	0	0
	%	0.1	0.5	0	0	0	0.2	0	0	0	0	0	0

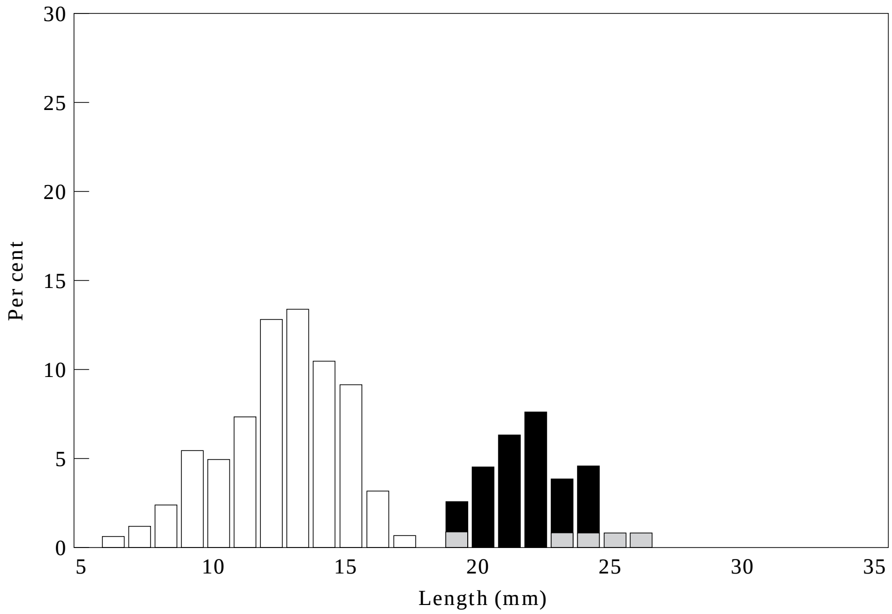

Figure 7. *C. edule*. Histograms of shell lengths in rejects from the dredger when operating just after the main trial on two sites near area A. Year class: □ = 1992, ■ = 1991, ▨ = 1990+.

A few unburied cockles of the 1991 and older groups were noticed lying on the beach on the day after dredging. Richardson *et al.* (1993) observed that cockles are well able to bury themselves following emergence and dispersal. Presumably, the individuals left on the surface were damaged by the dredger and so unable to rebury; many would have been removed by the tide. Young cockles with light shells are likely to have been most vulnerable to mechanical damage in the dredger's riddle. The counts of damaged individuals shown in Table 4 represented those that were found on the dredged plots after two tidal submersions, usually beneath the surface. Aerial exposure alone is seldom lethal to *C. edule* (Boyden, 1972).

It is reassuring to note that following the losses caused immediately by the dredger, subsequent losses attributable to dredging were not observed on the dredged plots relative to the control plots over the 373 days of the trial. However, the 1990+ age group showed a 53% decline in numbers on the control plots of area A, Figure 4(a). It is believed that no fishing took place on these plots after the dredging trial, so presumably this represents natural mortality over winter. Others have observed comparable mortality rates. Hancock and Urquhart (1965) reported annual mortalities of 43% for cockles of equivalent age (third winter and older). Walker (1993) reported 85% mortality in this age group over the rest of the Llanrhidian flats where hand gathering was taking place.

Mortality on the control plots of area A may have been density dependent since the adjacent, dredged plots which started the winter with low numbers did not show a proportionate drop in numbers (Fig. 4a). No effects of dredging on shell growth were observed, suggesting perhaps that density dependent mortality, if it occurred, did not result from limited food supplies. Possibly, density dependent predation by birds was important. There may also have been mixing of cockles between dredged plots and the adjacent control plots, but if so, numbers on the dredged plots would have increased, and numbers on the control plots declined to a common value, a result which was not observed. Hancock (1970, 1973) extensively discussed the complexity of density dependent factors in the mortality and growth of cockles in Burry Inlet, based on the results of stock surveys between 1958 and 1970. If density dependent mortality is general, the thinning of dense aggregations of adult cockles by mechanised harvesting may prove to be a sensible option for managers of the fishery, but this needs further investigation on a site specific basis before firm recommendations could be made.

The mortality rates estimated here, adjusted appropriately to take into account the percentage of the ground that was dredged, might usefully be applied in a study of cockle population dynamics in order to estimate the long term effects on stocks of harvesting by tractor dredging. Knowledge of the effects of dredging on the success of subsequent spatfall then becomes important. However, results for the 1993 year class were contradictory, area B apparently showing adverse effects, while area A was unaffected, or possibly, beneficially affected. One may speculate that dredging alters the substrate in a way that discourages spat settlement; alternatively, that reduced numbers of adults encourage settlement and growth by reducing competition for space and food, as discussed by Hancock (1970, 1973). The present results lend little weight to either idea. Major effects on spat success, had they occurred, almost certainly would have been found with the experimental design employed and the standard errors observed, but were not. However, the supply of spat would hardly have been affected by the experiments because the dredged areas were very small in relation to the extent of cockle populations in the Burry Inlet.

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