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17. Ecological Effects of Pump-scoop Dredging for Cockles on the Intertidal Benthic Community

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Awareness of the ecosystem effects of fishing activities on the marine environment means that there is a vital need to assess the direct and indirect effects of those activities that may have negative effects on target and non-target species. The Edible Cockle *Cerastoderma edule* is the target of an artisanal and commercial fishery that occurs in estuarine and intertidal habitats across northern Europe. Poole Harbour has opened up its cockle beds to pump-scoop dredging over the last few years. This study investigated the effect of pump-scoop dredging on the intertidal sedimentary environment and the macro-infaunal community. The results demonstrated that the dredging did not have an effect on the size distribution of sediment particles. After the fishery opened, no immediate impact of cockle dredging on the infaunal community was observed. Within 3 months, however, a reduction in species richness and abundance of the benthic community was noted. This may be indicative of a chronic rather than acute impact. However, further investigations are required to assess whether this was directly related to pump-scoop dredging. The findings of this study are discussed in relation to possible impacts on the ecosystem as a whole.

Introduction

One of the most pressing issues in coastal zone management is how to accommodate the wide range of uses and activities in the coastal margin such that the ecology of intertidal and nearshore marine habitats is protected (Kaiser *et al*., 2001; Hiddink, 2003). In particular, fisheries management needs to consider both environmental and political sensitivities in coastal habitats owing to the extractive nature of harvesting processes, disturbance to the habitat and potential conflicts between multiple users (Kaiser *et al*., 2001; Atkinson *et al*., 2003).

Harvesting of the Edible Cockle (*Cerastoderma edule*) has taken place in Britain at least since mediaeval times (Rostron, 1995). Traditionally, cockles have been harvested from intertidal sediments at low tide, using hand rakes and riddles, the latter used to separate out undersized individuals (Jenkins, 1991). More recently, harvesting has become mechanized with the use of hydraulic dredges (Hall *et al*., 1990). Due to its greater efficiency, a hydraulic dredge can remove a larger number of cockles from an area than several men raking for the same length of time (Pickett, 1973). Thus, a ground can be commercially ‘fished-out’ by dredges in a much shorter time and the cockle densities remaining are usually much less than those left after raking (Pickett, 1973).

Nearly all commercial concentrations of cockles occur on intertidal flats in lower reaches of estuaries. They live buried beneath the surface of fine and very fine sands and must be dislodged from sediments to be collected (Coffen-Smout, 1998). Consequently, all methods of gathering cockles inevitably involve mechanical disturbance of the habitat (Rees, 1996). This can have a variety of effects depending on the ambient community, area disturbed and fishing pressure, all of which vary among different fisheries and digging areas (Brown and Wilson, 1997). The main concerns regarding hydraulic dredging are that it might cause excessive stock depletion, impair future spatfall, and be damaging ecologically for both the benthos and birdlife (Broad, 1997; Cotter *et al*., 1997; Hall and Harding, 1998; Bradshaw *et al*., 2002). Consequently, harvesting may have an adverse effect on ecosystem functioning, leading to long-term changes in community structure (Gaspar *et al*., 2002; Hiddink, 2003).

Throughout north-west Europe, estuarine habitats are home to internationally important populations of shorebirds and are also of local economic importance, due to substantial stocks of commercially fished shellfish (Atkinson *et al*., 2003). Poole Harbour is no exception to this general rule. In its shallow waters, fishing activity is intense, including pump-scoop dredging for cockles (N. Richardson, pers. comm.). Pump-scoop dredging involves pumping seawater through a dredge to release the shellfish from the sediment before it is scooped up. In Poole Harbour, the cockle fishery is unlicensed and is, therefore, difficult to control (N. Richardson, pers. comm.). This has led to widespread concern about the impact that dredging may have on both the cockle stocks and other non-target species inhabiting the same habitat. The aim of this study was to assess the impact of pump-scoop dredging on the non-target intertidal macro-infauna.

Materials and methods

Two sites located within the Whitley Lake area of Poole Harbour were chosen for this study. Site A was to the east of Salterns Quay and Site B was situated east of the pier of the East Dorset Sailing Club based at Evening Hill, on Sandbanks Road. The substratum in the study area is mostly sandy mud with some patches of shingly ground close inshore. Both sites have a relatively flat and uniform topography. A constraint of the study was the lack of a suitable control site with the same environmental conditions but no cockle dredging. However, sampling did start before the cockle fishery opened and the work was conducted over the period of the year where the macro-faunal abundance and diversity would be expected to be highest (Souza and Gianuca, 1995; Tuya *et al*., 2001; Rueda and Salas, 2003).

At each site, samples were collected in April before the cockle fishery season opened, and then again in May, June and July during the season. Every month, samples were collected from five positions at each site. Each position was at least 25 m from the next, in a line approaching low water. To ensure that no area was resampled and that trampling effects of sampling were kept to a minimum, each month the sampling position was moved transversely along the shore, at least 2 m from the previous position.

To examine changes in sediment particle size composition that might occur due to the pump-scoop dredging, one core sample (measuring 100 mm x 100 mm x 100 mm) was collected each month from each sampling position. Before sieving, the samples were oven dried at 65 ºC. Once sieved, the degree of sorting, skewness and kurtosis (a measure of the peakedness of the distribution) were calculated. Changes in size distribution were analysed using Kruskal-Wallis tests (SPSS).

At each position, four sediment cores (measuring 200 mm x 200 mm x 100 mm depth) were collected at random for the infaunal survey. The cores were washed *in situ* over a 1 mm sieve. The residue was taken to the laboratory, where each sample was again washed over a 1 mm sieve and the remaining residue was preserved in 70% alcohol. The infauna was counted and identified to species level where possible. Species diversity was compared and contrasted using a variety of indices, including Margalef's Index (d), the Shannon Index (H') and Pielou's Evenness Index (J). These diversity indices were chosen as they are the most commonly used. Differences were tested statistically using analysis of variance (ANOVA) (SPSS). Prior to analysis, no significant differences were found between the individual quadrats for any single month and, therefore, these data were combined. In addition, the data were tested for homogeneity of variances using Levene's test. After ANOVA, Tukey HSD *post hoc* tests were conducted to assess where there were variations between months.

The infaunal data were also analysed using standard multivariate techniques with the package PRIMER (Plymouth Routines In Multivariate Ecological Research; Clarke, 1993). The Bray-Curtis similarity measure was used to calculate similarities among observations for cluster analysis and multidimensional scaling (MDS). Similarity percentages (SIMPER) were used to determine the characterizing taxa (i.e. accounted for 75% of the similarity) (Clarke, 1993). Variations in the abundance of these characterizing fauna were analysed using ANOVA (SPSS). No significant differences were found between the individual quadrats for any single month and, therefore, these data were combined for the remaining analyses. Prior to ANOVA, data were tested for homogeneity of variances using Levene's test. Heterogeneous data were square root transformed (Underwood, 1997). This, however, did not remove the heterogeneity. Underwood (1997) reported that for large balanced data sets, problems associated with violations of assumption of homogeneity and normality are unlikely to affect the F ratio. It was, therefore, decided to undertake the ANOVA using the non-transformed data, but with a more conservative probability of 0.01 (Underwood, 1997).

Results

Sediment results

The sediment from both sites was predominantly fine sand (Table 1). There was little change in the size distribution of the sediment on a monthly basis. No significant differences were observed for either site (Site A: K = 1.26, $P > 0.05$; Site B: K = 1.02, $P > 0.05$). In general, the sediment was found to be fine sorted and very leptokurtic (i.e. more peaks in the centre and tails of the size distribution relative to the normal distribution) (Table 1).

Community results

Prior to dredging, both sites exhibited a similar species richness (Site A: 17.2 ± 1.1; Site B: 17.0 ± 2.3) and total number of individuals (Site A: 412.8 ± 133.3; Site B: 439.6 ± 226.9). Three months after dredging began, species richness had declined (Site A: 12.6 ± 0.9; Site B: 14.8 ± 2.3) (Figure 1a). This reduction was found to be statistically significant (Table 2), with *post hoc* tests revealing significant differences between the July data and all other months. The reduction in the total number of individuals with the onset of dredging was more pronounced (Site A: 238.2 ± 84.6 per core; Site B: 216.8 ± 92.6 per core), declining by 42.3% at Site A and 50.6% at Site B (Figure 1b). This decline was found to be statistically significant (Table 2), with Tukey's test indicating April and July were significantly different.

Margalef's Index varied between the two sites. At site A, there was a general decline in the index whilst at Site B, there was an initial increase, followed by a decline (Figure 1c). These differences were found to be significant for both month and site (Table 2). *Post*

Table 1 Sediment analysis

	Site A (weight [g])				Site B (weight [g])			
	April	**May**	**June**	**July**	**April**	**May**	**June**	**July**
Modal grain size (mm)	0.212	0.212	0.212	0.212	0.212	0.212	0.212	0.212
Median grain size (mm)	0.168	0.512	0.552	0.516	0.151	0.278	0.156	0.123
Mean grain size (mm)	0.452	0.510	0.527	0.508	0.473	0.496	0.459	0.458
Sorting	0.462	0.453	0.451	0.465	0.486	0.448	0.464	0.478
Kurtosis	-2.254	-2.218	-2.259	-2.277	-2.393	-2.289	-2.252	-2.347
Skewness	0.253	0.185	0.154	0.186	0.199	0.167	0.269	0.234

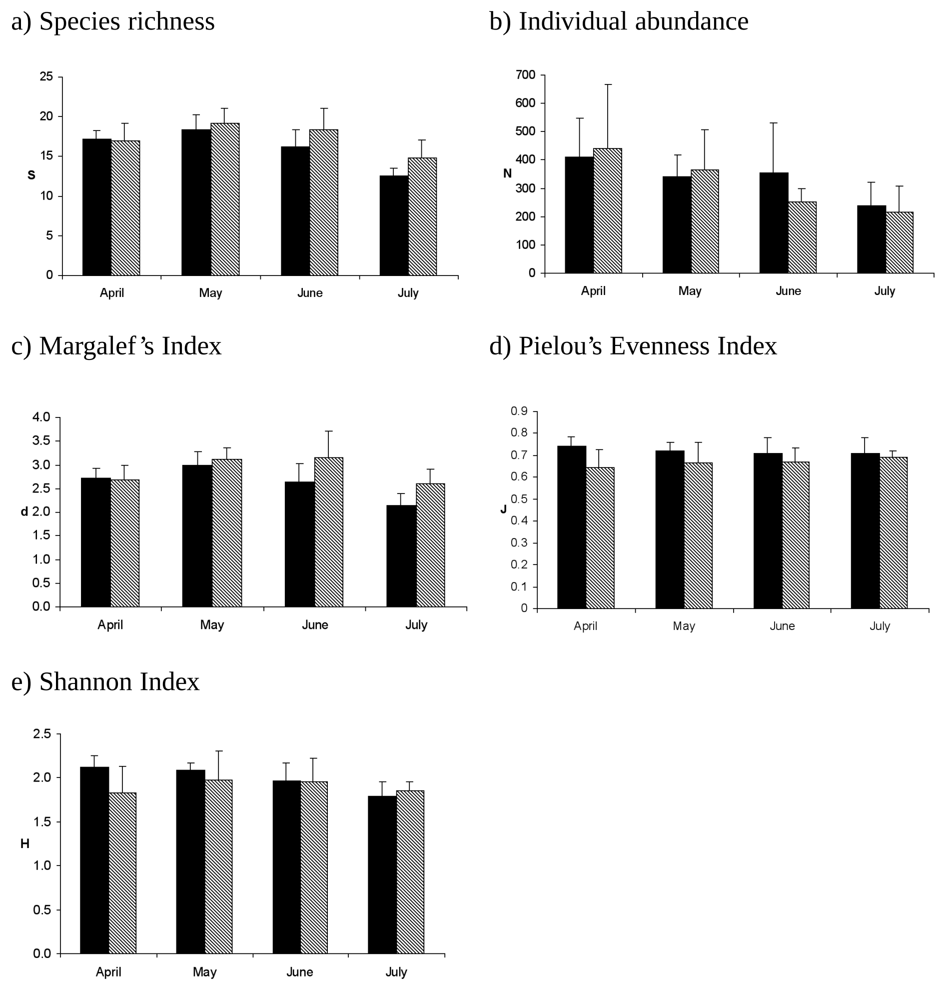

Figure 1 Changes in diversity as a response to cockle dredging (Site A: solid bars; Site B: striped bars).

hoc tests showed May and June to be significantly different from July. Little change was observed in Pielou's Evenness Index for Site A, whilst a slight increase was observed for Site B (Figure 1d). Statistical analysis showed significant differences between the two sites, but not between the different months (Table 2). Shannon's Index showed a general decline for both sites (Figure 1e), which was not found to be significant.

Table 2 Diversity ANOVA results

	Species richness		Total number of individuals	
	F	***P***	**F**	***P***
Site	4.006	ns	0.195	ns
Month	11.904	<0.001	3.863	<0.05
Site * Month	0.878	ns	0.495	ns

	Margalef's Index		Pielou's Evenness Index		Shannon Index	
	F	***P***	**F**	***P***	**F**	***P***
Site	6.236	<0.05	6.236	<0.05	1.682	ns
Month	8.057	<0.001	0.032	ns	1.687	ns
Site * Month	1.606	ns	0.727	ns	1.230	ns

ns – not significant at $P = 0.05$.

Cluster analysis of the abundance data identified the presence of four clusters or groups at a similarity level of 50% (Figure 2), which were also distinguished by multidimensional scaling. Group 1 consisted of all samples collected at Site B during April, May and June. Group 2 consisted of samples collected from Site A during April, May and June. Group 3 consisted of samples collected in July at Site A and Group 4 contained the Site B July samples.

Effects on individual species

SIMPER was used to identify the characterizing species at each site and for each month. The characterizing species at Site A, accounting for 80% of the similarity, were *Cingula trifasciata* (a gastropod mollusc), *Scoloplos armiger* (a polychaete worm), *Hydrobia* spp. (spire shells) and *Arenicola marina* (lugworm). At Site B, they were *S. armiger*, *A. marina*, *C. trifasciata*, *Corophium* spp. (an amphipod crustacean) and *Urothoe* spp. (an amphipod crustacean). The characterizing species for April, accounting for 80% of the similarity, were *S. armiger*, *Cingula trifasciata* and *Hydrobia* spp. May and June were similar to April, with the addition of *A. marina*. In July, *Urothoe* spp., *C. trifasciata*, *A. marina* and *Corophium* spp. were identified as characterizing species. Additional individual investigations were, therefore, conducted for: *S. armiger*, *Cingula trifasciata*, *A. marina*, *Hydrobia* spp., *Corophium* spp. and *Urothoe* spp.

The most obvious change in abundance throughout the duration of the sample collection was observed in *S. armiger*. Prior to dredging in April, both sites contained this species. However, with the onset and continuation of dredging, abundance decreased to zero in July at both sites (Figure 3a). Using a two-way ANOVA, these differences were found to be significant (Table 3), with Tukey’s HSD test identifying April as being significantly different from June and July.

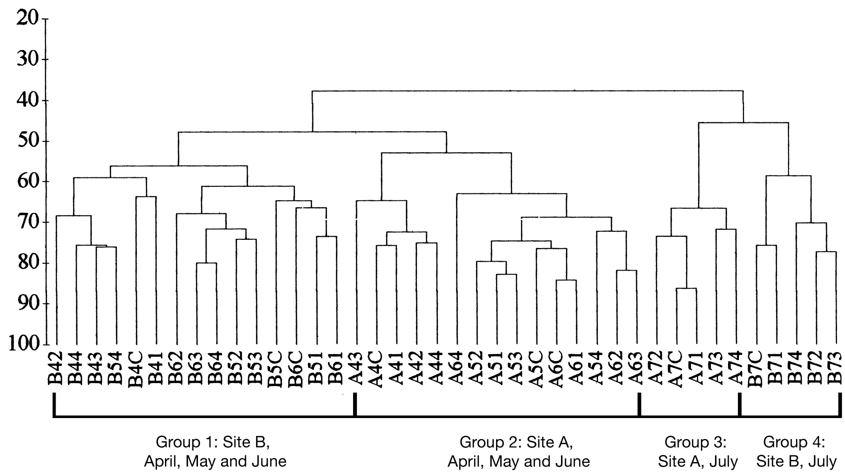

Figure 2 Cluster analysis results. Core coding: the letter refers to the site, the first number represents the month (4 – April, 5 – May, 6 – June, 7 – July) and the second, the sampling position.

Table 3 Species ANOVA results

	Scoloplos armiger		***Cingula trifasciata***		***Arenicola marina***	
	F	***P***	**F**	***P***	**F**	***P***
Site	15.184	<0.001	13.868	<0.001	6.755	<0.01
Month	57.919	<0.001	4.814	<0.01	4.144	<0.01
Site * Month	3.020	ns	3.674	ns	1.852	ns
	***Hydrobia* spp.**		***Corophium* spp.**		***Urothoe* spp.**	
	F	***P***	**F**	***P***	**F**	***P***
Site	77.201	<0.001	51.616	<0.001	58.349	<0.001
Month	5.553	<0.001	1.545	ns	33.540	<0.001
Site * Month	3.391	ns	1.520	ns	2.000	ns

ns – not significant at $P = 0.05$.

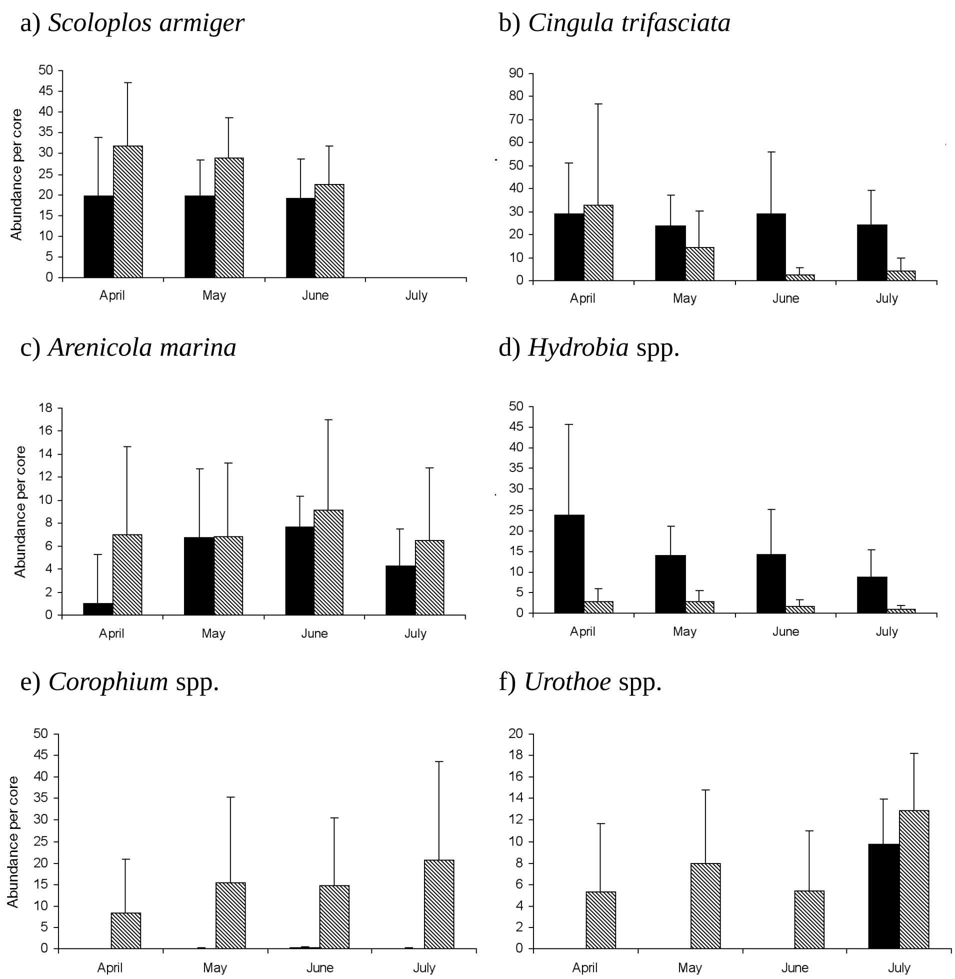

Figure 3 Variation in abundance of key species (Site A: solid bars; Site B: striped bars).

Cingula trifasciata showed relatively little change in abundance at Site A and a reduction at Site B (Figure 3b). These differences were found to be significant (Table 3). *Post hoc* tests indicated that July was significantly different from all other months. In contrast, the abundance of *Arenicola marina* at Site A showed a general increase, whilst at Site B numbers remained relatively constant (Figure 3c). ANOVA indicated that significant differences occurred between site and month (Table 3), with April and June being significantly different from one another.

Hydrobia spp. were more abundant at Site A than Site B, and showed a reduction in abundance at both sites with the onset of cockle dredging (Figure 3d). Significant differences were found between the sites and over the months (Table 3), with April and July being significantly different. In contrast to *Hydrobia* spp., *Corophium* spp. were more abundant at Site B, and were found to increase in abundance during the survey (Figure 3e). At Site A, this species was poorly represented and showed little variation in abundance (Figure 3e). Only site was found to be a significant factor for this species (Table 3). *Urothoe* spp. were also more abundant at Site B compared with Site A (Figure 3f). Increases in the abundance of this species were observed throughout the study period at both sites. This was particularly noticeable for Site A where the species was poorly represented in the first 3 months and showed a large increase in July, almost to the level of abundance observed at Site B (Figure 3f). These variations were found to be statistically significant (Table 3).

Discussion

Effects on the sediment composition

Fishing disturbance can have an indirect effect on benthic communities through the alteration of the substratum (Bradshaw *et al*., 2002). One of the immediate effects of bottom fishing is to suspend fine sediments into the water column, resulting in a coarsening and destablization of the sedimentary environment (Langton and Robinson, 1990; Messieh *et al*., 1991; Currie and Parry, 1996). However, Eleftheriou and Robertson (1992) observed rapid resettling of suspended material with little alteration of the sediment size distribution. In the current study, no significant effect on sediment particle size distribution was observed. However, although not investigated in the current study, the layering within the sediment was likely to be affected. This type of modification may lead to changes in the infaunal community through the alteration of elements of the physical environment such as water, oxygen and organic content.

An additional effect of pump-scoop dredging was its aesthetic impact, i.e. the significant scarring of sediment when the tide is out (Figure 4). The scarring effects, however, may only persist for a short period. The rate at which trenches and depressions that result from harvesting activities disappear depends on sediment bed-load transport, suspended sediment load in the water column, exposure to wave action and the harvesting techniques used (Kaiser *et al*., 2001). Hall *et al*. (1990) observed no detectable effect of suction dredging after 40 days and Hall and Harding (1998) found that trenches made by tractor dredges in the Solway Firth were no longer visible one day after harvesting. Surveys will be required after the close of the cockle fishery in Poole Harbour to assess how long the scarring marks persist.

Effects on the infaunal community

Margalef's and Pielou's indices detected changes in the infaunal community whilst the Shannon Index did not, despite some quite significant reductions in the abundance of individual species. Margalef's Index is a simple total species-abundance ratio, whilst the Shannon Index is based upon proportional abundance of the species. In contrast, Pielou's

Figure 4 Visual impact of pump-scoop dredging in Poole Harbour (source: Linda Parker).

Evenness Index examines the spread of individuals between species. It is a consequence of these differences that the variation in results at the community level was observed. Ghazanshahi *et al*. (1983) and Keough and Quinn (1991) both observed significant changes in abundance of individual species on rocky shores impacted by human activity, however, when the data were used to calculate the Shannon Index, no significant differences were observed. The Shannon Index is unduly influenced by dominant species (Kempton and Taylor, 1976; Pearson and Rosenberg, 1978; Magurran, 1988). In the current study, although the dominant species changed between months, the proportion of dominant species in the community remained relatively constant at approximately 35%, with the second most abundant species contributing approximately 15%. This consistency resulted in very little variation in the Shannon Index.

Messieh *et al*. (1991) and Hall and Harding (1998) reported 40–50% reductions in the abundance of individuals following trawling and tractor dredging activity, respectively. In addition, Hall *et al*. (1990), Brown and Wilson (1997), and Collie *et al*. (2000) also reported significant reductions in infaunal abundance and species composition as a response to suction and other dredging activity. In the current study, however, no significant differences were observed in the infaunal communities between April and May. This indicates that either fishing effort was initially low (scarring marks were, however, observed) or that there was no acute impact of pump-scoop dredging on the benthic community.

Significant differences in the infaunal community were, however, detected 3 months after the cockle fishery opened. By July, overall infaunal abundance had decreased by 42.3% at Site A and by 50.6% at Site B when compared with the closed season for cockle dredging. This change in the benthic community between June and July may be attributable to factors such as a sudden change in temperature, mortality following reproduction or disturbance from a source other than pump-scoop dredging (see below for further discussion). In addition, the reduction in infaunal abundance may be due to an increase in fishery effort. However, little evidence of this was observed in terms of scarring marks. Alternatively, these reductions may be indicative of a chronic effect of pump-scoop dredging. A single pump-scoop dredging event may not have a particularly significant impact on the benthic community. However, over time these disturbances are compounded and eventually the species present succumb to the effect of pump-scoop dredging.

Although these changes may be in response to pump-scoop dredging, it should be noted that other potentially disturbing activities occur at the study sites. These include hand raking for cockles and bait digging. The disturbance caused by hand raking is likely to be relatively similar to that of pump-scoop dredging, although on a much smaller scale. In recent years, bait digging in Poole Harbour has increased dramatically (N. Richardson, pers. comm). Elsewhere this activity has been found to have significant impact on the benthic community (McLusky *et al*., 1983; Heiligenberg, 1987; Wynberg and Branch, 1994, 1997). Within Poole Harbour, bait digging tends to be done by hand, which has been found to have less of an impact than mechanical harvesting (Heiligenberg, 1987). In addition, because bait digging is a year round activity in the harbour, its impacts are more likely to form a constant background to other disturbances. Further investigation will be required to verify that the disturbance effects observed in the current study were directly related to pump-scoop dredging.

Two processes are likely to play a part in returning the abundance of species in disturbed areas to pre-impact levels: migration by larval and adult infauna, and passive translocation resulting from wind and tide-induced sediment transport (Hall *et al*., 1990; Hall and Harding, 1998; Ferns *et al*., 2000). However, the recovery rate of the sediment habitat and its associated fauna is highly variable, depending upon sediment type, local environmental conditions and the type and frequency of harvesting process employed (Kaiser *et al*., 2001; Piersma *et al*., 2001). In the current study, it was not possible to examine recovery of the infauna. However, because the sediment is naturally mobile and there is a good local adult population in the surrounding area, it is likely that recovery will be fairly rapid.

One of the original concerns raised regarding pump-scoop dredging in Poole Harbour, was the potential impact on important bird populations, particularly through a reduction in infaunal prey species. Two species commonly cited as important prey are *Arenicola marina* and *Corophium* spp. (e.g. Ferns, 1992). The current research observed no obvious reduction in either of these species as a response to pump-scoop dredging. This suggests that the dredging may not have an obvious detrimental impact on the bird populations through impacts on the infaunal community. However, the noise associated with the dredging activity and the subsequent change to seabed topography may affect bird foraging and other activities.

Summary

Pump-scoop dredge harvesting of cockles does not have an acute impact on the infaunal community of Poole Harbour. However, there may be a chronic effect as the fishery season progresses, causing declines in the abundance of many non-target infaunal species during dredging. Due to the long-term nature of the fishery season, from May to the end of January, it was not possible to determine whether the benthic community recovers from this disturbance. However, since this is not a brand new fishery technique within the harbour, it is likely that recovery is fairly rapid and occurs before the next season begins. Therefore, the environmental impact of these dredging events in the shallow intertidal waters is unlikely to be a factor in their long-term environmental and biological condition. Conflicts with other fishery interests (e.g. bait digging and hand rakers for cockles) and issues related to the biology/ecology of target and non-target species, are elements that need to be addressed before the full impact of the pump-scoop dredging fishery can be assessed.

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