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The role of commercial digging of mudflats as an agent for change of infaunal intertidal populations

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Abstract

This study assessed the influence of commercial digging for worms and clams of a mudflat on the associated benthic infaunal community in Lowes Cove, Walpole, Maine, USA. Four replicate experimental sites were established within each of which were two 1 m^2 digging plots and one 1 m^2 undug, control plot. Digging was done with a four-tined hoe by thrusting the tines into the sediment surface and pulling the sediment towards the digger. Such digging was repeated until an entire plot was dug. Two digging intensities were analyzed: low frequency digging (plot was dug twice a month) and high frequency digging (plot was dug twice a week). By the end of the 2.5 month experiment, the density of polychaetes *Heteromastus filiformis* (Claparède), *Streblospio benedicti* (Webster and Benedict), and *Tharyx acutus* (Webster and Benedict) as well as the total number of taxa were significantly reduced in the plots that had been dug (regardless of frequency) relative to those of the control. Other densities (total number of individuals, *Scoloplos fragilis* (Verrill), *Exogone hebes* (Webster and Benedict), *Hydrobia totteni* (Morrison), total oligochaetes) were not affected by the digging. The lack of undug mudflats in Maine makes comparison of these results to benthic communities in undisturbed areas virtually impossible. © 1997 Elsevier Science B.V.

Keywords: Commercial digging; Disturbance; Baitworms; Clams; Soft-sediment community; *Heteromastus filiformis*; *Streblospio benedicti*; *Tharyx acutus*

1. Introduction

Mudflats are often sources of natural resources that are harvested for financial gain. Most often, harvesting of the fisheries involves turning over the sediments to obtain bivalve molluscs and sometimes polychaetous annelids. This disturbance could have a

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variety of effects depending on the ambient community, area disturbed, and fishing pressure, all of which vary among different fisheries and among digging areas.

Maine's mudflats are dug primarily for three species: soft-shelled clams *Mya arenaria* Linnaeus, sandworms *Nereis virens* Sars, and bloodworms *Glycera dibranchiata* Ehlers. Clams and baitworms are dug all year except when mudflats are covered with ice at low tide. Harvesting is highest during the summer. One is hard pressed to find a mudflat in Maine that is untouched by diggers. Even the small mudflat in Wiscasset, Maine set aside by Maine's Department of Marine Fisheries for research has been observed to have digging trails through it (B. Brown, pers. obs.).

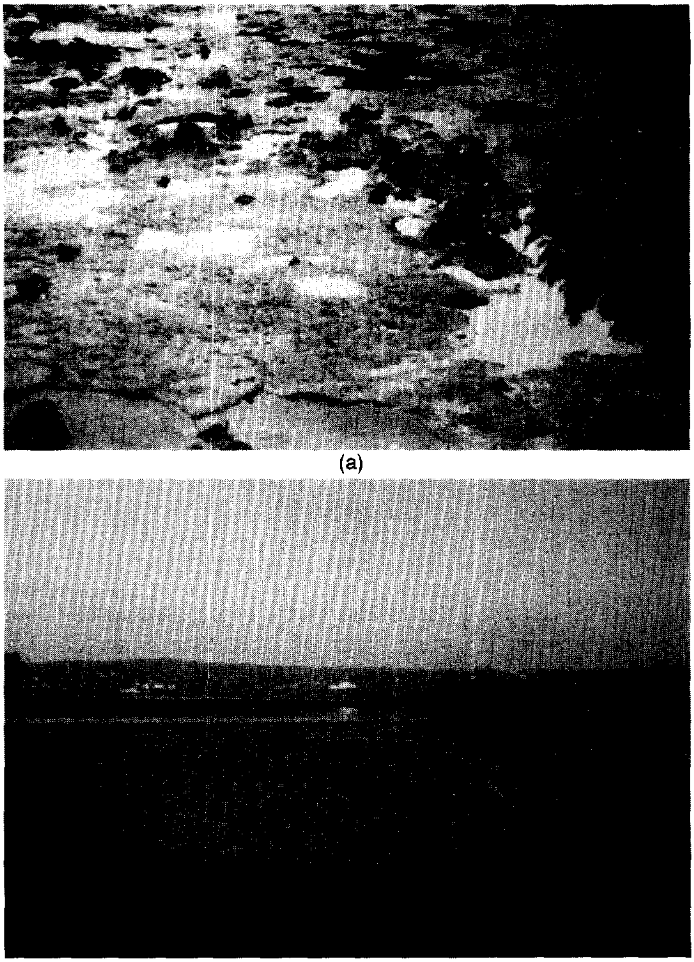
Both clam and baitworm diggers use a hoe with a short handle and four to six tines approximately 20–30 cm long (see Creaser et al., 1983; Brown, 1993). Clam diggers move about a mudflat from spot to spot where surface marks indicate the presence of clams and turn over the sediment with the hoe to unearth them. Because surface marks do not exist to indicate the presence of baitworms, worm diggers tend to dig in rows, collecting worms exposed when the sediments are displaced (Fig. 1a,b).

Even if some flats are closed to shellfish removal due to high bacterial densities or presence of red tide, Maine's mudflats are closed to diggers only on one day per week. In general, mudflats dug for baitworms are not dug for clams. During the digging season in Maine, good baitworm flats can be turned over several times by the diggers and clam flats can be turned over at least once (B. Brown, pers. obs.). Baitworm flats can look like agricultural farms from a distance because of the methodical and intense fishing pressure. Such large disturbances lead to the question of the influence of clam and worm digging of mudflats on the benthic infauna. Disturbance of soft-bottom communities has been shown to affect the community composition (Gordon and Desplanque, 1983; Dayton, 1984; Levin, 1984; Ambrose, 1993). This paper reports on analyses of a controlled experiment conducted in Lowes Cove, Damariscotta River, Maine, USA to assess the possible effect of two levels of digging frequency on benthic infauna. This study has application to areas where clams and baitworms are dug and has relevance to the sandworm and bloodworm fisheries in both the U.S. and Canada, which are positioned to expand with any increase in market demand (E. Creaser, Dept. of Marine Fisheries, W. Boothbay Harbor, ME, USA, pers. comm.).

2. Materials and methods

The study site for this investigation was located on the north side of Lowes Cove (Walpole, ME) (43°57′21″, 69°33′33″) which joins the Damariscotta River at its western end. This site was chosen because of its proximity to the Ira C. Darling Marine Laboratory of the University of Maine and because soft-shelled clam diggers in the Cove are known for respectfully avoiding the study sites of scientists working in the area. The site has been dug for many years for soft-shelled clams.

To study the influence of mudflat digging on intertidal infauna, four replicate sampling sites were established, each encompassing three digging treatments. The three treatments were as follows: no digging, low level digging (twice per month), and high level digging (twice per week). Frequency and intensity of commercial digging of clams



(a)

(b)

Fig. 1. Photographs of recently dug mudflats at low tide: a, Clam flat located in Lowe's Cove, Walpole, ME; b, Baitworm flat—Wiscasset, ME. Clam diggers leave irregular "potholes" on the surface of a mudflat whereas baitworm diggers leave distinct rows over the mudflat surface giving the appearance of an agricultural field.

and worms varies depending on factors such as locale, season, and species dug. Our digging rates are realistic compared to those of many mudflats in Maine. The sites were divided into five 1 m^2 plots and were located 5 m apart from each other at the same tidal height, 0.3 m above mean low water, along the shore. Within each site, the first, third, and fifth plot were used for the treatments, while the second and fourth were not sampled and served as buffers between plots. Each of the three treatments were conducted in each of the sites. A random numbers table was used to determine assignment of treatments among the first, third, and fifth plots. The low digging and high digging plots were dug using a hoe (four tines, each 20 cm long) was placed into the sediment to a depth of about 25 cm and pulled towards the digger, turning over a section of sediment (surface area dimensions of a single digging stroke were approximately 15 × 15 cm). Turns of the hoe were repeated until a 1 m^2 digging plot was entirely dug.

The experimental plots were sampled at the start of the experiment on 19 January 1993, one month later on 14 February 1993, and again on 6 April 1993. A core, 10 cm in diameter (sampling an area of 0.0081 m^2), was pushed into the sediment to 15 cm at a randomly chosen point in a plot, and the enclosed sediment was extracted and placed in buckets for processing in the laboratory. Samples were sieved through a 0.5 mm mesh screen and preserved in 10% formalin in seawater. Samples were transferred to 70% ethanol for sorting and identification. For dominant groups (grand mean of more than 5 per core), one-way ANOVA was used to compare differences in the treatment effects during different months, using a significance level of $P \leq 0.05$. All data were transformed with a log $(x + 1)$ transformation to homogenize the variances. If an ANOVA indicated significant differences, pair-wise post hoc contrasts were done using Fisher's protected least significant difference test.

3. Results

Most of the 26 taxa identified during the study were polychaetes (Table 1); several species were abundant enough (grand mean of more than 5 per core) to be used to compare patterns of response to the treatments. Grand means of 11.6 taxa per core and 148.3 individuals per core were determined. In January and February, no differences among treatments were found for any of the taxa analyzed statistically (Figs. 2–4).

In April, numbers of three species were reduced significantly in the low and high digging treatments compared to the undug treatment. For these April data, 54% and 66% fewer *Tharyx acutus* were found in the low and high treatments, respectively, than in the controls ($F_{2,11} = 7.24$, $P = 0.01$) (Fig. 2). Densities of the polychaete *Streblospio benedicti* were also significantly lower in April ($F_{2,11} = 5.61$, $P = 0.03$) when there were 77% and 75% fewer *S. benedicti* in the low and high treatments, respectively, than in the controls (Fig. 2). *Heteromastus filiformis* densities were significantly reduced in April ($F_{2,11} = 8.54$, $P = 0.01$) by 61% and 83% in the low and high treatments compared to the controls (Fig. 2). The total number of taxa found in April was significantly lower ($F_{2,11} = 6.65$, $P = 0.01$) in the low and high digging treatments than in the sites that were not dug (Fig. 3). The total number of taxa decreased by 37% and 23% in the low and high treatments, respectively, compared to the controls. For the preceding three species and total taxa, there was no difference between the two digging treatments in April.

For all months, there was no significant response among the treatments for the polychaetes *Exogone hebes* and *Scoloplos fragilis*, total oligochaete abundance, the gastropod *Hydrobia totteni*, and total number of individuals (Figs. 3 and 4).

4. Discussion

In soft-sediment systems, there are many types and scales of disturbance that often

Table 1
Species composition and densities for organisms identified from Lowes Cove, Damariscotta River, Walpole, ME, USA

Taxa				Densities (Grand Mean per Core)
Nemertea	–	–	–	0.43
Annelida	Oligochaeta	–	–	5.89
Annelida	Polychaeta	Capitellidae	*Capitella capitata*	0.11
Annelida	Polychaeta	Capitellidae	*Heteromastus filiformis*	16.06
Annelida	Polychaeta	Cirratulidae	*Tharyx acutus*	62.51
Annelida	Polychaeta	Glyceridae	*Glycera dibranchiata*	0.06
Annelida	Polychaeta	Maldanidae	*Clymenella torquata*	0.49
Annelida	Polychaeta	Nephtyidae	*Nephtys bucera*	0.06
Annelida	Polychaeta	Nephtyidae	*Nephtys discors*	0.11
Annelida	Polychaeta	Nephtyidae	*Nephtys longosetosa*	0.03
Annelida	Polychaeta	Nephtyidae	*Nephtys* sp. juvenile	0.40
Annelida	Polychaeta	Nereididae	*Nereis virens*	0.20
Annelida	Polychaeta	Orbiniidae	*Scoloplos fragilis*	14.31
Annelida	Polychaeta	Phyllodocidae	*Eteone longa*	2.97
Annelida	Polychaeta	Spionidae	*Polydora ligni*	0.14
Annelida	Polychaeta	Spionidae	*Polydora socialis*	0.57
Annelida	Polychaeta	Spionidae	*Polydora* sp.	0.03
Annelida	Polychaeta	Spionidae	*Spio filicornis*	1.03
Annelida	Polychaeta	Spionidae	*Streblospio benedicti*	10.51
Annelida	Polychaeta	Syllidae	*Exogone hebes*	8.57
Annelida	Polychaeta	Terebellidae	*Polycirrus* sp.	0.26
Mollusca	Gastropoda	Hydrobiidae	*Hydrobia totteni*	19.40
Mollusca	Bivalvia	Tellinidae	*Macoma balthica*	2.20
Mollusca	Bivalvia	Myidae	*Mya arenaria*	1.24
Arthropoda	Insecta	Chironomid larvae	–	0.03
Arthropoda	Amphipoda	Corophiidae	*Corophium volutator*	0.06
Hemichordata	Enteropneusta	Harrimaniidae	*Saccoglossus bromophenolosus*	0.23

intergrade (Dayton, 1984). Disturbances that have been analyzed include abiotic ones such as ice scour (Wilson, 1991a), wave action (Grant, 1981), hypoxia (Santos and Simon, 1980), temperature stress (Allee, 1923; Beukema, 1989), trawling (Currie and Parry, 1996; Kaiser and Spencer, 1996) and loading of organic materials (Pearson and Rosenberg, 1978; Dauer, 1984). Biotic disturbances such as bioturbation (Posey, 1986; Flach, 1992), subsurface disturbance by burrowers (Brenchley, 1981), surface disturbance by predators (Ambrose, 1984; Bell and Woodin, 1984; Botton, 1984; Reise, 1984; Smith and Brumsickle, 1989; Wilson, 1991b; Ambrose, 1993), and human manipulations (Jackson and James, 1979; Emerson, 1990) have also been demonstrated. The magnitude of disturbances can vary enormously. For instance, biotic disturbances range from large sections of the bottom being displaced during foraging and feeding of walrus *Odobenus rosmarus* (Oliver et al., 1983, 1985) and gray whales *Eschrichtius robustus* (Oliver et al., 1982; Oliver and Slattery, 1985) to smaller areas being disturbed by cockles *Cerastoderma edule* (Jensen, 1985) and dabs *Limanda limanda* (Hall et al., 1990).

Small, surface-dwelling polychaetes and other taxa appear to be sensitive to disturbance of sediment structure. The surface-dwelling polychaetes *Tharyx acutus* and

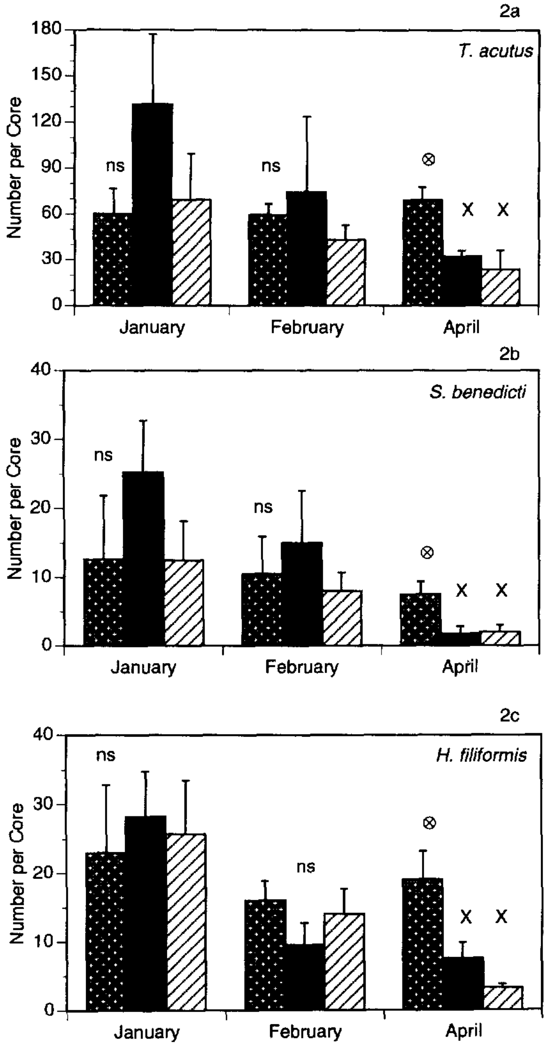


Fig. 2. Number per core in three treatments at each sampling period. Grey = no digging, black = low digging, diagonal = high digging. Error bars = standard error. a, *Tharyx acutus*; b, *Streblospio benedicti*; c, *Heteromastus filiformis*. In months where significant differences were found, symbols above the bars indicate where differences lie (Fisher's PLSD test); treatments sharing the same symbol are not statistically different, but differ from means with different symbols. ns = months in which treatments did not differ significantly.

Streblospio benedicti were reduced significantly by April, even at low frequency digging (Fig. 2). Several researchers have found similar decreases. Wilson (1981) demonstrated that the density of the small polychaete *Pygospio elegans* decreased in proximity to a small-scale sediment disturbance by the bioturbating lugworm *Abarenicola pacifica*. Bioturbation by the lugworm *Arenicola marina* caused reduction of densities of the

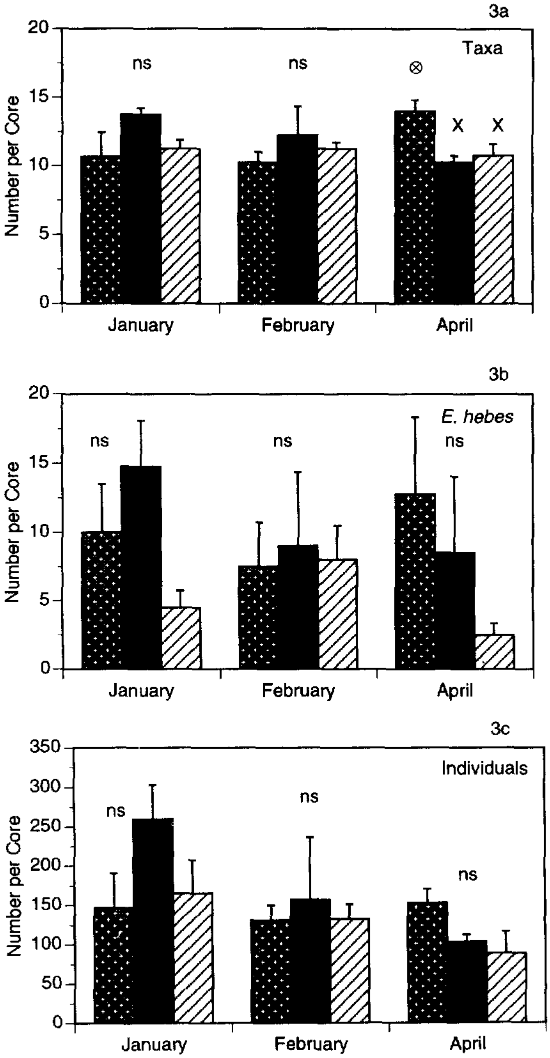


Fig. 3. Number per core in three treatments at each sampling period. Grey = no digging, black = low digging, diagonal = high digging. Error bars = standard error. a, Total Taxa; b, *Exogone hebes*; c, Total Individuals. In months where significant differences were found, symbols above the bars indicate where differences lie (Fisher's PLSD test); treatments sharing the same symbol are not statistically different, but differ from means with different symbols. ns = months in which treatments did not differ significantly.

amphipods *Corophium volutator* (Flach, 1992). Small, surface-dwelling, tube-building polychaetes *Rhynchospio arenincola* and tanaids *Leptochelia dubia* were similarly influenced by surface deposition of sediments (Brenchley, 1981). In the presence of the surface-foraging ophiuroids *Ophiura affinis* and *O. albida*, polychaetes inhabiting the top 3 cm of sediment were reduced 30% in abundance and surface-dwelling, deposit-

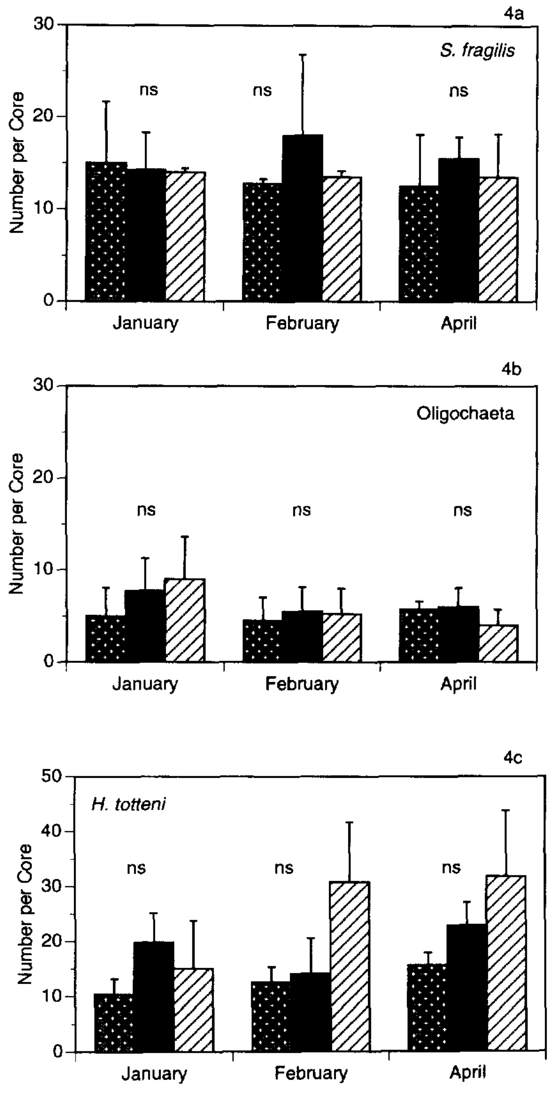


Fig. 4. Number per core in three treatments at each sampling period. Grey = no digging, black = low digging, diagonal = high digging. Error bars = standard error. a, *Scoloplos fragilis*; b, Total oligochaetes; c, *Hydrobia totteni*. In months where significant differences were found, symbols above the bars indicate where differences lie (Fisher's PLSD test); treatments sharing the same symbol are not statistically different, but differ from means with different symbols. ns = months in which treatments did not differ significantly.

feeding, sedentary infauna were reduced 40% (Ambrose, 1993). Similarly, the densities of surface-dwelling tube builders *Streblospio benedicti*, *Pseudopolydora kempi*, *Corophium acherusicum*, and *Leptochelia dubia* were reduced in the presence of the suspension-feeding burrowing shrimp *Upogebia pugettensis* (Posey et al., 1991).

That the benthic community structure was highly modified in this study is indicated by the significant reduction in the total number of taxa found in the plots (Fig. 3). Such changes in the bottom community have been observed with different types of disturbances as feeding and foraging by walrus and gray whales (Oliver et al., 1982, 1983, 1985), predation and surface sediment disturbance (Woodin, 1978; VanBlaricom, 1982), and bioturbation (Brenchley, 1981).

The density of the subsurface, deposit-feeding polychaete *Heteromastus filiformis* had decreased significantly by the end of this study in both digging treatments compared to the undug controls (Fig. 2). Posey et al. (1991) found that *H. filiformis* densities were higher in the presence of burrowing shrimp *Upogebia pugettensis* than in its absence. In this case, the mechanism by which *U. pugettensis* affected associated species was unknown and was speculated to be through its bioturbation activities and its burrowing activities. The bioturbation rates were low, especially compared to a confamilial species (*Callianassa californiensis*) (Posey et al., 1991), and the burrowing activities were probably not sufficient to expose the subsurface sediments in which *H. filiformis* lives to the oxygenated surface. Wilson (1991a) found that in an area where ice scour reduced the densities of surface deposit feeders, density of *H. filiformis* actually increased, an increase which Wilson presumed was due to rafting of sediment. Conversely, Flach (1992) observed that juvenile *H. filiformis* decreased in the presence of bioturbation by lugworms *Arenicola marina*. *H. filiformis* feeds by ingesting sediment from at least 15 cm below the sediment–water interface and appears to use both dissolved and particulate carbon sources within the anoxic and sulfur-rich sediments that are not used by other deposit-feeding organisms (Clough and Lopez, 1993). The present experiments exposed unoxygenated sediments of the Lowes Cove mudflat to the sediment surface. Thus, the reduction in density of *H. filiformis* in low and high digging treatments may have been due to exposure of the worms to the more oxygenated surface milieu, the inability of *H. filiformis* to burrow fast enough to re-establish after being brought to the surface, or direct mortality of the worms during digging.

Two taxa, total oligochaetes and *Scoloplos fragilis*, were not affected by the digging (Fig. 4). These taxa are both subsurface, burrowing deposit feeders which apparently were capable of withstanding the turnover of the sediment. Wilson (1981) found that total oligochaete abundance was unaffected by bioturbation of the lugworm *Abarenicola pacifica*. *S. fragilis* is a burrower capable of rapidly recolonizing a site through migration of adults, presumably through the water column (Brown, 1982). Van den Heiligenberg (1987) observed that a related species *Scoloplos armiger* recruited to areas that had been dug for collection of lugworms *Arenicola marina*.

For *Exogone hebes*, *Hydrobia totteni* and total number of individuals, the variance was unexpectedly high and no difference in treatments was found (Figs. 3 and 4). Additional replicates would have increased the power of the analyses to allow detection of significant differences. The power of any ANOVA with four replicates to detect significant differences of small or medium effect (see Cohen, 1988) is low. Therefore, our failure to accept the alternative hypothesis should not be taken as acceptance of the null hypothesis for these two cases. Rather, we consider the results of the ANOVA inconclusive. Greater replication might well have allowed us to reject the null hypothesis ($P < 0.05$).

Other authors have examined the effect of digging disturbance on benthic infauna (Jackson and James, 1979; McClusky et al., 1983; Howell, 1985; Cryer et al., 1987; Van den Heiligenberg, 1987; Olive et al., 1993), but none of these studies is directly comparable to the one described herein. All but Jackson and James (1979) failed to conduct controlled experiments. Jackson and James (1979) experimentally examined the influence of baitworm (*Arenicola marina*) digging on cockle densities over a 13 day period. However, a single area was experimentally dug. Multiple samples of the experimental and control area were taken but treated as independent replicates; hence, the design is pseudoreplicated (Hurlbert, 1984), precluding valid statistical tests of experimental effects.

The most comparable published study is that of Van den Heiligenberg (1987) who followed recolonization of dug areas in the Danish Wadden Sea. He examined two areas dug by machines and one dug by hand. Control sites were nearby areas that did not appear disturbed. This sampling design suffers from a problem of pseudoreplication that the present study does not. Further, Van den Heiligenberg (1987) used a 1.0 mm mesh screen to sieve his animals from the sediment and many of the smaller species were likely lost through the large mesh. In the research reported herein, a 0.5 mm mesh screen was used which provides a more thorough analysis by sampling a broader spectrum of the benthic infauna (e.g., more individuals, more of the smaller species).

These experiments were conducted in the winter to avoid possible confounding influences of recruitment. Settling larvae of diverse taxa are known to be influenced by the presence of small-scale disturbances with their associated changes in the chemical milieu (Woodin, 1991; Woodin et al., 1993). Preferential recruitment into undisturbed areas might result in increases in control areas that are indirect effects of the experimental digging manipulations. Performing the experiments in the winter minimizes these potential artifacts as most of the infaunal populations in Lowes Cove reproduce in the spring and summer.

The results of these small-scale experiments indicate that commercial digging can have a negative impact on several infaunal species. The effect is not immediate as the lack of differences in February suggests that the disturbance results in a cumulative impact which takes more than one month to establish statistically differences in the taxa measured.

We did not attempt to distinguish emigration from mortality in these experiments. It is possible that individuals displaced by the digging may have entered the water column and dispersed laterally out of the experimental area. Experiments performed at different scales would lend insight into the relative importance of mortality and emigration in explaining the reduced number of *Tharyx acutus*, *Streblospio benedicti* and *Heteromastus filiformis* (see Wilson, 1994).

Other consequences of clam and baitworm digging on mudflats have yet to be addressed. For example, it would be of value to know if food resources for demersal fishes are reduced, if changes occur in transfer of organic material between sediment layers and between sediments and the overlying water column, or if benthic productivity is reduced or enhanced. It would be of interest to have been able to conduct this experiment on a mudflat that had not been dug. No such flats have been identified to date.

These data indicate that even low intensity digging affects benthic community structure in a short period of time. These results have implications for those initiatives involved with establishing baselines for natural mudflat ecosystems and with identifying areas of concern for preservation of natural biodiversity. Because digging occurs on so many mudflats in Maine, we have no idea what the composition of a natural mudflat community in Maine undisturbed by human activity really is. Natural disturbances occur and, from the literature, we can expect that natural disturbances that overturn sediments (e.g., storms, ice scour) have many similar effects to that of digging. However, baitworm and clam digging can penetrate quite deeply into the sediments and, thus, probably have a greater effect than most natural disturbances.

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