Impacts of Flounder Trawls on the Intertidal Habitat and Community of the Minas Basin, Bay of Fundy

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Four experimental trawls were made at highwater over the intertidal zone of the Minas Basin and the effects assessed when the tide was out to determine the physical and biological impacts of groundfish trawling on the benthos. The trawl doors made furrows 30–85 cm wide and up to 5 cm deep. The rollers compressed surficial sediments but did not scour a depression. The bridle caused no obvious disturbance. Door furrows and roller marks remained visible for 2–7 mo. No significant impacts were observed on either benthic diatoms or macrobenthos. The macrobenthos was dominated by polychaetes, some of which may have the ability to take evasive action as a trawl approaches. There were few molluscs, crustaceans, or echinoderms present; these taxa have been shown to be more susceptible to trawling damage in studies done elsewhere. Nematode numbers were initially depressed in the door furrows but did recover with time. It is not known whether nematodes were killed or displaced but the latter is thought more likely. Overall, the impacts in this particular environment are judged to be minor, especially since the intertidal sediments of the Minas Basin are already exposed to similar natural stresses imposed by storms and winter ice.

Nous avons effectué quatre traits de chalut expérimentaux à marée haute au-dessus de la zone intertidale du bassin des Mines, et nous en avons évalué les effets à marée basse pour déterminer les impacts physiques et biologiques sur le benthos du chalutage du poisson de fond. Les panneaux du chalut ont creusé des sillons de 30–85 cm de largeur et d'une profondeur allant jusqu'à 5 cm. Les rouleaux comprimaient les sédiments superficiels mais n'ont pas creusé de dépression. Les bras ne semblent pas avoir causé de perturbation. Les sillons creusés par les panneaux et les marques des rouleaux sont restés visibles pendant 2 à 7 mo. Nous n'avons observé aucun impact notable sur les diatomées benthiques ni sur le macrobenthos. Ce dernier était dominé par les polychètes, dont certains peuvent avoir la possibilité de s'éloigner quand le chalut approche. Il y avait peu de mollusques, de crustacés ou d'échinodermes sur place; on a montré dans des études réalisées ailleurs que ces taxons sont plus vulnérables aux dommages causés par le chalutage. L'effectif des nématodes a été réduit au départ dans les sillons des panneaux, mais s'est rétabli avec le temps. On ne sait pas si les nématodes ont été tués ou déplacés, mais il est plus vraisemblable qu'ils ont été déplacés. En gros, les impacts sur ce milieu particulier sont jugés peu importants, d'autant plus que les sédiments intertidaux du bassin des Mines sont déjà exposés à des stress naturels similaires imposés par les tempêtes et par les glaces d'hiver.

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For centuries, fishermen have used various kind of trawls, rakes, and dredges to capture bottom-dwelling finfish and shellfish. It has long been recognized that such mobile fishing gear may affect benthic habitat and communities, but few quantitative studies have been done to determine the kind and scale of potential impacts. This issue has been of concern in Canada since at least the mid-1940s (Ketchen 1947). It has been suggested that the species composition and production rate of benthic communities may be altered in heavily trawled areas. Recently, investigations with different types of mobile gear have been conducted in both European (e.g., de Groot 1984; Krost et al. 1990; Rumohr and Krost 1991; Bergman and Hup 1992) and North American (e.g., Caddy 1973; Peterson et al. 1987; Langton and Robinson 1990) waters. Reviews of the issue have recently been prepared by Messieh et al. (1991) and Jones (1992). It is clear from the limited amount of research conducted so far that mobile gear can change the physical properties of surficial sediments, influence chemical exchanges between sediments and water, and alter the composition of benthic communities. These impacts must be understood and addressed by both habitat and fisheries managers to ensure the long-term sustainability of commercial fisheries and the habitats supporting them.

In 1990, the Department of Fisheries and Oceans began a new research program to investigate the potential environmental impacts of mobile fishing gear in marine benthic habitats in eastern Canada. An initial field project was conducted in the Minas Basin of the Bay of Fundy, in collaboration with the Acadia Centre for Estuarine Research at

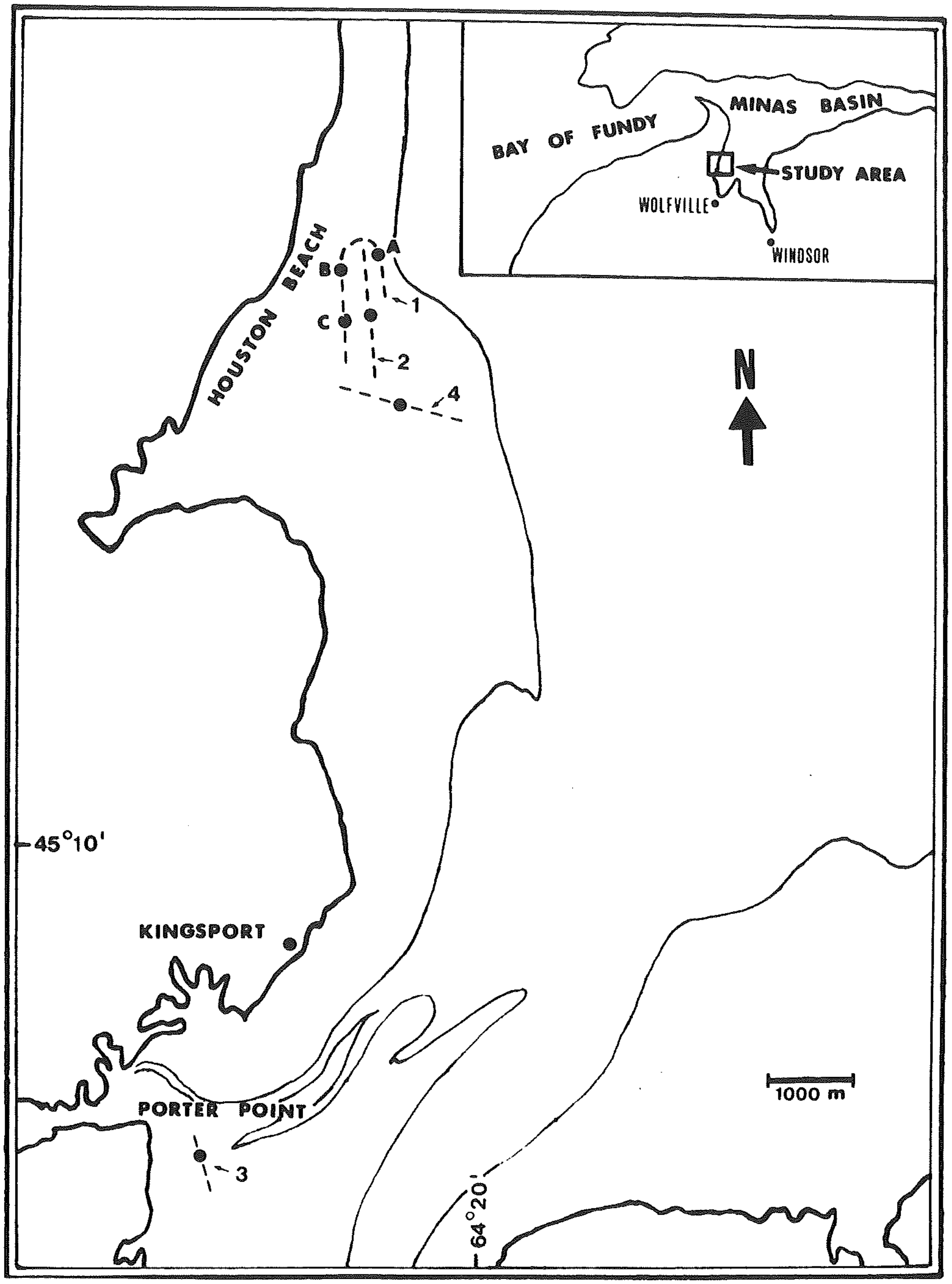

FIG. 1. Map of the study region showing location of experimental trawls (broken lines) and sampling stations (solid circles). Numbers refer to experiments.

Acadia University. The Minas Basin currently supports about six small draggers (12–13 m) which fish for winter flounder (*Pleuronectes americanus*). In the late spring and early summer, as many as 15 additional draggers come into the Basin from other areas and fish for periods of up to 2 mo. Much of the flounder trawling is done over the intertidal zone near the time of high water leaving trawl marks that are clearly visible when the intertidal flats are exposed (see Fig. 2).

The objectives of the project were to evaluate the initial extent of physical and biological disturbance caused by flounder dragging activities in the intertidal and to document the recovery processes over time. The Minas Basin was selected for this study because its macrotidal character affords a unique sampling opportunity; experimental trawls could be made over the intertidal region at high water, and detailed information on the impacts could be easily and inexpensively obtained when the trawl tracks were exposed.

Description of the Study Area

The Minas Basin is a macrotidal estuary in the upper reaches of the Bay of Fundy, Nova Scotia, Canada (Fig. 1). Tidal range averages about 11 m but can reach 16 cm on exceptional spring tides. Tidal current velocities frequently exceed 1 m/s. The extensive intertidal zone, often several kilometres wide, is characterized by saltmarshes and mudflats in protected areas and by sandflats and sandbars in the more

TABLE 1. Details of trawling impact experiments. Initial date indicates the day that experimental trawling was conducted. Gear was towed at approximately 1 m/s following usual fishing procedures.

Experiment	Gear	Duration
1 (Houston Beach)	18-m trawl and 180-kg Westpick wooden doors	22 Oct. – 18 Dec. 1990
2 (Houston Beach)	18-m trawl and 180-kg Westpick wooden doors	28 May – 15 July 1991
3 (Porter Point)	18-m trawl and No. $2^1/_2$ (200-kg) metal Bison doors	29 May – 2 Oct. 1991
4 (Houston Beach)	24-m trawl and No. 6 (270-kg) metal Bison doors	16 June – 3 Oct. 1991

exposed locations. The general environmental setting is described in more detail in Bleakney (1972).

Experimental studies were conducted at two areas within the midintertidal zone along the western shoreline of the Basin: off Houston Beach and Porter Point (Fig. 1). The site off Houston Beach was characterized by relatively coarse sand overlain by a silty layer which varied in thickness from one to several centimetres. The site off Porter Point had siltier sediment which was relatively uniform to a depth of at least 10 cm. At both sites the intertidal area is about 1.5 km wide and the midintertidal zone is exposed for 2–4 h each low tide (every 12.5 h).

Methods

Trawling

Four separate trawling experiments were conducted at high water. Trawls were made roughly parallel to the shoreline (Fig. 1) at water depths of 6–8 m using procedures normally employed during fishing operations (speed about 1 m/s). Two types of flounder trawls and three types of doors were used (Table 1). The footline of all trawls was equipped with spherical, 29-cm-diameter, 4-6-kg rubber rollers (12 on the 18-m trawl and 16 on the 24-m trawl). None of the trawls was equipped with tickler chains. As soon as the tide receded, the fresh trawl tracks were examined and sampling stations established at representative locations.

Physical Disturbance

Qualitative assessments of the initial physical disturbance to surficial sediments as well as the rate of recovery over time were made by eye. Numerous photographs were also taken during all experiments, both from the ground and from a helicopter at an altitude of about 150 m. Quantitative information was obtained using a 150-cm-long aluminum metering bar which was set horizontally on two reference stakes across the door track. The distance from the bar to the sediment surface was measured at 5-cm intervals across the track on each sampling date. During Experiment 1, the metering bar was left in position between sampling dates and this resulted in considerable erosion within the area immediately under the bar. Hence, it was not possible to quantitatively document the physical recovery of the door furrow. During later experiments, the bar was placed in position only when measurements were being made. Measurements of the distance between doors and the area impacted by the net and footline rollers were also made.

Biological Effects

Samples for chlorophyll *a* analysis, an estimate of benthic diatom abundance, were collected with a 1.2-cm-diameter syringe which was modified to sample the upper 5 mm of sediment. Samples were stored frozen in scintillation vials until analysis. Chlorophyll was extracted by adding 5 mL of 90% acetone to the vial, shaking vigorously by hand, and allowing extraction to proceed for 24 h in the dark under refrigeration. The supernatant was then transferred to a 1-cm-pathlength cuvette and measurements of absorbance made at wavelengths of 664 mm for chlorophyll and 750 nm for turbidity before and after acidification with 0.1 mL of 10% Hcl. Chlorophyll *a* concentration was calculated according to Lorenzen (1967). The sediment weight of each sample was determined after oven drying at 70°C for 24 h.

Meiofaunal samples, which consisted almost exclusively of nematodes (>99%), were collected using a 2.6-cm-diameter syringe modified to sample the top 2 cm of sediment. Samples were transferred to vials and preserved in 10% formalin. Prior to enumeration, samples were diluted, stained and homogenized by transferring each sample to a beaker containing 75 mL of filtered seawater containing rose bengal. Numbers were determined by subsampling the mixture while it was slowly stirred, transferring the subsample (0.5–2.0 mL depending on turbidity) to a petri dish, and counting under a binocular microscope. Subsampling continued until further analysis produced little change in the mean number of nematodes per sample. In most cases, five subsamples proved adequate.

Samples for benthic macrofauna were collected with a 10-cm-diameter metal core that was inserted into the sediment to a depth of 10 cm. Samples were gently sieved in the field through a 850-μm-mesh screen, preserved in 70% alcohol, and later sorted and enumerated by species.

The number, kind, and frequency of samples collected varied with the experiment. During Experiment 1 (Houston Beach), sampling was conducted at three stations along the trawl track (Fig. 1). At each station, three locations were sampled in triplicate: within the furrow created by the door, within the area compacted by the rollers, and within an undisturbed area immediately outside the track (i.e., control). Sampling interval ranged between 2 and 9 d. Meiofaunal samples were not collected. During Experiments 2–4 (Houston Beach and Porter Point), one sampling station was established along each trawl track (Fig. 1). Replicate samples (three for macrofauna, three for meiofauna, six for chlorophyll) were collected from within the door furrow and from an adjacent control area on each sampling date. The area compacted by the rollers was not sampled. The sampling interval varied according to the rate of physical recovery and differences in biological variables between door furrow and control samples. It averaged about 1 wk during the first few months and declined to about 3 wk thereafter.

All samples at a given location were taken in close proximity to minimize large-scale differences in sediment characteristics and biology. Areas disturbed by previous sampling were avoided.

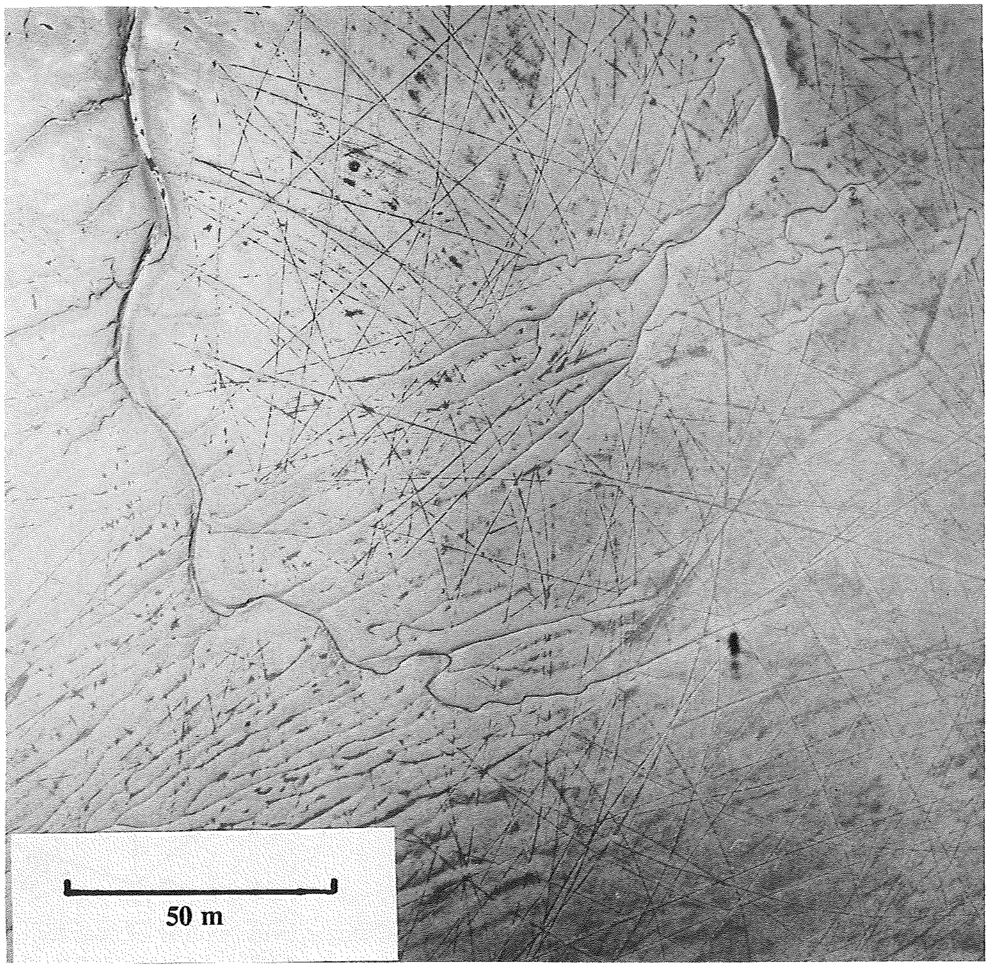

FIG. 2. Aerial photograph of trawl marks resulting from normal fishing activity off Porter Point taken in June 1991 from an altitude of approximately 150 m. (Courtesy of BIO Photo Laboratory).

Statistical Analysis

For each parameter, differences between treatments (control, roller, and door for Experiment 1 and control and door for Experiments 2–4) were investigated using analysis of variance (ANOVA). Bonferroni-adjusted probabilities (Neter and Wasseman 1974) were used in multiple comparisons of treatment effects. All data were log $(x + 1)$ transformed before analysis. Bartlett's test (Winer 1971) was used to test for homogeneity of variances of the transformed data.

Results

Physical Disturbance

Initial

The flounder trawls produced two kinds of physical disturbance. Most visible were the two parallel furrows made by the doors which keep the net spread open during towing. The door passes over the bottom at an angle, the front of the door being outward of the tail end, and tends to move sediments toward the inside of the trawl track. The furrows were about 23 m apart with the 18-m trawl used in Experiments 1–3. Less pronounced marks, about 10 cm wide, were made by each of the rollers on the trawl's footline. The bridle left no visible mark. About 12% of the total seafloor area between the outer edges of the doors was visibly disturbed.

Aerial photographs taken during June 1991 indicate that considerable commercial trawling activity took place off Porter Point in the spring of 1991 (Fig. 2). A 100 × 100 m area in the most heavily disturbed area was crossed by approximately 12 trawls. Since each trawl disturbs an area approximately 3 m wide (two doors plus the rollers), 12 trawls would disturb on the order of one third the sediment surface. The amount of disturbance could be expected to be greater by the end of the summer, since commercial trawling often continues until early August. Examination of aerial photographs also indicated that in some instances, door furrows never filled in and became incorporated into the natural drainage system.

The extent of the initial physical disturbance varied widely (Fig. 3 and 4). In Experiment 1 (Houston Beach), both the door furrow and roller marks were clearly visible immediately after the trawl was conducted. The door scoured a furrow about 85 cm wide and 2–4 cm deep (Fig. 3), while the roller marks appeared to be caused more by compression than scouring. The initial physical disturbance in Experiment 2 (Houston Beach) was much less, even though the same gear was used. Sediment appeared to have been compressed to a depth of 1–2 cm over a width of 50–80 cm by the doors

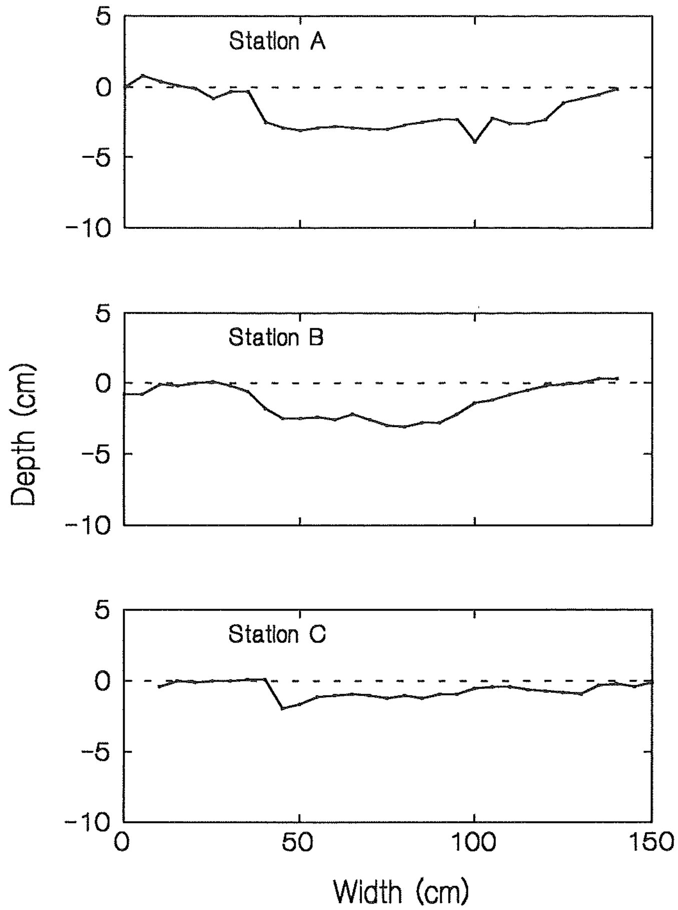

FIG. 3. Profiles of door furrows on day 1 in Experiment 1 (Houston Beach) (outside of trawl track on right).

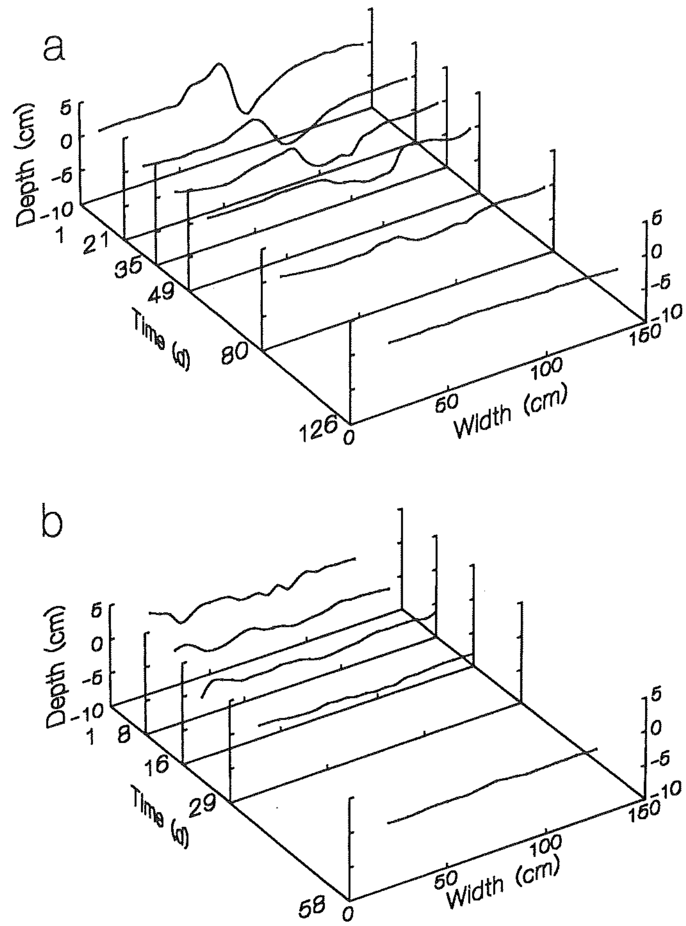

FIG. 4. Changes in the profiles of door furrows with time (outside of trawl track on right) in (a) Experiment 3 (Porter Point) and (b) Experiment 4 (Houston Beach).

but there was little evidence of actual scouring, and the roller marks were not discernible. The third experiment at Houston Beach (Experiment 4), using larger and heavier gear, created an intermediate level of initial disturbance. The doors left a furrow about 80 cm wide which varied in depth to a maximum of about 2 cm (Fig. 4a). At Porter Point (Experiment 3) the doors created a furrow about 30 cm wide and 5 cm deep and deposited the displaced sediment as a mound about 5 cm high and 30 cm wide along the inside edge of the furrow (Fig. 4a). Although the total width of sediment surface disturbed was less than at the Houston Beach experiments, the amount of disturbance appeared greater as a result of deeper penetration by the doors over a wider portion of the door furrow. Roller marks were clearly visible and, as at Houston Beach, seemed to be the result of sediment compression rather than scouring.

Recovery

Physical recovery during Experiment 1 (Houston Beach) was slow despite numerous periods of strong wind and wave activity. For example, a week after the experiment started, a storm removed the upper 1–2 cm layer of silty sediment and created bedforms in the exposed sandy sediments. While some degradation had taken place, both the furrows made by the doors and the roller marks were clearly visible from the air after 47 d and from the ground after 57 d (the last day of sampling). In June 1991, 7 mo later, portions of the door furrows could still be observed from the air. Despite minimal initial disturbance, the trawl tracks in Experiment 2 (Houston Beach) remained clearly visible for about 40 d. They began to degrade thereafter and could no longer be seen from the ground after 130 d.

The rate of recovery in Experiments 3 and 4 was determined quantitatively using the metering bar. Recovery in Experiment 3 (Porter Point) took over 80 d (Fig. 4a). After 49 d, the furrow created by the door was half filled in and the mound beside the furrow had disappeared. After 126 d, the furrow was completely filled in, but was still visible from the ground. The most rapid recovery occurred during Experiment 4 (Houston Beach) (Fig. 4b). After just 16 d, the door track was less than 1 cm deep and it was no longer visible after 58 d.

Collectively, these data clearly indicate that the physical disturbance caused by flounder trawls in the Minas Basin intertidal sediments can persist for at least 2–7 mo.

Biological Effects

Nature of the biological community

The dominant groups of marine organisms present at both study sites are benthic diatoms, nematodes, and polychaete worms. With the exception of low densities (<2 m^2) of the mud snail (*Ilyanassa obsoleta*), epibenthic macrofauna were absent. No large invertebrates were collected in the experimental trawls. Benthic diatom abundance, as estimated by chlorophyll *a*, and nematode abundance were about twice as great at Porter Point compared with Houston Beach which

TABLE 2. Macrofauna present at study sites (in order of decreasing abundance).

Houston Beach (1991), Experiment 1	Houston Beach (1992), Experiment 2	Porter Point (1992), Experiment 3	Houston Beach (1992), Experiment 4
Clymenella torquata	*Clymenella torquata*	*Heteromastus filiformis*	*Clymenella torquata*
Glycera dibranchiata	*Spiophanes bombyx*	*Corophium volutator*	*Spiophanes bombyx*
Phyllodoce mucosa	*Nephytys caeca*	*Streblosoma benedicti*	*Nephytys caeca*
Crangon septemspinosa	*Phyllodoce mucosa*	*Spiophanes bombyx*	*Phyllodoce mucosa*
Nereis diversicolor	*Pygospio elegans*	*Cerebratulus lacteus*	*Heteromastus filiformis*
Odostomia bisuturalis	*Nereis diversicolor*	*Tharyx acutus*	*Crangon septemspinosa*
Chiridotea ceoca	*Heteromastus filiformis*	*Eteone heteropoda*	*Eteone trilineata*
Idotea phosphorea	*Streblosoma benedicti*	*Glycera dibranchiata*	*Spiophanes benedicti*
Crenella glandula	*Nassarius trivittatus*	*Eteone lactea*	*Nassarius trivittatus*
Glycera robusta	*Eteone trilineata*	*Eteone trilineata*	*Oxyurostylis smithi*
Ophioglycera gigantia	*Glycera dibranchiata*	*Phyllodoce mucosa*	*Buccinium totteni*
Cancer borealis	*Mercenaria mercenaria*	*Gemma gemma*	*Gammarus duebeni*
Corophium volutator	*Ilyanassa obsoleta*	*Crangon septemspinosa*	*Turbonilla interrupta*
Nassarius trivittatus		*Mya arenaria*	*Euclymena zonalis*
Cancer irroratus		*Scoloplos armiger*	*Corophium volutator*
Cerebratulus lacteus		*Ilyanassa obsoleta*	*Nereis diversicolor*
Ilyanassa obsoleta			*Ilyanassa obsoleta*

TABLE 3. Summary of F values for time, treatment (control, door, and roller), and interaction effects on sediment chlorophyll a concentration, total number of polychaetes, and number of dominant polychaetes for Experiment 1. Levels of significance: ns, $P > 0.05$; *$0.01 < P \leq 0.05$; **$P \leq 0.01$.

	df	Sediment chlorophyll a	Total no. of polycheates	No. of *C. torquata*	No. of *G. dibranchiata*
Station A					
Time	10	10.25**	2.84**	2.58*	1.52 ns
Treatment	2	13.12**	1.41 ns	0.77 ns	2.09 ns
Interaction	20	1.71 ns	1.00 ns	0.71 ns	3.05*
Bartlett's (χ^2)	32	37.03**	29.18**	50.24**	49.86*
Station B					
Time	11	5.95**	2.16**	0.67 ns	1.51 ns
Treatment	2	3.84*	1.90 ns	0.16 ns	3.95*
Interaction	22	1.90*	1.42 ns	0.90 ns	0.69 ns
Bartlett's (χ^2)	35	39.42**	36.09**	22.73**	43.47*
Station C					
Time	11	16.09*	1.57 ns	2.03*	4.04*
Treatment	2	1.54 ns	0.77 ns	0.56 ns	1.66 ns
Interaction	22	12.31 ns	1.43 ns	1.62 ns	1.63 ns
Bartlett's (χ^2)	35	58.09*	43.17**	34.45**	61.57 ns

is in keeping with the finer nature of the sediment. At all sites the dominant macrofauna were polychaetes (Table 2). At Houston Beach, the dominant polychaete was *Clymenella torquata*, a nonselective deposit feeder which forms long vertical tubes of sand and mucus and occurs mainly subtidally. During Experiment 1, *Glycera dibranchiata*, a deep burrowing carnivorous polychaete, was also abundant. Although *G. dibranchiata* occurs mainly intertidally, it can be found to depths of 400 m. During Experiments 2 and 4, *C. torquata, Spiophanes bombyx*, a selective surface deposit feeder, and *Nephytys caeca*, a highly mobile predacious burrowing polychaete, were the dominant species. Both *S. bombyx* and *N. caeca* occur subtidally to depths of 100 m. These polychaete species constituted about 90% of the total number of macrofauna at all Houston Beach sampling locations. Macrofauna at Porter Point was dominated by a single polychaete species, *Heteromastus filiformis*, a tube-building, nonselective deposit feeder commonly found in fine sediments around the Bay of Fundy both intertidally and to depths of 60 m.

Impact on benthic diatoms and recovery

Trawling does appear to have some minor impacts on benthic diatoms (Fig. 5 and 6). In Experiment 1 (Houston Beach), an initial ANOVA indicated significant differences in sediment chlorophyll a concentration between stations; therefore, the data for each station were subjected to a separate ANOVA (Table 3). Significant treatment effects were observed for Stations A and B, but not for Station C. An analysis of Bonferroni-adjusted pairwise comparisons indicated that at Station A, chlorophyll a concentrations were significantly lower in both the door furrow and roller marks, and at Station B, chlorophyll a concentrations were significantly less in only the door furrow. All three stations showed

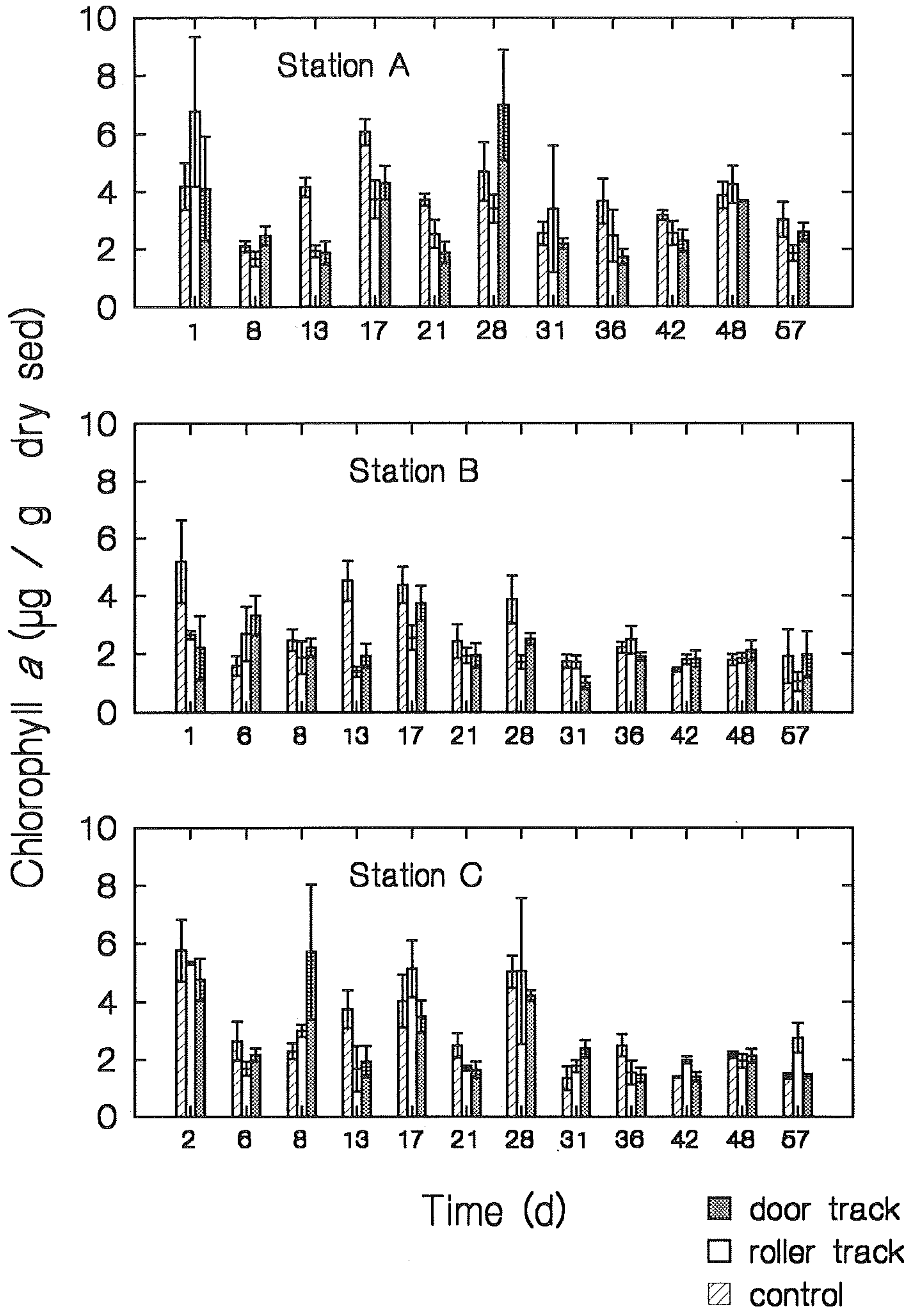

FIG. 5. Time series of sediment chlorophyll *a* at each station in Experiment 1 (Houston Beach). Error bars are 1 SE of the mean.

decreasing chlorophyll *a* concentrations with time which was presumably due to the decreasing levels of solar radiation at this time of year (October–December).

In contrast, chlorophyll *a* was lower in the door furrows than in control samples (Table 4) at the beginning of Experiments 2–4 (which were conducted during the late spring and summer) and remained so for approximately 1 mo (Fig. 6). However, after 80 d, a reverse trend occurred in Experiment 3 (Porter Point) where chlorophyll *a* in the door furrow was about twice that in control samples. On the final sampling day (day 126) the difference was fourfold, and this apparent bloom of algae in the furrow was clearly visible to the naked eye.

Impact of nematodes and recovery

Experiments 2–4 indicate that trawling can have impacts on nematodes (Fig. 7; Table 4). In all cases, nematode numbers were markedly lower in the door furrows than in control samples at the beginning of the experiments. However, after 4–6 wk, numbers returned to levels similar to controls. The impacts appeared to be greater at Porter Point which had higher initial concentrations of nematodes.

Impact on polychaetes and recovery

There was little evidence that trawling had any impact on either the species composition or number of polychaetes that dominated the benthic macrofauna community at the Houston Beach sites. In Experiment 1, there were very few differences in polychaete numbers which could be attributed to trawling (Fig. 8). An initial ANOVA showed significant differences among stations in the total number of polychaetes, so the data for each station were analyzed sep-

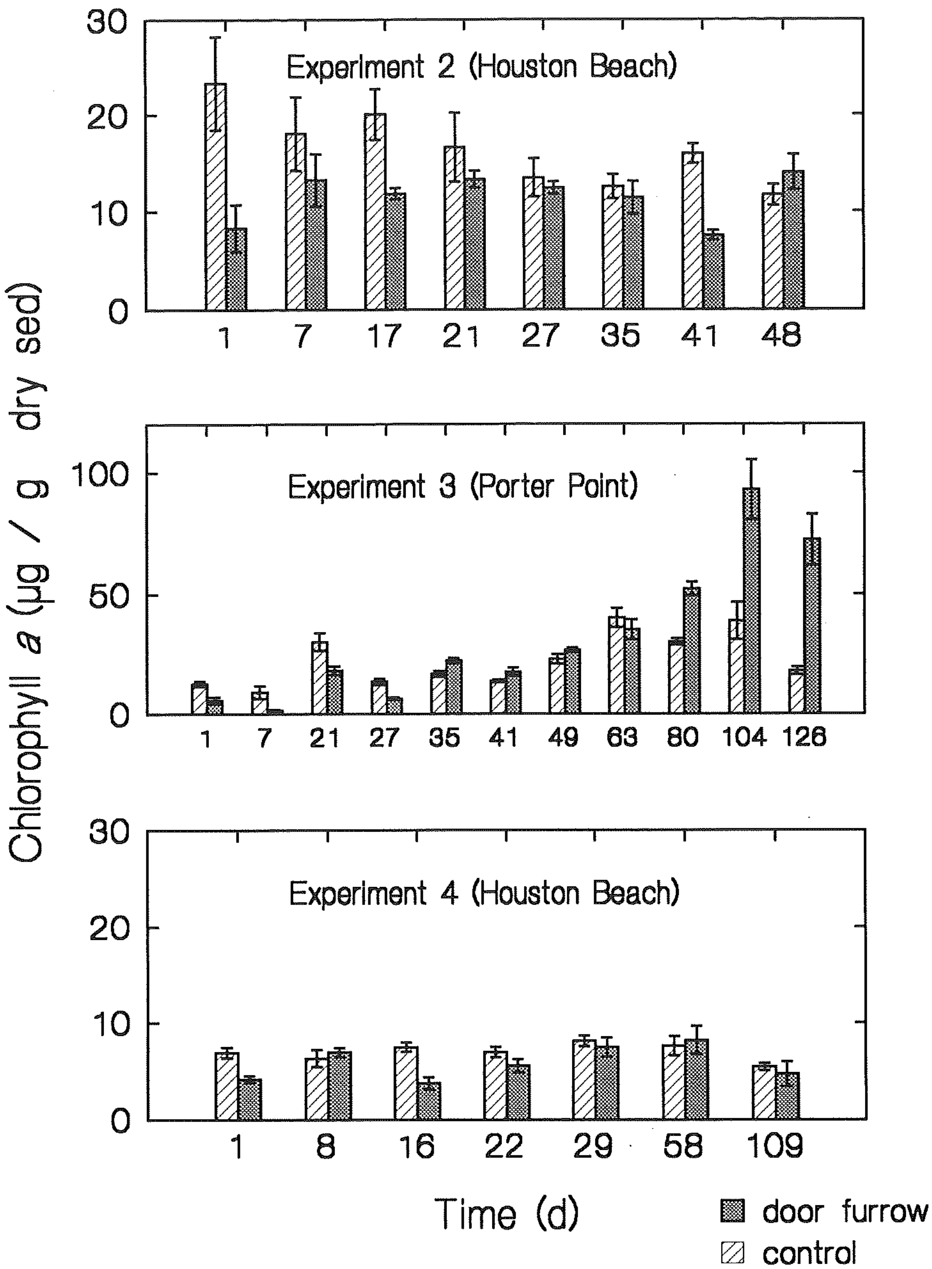

FIG. 6. Time series of sediment chlorophyll *a* in Experiments 2–4 (Houston Beach and Porter Point). Error bars are 1 SE or the mean.

arately. An ANOVA for each station (Table 3) revealed no significant treatment effect on the total number of polychaetes, and in only one instance (*G. dibranchiata* at Station B) was there a significant treatment effect (greater number in the control) on one of the dominant polychaetes. In Experiments 2 and 4, polychaete numbers were slightly lower in the door furrows on day 1 (Fig. 9), but these differences were not statistically significant. There were no consistent differences between the door furrows and controls for the rest of the experiments.

Polychaete numbers were very low at the beginning of Experiment 3 (Porter Point) and there was no sign of any initial impact (Fig. 9). After about 1 mo, polychaetes began to increase in both door furrow and control samples. At first, the rate of increase was greater in control samples, but after about 7 wk, there was little difference between control and door furrow samples.

Discussion

The amount of initial physical disturbance caused by trawling varied markedly and seemed to be influenced primarily by the kind of sediment and the type of doors used. Disturbance was greater in the finer sediments off Porter Point and with the heavier doors used in Experiments 3 and 4. Even though the maximum depth of scour recorded was only 5 cm, the disturbance left by the doors and the rollers was easily visible from both the ground and the air when the intertidal area was exposed. The data collected during these experiments indicate that trawl tracks on the intertidal flats of the Minas Basin can persist for 2–7 mo. This persistence of trawl tracks in the intertidal zone is somewhat surprising considering that the tracks are exposed to wave activity twice within a 12.5-h period, tidal currents inundation, and the erosive effects of precipitation during

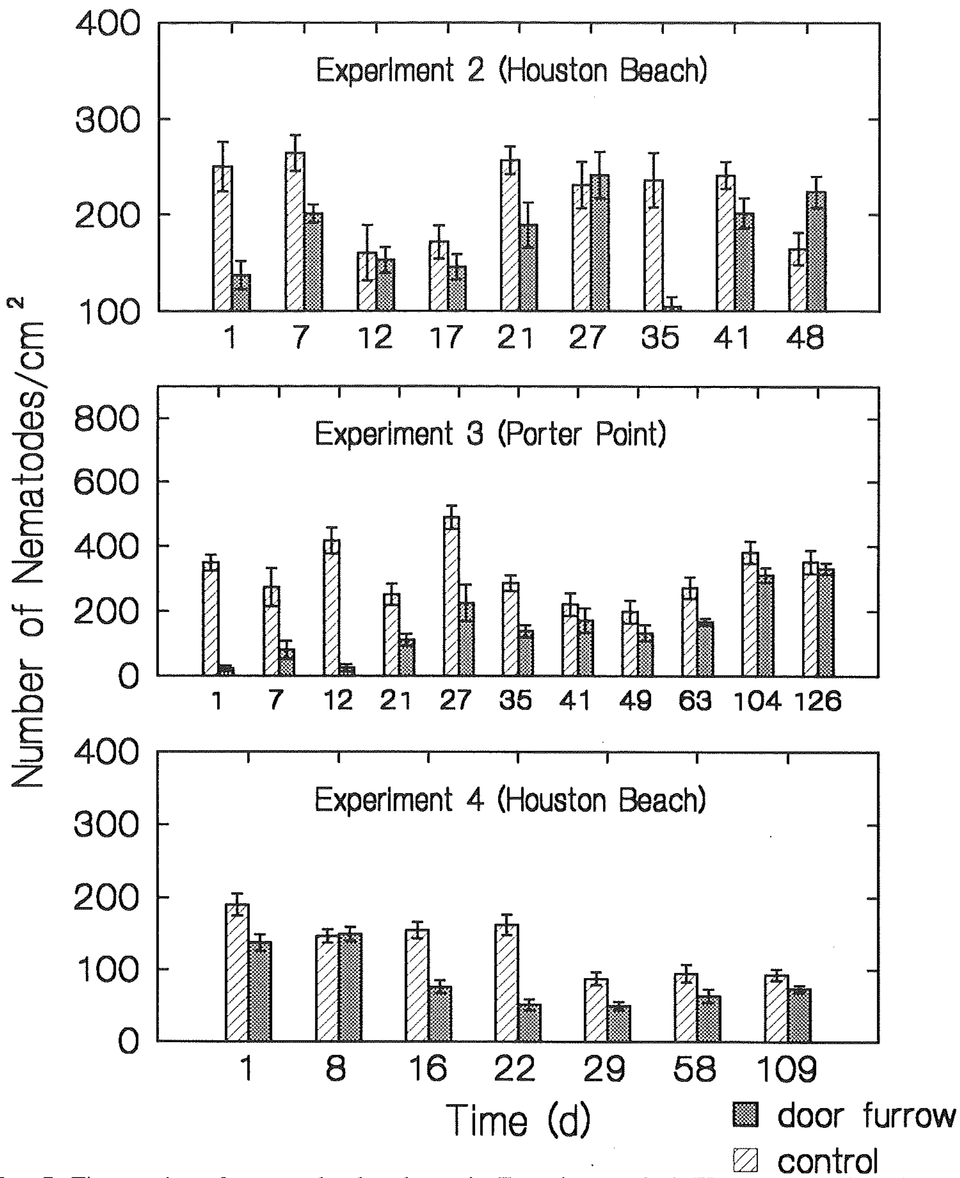

FIG. 7. Time series of nematode abundance in Experiments 2–4 (Houston Beach and Porter Point). Error bars are 1 SE of the mean.

TABLE 4. Summary of F values for time, treatment (control and door), and interaction effects on sediment chlorophyll *a* concentration, total number of nematodes, total number of polychaetes, and number of dominant polychaetes for Experiments 2, 3, and 4. Levels of significance: ns, $P > 0.05$; *$0.01 < P \leq 0.05$; **$P \leq 0.01$.

	df	Sediment chlorophyll *a*	Total no. of nematodes	Total no. of polychaetes	No. of *C. torquata*	No. of *S. bombyx*	No. of *N. caeca*
Experiment 2							
Time	7	17.25**	2.46*	0.70 ns	0.92 ns	7.84**	1.75 ns
Treatment	1	15.56**	9.14**	1.20 ns	2.18 ns	0.83 ns	0.09 ns
Interaction	7	2.21 ns	2.36*	2.84*	2.58*	1.20 ns	0.87 ns
Bartlett's (χ^2)	15	27.47*	29.13*	29.29*	24.73**	27.46*	38.13 ns
Experiment 3							
Time	10	77.34**	3.08**	25.37**			
Treatment	1	33.71**	42.02**	23.46**			
Interaction	10	14.73**	3.91*	4.35**			
Bartlett's (χ^2)	21	29.09*	38.08*	38.90*			
Experiment 4							
Time	6	8.71**	10.92**	2.14 ns	1.54 ns	7.19**	1.32 ns
Treatment	1	4.21**	37.19**	3.15 ns	0.89 ns	1.35 ns	0.49 ns
Interaction	6	5.03**	3.30**	1.50 ns	0.96 ns	1.63 ns	1.47 ns
Bartlett's (χ^2)	13	25.75*	12.48**	27.59*	43.41 ns	15.58**	26.02*

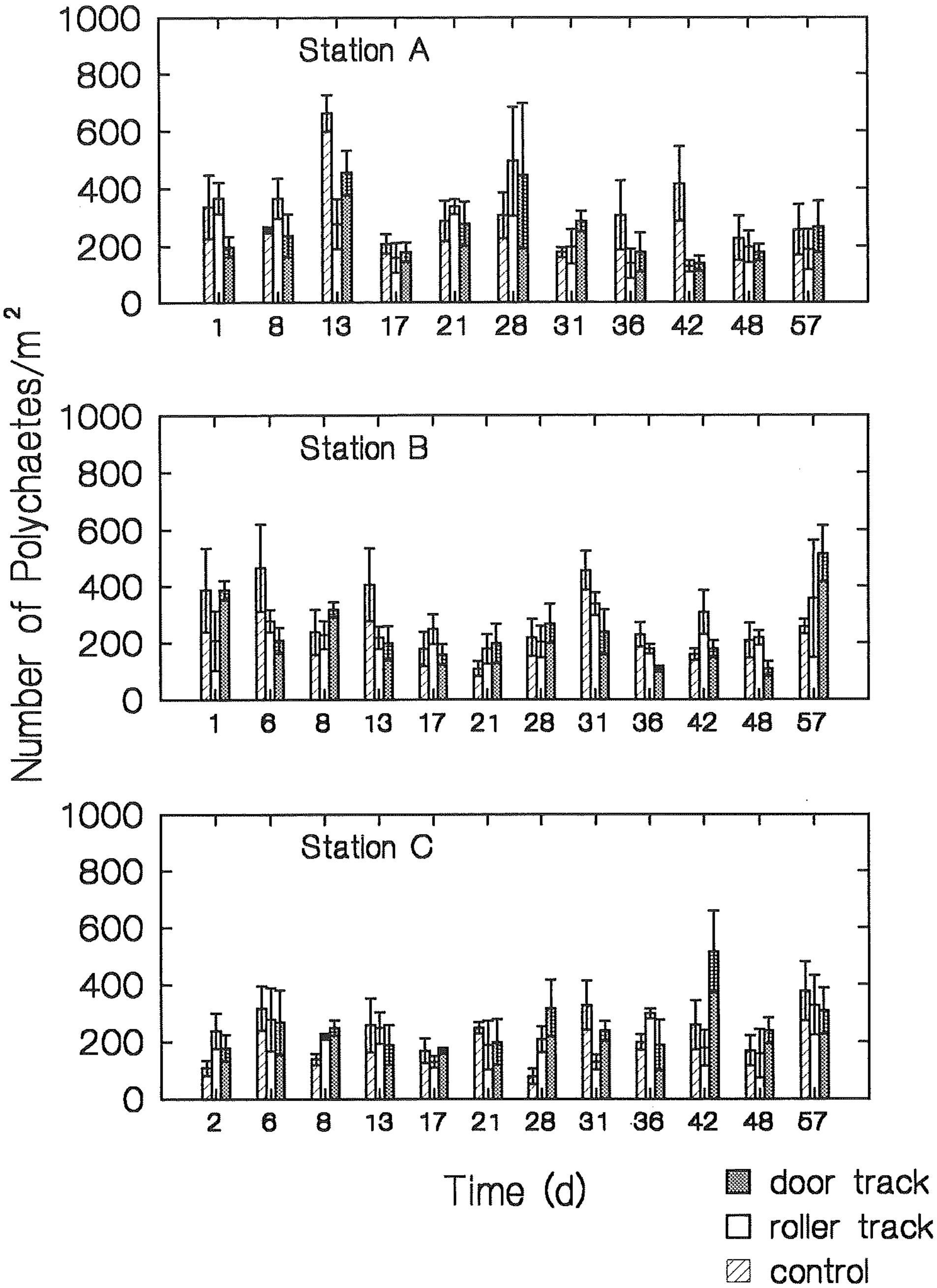

FIG. 8. Time series of polychaete abundance in Experiment 1 (Houston Beach). Error bars are 1 SE of the mean.

inundation, and the erosive effects of precipitation during exposure.

Although there was some evidence of depression of sediment chlorophyll *a* levels at Station A in Experiment 1, there was little indication that the rollers had any biological impact. The only biological impacts observed, which were quite minor, were caused by the doors. In the three Houston Beach experiments, there was generally little difference between control samples and door furrows in chlorophyll *a* levels or macrofauna abundance, either immediately after the trawl was made or as long as the disturbance was visible. There were also no obvious differences, other than the amount of physical disturbance created, that could be related to the time the trawls were made or the type of trawl used. In the Porter Point experiment, the initial impact was more obvious, probably because of the finer sediment and greater initial physical disturbance. Chlorophyll *a* levels in the door furrow were initially depressed relative to the control and this persisted for about 1 mo. After that time, however, chlorophyll *a* levels increased at a much faster rate within the door furrow and eventually became 2–4 times as great as the control, perhaps as a result of increased nutrient availability resulting from disturbance of the sediments. Polychaetes, however, differed little between the door furrow and control samples in either abundance or rate of increase in abundance. The greatest biological impact of the flounder trawls was the depression in the number of nematodes within the door furrow relative to the control samples. This was obvious in Experiments 2–4 but was most pronounced in Experiment 3 (Porter Point) where it persisted for almost 2 mo.

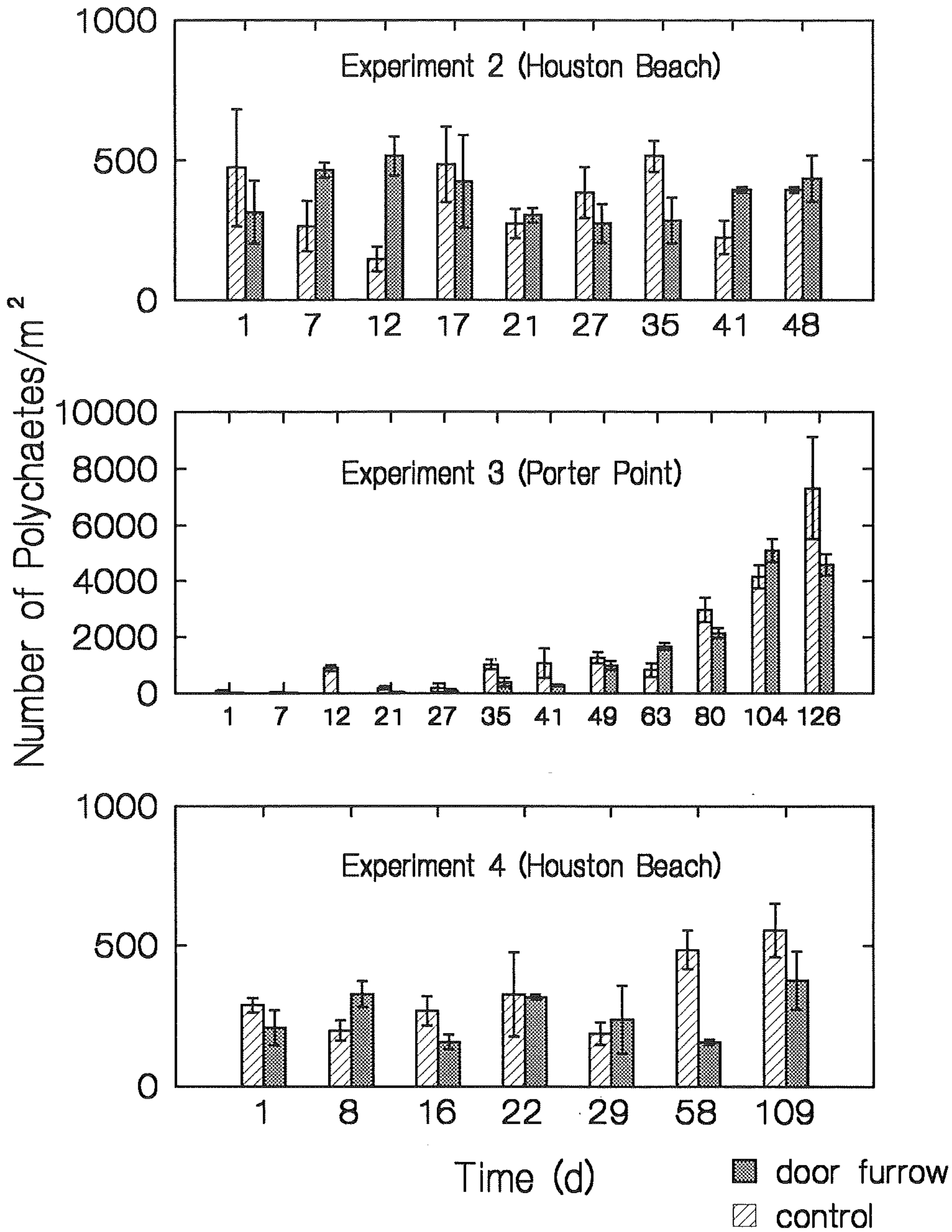

FIG. 9. Time series of polychaete abundance in Experiments 2–4 (Houston Beach and Porter Point). Error bars are 1 SE of the mean.

The general lack of a significant impact on benthic diatoms is not surprising, since they have a very rapid division rate (on the order of once a day) and are subject to suspension and redistribution during periods of strong winds (de Jonge and van den Bergs 1987). The fate of the nematodes lost from the door furrows is unknown. While some may have been killed by the doors, it is more likely that most of them were resuspended or displaced with the sediment. If this is true, the nematodes may have continued to live and thus the overall impact may be less than the data suggest.

At first, the lack of impact on the macrofauna may seem surprising, since other studies have demonstrated that at least some species of polychaetes can be affected by trawling, for example, *Lanice conchilega*, *Magelona papillicornis*, and *S. bombyx* in the North Sea (Bergman and Hup 1992). However, the polychaetes dominant at the Minas Basin study sites (Table 2) were predominantly tube-dwelling, upside-down-feeding, nonselective deposit feeders or burrowing carnivores. These species may be able to better sense the approach of the trawl doors and take evasive action by either moving down their tubes (which generally extend deeper than 5 cm) or burrowing deeper. Selective surface deposit feeding species, such as *S. bombyx*, may be more susceptible to damage. The fact that *S. bombyx* was not noticeably impacted in this study, but was in the North Sea (Bergman and Hup 1992), could be explained by the type of gear used. The latter study employed a beam trawl equipped with tickler chains which affects an area 12 m wide and at least 6 cm deep. In general, polychaetes are well known for their ability to withstand stress and there is evidence that their relative abundance in the Wadden Sea is increasing due to habitat disturbance (Reise 1982). Impacts on the macrofauna would probably have occurred if other classes of infaunal organisms or epibenthic organisms had been present at the study sites. For example, crustaceans, molluscs, and echinoderms appear to be much more susceptible to trawl damage (e.g., de Groot 1984; Langton and Robinson 1990; Rumohr and Krost 1991; Bergman and Hup 1992).

The results of this study indicate that the impact of flounder draggers on the intertidal benthic community of the Minas Basin is minor and not cause for serious concern at the present time. This conclusion, however, should not be applied to other benthic habitats which have quite different sedimentological conditions and biological communities and which can be disturbed by other kinds of fishing gear (scallop rakes, clam dredges, etc.). Further investigations in subtidal areas are necessary. If trawl marks can last for 2–7 mo in intertidal sediments, which are subjected to the various physical stresses discussed above, they could last longer in subtidal sediments, except perhaps in areas of strong tidal currents. However, some of the results of this intertidal study may be applicable to subtidal habitats. For example, the dominant polychaete species in this study also occur subtidally to depths of at least 60 m, so it is unlikely that they would be affected by trawling in deeper water.

While trawling does appear to cause a substantial amount of physical disturbance, it must be appreciated that this activity is superimposed upon a variety of natural processes that make the intertidal zone of the Minas Basin a heavily stressed environment due to wave action and storms. Storms can cause very high levels of mortality in benthic organisms (Yeo and Risk 1979). During the winter, the intertidal zone is subjected to the erosive effects of moving ice (Knight and Dalrymple 1976) which create abundant furrows on the order of several centimetres deep (Gordon and Desplanque 1983). Therefore, it is not surprising that the intertidal benthic community in the Minas Basin is little affected by the additional stress of trawling. Another anthropogenic disturbance which has taken place in recent years in the Minas Basin is bait digging for blood worms (*G. dibranchiata*) but this has not been quantified. Visual impressions suggest that this activity is likely to have far more impact on the sediments, bottom morphology, and the benthos in areas where it takes place.

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