CHAPTER V

Are strandline meiofaunal assemblages affected by mechanical beach cleaning? Experimental findings

Results presented as

GHESKIERE T, VINCX M, VAN DE VELDE B, PISON G, DEGRAER S (paper submitted)
Are strandline meiofaunal assemblages affected by mechanical beach cleaning?
Experimental findings
Marine Ecology Progress Series

ABSTRACT

The increasing usage of sandy beaches as recreational resources has forced regional authorities of many tourist countries to remove all litter of fabricated origin and natural wrack from the beach. Consequently, a variety of heavy equipment has been developed during the last decades and is now used almost daily in many tourist resources. A field experiment, following a BACI-design, was conducted at the strandline of De Panne (Belgium) to investigate the impacts of mechanical beach cleaning on the strandline-associated meiofaunal assemblages, focussing on the free-living nematodes. Natural strandline assemblages were exposed to a one-off 5 cm deep mechanical beach cleaning and observed for 24 hours. We assessed the power of the experiment to detect the effects of mechanical beach cleaning and recorded a 99% chance of detecting a 50% change in total abundance, evenness and taxonomic diversity and a 74% chance in detecting a 50% change in species richness. Differences between cleaned plots and those from the un-cleaned control plots in terms of decreased percentage of organic matter, total abundance and changed community structure were noticed from immediately after the experimental cleaning onwards and came again to initial values after the following high water. Any impacts due to cleaning on species richness, evenness and taxonomic diversity were showed to be minor in relation to the daily changes. Recolonization in the cleaned sediments is assumed to occur from the underlying sediments initiated by the elevated water table during the rising tide. We suggested that strandline meiofauna are more resistant to mechanical beach cleaning than are macrofauna.

KEYWORDS: meiofauna, free-living nematodes, sandy beach, mechanical beach cleaning, disturbance, recovery

INTRODUCTION

The strandline is an ephemeral or permanent accumulation area of debris on of the beach where the high tide deposits material from the sea. It provides a very unique although fringe habitat, exclusive neither marine nor terrestrial, and is colonised by invertebrates from both ecosystems (Gheskiere *et al.* 2005a). Strandlines are of great ecological importance, especially on shores where they can act as precursors to sand dunes, enabling the formation of embryonic dunes and subsequently fore dunes (Davidson *et al.* 1991).

Strandline deposited material includes both wrack and inorganic beach-cast material. Wrack beach-cast material or natural flotsam refers to any organic debris of marine and terrestrial origin (Lord and Burger 1984). Once wrack is cast ashore it decomposes very quickly as it undergoes physical processes of fragmentation and biological processes of decomposition and remineralization. On a South African beach, Koop and Griffiths (1982) found that within eight days the weight of algal debris decreased by 73 to 77%. A small amount of the organic matter was consumed by the macrofauna but more than 90% was mineralized by micro-and meiofauna. In their recent review, Colombini and Chelazzi (2003) have described the macrofaunal beach-wrack assemblages and species succession associated with decaying organic matter, including marine as well as terrestrial representatives. This fauna is generally diverse to location, beach morphology, season, climate and vegetation cover. Common terrestrial groups feeding on rotting seaweed are Helcomyzidae (sub-Antarctic kelp flies), Coelopidae (kelp flies), Sphaeroceridae (lesser dung flies), Canacidae (beach flies), Ephydridae (shore or brine flies), darkling beetles (Tenebrionidae) and rove beetles (Staphylinidae), all feed on rotting material. There are also several species of terrestrial spiders, which use the upper strandline for shelter and hunting (Speybroeck *et al.* 2004). Of the marine macrobenthic invertebrates, besides Polychaeta and Bivalvia, especially the Amphipoda (Sandhoppers) are dominant in strandlines all over the world (Llewellyn and Shackley 1996). These macrofaunal organisms are important prey resources, being commonly exploited by large numbers of shorebirds and even passerines (Cramp and Simmons 1983; Davidson *et al.* 1991).

The deposit of manufactured debris has become a growing concern in many countries. Origins of this litter are both oceanic, *e.g.* from ships dumping at sea, and shore based, *e.g.* from rivers, sewage, or careless visitors. Stranded beach litter is more than a visible care, causing a significant threat to many animal life forms (*e.g.* birds) through entanglement or ingestion (Laist 1987) and, occasionally, the debris may become harmful to human health (Philipp *et al.* 1997). The increasing usage of sandy beaches as recreational places has forced regional authorities of many tourist countries to remove all natural wrack and litter of fabricated origin (Ryan and Swanepoel 1996). Consequently, a variety of cleaning techniques (front-end loaders, suction devices ...) has been developed in tourist coastal regions all over the world (Taylor *et al.* 1994; Engelhard and Withers 1997). Especially cleaning with large tractor-pulled sieving machines has been seen as a cost-effective way of removing the "unwanted" strandline and has become an almost daily phenomenon on tourist sandy beaches (Gheskiere *et al.* 2005b). Along with the removal of

wrack and litter almost every macroscopic item is removed from the sand as the beach cleaner shovels up the upper sediment layer with a fast-turning mixer or brush, replaces the sand after sifting and finally compresses the sediment with a dragged weight (personal observation). There is however, a growing concern about the use of these machines and the damaging impact of these cleaning activities on the overall strandline-related species diversity and abundance (Belpaeme *et al.* 2004). On the invertebrate level this has already been documented extensively (*e.g.* Davidson *et al.* 1991; Kirby 1992; Llewellyn and Shackley; 1996, Weslawski *et al.* 2000; Dugan *et al.* 2003). However, these studies have focused on the larger macrofauna and habitat forming species, primarily because reductions in their abundance and species diversity are an important conservation issue. Studies dealing with the possible impacts on the meiofauna (all Metazoa <38 µm) of strandlines are lacking. Usually, free-living nematodes dominate the meiofauna of sandy beach sediments (Brown and McLachlan 1990). Nematodes are generally considered as an excellent taxon to use as ecological indicators for benthic habitats and for studying the impacts of different kinds of natural and anthropogenic disturbances in the marine environment (Heip *et al.* 1985; Schratzberger *et al.* 2000; Gheskiere *et al.* 2005b). They reach very high abundances, so a small sediment sample yields enough animals to make scientifically sound statements. They have a ubiquitous distribution, a high diversity (with a range from very tolerant to very sensitive species), short generation time and a continuous reproduction. Moreover, they are restricted to the sediments throughout their life.
This paper has three major aims:

(1) to describe the meiofaunal diversity of a freshly deposited strandline,

(2) to asses the possible influence of a mechanical beach cleaner on the meio-nematofaunal diversity, community structure and

(3) to asses the recovery of the assemblages after cleaning.

In the context of the present study, we define recovery of an impacted area as having occurred when the cleaned sediments have attained a state that is no longer significantly different to the composition of the control plots.

MATERIAL AND METHODS

Study site

This study was performed at the beach of De Panne (51°05'30"N, 02°34'01"E) at the western Belgian coast, nearby the Belgian-French border, in front of the 'Westhoek' nature reserve. This beach is an, relatively, undisturbed ultra-dissipative, macrotidal, fine-grained sandy beach with a natural strandline. More details about the granulometry and morphodynamics of this beach are described in Gheskiere *et al.* (2004). During the experiment air temperature varied between 17.6°C and 18.4°C (Oceanographic Meteorological Service Zeebrugge) while interstitial temperature varied between 19.6°C and 19.8°C. Salinity was constant (34 PSU) during the experiment. Gheskiere *et al.* (2002, 2004) give detailed information about the nematode and meiofaunal species composition of this beach.

Sampling strategy and techniques

The experiment was started on 26 August 2002 when high water was scheduled at 03.52am. To account for any environmental gradient along the strandline, the strandline was divided into five 'blocks' as recommended by Dutilleul (1993). Just after the start of the outgoing tide, the five blocks, each with two plots (Cleaned (C) and Un-cleaned control (U) each 10m x 4m) were delineated and marked with little floats in the freshly formed high water mark (Figure 1). Generally, the strandline was only sparsely loaded with flotsam. If there was any unanticipated spatial variability across the strandline, blocking of the cleaning experiment was expected to be an efficient way to estimate the effects of this variability against the cleaning effect (Underwood 1997). Meiofauna and percentage Total Organic matter (%TOM) were sampled randomly at control and cleaned plots in each block, once before and on several occasions after the experimental cleaning. The design used was, therefore, a "Before-After, Control-Impact" (BACI) design in which the evidence for an impact appears as significant Time (before versus after) by Treatment (cleaned versus control) interaction (Green 1979). Samples were taken using transparent perspex cores (10 cm^2) to a depth of 5 cm. After the initial sampling, one plot in each block was cleaned with a 100 horse power, 2.5 m wide mechanical beach cleaner (Hurricane-Eco type©, see Photo 1) and repeated meiofauna sampling was completed in control and cleaned plots in each block. (Figure 2).

Along with the removal of algae and wrack, the beach cleaner scrapes up the upper sand layer (5 cm) with a fast-turning wheel equipped with little shovels (540 tr./min) and replaces the sand after sifting. The machine was fitted with a 30 mm mesh sieve allowing sand to pass and falling down on the beach again. Working speed was adjusted at 5 km/h. Settings of the beach cleaner were the default settings used for the daily cleaning on the Belgian tourist beaches. After experimental cleaning the machine's container contained parts of four different species of brown algae (*Fucus vesiculosus*, *Ascophylum nodosum*, *Sargassum*

muticum and *Himanthalia elongata*), parts of *Rhizostoma* sp., several carapaces of *Carcinus maenas*, a dead *Pleuronectes platessa* and considerable amounts of razor shells (*Ensis* sp.).

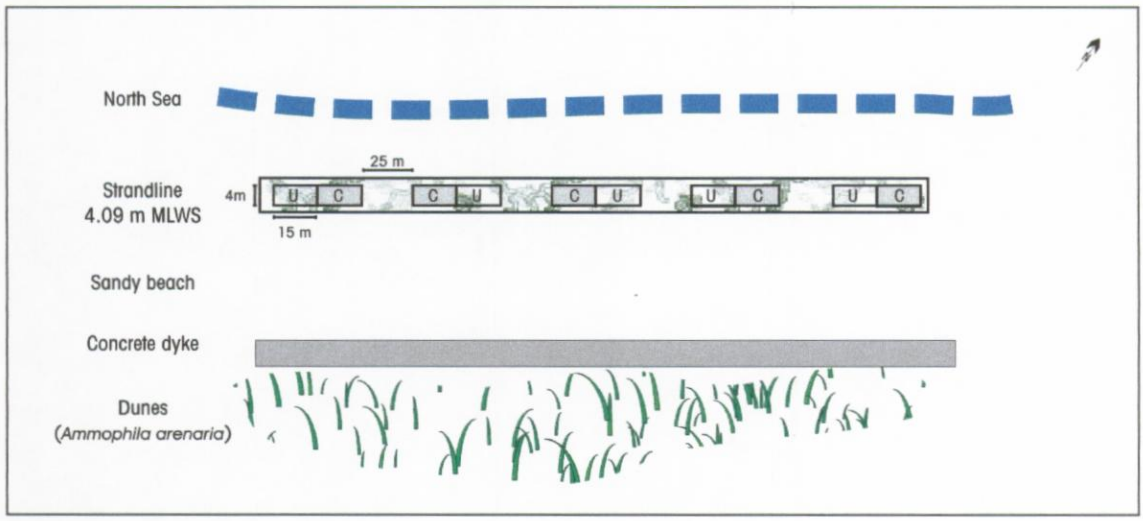

Figure 1: Experimental design on the beach of De Panne Westhoek (Belgium). (C=Cleaned plots, U=Un-cleaned control plots)

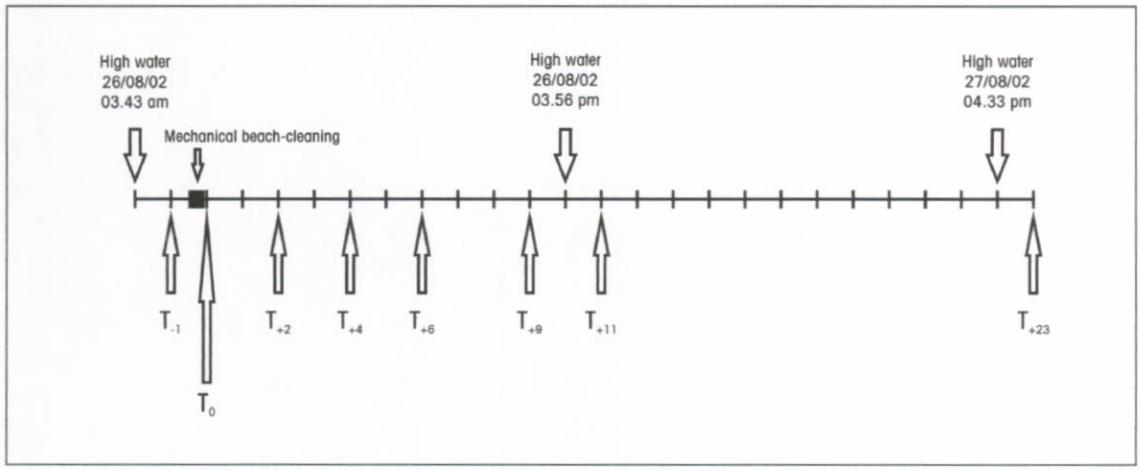

Figure 2: Time schedule of the experimental cleaning. Arrows indicate sampling occasions relative to tides and experimental beach cleaning. Numbers associated with the sampling occasion indicate the time (hours) relative to the experimental beach cleaning.

Photo 1: One of the most used types of mechanical beach-cleaners; the Hurricane-Eco type©.

Laboratory treatment

In the laboratory, meiofauna samples were rinsed with a gentle jet of freshwater over a 1 mm sieve to exclude macrofauna and washed onto a 38-µm sieve. The residue from the 38-µm sieve was separated into heavy and light fractions using repeated decantation (10 times). The light fraction (containing the meiofauna) was centrifuged three times with Ludox© HS40 (specific density is 1.18) and stained with Eosin (Heip *et al.* 1985). The extract was then placed into a beaker, made up to a standard volume with filtered tap water and homogenized into suspension before a constant proportion (30%) of the sample was taken with a semi-automatic pipette. Per sub-sample all meiofauna was counted and identified at the taxon level. All nematodes per sub-sample were picked out, transferred from formalin to glycerol through a series of ethanol-glycerol solutions and mounted on Cobb slides. Afterwards, nematodes were identified to the species level and classified, in order to use the taxonomic diversity index, according to the phylogenetic system of De Ley and Blaxter (2003). Sediment samples were oven-dried at 105°C for 12 h and ashed at 500 ± 50°C for 2 h to determine the %TOM by loss of mass. The sediment fractions were defined according to the Wentworth scale (Buchanan 1984); sediment-sorting coefficient and other granulometric characteristics were calculated as described by Dyer (1986).

Data processing

Meiofauna species abundance data (N) (Ind/10 cm^2) were used to calculate the diversity as the expected number of species per sample based on 100 individuals ES(100) (Sanders 1968; Hurlbert 1971) and Pielou's evenness (J'), the last index using $\log_e$ in the formulation. Average taxonomic diversity (Δ) (Warwick and Clarke 1995) was calculated using only the nematode species data. Equal step-lengths between each taxonomic level were assumed for the calculation of the taxonomic indices, setting the path length ω to 100 for two species connected at the highest (taxonomically coarsest) possible level as stated by Clarke and Warwick (1999). Eight taxonomic levels were used (species, genus, family, superfamily, suborder, order, subclass and classis). Consequently, weights are ω=12.5 (species in the same genus), 25 (same family but different genus), 37.5 (same superfamily but different family), 50 (same suborder but different superfamily), 62.5 (same order but different suborder), 75 (same subclass but different order), 87.5 (same classis but different subclass) and 100 (different classes), respectively.

The power of the experimental design (the probability of obtaining a statistically significant response for an assumed size of experimental effect) was computed and evaluated using the observed estimates of the residual variances (Cohen 1977, Lipsey 1990) for each biological response (*i.e.* abundance, ES(100), evenness and average taxonomic diversity).

Differences in density, richness measures, most dominant species and %TOM were analysed using a repeated measure ANOVA design (Hall and Harding 1997) with model terms added: Time (hours before and after the cleaning), Treatment (control or cleaned plots) and Block (five blocks across the strandline). As the same plots were sampled throughout the experiment, there was a probability of non-independence among sampling times consequently leading to an increased or decreased probability of Type I error in assessing differences among times (Underwood 1997). Therefore, to test the effect of Time and Treatment on the biological responses, repeated measure ANOVA tests were conducted in which Treatment and Time were fixed factors and Block was considered a random factor (Green 1993). Bartlett's and Cochran's tests were used to verify for homogeneity of variances prior to the analysis. A multivariate analysis of variance (MANOVA) using the Pillai Trace test statistic (Chatfield and Collins 1980) was performed based on the abundances of the seven most abundant species (accounting for >50% of the total number of individuals) in order to test if the species composition changed as a function of Time, Treatment and Time x Treatment. The abundances were square root transformed to reduce heterogeneity of variance. All power and statistical analyses were performed utilizing the S-PLUS 6.1 software package (Insightful Corp. 2002).

The meiofaunal data were used to produce Detrended Canonical Analysis (DCA) ordination plots (Ter Braak 1988) and non-metric Multi-Dimensional Scaling (MDS) plots (Kruskal 1964). Two-way crossed analysis of similarities (ANOSIM, Clarke 1993) was carried out to test for a Block effect. Where none was found, two-way crossed ANOSIM was repeated with factors Time and Treatment and one-way ANOSIM was carried out to test the significance in meiofaunal assemblages on different sampling occasions. The similarity of percentages programme (SIMPER, Clarke 1993) was applied to determine the contribution of individual species and higher taxa towards the discrimination between samples. The Index of Multivariate Dispersion

(IMD, Warwick and Clarke 1993) has been applied here as a measure of community stress. The IMD is a measure of the increase in variability among replicate samples from cleaned versus control plots. The index contrasts the average rank of the dissimilarities among one set of samples (control) with the average rank among the other set (cleaned), re-ranking the full triangular matrix ignoring all between-group dissimilarities. The IMD is standardised to have a maximum value of +1 when all the dissimilarities among the control samples are higher than any dissimilarities among the cleaned samples and -1 when the reverse is true. All the above-described analyses involved constructing lower triangular similarity matrices from the square-root transformed abundance date using the Bray-Curtis similarity coefficient (Bray and Curtis 1957). Transformation was chosen in order to limit the contributions of the most dominant species, and therefore allow the rarer species to influence the analyses (Elliot 1971). Community analyses were performed using PRIMER version 5.2.9 (Clarke and Gorley 2001). A significance level of $p<0.05$ was used in all tests.

In the context of the present study, we define recovery of an area as having occurred when the impacted community has attained a state that is no longer significantly different to the composition of the control plots.

RESULTS

Power analysis

Sandy sediment assemblages are known to be highly variable and detection of subtle changes in faunal communities is heavily dependent on the statistical power of the experimental design. Therefore, a power analysis was performed on the data for abundance, species diversity, taxonomic diversity and evenness. This gives the probability of obtaining a statistically significant result for a given effect size based on our sampling design and sample variance from data collected from the control plots immediately after the experimental cleaning, and is simply based on the assumption that sample variability does not change over time (Cohen 1988). Relative to the control plots, a biological response is assumed to decrease by p% immediately after the mechanical beach cleaning and to have recovered by the next or second next high water after the cleaning (Figure 3). This assumption is based on the sediment disturbance experiment of Sherman and Coull (1980) which recorded recovery within two tidal cycles after disturbance.

Generally, changes of <50% of the control mean are not considered ecologically meaningful in a dynamic and highly variable environment like shallow sandy sediments (Southwood 1978, Shaw *et al.* 1994, Schratzberger *et al.* 2002), so we adapted that standard.

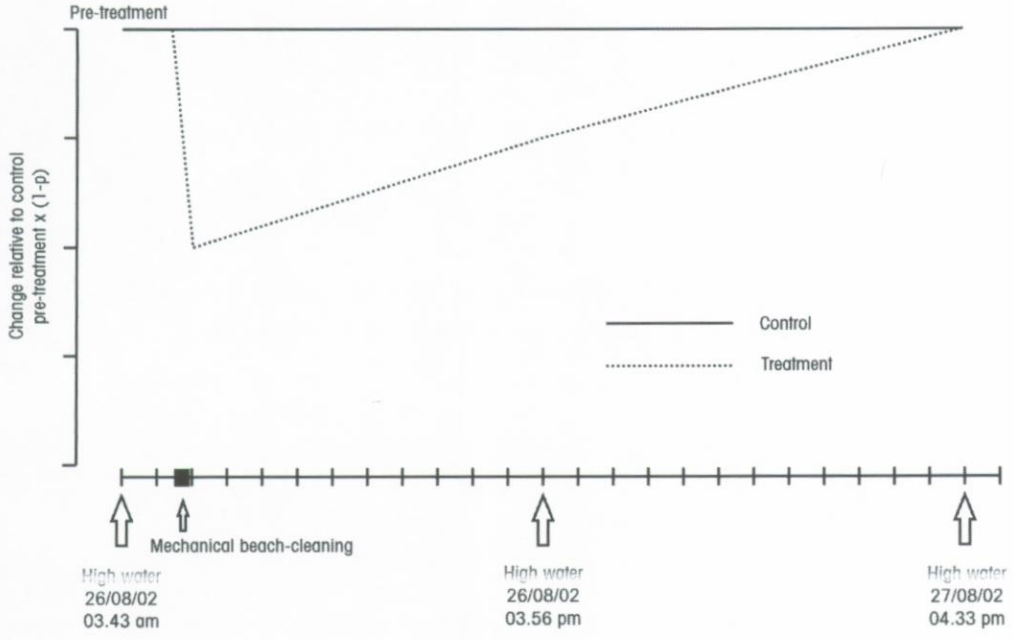

Figure 3: The probability of obtaining a statistically significant result given an assumed size of experimental treatment effect.

Figure 4 reports for each biological response the *a priori* power of the experimental setup corresponding to a hypothetical impact of p% on the sampling immediately after the strandline cleaning. The 5% significance level (corresponding to an impact of 0%) is shown for reference. Abundance (N), Evenness (J'), ES(100), abundance (N), average taxonomic diversity (Δ) are all seen to be extremely sensitive biological responses as the power to detect an ecologically significant change is >99%. The power to detect a 50% change in ES(100) is 74%.

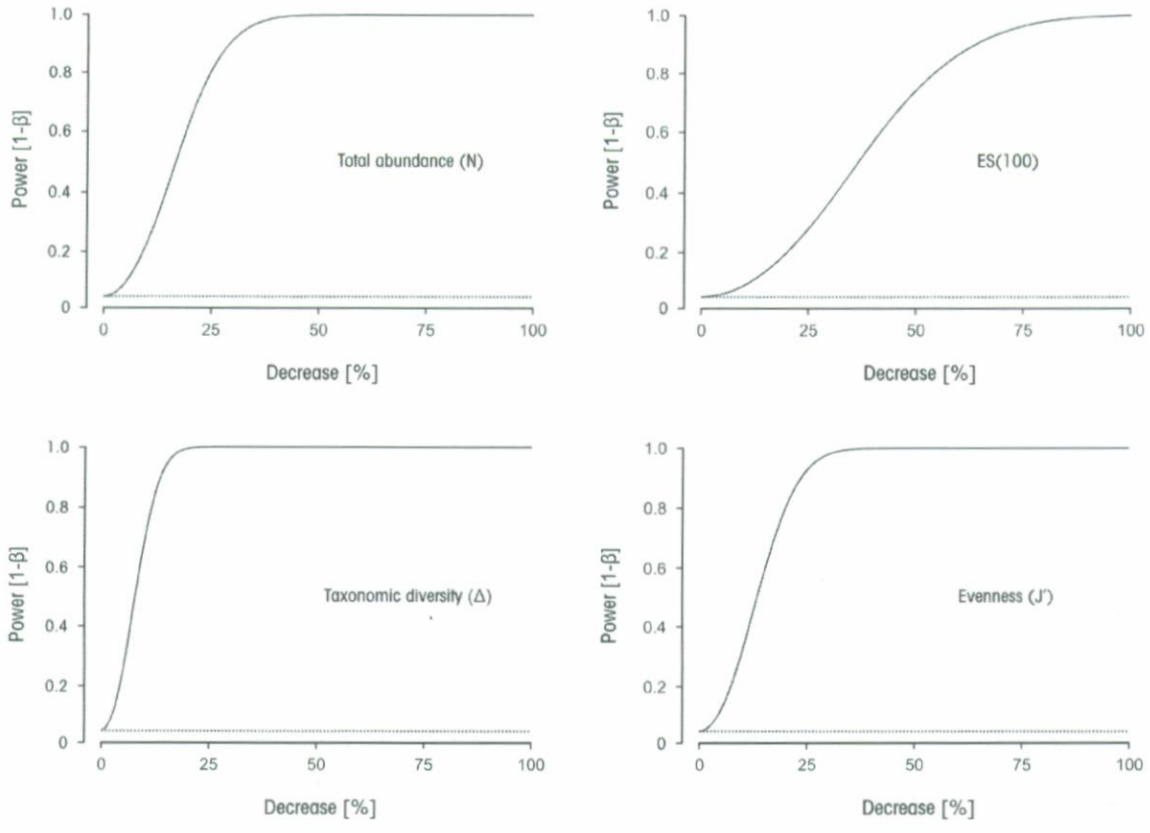

Figure 4: Power of the experimental design corresponding to a hypothetical impact of p% on the first sampling occasion immediately after the experimental cleaning for each biological response. The dotted line indicates the 5% significance level.

The abiotic environment

Generally, no significant granulometric differences (grain size, sorting, skewness, size class distribution) were noted between cleaned and control plots (data not shown). The sediments fell within the category of fine to medium sands, consisting on average of 7% shell fragments, 7% very coarse sand, 10% coarse sand, 33% medium sand, 56% fine sand and 1% very fine sand. Figure 5 reveals the changes of percentage Total Organic Matter (%TOM) at control and cleaned plots during the investigated period. Immediately following the experimental cleaning, the %TOM decreased to a level considerably lower at the

cleaned plots than at the control plots. After the next high water (T_{+11}) the %TOM raised again to more or less the same values compared to the control plots. Variation of %TOM at the control plots was negligible throughout the experiment. No block effects were recorded. Repeated measures analysis of variance indicated a significant effect of Time ($p<0.02$), Treatment ($p<0.01$) and Time x Treatment ($p<0.001$).

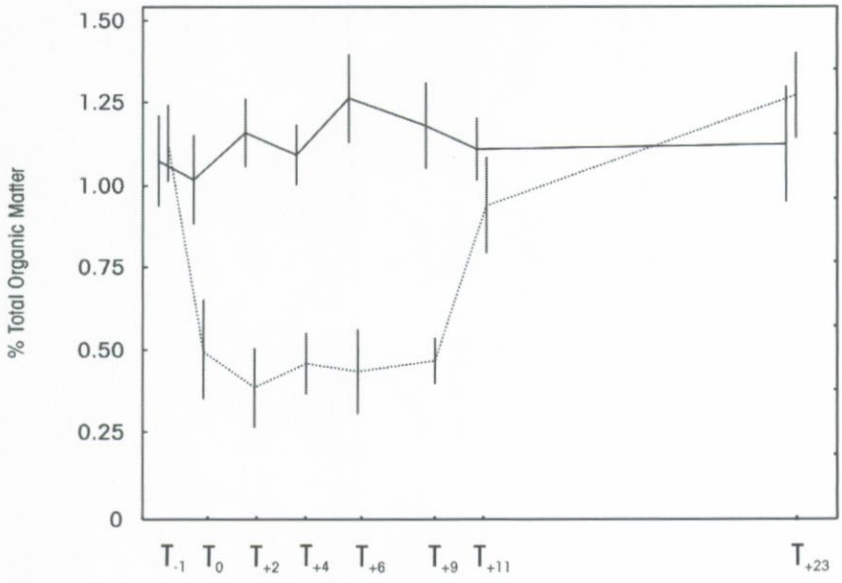

Figure 5: Means of % Total Organic Matter (%TOM) plotted against hours after the experimental cleaning. Solid line: control plots, dotted line: cleaned plots. Vertical lines correspond to 95% confidence limits. (n=5)

Abundance and richness measurements

In total 13 higher meiofauna taxa were recorded in the freshly deposited strandline dominated by nematodes (69% including 55 species), Harpacticoida + nauplii (14%), Oligochaeta (10%) and Turbellaria (4%). Other groups (3%) were present in low numbers or were found only sporadic; these included Polychaeta, Tardigrada, Diptera, Hydrozoa, Ostracoda, Cladocera, Gastrotricha, Aranea and Rotifera. The effect of the cleaning was manifested as a decrease in the total abundances in comparison to the control plots. Immediately after the experimental cleaning (T_0) the total abundance of the cleaned plots, 338 ± 41 Ind/10 cm^2, is seen to decrease significantly to 191 ± 65 Ind/10 cm^2 from where it more or less stabilised until it raises again to 261 ± 48 Ind/10 cm^2. After the second high water, recovery is almost complete and initial values are reached again. Remarkably is the drop in taxonomic diversity between two high waters. (Figure 6) Repeat measure ANOVA showed that there were significant effects of both Treatment ($F=9.47$, $p<0.01$) and Time ($F=2.17$, $p<0.02$) with respect to the total abundance (N). For average taxonomic diversity (Δ), any impacts of cleaning were minor in relation to temporal changes in the nematode assemblages during the progress of the experiment ($F=4.08$, $p<0.02$).

No changes, neither due to the cleaning nor temporal, were noted for Evenness (J') and ES(100). A statistically significant interaction Time x Treatment at the level of 5% was only noted for total abundance ($F=1.45$, $p<0.01$). (Table 1)

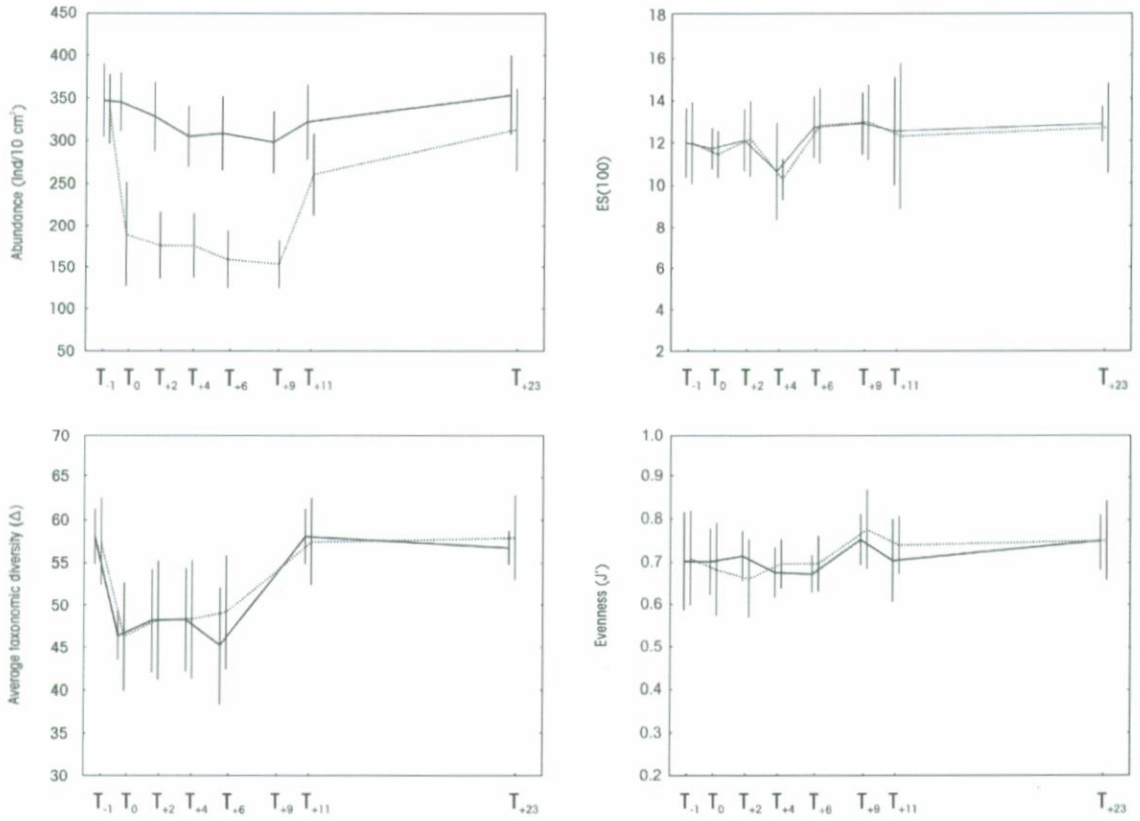

Figure 6: Means of the total abundance, ES(100), average taxonomic diversity (Δ) and evenness (J') plotted against hours after the experimental cleaning. Solid line: control plots, dotted line: cleaned plots. Vertical lines correspond to 95% confidence limits.

	df	F	p		df	F	p
Abundance (N)				**Evenness (J')**			
BLOCK	4	3.71	0.20	BLOCK	4	1.48	0.23
TREATMENT	1	9.47	<0.01	TREATMENT	1	3.10	0.09
TIME	7	2.17	<0.02	TIME	7	2.94	0.07
TIME X TREATMENT	7	1.45	<0.01	TIME X TREATMENT	7	1.21	0.32
Richness ES(100)				**Taxonomic diversity (Δ)**			
BLOCK	4	1.26	0.30	BLOCK	4	1.62	0.2
TREATMENT	1	0.28	0.60	TREATMENT	1	2.55	0.11
TIME	7	8.96	0.09	TIME	7	4.08	<0.02
TIME X TREATMENT	7	0.47	0.80	TIME X TREATMENT	7	0.97	0.45

Table 1: Results from the repeated measures analysis of variance of univariate indices.

Meiofaunal assemblages

Results from the two-way crossed ANOSIM showed no statistically significant block effect on the meiofaunal assemblages collected up to 23 hours after the beach-cleaning (R=0.194, p=0.09). The experimental treatment effect (averaged across all sampling dates; R=0.403, p<0.01) and the time of sampling collection (averaged across treatment groups; R=0.538, p<0.03) were statistically significant.

The one-way ANOSIM (Table 2) shows that differences in meiofaunal community structure collected at the cleaned plots were more pronounced than at the control plots. Pairwise comparisons derived from the ANOSIM test for each sampling occasion showed that highest dissimilarity between control and cleaned plots occurred within the first 9 hours after the experimental cleaning (Table 3). Dissimilarities were most distinct 4 hours after cleaning (48%). A higher value of R is indicative of larger relative differences between the fauna; thus, the decrease in the value of the R-statistic from T_4 onwards gives some indication of the recovery trajectory of the cleaned plots. The meiofaunal assemblages from the cleaned plots remained significantly different from the control plots until T_{11} at which point they had recovered (R=0.115, p=0.231). At each sampling occasion (excepted T_{23}), the inter-variability is higher among cleaned assemblages, giving a negative value for the Index of Multivariate Dispersion, and thus indicating higher community stress. Highest negative IMD-values were noted within the first 2 to 4 hours after experimental cleaning. At T_{-1}, T_{11} and T_{23} IMD-values were close to zero implying negligible differences between control and cleaned samples.

	T_{-1}	T_0	T_2	T_4	T_6	T_9	T_{11}
T_0	35*	-					
T_2	37*	22	-				
T_4	40*	30*	27	-			
T_6	48*	37*	33	31	-		
T_9	34*	34	36	35	25	-	
T_{11}	32	35*	33	23	34*	25	-
T_{23}	35	34*	33*	31*	39*	32*	27

	T_{-1}	T_0	T_2	T_4	T_6	T_9	T_{11}
T_0	29	-					
T_2	30	18	-				
T_4	24	31*	27	-			
T_6	26	33	37	25	-		
T_9	30*	25	22	26	25	-	
T_{11}	18	30	33	28	36*	29	-
T_{23}	16	27	29	29	33	22	29

Table 2: Dissimilarities [%] on different sampling occasions based on square-root transformed species abundance data. *Significant differences at p<0.05 based on ANOSIM test. Cleaned plots (left), Control plots (right).

	Dissimilarity [%]	R	p	IMD
T_{-1}	21	0.042	0.451	-0.090
T_0	33*	0.531	0.029	-0.556
T_2	36*	0.771	0.029	-0.742
T_4	46*	0.801	0.001	-0.740
T_6	48*	0.586	0.037	-0.566
T_9	40*	0.548	0.010	-0.350
T_{11}	26	0.115	0.231	-0.118
T_{23}	20	0.240	0.810	+0.111

Table 3: Dissimilarities [%] and Index of Multivariate Dispersion (IMD) between cleaned and control plots on different sampling occasions based on square-root transformed species abundance data. *Significant differences at $p<0.05$ based on ANOSIM test.

According to the SIMPER-analyses (not shown) significant differences in assemblages within the hours after experimental cleaning mainly occurred as a result of reduced numbers of individuals from the dominant nematode species (*Theristus otoplanobius*, *Trissonchulus benepapilosus*, *Chromadorina germanica*) and Harpacticoid Copepod sp. in the cleaned plots.

Analyses of changes in abundance over time for the seven most abundant species (accounting for >50% of the total number of individuals) are reported in table 4. Univariate analyses on the individual species elucidate that, with exception for Oligochaeta sp., the abundances were not significantly influenced by Time. Four out of seven species; *Theristus otoplanobius*, *Harpacticoida* sp., *Chromadorina germanica* and *Trissonchulus benepapilosus* were significantly influenced by the experimental cleaning (Treatment) and showed a significant Time x Treatment interaction. Multivariate analysis of variance (MANOVA) revealed that meiofauna species composition was not significantly affected by Time; however exhibit a significant effect of the experimental cleaning as well as a significant Time x Treatment interaction effect. The combination of both uni- and multivariate analyses demonstrated that there is evidence that, although there are no statistically significant changes in diversity measurements, there were changes in individual species abundances because of the experimental cleaning, *i.e.* the composition structure of the meiofaunal assemblage varies significantly in time because of the experimental cleaning. (Table 4)

The non-metric multi-dimensional scaling ordination plot clearly indicated a split between control and cleaned plots from immediately after the cleaning onwards and thus closely mirrored the results from the ANOSIM. Samples collected 11 hours and 23 hours after experimental cleaning clustered more or less together, suggesting a more similar (recovered) fauna. (Figure 7)

	Time			Treatment			Time x Treatment		
Univariate test	df	F	p	df	F	p	df	F	p
Theristus otoplanobius	7	1.220	0.319	1	10.896	0.002	7	0.813	0.048
Harpacticoida sp.	7	6.673	0.613	1	3.728	<0.001	7	0.748	0.036
Onyx saggittarius	7	1.670	0.167	1	0.280	0.600	7	1.258	0.302
Oligochaeta sp.	7	14.251	<0.001	1	0.166	0.686	7	0.860	0.517
Chromadorina germanica	7	10.800	0.362	1	0.851	<0.001	7	0.597	0.002
Hypodontolaimus schuurmansstekhoveni	7	1.516	0.209	1	0.002	0.963	7	2.175	0.079
Trissonchulus benepapilosus	7	12.855	0.346	1	0.911	<0.001	7	1.034	0.013
Multivariate test	7	3.106	0.209	1	2.601	<0.001	7	1.214	<0.001

Table 4: Univariate and Multivariate ANOVA test based on square-root transformed abundance data for the 7 most abundant species.

Figure 7: Non-parametric multidimensional scaling (MDS) ordination for meiofaunal assemblages collected from control and cleaned samples at several sampling occasions before and after experimental cleaning. (based on square-root transformed species abundance data) (n=5)

DISCUSSION

The strandline meiofaunal assemblages

Results from this study indicate that strandline-related meiofaunal assemblages are species rich, even with only the nematodes identified at species level. Recorded abundances at the un-cleaned control plots (on average 509 ± 60 Ind/10 cm²) were seen to be equal over time, which is in contrast with literature where rapid increase after a new deposit of wrack is often reported. (*e.g.* McGwynne *et al.* 1988 report an average abundance of 1712 Ind/10 cm² on a sparse-wrack sandy beach in South Africa). Alkemade and Van Rijswijk (1993) stated that the number of nematodes associated with wrack is depending on the height on the beach and the Carbon/Nitrogen ratio. They recorded significant higher abundances as the nitrogen content increased relative to the carbon content and for material higher on the beach (the higher a wrack deposit is located on the beach, the longer it is presumably present on the beach). As the strandline and the stranded material studied in this paper were freshly deposited, we can assume C/N values are high and this may explain the general low nematode and meiofaunal abundances in comparison with other strandline studies. High C/N values may also explain the low densities of dipteral larvae in our samples compared other studies (Colombini *et al.* 2000).

At first sight the presence of oligochaetes as third-largest group seems unexpected as meiofaunal studies usually record oligochaetes only in very small numbers (Higgins and Thiel 1988). However, when searching the literature (Giere and Plannkuche 1982; Koop and Griffiths 1982, McLachlan 1985, McGwynne *et al.* 1988, Jedrzejczak 2002a, b) oligochaetes are generally found to be a high-abundance taxon in assemblages associated with decomposing wrack accumulations or in the sand beneath wrack. Giere (1975) and Koop and Griffiths (1982) indicate that the presence of high numbers of both nematodes and oligochaetes are directly related to the distribution of wrack, below which concentrations of Dissolved Organic Matter (DOM) can be high, and suggested that meiofauna use this as a direct food source. However, following McLachlan (1985), the possibility that the DOM is initially used by bacteria, which in turn are used a food source by the meiofauna cannot be precluded. Moens and Vincx (1996) assumed that meiofauna is not able compete for DOM with bacteria in view of their much longer turnover times. Jedrzejczak (2002a) suggested that oligochaetes feed on the metabolites of the other meiofaunal groups rather than directly on bacteria or DOM.

During this study, 55 different species of free-living nematodes were recorded in the strandline. 34 Species were only recorded sporadically or in very low abundances (0.1% of total recordings). *Theristus otoplanobius* (35%) was found to be the dominant nematode species and this is in concordance with earlier studies on this beach (Gheskiere *et al.* 2002). Little is known about the structure of the strandline nematode assemblages from other places with exception of the Antarctic strandline study of Alkemade and Van Rijswijk (1993) where eight nematode species were recorded. Only *Pellioditis marina* and *Monhystera disjuncta* were found to be in common with this study. *P. marina* has a cosmopolitan distribution and is

typically associated with stranded decomposing wrack (Inglis and Coles 1961, Inglis 1966). Two other genera that are frequently reported in literature as 'associated with decomposing matter and/or high shore', namely *Diplolaimella* and *Diplolaimelloides* (Bouwman *et al.* 1984; Warwick 1976) were not recorded. The fact that strandline studied here was fresh and decomposition was thus in a very initial phase could possibly explain the low abundances of *P. marina* and the absence of the two above-mentioned genera. Nevertheless, it is remarkably that 55 different nematode species can coexist in such a narrow stripe on the beach. One explanation may be that the general high bacterial and protist diversity associated with the strandline deposited wrack (Olanczuk-Neyman and Jankowska 1998, Armstrong *et al.* 2000), combined with the high habitat heterogeneity and good water percolation, result in attractive and diverse bacterial '*aufwuchs*'. Seeing that nematodes are highly able to partition their environment extensively in various ways (*e.g.* food partitioning (Platt and Warwick 1980)), these bacterial '*aufwuchs*' can support species rich nematode assemblages.

Impact of cleaning

BACI designs have been widely used in environmental impact studies on the mean abundances of populations as well as on the community structure (*e.g.* Drabsch *et al.* 2001; Schratzberger *et al.* 2002). The principle of a BACI design is that a disturbance at the impacted plots will cause a different pattern of change from compared with natural change at the control plots (Underwood 1997). With the sampling intensity of this experiment, the power to detect specified changes in density, richness, evenness and taxonomic structure is generally high and therefore all are effective in detecting changes due to experimental cleaning. In other words, the risk of conducting a type II error (assuming no impact exists when in fact it does) is low. Beach cleaning (or beach grooming) is only a recent phenomenon in the coastal environment and so are the studies about the impacts. To date all studies have been concentrated on changes in abundance at macrofauna level (*e.g.* Davidson *et al.* 1991; Kirby 1992; Llewellyn and Shackley; 1996, Lavery *et al.* 1999; Dugan *et al.* 2003), whereas meiofauna have been largely neglected. After an extensive survey of 15 Californian strandlines Dugan *et al.* (2003) concluded that significant differences in community structure, including depressed species richness, abundance, and biomass of macrofauna were associated with beach grooming. This was most obvious for the typical wrack-associated herbivore taxa (talitrid amphipods, kelp flies and coleopterans) which are important prey for vertebrate predators, such as several species of shorebirds and insectivorous passerines. Malm *et al.* (2004) noted that the organic content of the sand (%TOM) was significantly reduced by beach cleaning, which is in accordance with our results. They suggested that the largest impact of beach cleaning seems to occur at the microbiological level, with a substantial reduction of the bacterial production and significantly less large ciliates at the cleaned beach, compared with the un-cleaned beach. Our cleaning experiment at the strandline of De Panne showed that there were no impacts of the beach cleaning on univariate measurements such as diversity, evenness and the taxonomic diversity. The only measurable impacts that could be attributed to the cleaning

were an immediate decrease in faunal density and change of assemblage structure. As the decrease in meiofaunal density relative to the control was 43%, this impact cannot be considered as ecologically significant. The multivariate species-dependent MDS ordination was seen to be more sensitive in discriminating the assemblages collected at both treatment and control plots, suggesting that the dominance relationships among species had changed at the treatment plots compared to the controls. The results of this study contrasted with the above-mentioned studies, which generally recorded, in addition to an immediate decreased number of individuals, a depressed biodiversity and even a complete disappearance of some species at cleaned sites compared to non-cleaned ones. These macrofauna studies, however, included many more taxa and a much wide range of size classes compared to the present study.

Since meiofauna are among the smallest animals in benthic ecosystems and have very fast turnover times, they may be expected to show little responses to beach cleaning, as they are less susceptible to the brooms or mixers on the cleaners and can easily pass through the sieves (30 mm). Indeed, intuitively one may suspect that the susceptibility of species to beach cleaning/grooming is largely determined by their body size and turnover, with large slowly reproducing species being more susceptible than smaller, faster reproducing ones. In this respect, it is not unexpected that some of the larger nematode species like *Trissonchulus benepapilosus* (body length: 2.5-3.2 mm, Van der Heiden 1976) are significantly affected by the cleaning as they are probably crushed by the mixer. The fact that harpacticoid copepods are affected by the cleaning is also not unusual, as the crustacean meiofauna regularly seems to be the most affected in perturbation studies, mainly because of their fragile body parts (Coull 1988).

Resilience of ecosystems (*i.e.* the rate, manner and pace of restoration of initial structure and function in an ecosystem after disturbance), *sensu* Westman (1978) has become a subject of growing importance in stress ecology studies. Due to ever-increasing technology and greater risks of catastrophic human-induced disturbances, studies discovering the recovery rates of a variety of ecosystems are being actively explored (*e.g.* recovery after deposit of dredged material by Schratzberger *et al.* 2004a). Samples collected immediately after the high water following the cleaning (T_{11}) revealed that meiofaunal abundances were again at initial values. Such fast recolonization rates of meiofauna have been recorded frequently in literature. After a mechanically induced disturbance, Sherman and Coull (1980) observed that meiofaunal densities reached the same levels as those at the control sites after just 12 hours. Sun and Fleeger (1994) reported during an investigation of meiofaunal colonization into mimic sediment depressions that abundances of the dominant copepods showed no significant differences between experimental and control sediments after 24-48 h. Le Guellec (1988), working with exogenous sand, reported similar densities at experimental and control plots after two tidal cycles. All these studies suggest somewhat a restoring effect of the tides as it is indeed very unlikely that meiofaunal organisms can crawl distances in only hours (Schratzberger *et al.* 2004b). The tidal rise and fall across the intertidal region of a sandy beach produces an alternately land-directed and then seaward-directed hydraulic gradient at the frequency of the local tides. Following Darcy's law (describing the flow through a porous medium such as sand), this necessitates the flow of water into and out the beach (Manning 1997). Due to the ability of sea water on the upcoming tide to infiltrate vertically into a beach much more rapidly than it can drain nearer horizontally on the falling tide (Neilsen 1990), there is a tendency for elevation of the beach water table above the mean sea level. Water

input therefore only occurs when the elevation of the tide exceeds the elevation of the beach water table, thus water input occurs on the rising tide and water discharge mainly on the ongoing tide. As the beach of De Panne is an ultra-dissipative flat sandy beach, the ground water table is close to the sediment surface (Lebbe 1981, Gheskiere *et al.* 2004). Together with the elevation of the water table as the tide raises, probably also the interstitial meiofauna from deeper layers is elevated to the upper layers (*i.e.* passive vertical migration). This hypothesis is supported by the study of Van de Velde (2002) who noted during a survey of the vertical meiofaunal distribution of the same strandline that there are no significant differences in meiofaunal assemblage between the upper 0-5 cm layer and the 5-10 cm layer. Since the water table from the studied beach is known to harbour several terrestrial and brackish water nematodes (*e.g. Pellioditis marina, Aporcellaimus* sp.) (Gheskiere *et al.* 2004), this may explain the peak in taxonomic diversity in the samples immediately after the high tides (T_{-1}, T_{11}, T_{23}). At first thought, recolonization via water column migration seems also a possibility. Hagerman and Rieger (1981) and Savidge and Taghon (1988) gave evidence for this as they found that considerable portions of interstitial meiofauna were suspended in the water column by shoaling and breaking waves. Ullberg and Olafsson (2003a) suggest that settling of suspend marine, free-living, benthic nematodes is not entirely a random or passive process since several, particularly very small, species, belonging to different genera and families, were clearly able to choose settling points through active swimming. However, for this cleaning experiment it seems very unlikely that the recolonization occurred via water column modes, mainly because of two reasons. (1) Erosion of meiofauna from sediments by shoaling and/or breaking waves is in the first place controlled by the friction velocity or shear stress (Palmer and Gust 1985, Ullberg and Olafsson 2003b). Seeing the morphodynamics of the studied beach and the location of the experiment on the beach (the strandline), the erosive force imparted by the flowing water on the bottom sediments is assumed to be extremely low (Short 1999) as on this type of beach wave energy is dissipated at a considerable distance from the shore (on the subtidal sandbanks). (2) The meiofaunal community of a strandline is a very narrow and sharply defined community, characterised with species which are absent on very ambient parts of the beach (Gheskiere *et al.* 2004). Thus, if passive erosion of meiofauna from elsewhere (lower) on the beach should have occurred, a different meiofauna should be found in the cleaned plots after the tides. This was certainly not the case as the experimental plots were recolonized by exactly the same strandline-specific meiofauna.

However, an active upward migration of nematodes from deeper sediment layers during submersion cannot be fully excluded. Steyaert *et al.* (2001) observed such species-specific active vertical movements of Enoplid nematodes in their search for food on a hydrodynamically benign tidal sand flat in the Westerschelde.

CONCLUSIONS

Concluding, we have demonstrated that total density, species-specific densities and assemblage structure are all significantly, although not ecologically significant, influenced by mechanical beach cleaning while number of species and taxonomic richness suffer no direct impacts. We assumed that recolonization occurred via passive vertical migration, forced by the upcoming tide, from the underlying sediment layers. These findings are based on a once-only, limited, small-scale cleaning experiment. Therefore, it would be unwise to generalize that strandline meiofauna recover quickly from mechanical beach cleaning. Deeper, more catastrophic or repeated cleanings may certainly result in much slower recolonization rates.

ACKNOWLEDGEMENTS

The Institute for the Promotion of Innovation through Science and Technology in Flanders (IWT-Vlaanderen) financially supported the first author.

The local authority of De Panne is acknowledged for facilitating sampling opportunities and use of the mechanical beach cleaner. Several persons assisted in the field and in the laboratory; special thanks to Robert Verstraete (driving the beach cleaner), Henni Hampel, Maarten Raes, Guy De Smet (sampling), Annick Van Kenhove (nematode slides) and Daniëlle Schram (granulometry and %TOM analyses).

dr. Michaela Schratzberger (CEFAS, UK) and Prof. dr. Stefan Van Aelst (UGent) are acknowledged for advice on power analyses.