

NEMATODE ASSEMBLAGES FROM EUROPEAN SANDY BEACHES – DIVERSITY, ZONATION PATTERNS AND TOURIST IMPACTS

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Sandy beaches are among the most extensive intertidal systems worldwide (Short, 1999), dominating most temperate coastlines where they represent both important recreational assets and buffer zones against the physical forces of the sea (Davies, 1972; McLachlan, 1983). Sandy shores generally consist of three components: near shore zones, beaches and dunes which are linked by the interchange of material, particularly sand. Together they comprise a single geomorphic system, termed the littoral active zone (Tinley, 1985). This is the part of the coast characterised by wave- and wind-driven sand transport and it lies between the outer seaward limit of wave effects on bottom stability and the landward limit of aeolian sand transport (*i.e.* the landward edge of the active dunes). A remarkable feature of beaches as a habitat is its narrowness (e.g. 500 km of continuous sandy coast, covers only 5 to 10 km²). Partly due to their barren and arid appearance sandy beaches have not been regarded as vulnerable to human disturbance and, consequently, coastal tourism and recreational activities are increasing rapidly in developed countries since the last decades as people enjoy more leisure time and higher standards of living.

Pristine sandy beach sediments offer a considerable range and diversity of biotic habitats: horizontally, the sub-aerial (dunes and upper beach), the intertidal (swash zone/shoreline) and the subtidal area (surfzone and near-shore) while vertically there are pelagic, benthic and interstitial environments. These interstitial environments are directly determined by the sediment properties. Grain size, shape and sorting are cardinal factors in fixing porosity and permeability which influence water filtration or drainage. As the beach is the dynamic interface between the terrestrial and marine ecosystem, several biotic and abiotic gradients characterize this narrow interface. Most of the interstitial faunal research on sandy beaches has been mainly concentrated on macrofauna (all metazoans >1 mm) (McLachlan and Jaramillo, 1995 and references therein), while more recently also shore birds has become a well-studied group (e.g. Cornelius *et al.*, 2001).

In contrast, sandy beach meiofauna (all metazoans between 1 mm and 38 μ m) have received considerably less attention notwithstanding their high diversity (even at taxon level) and density [up to 1.106 individuals per square metre (McIntyre, 1969)] in sandy sediments. Usually, free-living nematodes dominate the meiofaunal communities of sandy sediments. Nematodes are theoretically an excellent taxon to use as ecological indicator of different kinds of natural and anthropogenic disturbances within benthic marine habitats (Heip *et al.*, 1985; Sandulli and De Nicola, 1991; Schratzberger *et al.*, 2000). Despite their high dominance within the meiofauna and their favourable features for using them as bio-indicators of environmental conditions, research on sandy beach nematodes is mainly restricted to treating nematodes as a single

taxonomic unit within the taxon-rich meiofauna although the phylum in itself has been considered as a diverse (Heip *et al.*, 1985) and possibly as a hyper-diverse taxon (Lamshead and Boucher, 2003) with a global distribution in soils and sediments.

Because of the limited knowledge of the meiofaunal life in European sandy beach ecosystems, a thorough survey of the species biodiversity patterns is one of the general aims of this thesis (Chapter II and Chapter III). Three different European sandy beaches were investigated: one in the North Sea, one in the Baltic Sea and one in the Mediterranean Sea region respectively. In the second part of the thesis, the impact(s) of tourism and tourism-related activities on the sandy beach meiofaunal assemblages were evaluated (Chapter IV and Chapter V). Comparisons were made between tourist and non-tourist (pristine) beaches in the Baltic (Poland) and in the Mediterranean (Italy) region and a short-term experiment with emphasis on the immediate effects of beach cleaning was conducted on the relatively undisturbed beach in front of the Westhoek nature reserve in De Panne (Belgium).

Community structure, intertidal zonation and feeding structure of nematode species across a macro-tidal, ultra-dissipative, sandy beach (De Panne, Belgium) were investigated in Chapter II [Gheskiere T., Hoste E., Vanaverbeke J., Vincx M., Degraer S. (2004). Horizontal zonation patterns and feeding structure of marine nematode assemblages on a macrotidal, ultra dissipative sandy beach (De Panne, Belgium). *Journal of Sea Research* 52:211-226]. A total of 88 free-living nematode species was recorded along the studied transects. Average nematode densities increased from the upper beach towards the low-tidal level, which corresponds well to the better-known macrobenthic patterns on sandy beaches. While macrobenthic species richness usually increases towards the low-tidal level, nematode species richness reached highest values around the mid-tidal level. This can be explained by an optimal balance between time of submergence, oxygen supply and sediment stability in this zone. Multivariate analyses indicated four different nematode assemblages that reflect the tidal zonation patterns: the upper beach, the strandline, the middle beach association and the lower beach association. The assemblages were significantly different from one another although similarities tended to increase down the beach, indicating a more gradual transition between the mid-tidal and low-tidal assemblages. Non-selective deposit feeders were found to be the dominant feeding type in all zones except in the strandline, where epistratum feeders were dominant. Percentage of very fine sand and percentage of shell fragments provided the best granulometric variables in determining these assemblages.

Spatial patterns of nematode community structure and biodiversity patterns from two geographically spaced, intermediate, micro-tidal beaches in the Mediterranean and Baltic area were investigated in Chapter III [Gheskiere T., Vincx M., Urban-Malinga B., Rossano C., Scapini F., Degraer S. (2005). Nematodes from wave-dominated sandy beaches: diversity, zonation patterns and testing of the isocommunities concept. *Estuarine, Coastal and Shelf Science* 62:365-375]. Differences in the nematode assemblages were found to be significant and related to the morphodynamic characteristics of the studied zones (upper beach, swash/breakers and subtidal). Highest nematode densities and species diversities were recorded on the coarse-grained, more physically controlled, Mediterranean beach in contrast to the fine-grained more chemically controlled Baltic beach. This is in contrast to the worldwide patterns of

macrofaunal communities. As demonstrated by higher taxonomic distinctness measurements, upper beaches were found to harbour species from both the marine and terrestrial ecosystem and are considered to be important ecotones between these adjacent systems. The swash/breaker zones were characterised by the loss of distinctive species, caused by the high water percolation in these zones. At the meiofauna level, Por (1964) was the first to report that the phenomenon of 'parallel level-bottom communities' or 'isocommunities' was not only restricted to macrofauna but that the homogeneity and parallelism was even more pronounced for meiofaunal assemblages. He stated that isocommunities are typical for benthic environments and are defined as ecological parallel assemblages: 'the same types of bottoms are everywhere inhabited by species of parallel animal communities in which different species, of the same genera, replace one another as the characterising species'. We showed that this concept was only supported for the upper beaches.

The study in Chapter IV [Gheskiere T., Vincx M., Weslawski J.M., Scapini F., Degraer S. (2005). Meiofauna as descriptor of tourism-induced changes at sandy beaches. *Marine Environmental Research* 60:245-265] demonstrated, in two different coastal systems (Mediterranean and Baltic), that tourism-related activities are particularly affecting the sandy beach meio- and nematofauna in the upper beach zone, the specific ecotone in which many meiofauna species from both the marine and the terrestrial environment co-exist. Tourist upper beaches were characterized by a lower % Total Organic Matter (%TOM), lower densities (absence of Insecta, Harpacticoida, Oligochaeta, terrestrial and marine Ironidae nematodes) and higher community stress compared to nearby pristine, non-tourist locations. The %TOM was found to be the single most important factor for the observed differences in meiofauna assemblage structure at tourist versus non-tourist beaches in both the Mediterranean and the Baltic region. The free-living nematode assemblages from tourist upper zones departed significantly from expectations based on random selections from the regional nematode species pool. Furthermore, upper zone assemblages were characterised by a much lower species diversity consisting of taxonomically closely related nematode species with r-strategist features. Faunal differences between tourist and non-tourist beaches were generally decreasing towards the lower beach zones.

In Chapter V [Gheskiere T., Vincx M., Pison G., Degraer S. (accepted). Are strandline meiofaunal assemblages affected by a once-only mechanical beach cleaning? Experimental findings. *Marine Environmental Research*], a field experiment, following a BACI design (Before-After Control- Impact design) was conducted at the strandline of De Panne (Belgium) to investigate the impact of mechanical beach cleaning on the strandline-associated meiofaunal assemblages. Natural strandline assemblages were exposed to a one-off 5 cm deep mechanical beach cleaning (which completely removed the strandline) and observed for 24 hours. The power of the experiment to detect ecologically significant effects (50% change is considered to be ecologically significant sensu Shaw *et al.* (1994) of mechanical beach-cleaning was assessed and a 99% chance of detecting a 50% change in total abundance, Pielou's evenness and taxonomic diversity and a 74% chance in detecting a 50% change in species richness was recorded. This illustrated the sound use of these biological factors in this field disturbance experiment. We have demonstrated that total density, species-specific densities and assemblage structure are all significantly (statistically but not ecologically)

influenced by mechanical beach cleaning, while any impacts due to cleaning on species richness, evenness and taxonomic diversity were showed to be minor in relation to the normal daily changes. Differences between cleaned plots and those from the uncleaned control plots were visible from immediately after the experimental cleaning onwards and came again to resemble those in the control plots after the following high waters. Recolonization of the cleaned sediments was assumed to occur 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. Further research should include, deeper, more catastrophic or repeated cleanings replicated on different strandlines and on dry parts of the beach, in different seasons, using different sieving machines to further elucidate the impact of these cleaning machines on the beach biota. It is also difficult to assess the contribution of beach cleaning activities to the noticed decrease in diversity on the tourist upper beaches studied in Chapter IV as beach cleaning is only a part of the human-induced disturbances on these tourist beaches (next to human trampling, destruction of dunes,...).

Summarizing we conclude that nematode species assemblages show zoned distribution patterns (reflecting the tidal zonation) across sandy beaches; coarser and more physically-controlled beaches harbour higher meiofaunal densities and diversities than fine grained chemically-controlled ones; isocommunities only exist on the upper beach parts, which are considered to be important ecotones between the terrestrial and the marine environment and tourist or tourist-related activities mainly impact the upper beach zones.