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The influence of human activities and environmental factors on the presence of four dominant intertidal macro invertebrates on Dutch sandy beaches

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The Dutch coast is one of the most densely populated in the world, resulting in high pressures of human activities. On the beach this results in recreational activities like sunbathing and all kinds of water related activities (i.e. wind- and kite surfing). Moreover, due to coastal squeeze, many parts of the Dutch coast are subject to erosion. Because of that, since 1990, beach and foreshore nourishments have been taking place to counteract the erosional effects.

Basic ecological research on Dutch sandy beaches up to now has focussed on zonation patterns of macro invertebrates and differences in abundance and species richness between beaches have been related to abiotic factors. However, how macro invertebrate fauna on different beaches are influenced beach nourishments and other human pressures, additional to their abiotic and physical environment has not yet been investigated on Dutch sandy beaches.

There have been several investigations on the effects of single beach nourishments on macro invertebrate fauna, usually based on BACI like designs. Results were variable and in some cases no complete recovery of the fauna was reached at the end of the research period. To try to get some idea of the recovery of macro invertebrate fauna after beach nourishment, a different approach was adopted.

Beaches along the entire Dutch coast were sampled in a chronosequential manner. Thirteen beaches were nourished at different points in time and had different intensities of recreation. Also 4 control beaches were sampled where no nourishment had ever taken place and with low recreation intensities. For calculation purposes, the date of the control beaches was set on 1990: this year is, also in management, used as the baseline for the Dutch coast. The beaches and nourishment years were evenly respectively randomly distributed over the three main coastal areas: the Wadden Sea Islands, the Dutch main coast and the Delta area. We looked at four dominant intertidal species on Dutch beaches: *Scolelepis squamata* (adults and juveniles), *Eurydice pulchra, Haustorius arenarius and Bathyporeia sarsi*. Twenty samples per beach (20 cm diameter, 20 cm deep) were taken in a stratified random design, located between Mean High Water and Mean Tidal Level, according to the zonation of the sampled species. Several abiotic and physical variables were also measured, next to variables related to the mentioned human influences. To assess the effects of beach nourishments on the fauna, single and multiple regression was used. To relate the species to their environment redundancy analysis (RDA) was used.

Single regression analysis on the years of nourishment and each of the individual species all gave non-significant results with regression coefficients approaching zero. Exploration of the data showed a latitudinal effect for *S. squamata*. To account for this effect, a multiple regression was done with year and latitude and each of the species (Table I).

The results of the total model were highly significant for *S. squamata* with high regression coefficients. The partial regressions for both factors were significant or showed a very strong trend (year for the adults). The positive Beta coefficients show that *S. squamata* is positively affected by the beach nourishments. *S. squamata* profits from this disturbance and this is an indication that the species may be an opportunistic species. The model was not significant for the other species. Latitude seems to play some role for *B. sarsi* since it was close to significant.

The RDA showed that the total species variance explained by the environmental variables is 94%. A forward selection procedure with Monte Carlo permutation tests revealed that latitude, wave period, moisture and grain size contributed (almost) significantly to the variation in the total species data (p-values respectively: 0.002, 0.010, 0.044, 0.054). However, there are also species specific differences (Fig. 1), where the reactions to the environment of *S. squamata* versus the three crustacean species are almost independent of each other.

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S. squamata is mainly affected by latitude and wave characteristics (breaker height and wave period), while the amphipods *H. arenarius* and *B. sarsi* are, next to waves, are also affected by beach characteristics (moisture and slope resp. sand sorting). *H. arenarius* is also affected by spring tidal range. For *E. pulchra* beach characteristics (grain size, slope, moisture) are most important, while recreation negatively affects both *E. pulchra* and *B. sarsi*.

The overall results showed that from this investigation, there seem to be no negative effects of beach nourishments on the investigated species. *S. squamata* even profits from the nourishments. Recreation negatively affects two of the species.

Latitude is important for *S. squamata*, there might be some underlying factor that drives this, but this is not clear yet. The environment that affects the species mainly are physical factors that are linked to beach morphology, as is shown by many other researchers. The true abiotic factors seem to be less important.

Table I: Results of multiple regression analysis with year and latitude per individual species. Significant results are indicated in bold, nearly significant results are underlined.

	Total model		Year		Latitude	
Species	R^2	p	Beta coeff.	p	Beta coeff.	p
*S. squamata (*adults)	0,730	**0,000**	0,295	0,059	0,878	**0,000**
S. squamata (juveniles)	0,584	**0,002**	0,397	**0,043**	0,759	**0,001**
H. arenarius	0,159	0,298	-0,255	0,330	-0,376	0,160
E. pulchra	0,048	0,707	-0,114	0,677	0,161	0,559
B. sarsi	0,197	0,215	-0,077	0,761	-0,457	0,086

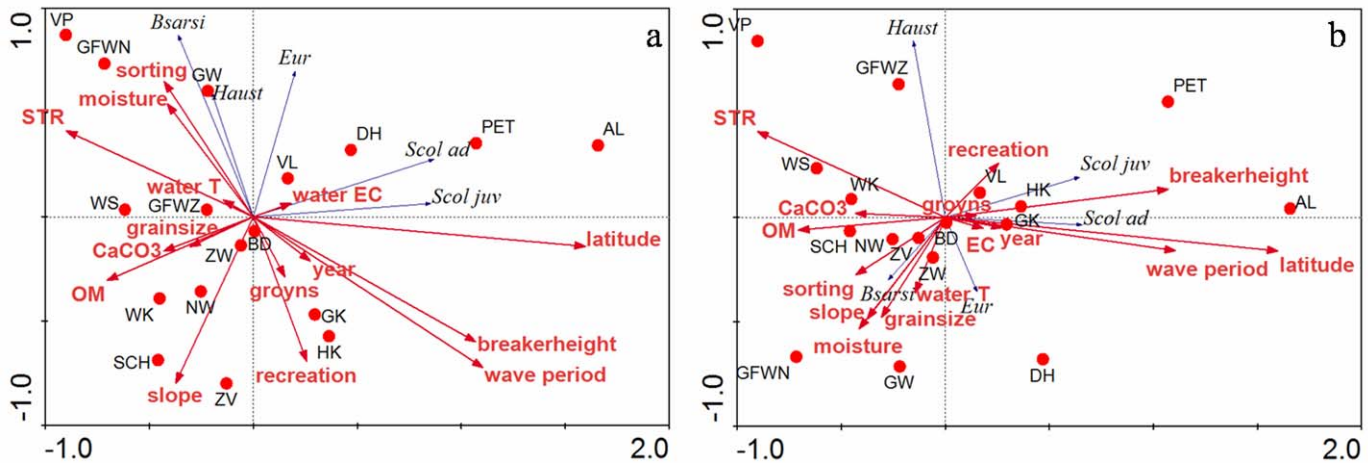

Figure 1: RDA ordination triplot with axes 1 and 2 (a) and axes 1 and 3 (b). Shown are species arrows (five in total, thin lines, text in italic), environmental arrows (fifteen, thicker arrows, text in bold) and samples (seventeen, after investigated beaches, dots with beach name codes, not mentioned in text). Species codes: *Scol ad: S. squamata* adults, *Scol juv: S. squamata* juveniles, *Haust: H. arenarius*, *Eur: E. pulchra*, *Bsarsi: B. sars*i. Axes 1 to 4 (axis 4 not shown) explain respectively 39%, 24%, 18% and 11% in the total of 94% explained species variation.