PRODUS 3: Interim Report:

The effect of mussel seed fishing on benthic communities in the Wadden Sea

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Samenvatting

Om het mogelijke effect van mosselzaadvissen op de bodembewonende levensgemeenschappen van de Wadden Zee te onderzoeken, werden op verschillende locaties verdeeld over het gebied grootschalig monsters met sedimentbaggermachines genomen. Elke locatie werd in twee aangrenzende monsterstations verdeeld, één open voor visserij en het andere dicht voor visserij. Alle organismen gevonden in de monsters werden geïdentificeerd en geregistreerd voor en na visserij die in het voorjaar en najaar van 2007 tot 2009 had plaatsgevonden.

Dit rapport is een interim en preliminaire studie van de eerste dataverkenning. Enkel locaties met een verwachte afname in mosselbiomassa in het gevist bemonstering station na visserij werd meegenomen in de analyse om andere variabelen zo veel mogelijk uit te sluiten. De vergelijking met de overige locaties zal in een volgende rapportage plaatsvinden. Er was een grote variatie in gemeenschapscompositie tussen plaatsen met geen duidelijke trend. De verandering in gemeenschapscompositie, soortrijkdom, verscheidenheid en 'evenness' van voor tot na het visserij was ook zeer veranderlijk tussen locaties. Verdere analyse van het volledige gegevensstel is vereist voordat algemene conclusies over het effect van mosselzaadvissen op bodembewonende levensgemeenschappen kunnen worden getrokken.

Summary

To investigate the possible effect of mussel seed fishing on the benthic communities of the Wadden Sea, large scale sampling using sediment dredges was conducted in various sites distributed throughout the area. Each site was divided into two adjacent sampling stations, one open to fishing activity and other closed to fishing. All organisms found in the samples were identified and recorded both before and after fishing had taken place during both Spring and Autumn from 2007 to 2009.

The present report is an interim and preliminary study of the initial data exploration. Only sites with an expected decrease in mussel biomass in the fished sampling station after fishing were included in the analysis to exclude other variables as much as possible. There was a wide variation in community composition between sites with no obvious trend. The change in community composition, species richness, diversity and evenness from before to after fishing had taken place was also highly variable between sites. Further analysis of the complete data set is required before general conclusions about the effect of mussel seed fishing on benthic communities can be made.

1 Introduction

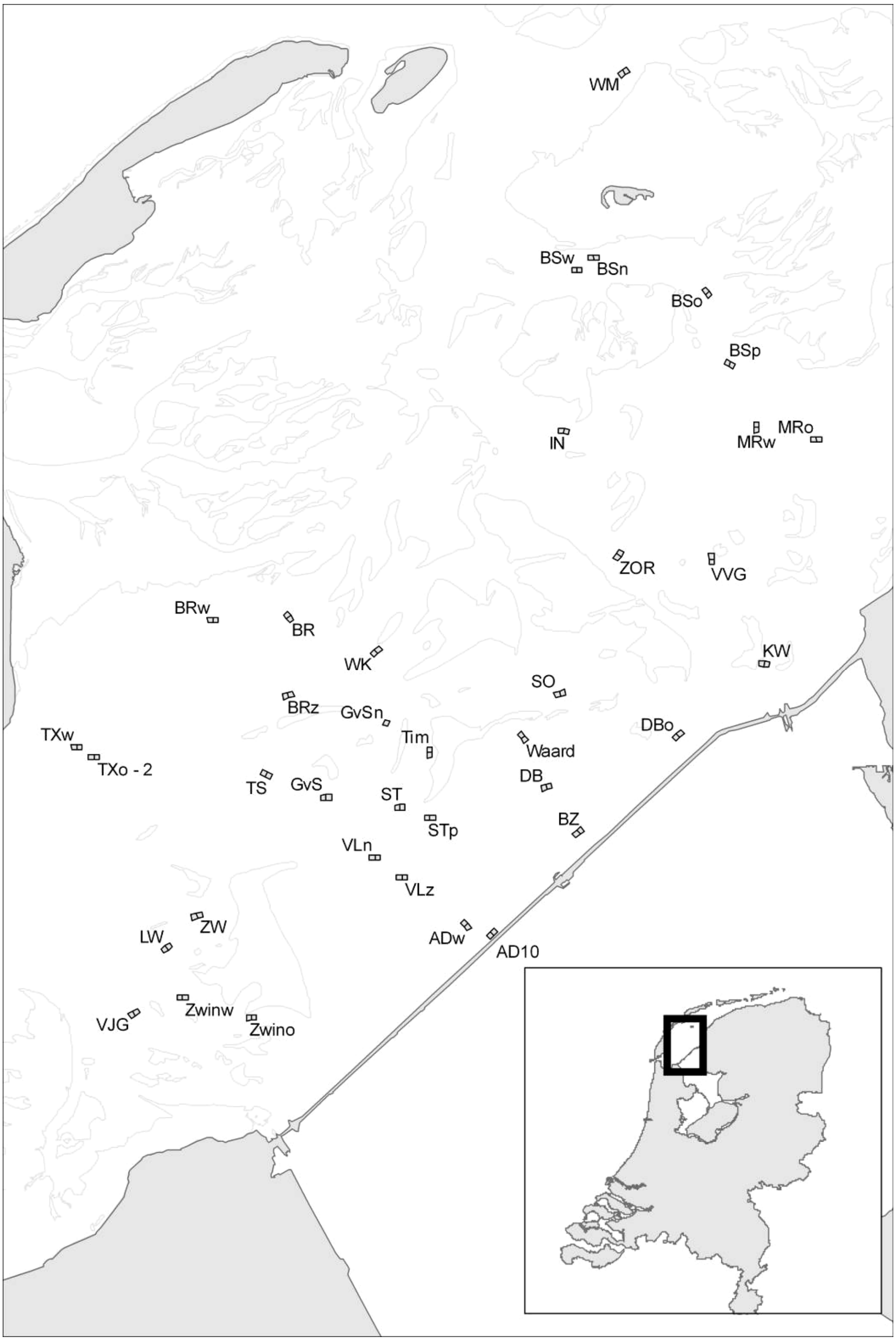
Mussel seed fishing in the Wadden Sea is a regular and widespread activity for the aquaculture industry. Using dredges to recover mussel seed risks disturbing and damaging the benthos as well as the benthic communities that exist there. These risks may vary between years and seasons, and between individual species within the community. Dredging may destroy vulnerable, slow-growing organisms while creating space for opportunistic organisms to take their place, and therefore alter the whole community structure.

This study is part of the PRODUS project (REF) that study investigates the effect of fishing on the benthic communities in the Wadden Sea. Within the context of PRODUS changes in biodiversity are studied in several ways. The current report is an interim report on the initial exploration of the data collected with an hydraulic dredge with the intention of identifying the possible variables for future use in data modelling. This research is financed by the Dutch Ministry of Agriculture, Nature and Food Quality (LNV) as part of the Produs research program (BO 02-012).

2 Materials and Methods

2.1 Locations

Within the Wadden Sea, 37 sites dispersed throughout the area were sampled (see Map 1 and Appendix A). In each site, two adjacent sampling stations, squares of 40000 m^2 each, were measured and labelled as either a reference station (Ref) or a fished station (Viss). Fishing only occurred in the Viss station and the Ref station was kept as a control.



Map 1. Locations of sampling stations in the Wadden Sea (for full names of locations and coordinates see Appendix A).

2.2 Sampling

Initial sampling prior to fishing (T0) was conducted in both the Ref and Viss stations in the spring (voorjaar) and autumn (najaar) of 2007-2009, and then again in both stations following fishing of the Viss stations (T1).

Samples were collected using a hydraulic dredge which takes 30 m^2 over 150 m. In deeper plots a standard dredge was used, which takes 15 m^2 over 150 m. The gaps in the dredge sieve allowed for all organisms larger than 5 mm^2 to be retained in the sample. Samples were sorted on the vessel and all organisms were identified and recorded.

2.3 Data Analysis

Of the 37 sites, sampling results for 29 sites were available for inclusion in the data. To Analyse the data collected and gain an indication of the effect of fishing on benthic communities, comparisons were made between sites, stations and treatments. Although not all organisms (e.g. Actinaria) were identified to species level, the lowest taxonomic groups to which all organisms were identified is referred to as 'species' in this report for ease of comparison and discussion.

2.3.1 Mussel Biomass

1. In order to eliminate variables other than fishing, sampling stations needed to be separated between those with the expected decrease in mussel biomass after fishing and those where mussel biomass did not decrease as expected and were therefore likely to have been affected by currently unknown factors. The initial step in data analysis therefore was to explore the effect of fishing on mussel biomass across sampling stations.

   In a dynamic system such as the Wadden Sea many factors other than mussel seed fisheries may cause seedbeds to disappear or benthic communities to change. As a result, some research sites did not show a decrease in mussel biomass after fishing. The current analysis does not intend to identify a mean effect of seed fisheries, but to unravel and explore a potential effect of the removal of seed mussels by fisheries and also lead to the possible identification of potential variables that may influence the results.

   For an initial indication of mussel biomass before and after fishing, all stations were pooled and mean mussel biomass in each treatment situation was compared (Figure 1).

2. For a more accurate indication of the effects of fishing on mussel biomass excluding other variables, all stations with comparable T0 and T1 Ref and Viss data (i.e. no missing data for either treatment) were selected and the differences in mussel biomass between T0 and T1 were calculated (mussel biomass T1 – mussel biomass T0).

3. Sampling sites were then separated between those where other variables may influence the results and those where fishing was likely to be the major cause of decreased mussel biomass.
   The parameters used to select sites where fishing is likely to have caused a reduction in mussel biomass were:
   a. Sites where the difference in mussel biomass between T0 and T1 Viss stations was below -1000 (i.e. mussel biomass reduced by over 1000 g/m^2 after fishing).
   b. Sites where the difference in mussel biomass in the Ref station was higher than -1000 g/m^2 (i.e. mussel biomass barely changed or increased in T1).
   c. Sites where the difference in mussel biomass in the Ref and Viss stations differed by more than 1000 g/m^2 (i.e. there was a definite difference between the fished and non-fished Reference sites at the same station)

   The threshold of 1000 g/m^2 was chosen arbitrarily to define a significant change in mussel biomass in a station.

Only sites fitting the above parameters were used in all following data analysis. Those stations not fitting the parameters (i.e. mussel biomass reduced by less than 1000 g/m^2 or increased in T1) were not included in the following analyses as other variables are likely to have influenced their results and will therefore require statistical modelling.

4. The difference in mussel biomass between T0 and T1 for sites that fitted the parameters of reduced mussel biomass after fishing were compared (Figure 2).

5. The mean mussel biomass in each treatment situation was compared again, but only for selected stations (Figure 3).

2.3.2 Community Composition

6. The difference in species richness (number of species) between T0 and T1 in each of the selected sites was calculated and compared (Figure 4).

7. The selected sites were pooled and the total N/m^2 was calculated for each species (excluding mussels, *Mytilus edulis*) and compared between T0 – T1 and Ref – Viss sites (Figure 5). Because of their dominance in the graph, two species, *Cerastoderma edule* and *Mya arenaria* were removed from the graph to more easily view the results of the other species (Figure 6).

8. With stations pooled, the proportion of the total number of individuals for each species in each treatment was compared (Figure 7).

2.3.3 Diversity Indices

9. To gain an indication of species diversity, the Shannon-Wiener Diversity Index was applied to the data with the equation:

$$H = - \Sigma\, p_i \ln (p_i)$$

Where p_i is the relative abundance of each species, calculated as the proportion of individuals of a given species to the total number of individuals in the community. This index measures the species composition of a sample by adding the relative abundance of each species. Greater scores indicate higher species diversity.

Evenness was also calculated with the equation:

$$E = H / \log(S)$$

Where S is the species richness (number of species). Evenness is the measure of how similar the abundances of different species are. When the proportions of all species in the sample are similar, evenness is high, while when the proportions are very dissimilar (some rare and some common species) the value decreases.
Mytilus edulis was included in these initial calculations.

10. The differences in Shannon-Wiener Diversity scores and Evenness scores between T0 and T1 at corresponding Ref and Viss stations at each site were compared (Figure 8 and Figure 9).

11. All stations were then pooled and the mean Shannon-Wiener index and Evenness scores were compared between treatments with *Mytilus edulis* included (Figure 10).

12. Steps 9. and 10. were repeated after *Mytilus edulis* was removed from the calculations (Figure 11 and Figure 13).

13. The Simpsons Index of Diversity was calculated as an additional indication of species diversity (excluding mussels) with the equation:

$$D = (\Sigma (n / N)^2)$$

The Simpson's Index of Diversity measures the probability that two individuals randomly selected from a sample will belong to the same species. We use 1-D (i.e. the probability that two individuals randomly selected from a sample will belong to different species) here for a more logical interpretation where a greater value indicates a greater sample diversity.

14. The Simpson's index of Diversity scores were compared between T0 and T1 for each station (Figure 14). Stations were then pooled and the indices compared between treatments (Figure 15).

15. The Shannon-Wiener and Simpson's indices were then compared for each Ref station (Figure 16) and each Viss station (Figure 17).

16. The Shannon-Wiener and Simpsons indices were then compared for pooled sites (Figure 18).

3 Results

3.1 Mussel Biomass

With all data pooled, Viss – T1 has considerably lower total mussel biomass than the other treatments. However, the standard error bars in Viss – T0 and Viss – T1 overlap, suggesting that the difference between T0 and T1 in the pooled Viss stations may not be significant (Figure 1).

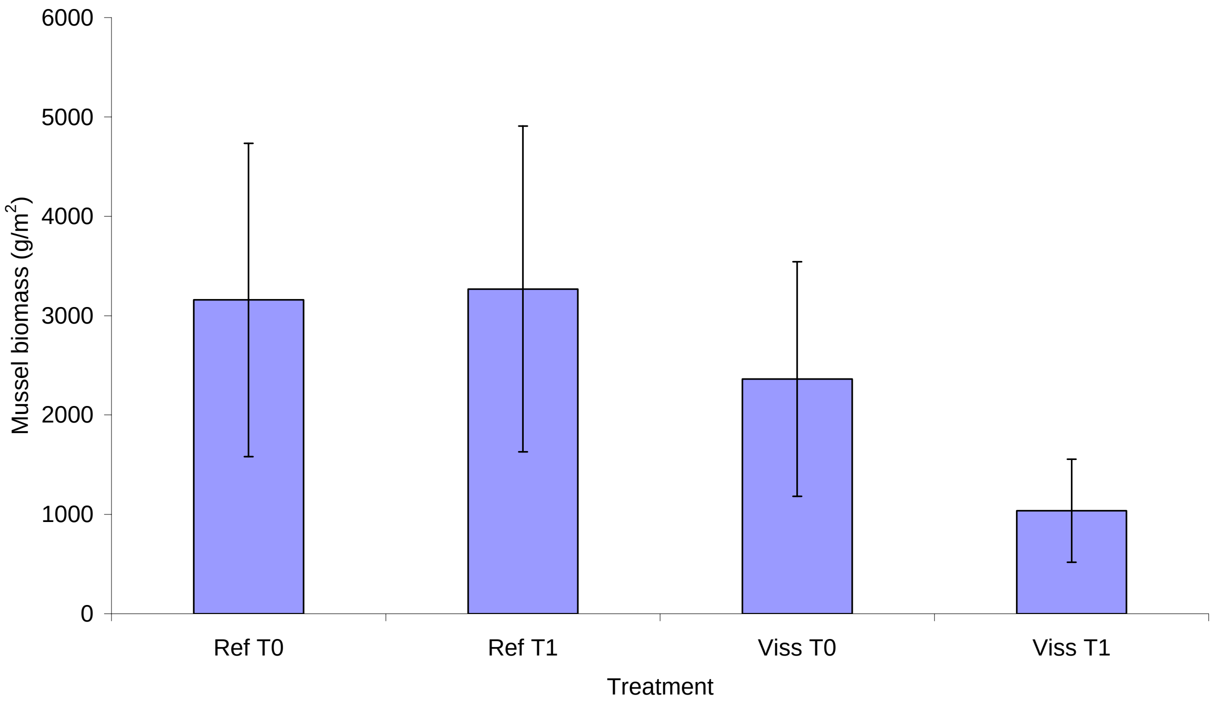


Figure 1. Comparsion of mussel biomass in all stations data between treatments.

Fifteen sites were found to fit the selection parameters (Table 1). When the sites fitting the parameters of expected decrease in mussel biomass after fishing were selected, the difference in mussel biomass differed between sites (Figure 2). The differences were often somewhat proportional to the increase in mussel biomass in the corresponding Ref station, for example site GvS xN had a small increase in mussel biomass in the Ref station of 2248 g/m^2, and also a small decrease in mussel biomass in the Viss station of 2071 g/m^2. Site Dbo xN showed a large increase in mussel biomass in the Ref site of 11 222 g/m^2 and also a large decrease in mussel biomass in the Viss station of 7796 g/m^2.

Five stations (ST-p xN, AD-w xZ, MR-w xN, Tlm xO and MR-O xN) showed a relatively stable mussel biomass in the Ref stations between T0 and T1 (i.e. little difference), but a comparatively large decrease in mussel biomass in the corresponding Viss stations.

Table 1. Sampling locations fitting the selection parameters.

Code	Location Name	Year	Season
GvS xN	Gat van Stompe noord	2007	najaar
ST-p xN	Stompe percelen noord	2007	najaar
AD-w xZ	A'dijk west	2007	voorjaar
MR-w xN	Molenrak west	2007	voorjaar
VJG xZ	Visjagersgaatje zuid	2007	voorjaar
Tim xO	Timmekesplaat oost	2008	najaar
MR-o xN	Molenrak oost noord	2008	voorjaar
VVG xN	Verversgat noord	2008	voorjaar
AD10 xW	Afsluitdijk - AD10 west	2009	voorjaar
BZ xO	Breezanddijk oost	2009	voorjaar
BZ xW	Breezanddijk west	2009	voorjaar
Dbo xN	Doove Balg oost (DB23) noord	2009	voorjaar
Dbo xZ	Doove Balg oost (DB23) zuid	2009	voorjaar
KW xO	Kornwerd - Boontjes oost	2009	voorjaar
KW xW	Kornwerd - Boontjes west	2009	voorjaar

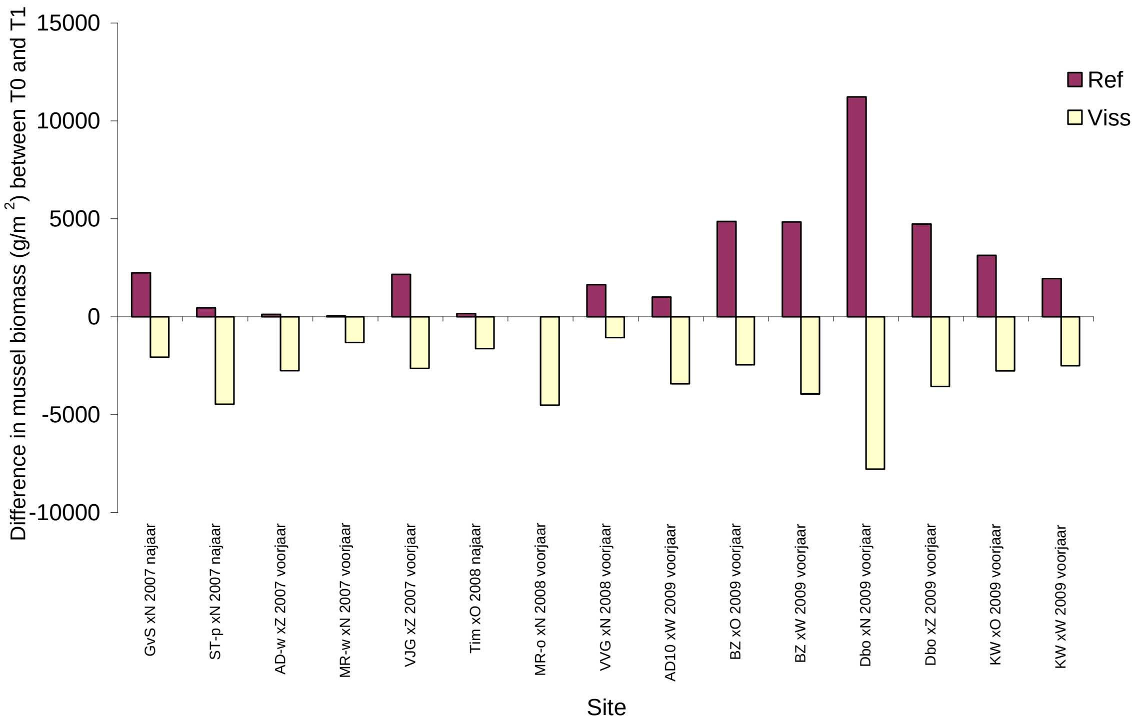


Figure 2. Difference in mussel biomass between T0 and T1 at corresponding Ref and Viss sites at each selected station.

When only the selected stations were considered, there was a much more prominent and significant difference between Viss – T1 (mean of 5343 g/m^2) and Viss – T0 (mean of 566 g/m^2) (Figure 3). Mussel biomass increased in the Ref station between T0 and T1, (from a mean of 2771 g/m^2 in T0 to 3694 g/m^2 in T1) while mussel biomass in Viss – T0 was greater than in either Ref station.

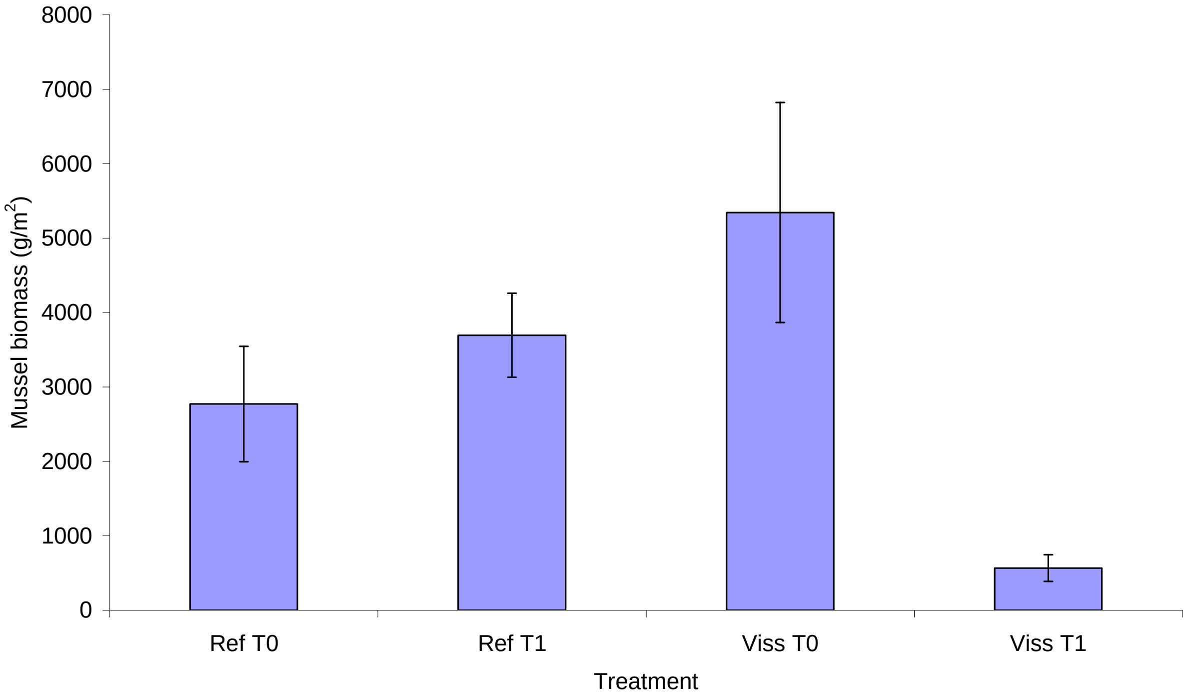


Figure 3. Comparsion of mussel biomass in selected site between treatments.

3.2 Community composition

Differences in species richness in both Ref and Viss stations between T0 and T1 varied in different sites. In most sites, species richness decreased in the Viss station after fishing, however in three sites (Db-o xN, Db-o xZ and MR-o xN) species richness increased in T1. In these three sites, change in species richness in the Ref station was different; in Db-o xN species richness decreased in the Ref station, in Db-o xZ species richness increased in the Ref station identically to the Viss station, and in MR-o xN there was no change in species richness in the Ref station.

In Ad10 xW and VVGxN species richness decreased by one in the Viss stations and increased by six and four species in the Ref sites respectively.

In KW xW and Ad-w xZ there was no change in species richness in the Viss station, but an increase in the Ref station, while in BZ xO species richness decreased by two in both the Ref and Viss stations.

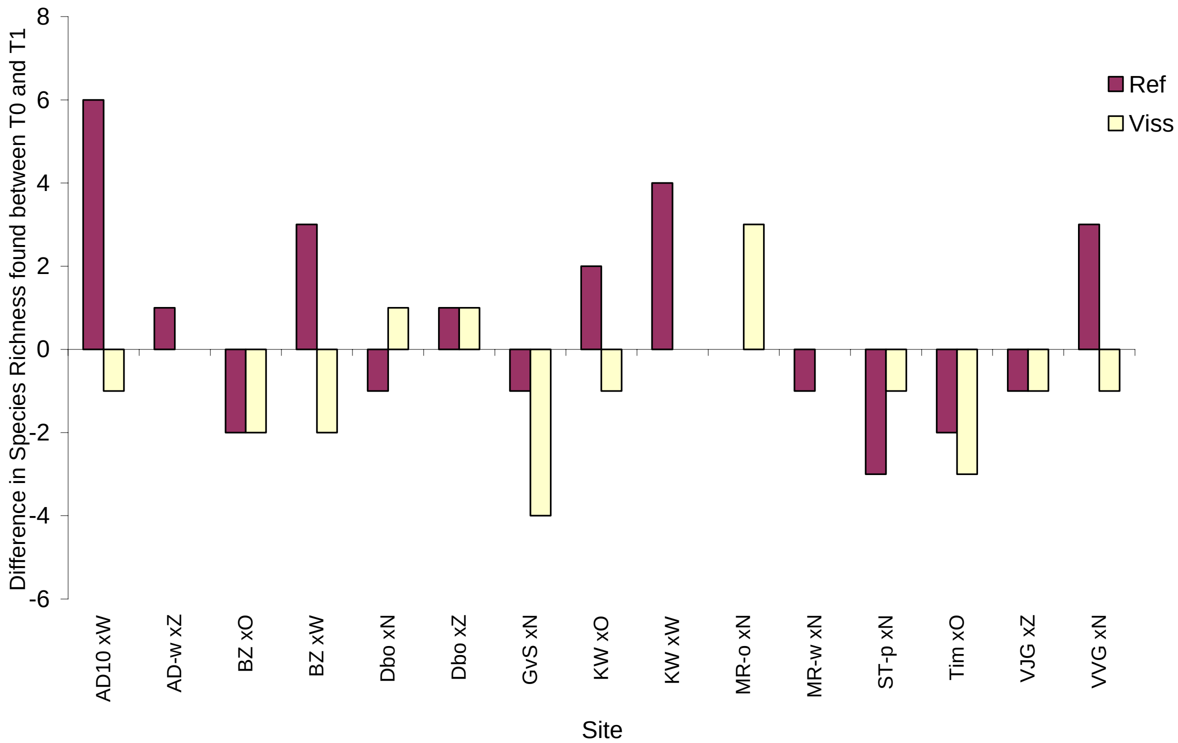


Figure 4. Difference in species richness (number of species) between T0 and T1 for each site.

The differences in number per m^2 for pooled sites varied for each species. Two species showed considerable difference of over 1000 individuals per m^2. *Cerastoderma edule* showed a decrease of 1368 individuals per m^2 in the Ref station only, while *Mya arenaria* decreased by around 1500 individuals per m^2 in both the Ref and Viss stations (Figure 5).

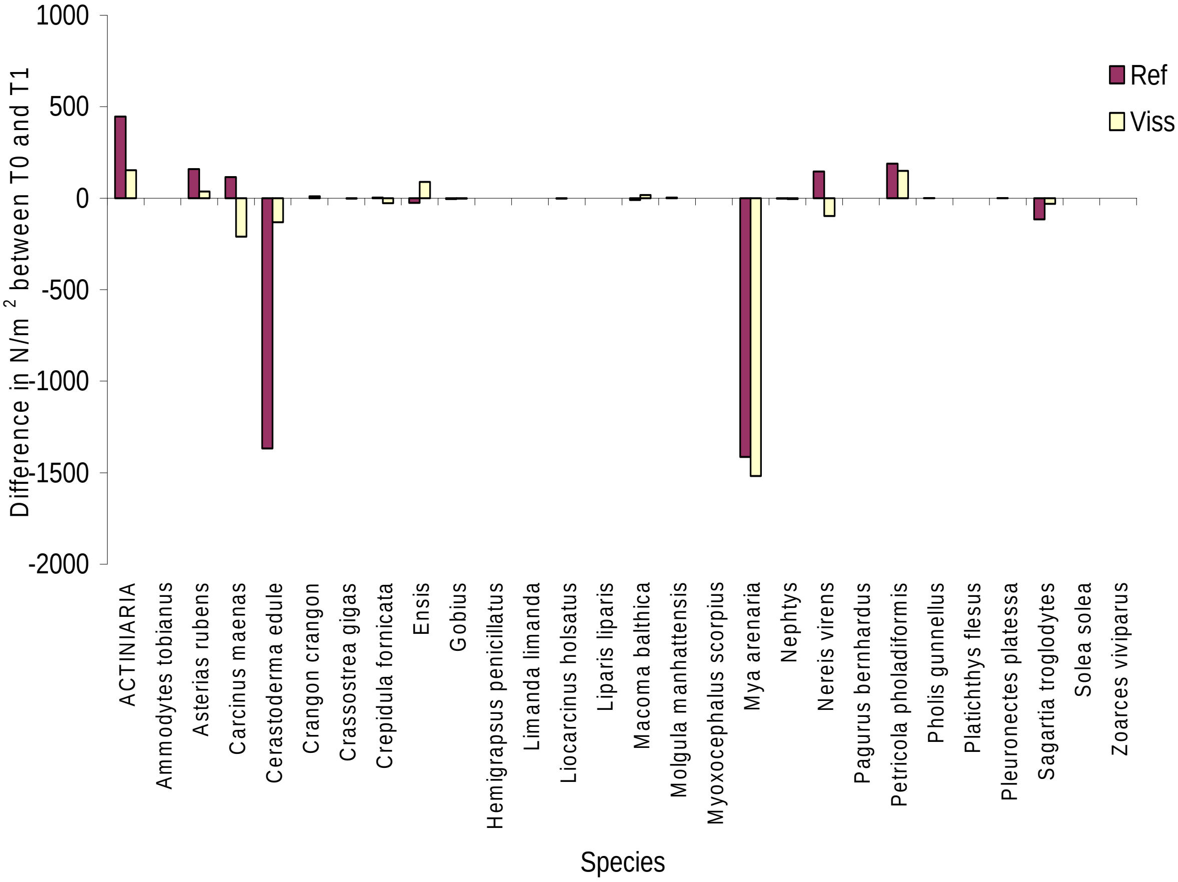


Figure 5. Difference in total N/m^2 for each species between T0 and T1.

Two species, *Carcinus maenas* and *Nereis virens* showed a considerable decrease in N/m^2 between T0 and T1 in the Viss station (210 and 98 individuals per m^2 respectively) and a considerable increase in the Ref station (116 and 146 individuals per m^2 respectively). Actinaria showed a particularly large increase of 445 individuals per m^2 in the Ref station and a smaller increase of 152 individuals per m^2 in the Viss station. There was similar increase in N/m^2 in both the Ref and Viss stations for *Petricola pholadiformis* (188 and 149 individuals per m^2 respectively). N/m^2 decreased in both the Ref and Viss stations for *Sagartia troglodytes*, but the decrease was larger in the Ref station (116 and 31 individuals per m^2 respectively). The six fish spcies (Gobius, *Molgula manhattensis*, *Myoxocephalus scorpius*, *Platichthys flesus*, *Solea solea* and *Zoarces viviparous*) showed virtually no change in N/m^2 in either the Ref or Viss stations. (Figure 6).

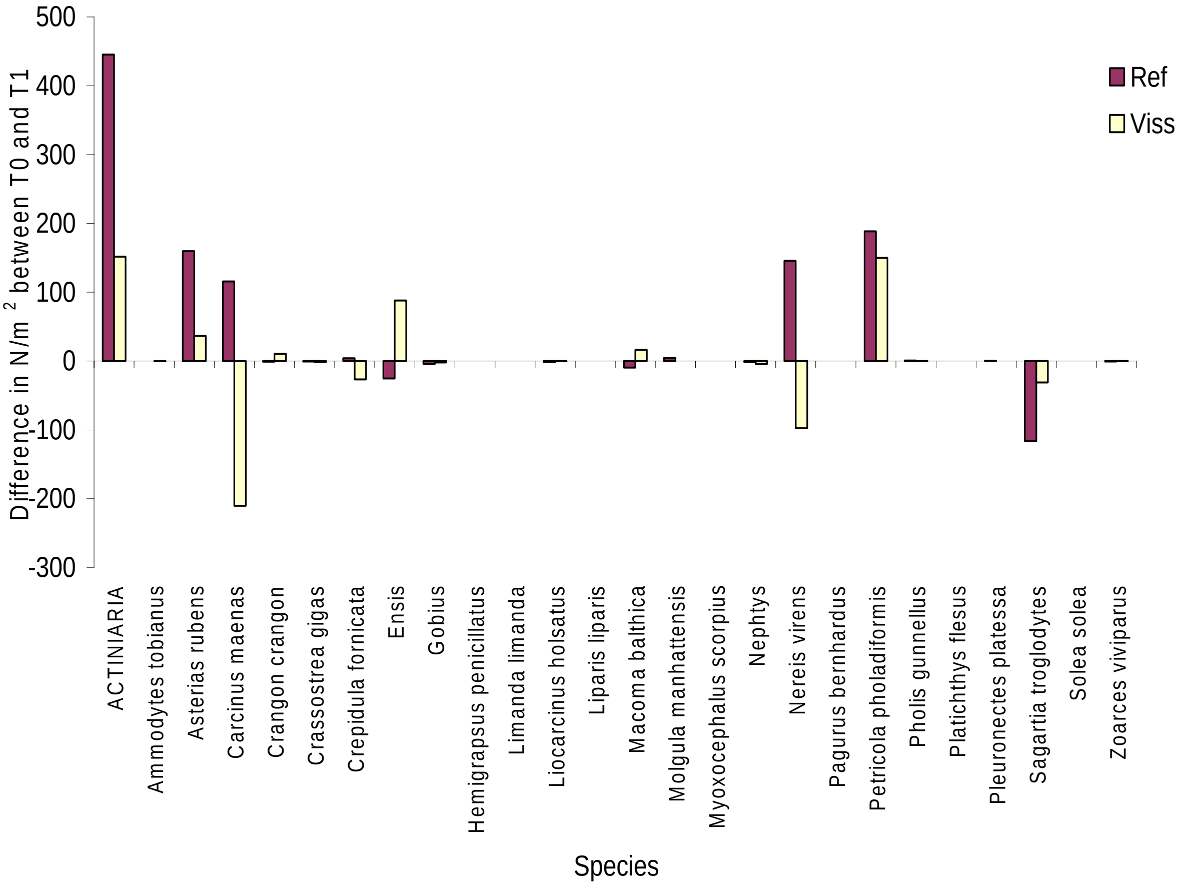


Figure 6. Difference in total N/m^2 for each species between T0 and T1 with *Cerastoderma edule* and *Mya arenaria* removed.

There appears to be few obvious differences in community structure between the treatments for pooled sites. *Mya arenaria* is dominant in all four treatments, but is less dominant in both Ref and Viss T1. The proportion of the community occupied by *Ensis* and *Petricola pholadiformis* increased in the Viss stations from T0 to T1. Actinaria is virtually absent in both Ref and Viss T0 treatments but is one of the more dominant species in both Ref and Viss T1 treatments. *Cerastoderma edule* occupies a large proportion of the community in Ref-T0 but a much smaller proportion in all other treatments (Figure 7).

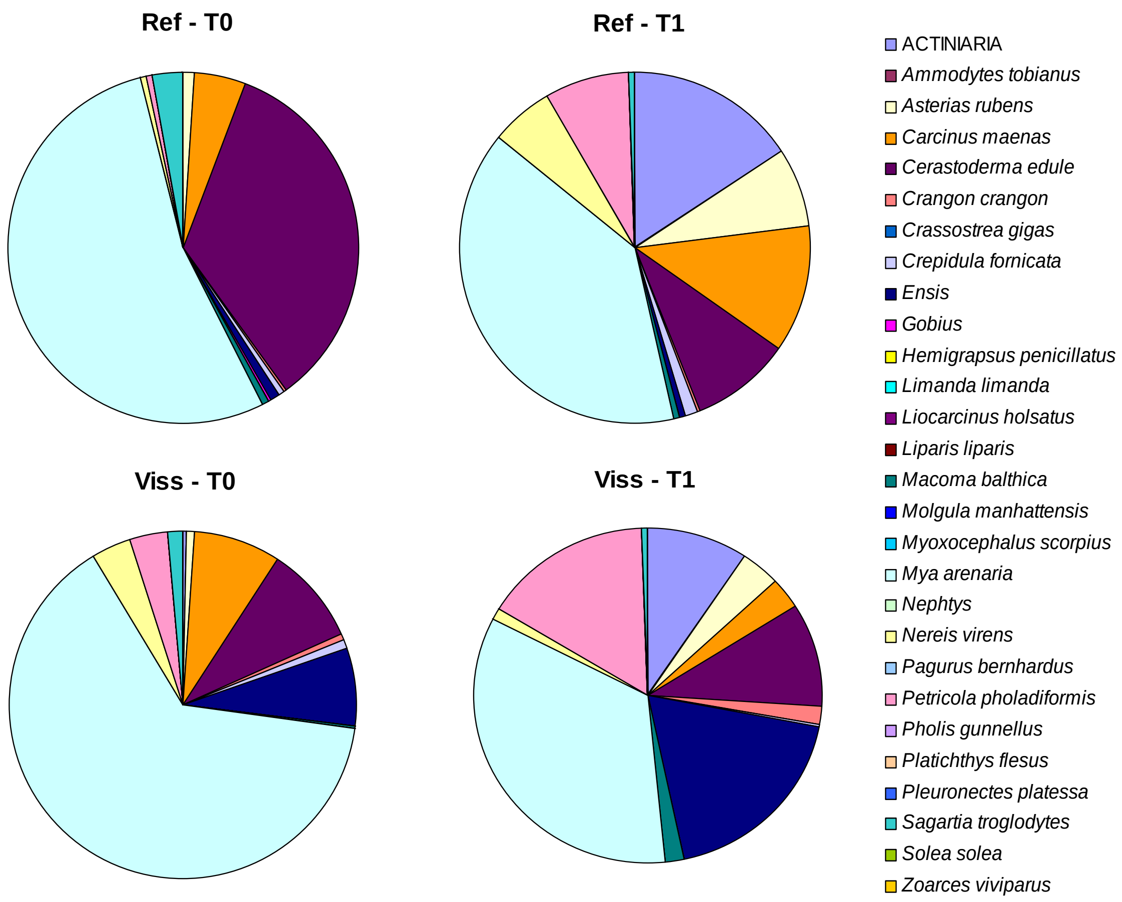


Figure 7. Community structure by number of individuals in pooled stations for each treatment.

3.3 Diversity Indices

Differences in the Shannon-Wiener Diversity Index including mussels varied across sites (Figure 8). All but one site showed an increase in diversity in Viss-T1 stations (MR-w xN decreased by a score of 0.3). Most Ref stations also showed an increase in diversity in T1 (except AD-w xN which decreased by 0.4, Dbo xN which decreased by 0.02 and Tim xO which decreased by 0.2).

The same trends were seen in evenness (Figure 9) with MR-w xN the only site with a decrease in Viss-T1 (by a score of 0.2) and AD-w xN, Dbo xN and Tim xO the only sites with a decrease in Ref-T1 (by a score of 0.3, 0.03 and 0.04 respectively).

When all sites were combined Viss-T1 had a considerably greater score for both the Shannon-Wiener Index and evenness (Shannon-Wiener score of 0.8 and evenness score of 0.4) (Figure 10).

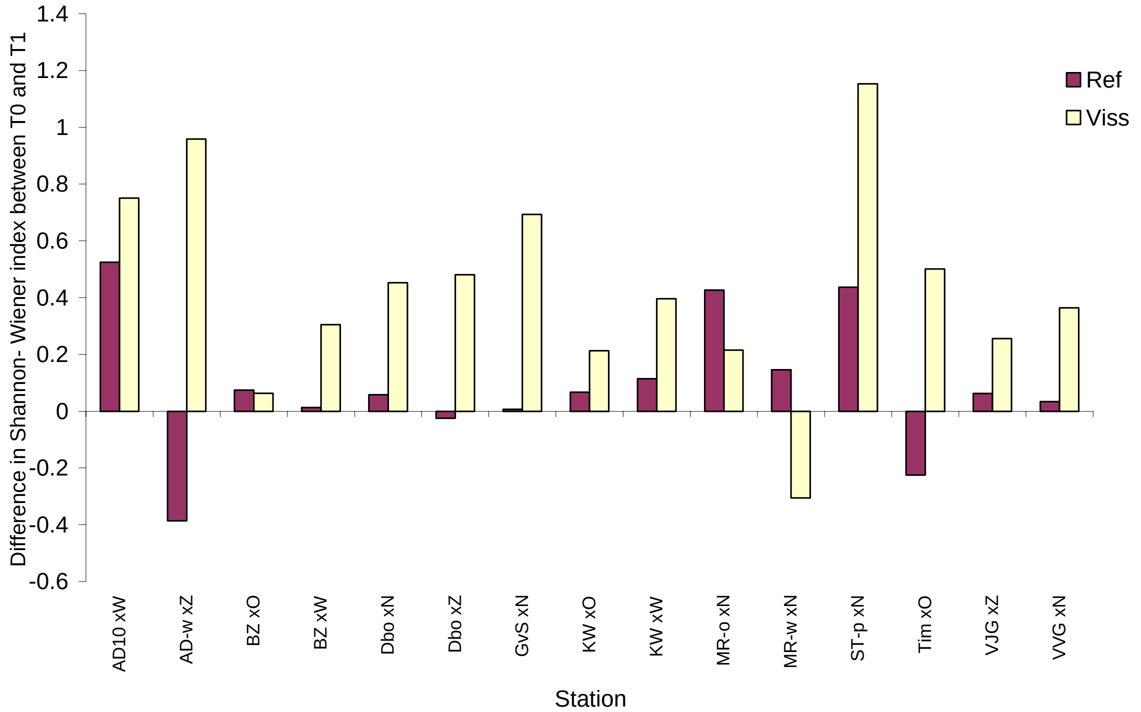


Figure 8. Difference in Shannon-Wiener Diversity Index between T0 and T1 for corresponding Ref and Viss stations at each site.

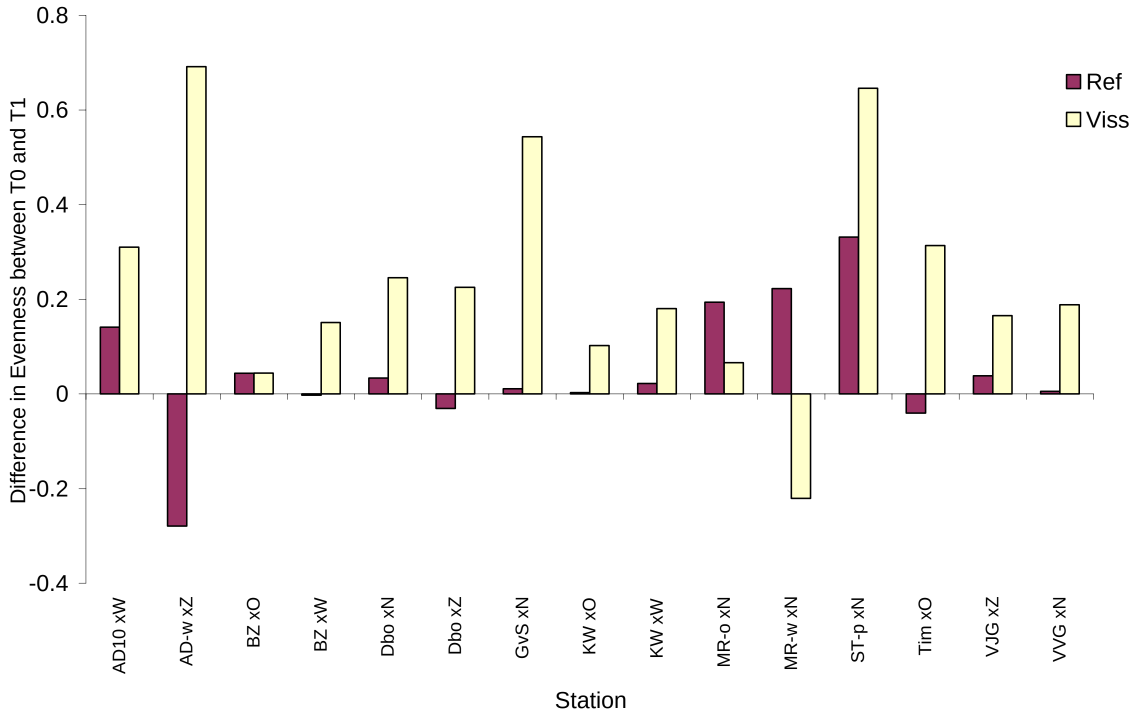


Figure 9. Difference in Evenness scores between T0 and T1 for corresponding Ref and Viss stations at each site.

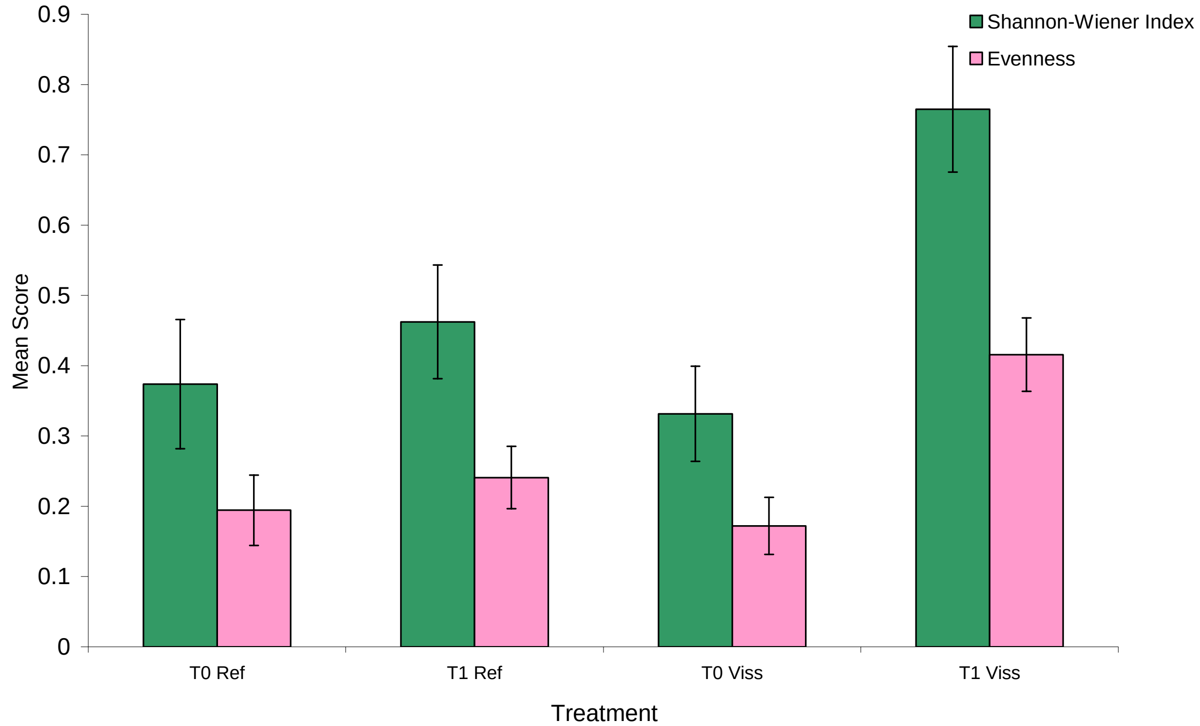


Figure 10. Mean Shannon-Wiener Index and Evenness scores for combined stations with each treatment.

When mussels were excluded from the calculations, the differences in Shannon-Wiener Index scores altered dramatically (Figure 11). Nine sites showed a decrease in diversity in both the Ref and Viss stations. Four sites showed an increase in diversity in both the Ref and Viss stations, and one site (ST-p xN) showed a decrease in diversity in the Ref station (by a score of 0.2) and an increase in the Viss station (by a score of 0.3). Although there was an increase in diversity in both Ref and Viss stations at K-w xW and Tim xO, the increase in the Ref stations were much greater than that in the Viss stations (by Viss scores of 0.3 and 0.06 respectively and Ref scores of 0.9 and 0.7 respectively).

Differences in evenness scores were also quite different when mussels were removed from the calculations (Figure 12). Only five sites had a difference in evenness greater than 0.2. Dbo xN showed an increase in evenness in the Ref station (by a score of 0.3), but little difference in the Viss station (difference of 0.05). GvS xN showed a considerable increase in evenness in both stations, although the increase in the the Ref station (0.7) was much larger than in the Viss station (0.2). MR-w xN showed a considerable increase in evenness in the Ref staion (of 0.5), but a small decrease in evenness in the Viss station (of 0.05). VVG xN showed a decrease in evenness in the Ref station and an increase in the Viss station to a relatively similar degree (~0.2). Evenness in Dbo xZ decreased in both the Ref and Viss stations, but to a much greater degree in the Viss station (a difference in score of 0.2 in the Ref station and 0.6 in the Viss station).

When all sites were pooled, the mean Shannon-Wiener scores were lower for both Ref and Viss T1 treatments (a score of 0.9 in both T0 treatments and 0.7 in both T1 treatments). However, mean evenness scores for Ref-T1 were slightly greater than for Ref-T0 and scores were almost identical in Viss-T0 and Viss-T1 (Figure 13).

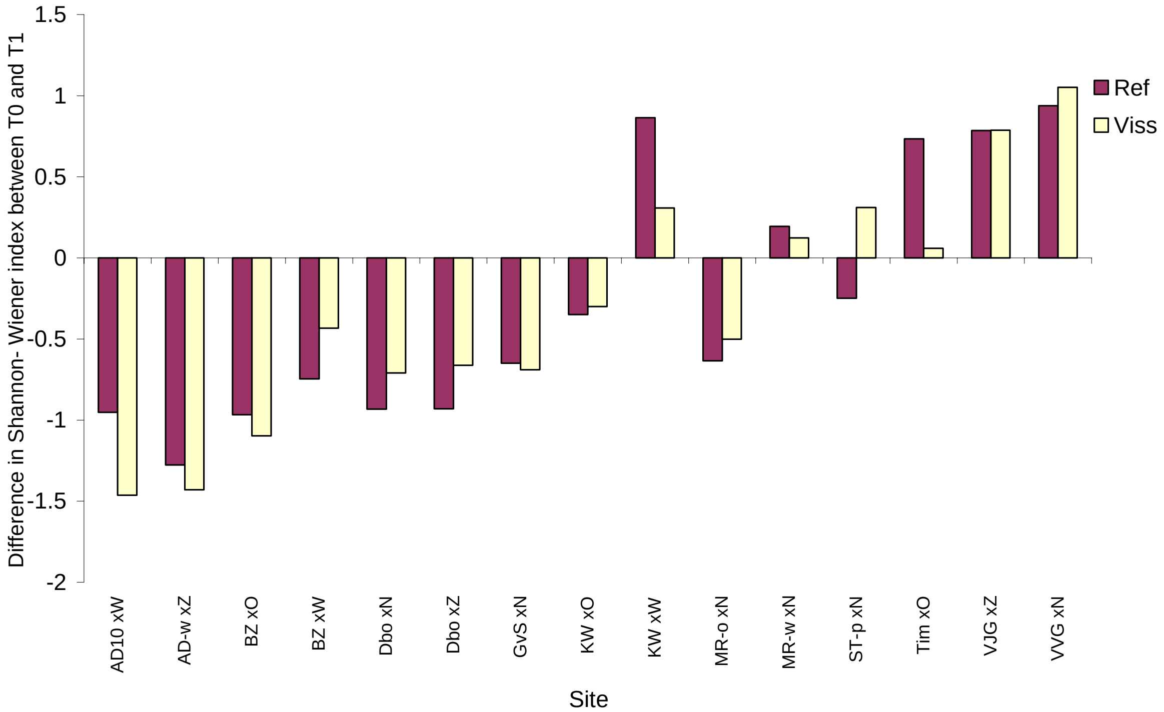


Figure 11. Difference in Shannon-Wiener Diversity Index between T0 and T1 for corresponding Ref and Viss stations at each site excluding mussels.

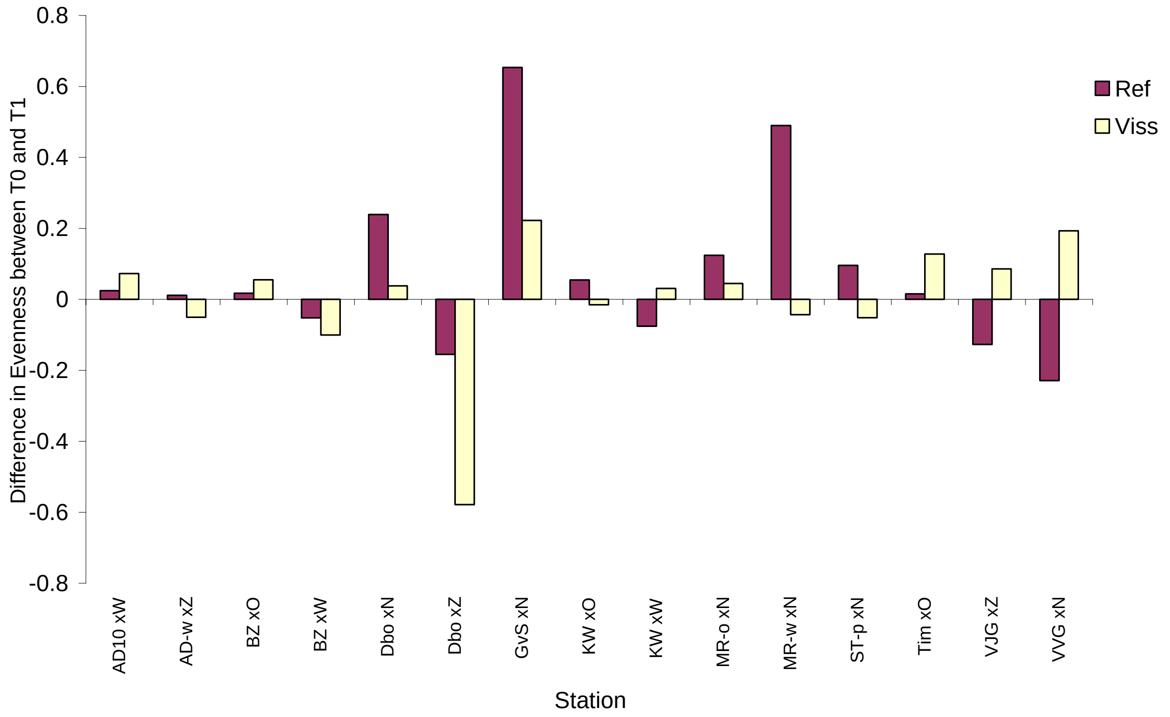


Figure 12. Difference in evenness between T0 and T1 for corresponding Ref and Viss stations at each site excluding mussels.

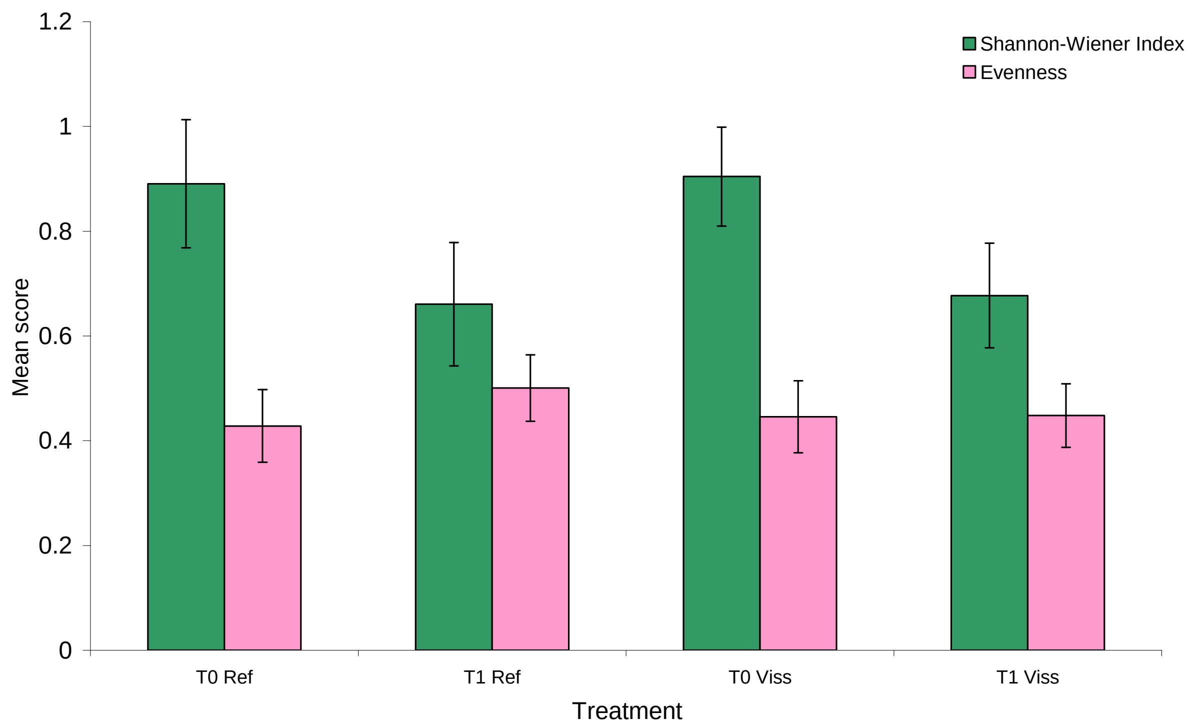


Figure 13. Mean Shannon-Wiener Index and Evenness scores for combined stations with each treatment, excluding mussels.

Differences in Simpsons Index of Diversity varied across sites and stations (Figure 14). According to the Simpsons index, there was an increase diversity in ten of the Ref stations and seven of the Viss stations, and a decrease in five of the Ref stations and seven of the Viss stations with the remaining Viss station showing virtually no change. Dbo xN showed an increase in diversity in the Ref station of 0.3, but only a small increase in the Viss station of 0.07. GvS xN showed a considerable increase in diversity in the Ref station (by a score of 0.5) and a much smaller increase in the Viss station (by a score of 0.1). MR-w xN showed a considerable increase in diversity in the Ref station (of 0.2), but a small decrease in diversity in the Viss station (of 0.05). Dbo xZ showed a small decrease in the Ref station (of 0.1) and a very large decrease in the Viss station (of 0.5).

With the sites pooled, there did not appear to be a significant difference in Simpson's Diversity Index score between treatments (Figure 14). However, the mean score in Ref-T1 (0.45) was higher than Ref-T0 (0.4), while the score for Viss-T1 (0.38) was slightly smaller than Viss-T0 (0.41).

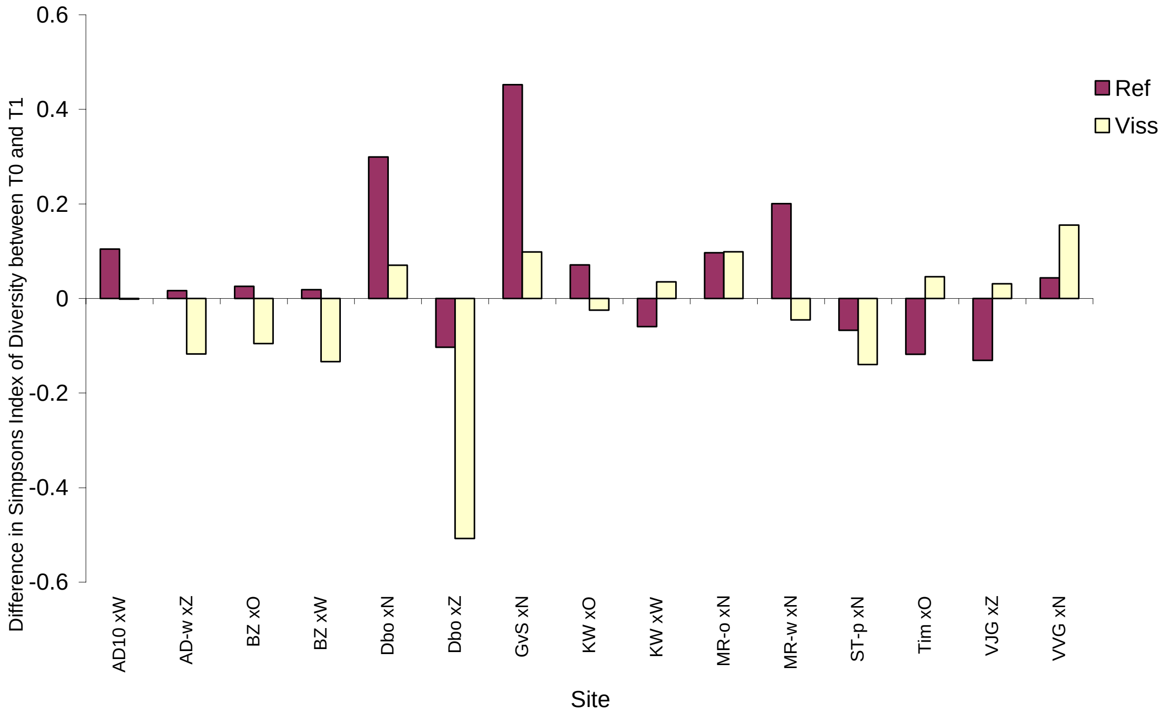


Figure 14. Difference in Simpsons Index of Diversity between T0 and T1 for corresponding Ref and Viss stations at each site excluding mussels.

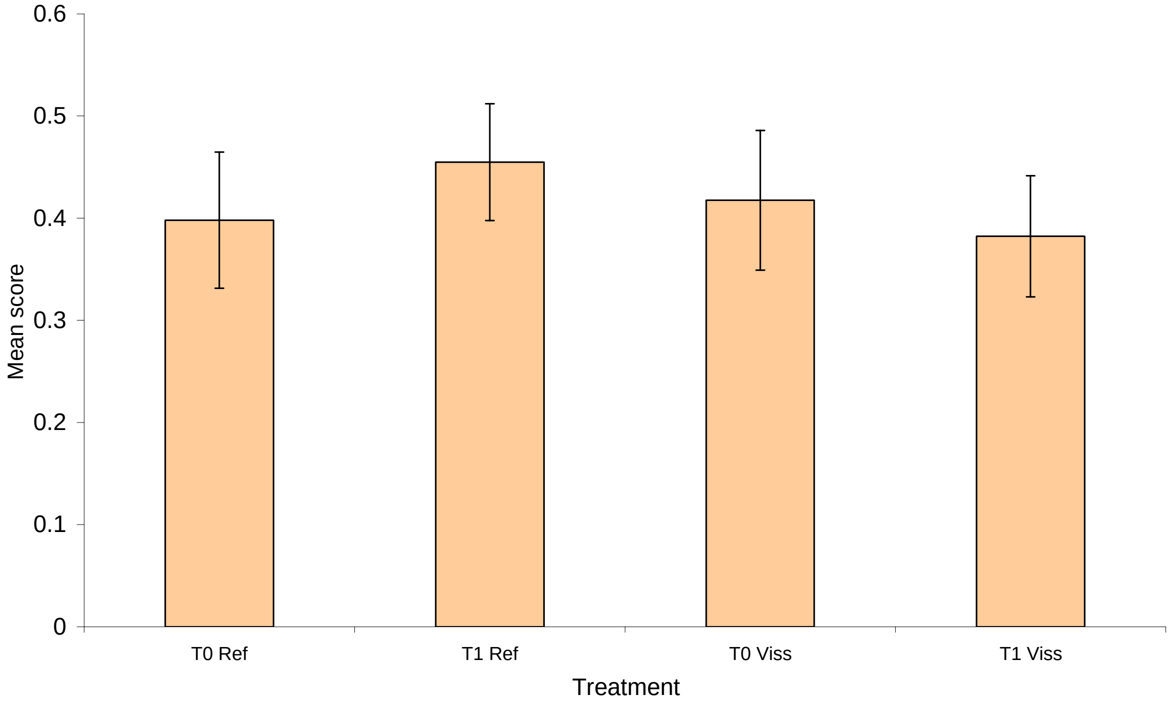


Figure 15. Mean Simpsons Index of Diversity for combined stations excluding mussels.

There was no obvious similarity between the scores for the Shannon-Wiener and Simpson's indices of diversity for either the Ref or Viss stations (Figure 16 and Figure 17). In the Ref stations (Figure 16) only two sites showed the same change in both indices; MR-w xN increased in both and VVG xN decreased in both, but these differences were not to the same degree. All other sites showed opposite differences and to varying comparative degrees.
In the Viss stations (Figure 17) nine sites showed the same change in both indices. AD-w xZ, BZ xO, BZ xW, Dbo xZ and KW xO all showed decreases in both the Shannon-Wiener and Simpson's indicies, while KW xW, Tim xO, VJG xZ and VVG xN showed increases in both indices. Again, these differences varied in comparative degree.

When sites were pooled and both indices compared there was no obvious similarity in the scores between treatments (Figure 18). While the mean Shannon-Wiener scores were lower for both Ref and Viss T1 stations than for the T0 stations, the Simpson's score for Ref-T1 was greater than for Ref-T0, but Viss-T1 was slightly smaller than Viss-T0. The differences in the Shannon-Wiener scores may be significant, while the Simpson's Diversity scores are unlikely to be significant as there is obvious overlap in the standard error bars.

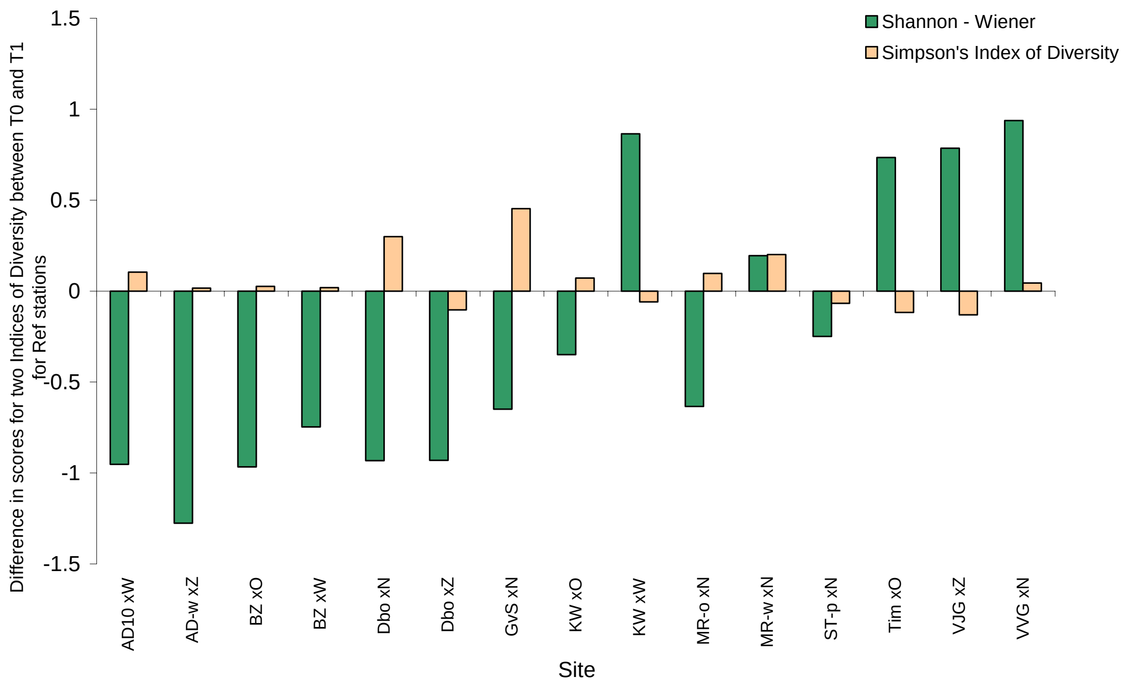


Figure 16. Comparison between the difference in scores for both Shannon-Wiener and Simpson's Diversity indices between T0 and T1 for Ref stations.

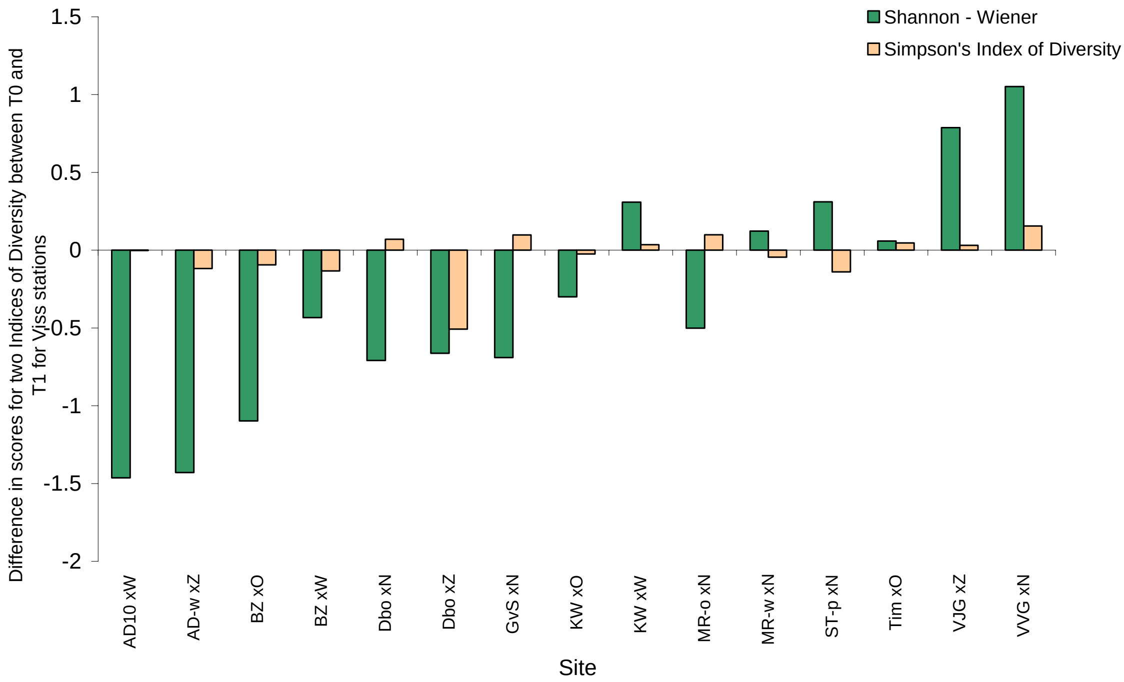


Figure 17. Comparison between the difference in scores for both Shannon-Wiener and Simpson's Diversity indices between T0 and T1 for Viss stations.

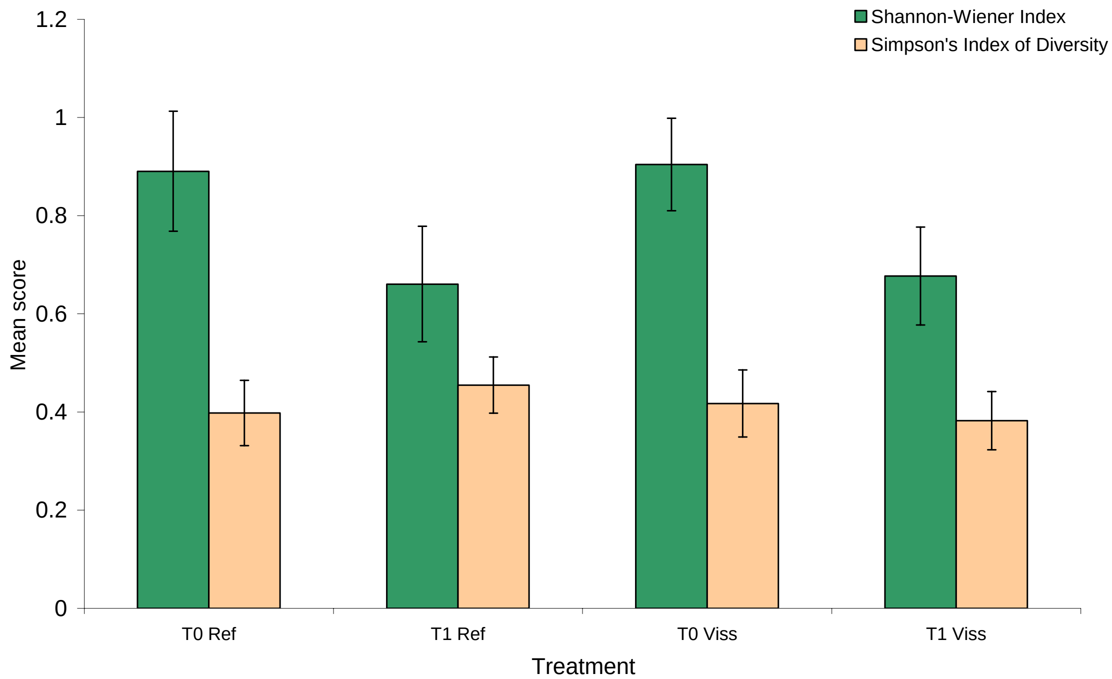


Figure 18. Comparison between the Shannon-Wiener and Simpsons indices for pooled sites.

4 Discussion

It is immediately obvious that there are many variables other than fishing that affect the benthic community in the Wadden Sea. Of the 29 sites sampled, only 15 showed the expected decrease in mussel biomass after fishing. This alone indicates that other variables must be taken into account before a general conclusion can be made about the effects of fishing on the benthic community.

There was also considerable variation in differences of mussel biomass and community structure in the selected sites from T0 to T1. The negligible change in the number per m^2 of the six fish species is likely to be due to their transient behaviour and motility. The increase in number per m^2 of the crab, *Carcinus maenus,* in the Ref station and the decrease in the Viss station can also be explained by their motility and by their likelihood of abandoning the Viss station after fishing due to the lack of mussels to feed on, and moving to the adjacent Ref station where mussels were still present. However, the causes of the large decrease in number per m^2 in Ref station for the cockle, *Cerastoderma edule*, and both the Ref and Viss station for the clam, *Mya arenaria,* require further analysis to reliably identify. It is possible that these large bivalves are particularly sensitive to mussel dredging as the process may severely damage them, and their slow growth may prevent the population recovering quickly.

The differences in Shannon-Wiener and Simpson's diversity scores for sites and treatments also varied remarkably considering they are both designed to measure the same characteristic. While the Shannon-Wiener index measures species richness and evenness, it has the base assumptions that all species in the community have been sampled and that the sampling was completely random. A higher score indicates either higher species richness or that all species are evenly represented, while a low score indicates the low species richness or the presence of a dominant species. The 1-D calculation of the Simpson's index of diversity estimates the probability that two randomly selected individuals will be from different species. The original, opposite calculation tends to be biased towards the most abundant species and is therefore is a type of measure of dominance. Therefore, in the 1-D calculation, it is a sort of measure of evenness. Both indices have appropriate applications and these should be considered when comparing them or interpreting the results.

There was a large variety of differences in diversity score in the sites and treatments for both the Shannon-Wiener and Simpson's indices. There was no obvious indication of a trend in the change of diversity over the sites for either index. There was also little similarity in differences of diversity scores for sites and treatments between both indices. This suggests that the biases in the calculations of the two indices influenced the results considerably to the point where they are barely comparable.

In some sites, however, there was a similarity between the differences of evenness score (which is based on the Shannon-Wiener index) and the differences in score for the Simpson's index of diversity. This is consistent with the Simpson's index being itself a sort of measure of evenness. However, in some stations there were opposite differences in evenness and Simpson's scores. This may be due to the Simpson's index also taking species richness into account, while evenness measures only relative abundance.

The experimental design in this study resulted in sampling with sediment cores along a 150 m area in each sampling station. From this it is reasonable to assume that the base assumptions for the Shannon-Wiener diversity index (that all species in the community were sampled and that the sampling was completely random) are met to an acceptable level. As the Simpson's index of diversity is a probability measurement and more of a measure of evenness, the Shannon-Wiener index is likely to be the more appropriate in this situation.

However, comparing both indices gives a more reliable indication of diversity. the Wadden Sea is a dynamic and variable environment with high spatial environmental heterogeneity. Different areas vary in certain environmental factors that may influence the benthic community regardless of mussel biomass, such as geographical location, freshwater input, exposure during low tide and distance from shore. Diversity therefore must be compared with these variables in mind. Consequently the two diversity indices should be compared for a more accurate indication of true diversity in such a changeable environment.

Further data analysis to continue the current investigation could be used to identify the other potential variables that may influence the benthic community and lead to a more reliable conclusion. Further analysis should include:

- Preliminary analysis of all sampled sites including those that did not fit the site selection parameters.
- The degree of change between T0 and T1 in Viss and Ref plots.
- The implementation of fishing as a linear predictor rather than a nominal variable by means of fishing intensity (which is currently prepared from blackbox data).
- Comparing dredge results with boxcore results (also sieved over 5mm) from the same sites
- Comparing biodiversity on experimental plots with Wadden Sea wide investigations.
- Distinguishing between changes in biodiversity due to fishing with change in biodiversity due to the loss of mussels in general.
- Comparing changes in diversity in experimental stations with changes in diversity in areas that are permanently closed for seed fisheries (e.g. de Vlieter).
- Comparing biodiversity in environmentally similar areas within the Wadden Sea
- Comparing results as factors of year and season to identify possible recruitment effects

Multivariate analysis is required to further investigate the data before any general conclusions can be made about the effect of mussel seed fishing on the benthic communities in the Wadden Sea. The wide variation in results indicates that factors other than fishing are influencing the data, and these need to be identified and taken into account to produce a reliable model to isolate the effect of fishing on the benthic community.

5 Quality Assurance

IMARES utilises an ISO 9001:2000 certified quality management system (certificate number: 08602-2004-AQ-ROT-RvA). This certificate is valid until 15 December 2009. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Environmental Division has NEN-AND-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 27 March 2013 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

Justification

Rapport Number: C139/09
Project Number: ~number~

The scientific quality of this report has been peer reviewed by the a colleague scientist and the head of the department of IMARES.

Approved: Drs. Martine van den Heuvel-Greve
Scientific Researcher

Signature:

Date: 16/12/2009

Approved: Birgit Dauwe
Head of Department

Signature:

Date:

Number of copies:	~number~
Number of pages	31
Number of tables:	1
Number of graphs:	18
Number of appendix attachments:	1

Appendix A. Full names and coordinates of sampling locations in the Wadden Sea.

	PRODUS	Season and year	Closed for fisheries				Open for fisheries			
	Code	**Location**	Position (WGS84)				Position (WGS84)			
	Map	started	**NB**		**OL**		**NB**		**OL**	
1 ZW 1	**LW**	**Lutjewaard**	**52**	59.985	**4**	59.019	**52**	59.985	**4**	59.019
1 ZW 1		nj 2006	**53**	00.077	**4**	58.919	**53**	00.077	**4**	58.919
1 ZW 1			**53**	00.135	**4**	59.073	**53**	00.016	**4**	58.766
1 ZW 1			**53**	00.044	**4**	59.170	**52**	59.925	**4**	58.867
1 ZW 1										
1 ZW 2	**ZW**	**Zuidwest**	**53**	00.713	**4**	59.998	**53**	00.713	**4**	59.998
1 ZW 2		nj 2008	**53**	00.607	**5**	00.042	**53**	00.607	**5**	00.042
1 ZW 2			**53**	00.579	**4**	59.868	**53**	00.633	**5**	00.219
1 ZW 2			**53**	00.685	**4**	59.820	**53**	00.740	**5**	00.174
1 ZW 2										
1 ZW 3	**Zwinw**	**Zwin west**	**52**	59.063	**4**	59.460	**52**	59.063	**4**	59.460
1 ZW 3		nj 2008	**52**	58.954	**4**	59.460	**52**	58.954	**4**	59.460
1 ZW 3			**52**	58.954	**4**	59.278	**52**	58.954	**4**	59.641
1 ZW 3			**52**	59.063	**4**	59.278	**52**	59.063	**4**	59.641
1 ZW 3										
1 ZW 4	**Zwino**	**Zwin oost**	**52**	58.613	**5**	01.767	**52**	58.613	**5**	01.767
1 ZW 4		nj 2008	**52**	58.504	**5**	01.770	**52**	58.504	**5**	01.770
1 ZW 4			**52**	58.508	**5**	01.949	**52**	58.498	**5**	01.587
1 ZW 4			**52**	58.617	**5**	01.943	**52**	58.607	**5**	01.583
1 ZW 4										
1 ZW 5	**VJG**	**Visjagersgaatje**	**52**	58.666	**4**	57.851	**52**	58.666	**4**	57.851
1 ZW 5		vj 2007	**52**	58.762	**4**	57.764	**52**	58.762	**4**	57.764
1 ZW 5			**52**	58.814	**4**	57.925	**52**	58.709	**4**	57.605
1 ZW 5			**52**	58.718	**4**	58.010	**52**	58.613	**4**	57.693
1 ZW 5										
2 TX 1	**BR**	**Breesem**	**53**	06.757	**5**	03.229	**53**	06.739	**5**	03.484
2 TX 1		nj 2006	**53**	06.826	**5**	03.370	**53**	06.672	**5**	03.341
2 TX 1			**53**	06.739	**5**	03.484	**53**	06.586	**5**	03.452
2 TX 1			**53**	06.672	**5**	03.341	**53**	06.654	**5**	03.596
2 TX 1										
2 TX 1.2	**BRw**	**Breesem west**	**53**	06.632	**5**	00.840	**53**	06.741	**5**	00.660
2 TX 1.2		nj 2009	**53**	06.741	**5**	00.840	**53**	06.632	**5**	00.660
2 TX 1.2			**53**	06.741	**5**	01.025	**53**	06.632	**5**	00.840
2 TX 1.2			**53**	06.632	**5**	01.025	**53**	06.741	**5**	00.840
2 TX 1.2										
2 TX 1.3	**BRz**	**Breesem zuid**	**53**	05.048	**5**	03.351	**53**	05.126	**5**	03.130
2 TX 1.3		nj 2009	**53**	05.154	**5**	03.308	**53**	05.020	**5**	03.177
2 TX 1.3			**53**	05.181	**5**	03.484	**53**	05.048	**5**	03.351
2 TX 1.3			**53**	05.074	**5**	03.528	**53**	05.154	**5**	03.308
2 TX 1.3										
2 TX 1.4	**WK**	**Westkom**	**53**	05.904	**5**	06.410	**53**	05.921	**5**	06.151
2 TX 1.4		nj 2009	**53**	05.990	**5**	06.289	**53**	05.833	**5**	06.271
2 TX 1.4			**53**	06.059	**5**	06.431	**53**	05.904	**5**	06.410
2 TX 1.4			**53**	05.976	**5**	06.549	**53**	05.990	**5**	06.289
2 TX 1.4										

	PRODUS	Season and year	Closed for fisheries				Open for fisheries			
	Code	**Location**	Position (WGS84)				Position (WGS84)			
	Map	started	**NB**		**OL**		**NB**		**OL**	
2 TX 2	**TXw**	**TXstroom-west**	**53**	04.114	**4**	56.111	**53**	04.223	**4**	55.928
2 TX 2		nj 2006	**53**	04.223	**4**	56.111	**53**	04.114	**4**	55.928
2 TX 2			**53**	04.223	**4**	56.292	**53**	04.114	**4**	56.111
2 TX 2			**53**	04.114	**4**	56.292	**53**	04.223	**4**	56.111
2 TX 2										
2 TX 4	**TXo - 2**	**TXstroom - oost**	**53**	04.009	**4**	56.682	**53**	04.009	**4**	56.682
2 TX 4		nj 2007	**53**	03.899	**4**	56.682	**53**	03.899	**4**	56.682
2 TX 4		**open verlegd**	**53**	03.899	**4**	56.497	**53**	03.899	**4**	56.861
2 TX 4			**53**	04.009	**4**	56.497	**53**	04.009	**4**	56.861
2 TX 4										
2 TX 5	**TS**	**Texelstroom - Scheurreak**	**53**	03.601	**5**	02.383	**53**	03.454	**5**	02.459
2 TX 5		nj 2007	**53**	03.506	**5**	02.302	**53**	03.549	**5**	02.541
2 TX 5			**53**	03.454	**5**	02.459	**53**	03.400	**5**	02.617
2 TX 5			**53**	03.549	**5**	02.541	**53**	03.497	**5**	02.705
2 TX 5										
3 ST 1	**ST**	**Stompe**	**53**	02.807	**5**	07.000	**53**	02.807	**5**	07.000
3 ST 1		vj 2006	**53**	02.699	**5**	07.000	**53**	02.699	**5**	07.000
3 ST 1			**53**	02.699	**5**	06.817	**53**	02.699	**5**	07.180
3 ST 1			**53**	02.807	**5**	06.817	**53**	02.807	**5**	07.180
3 ST 1										
3 ST 3	**STp**	**Stompe percelen**	**53**	02.582	**5**	08.183	**53**	02.473	**5**	08.000
3 ST 3		nj 2007	**53**	02.473	**5**	08.183	**53**	02.582	**5**	08.000
3 ST 3		**ook "Stompe zuid"**	**53**	02.473	**5**	08.000	**53**	02.584	**5**	07.818
3 ST 3			**53**	02.582	**5**	08.000	**53**	02.474	**5**	07.818
3 ST 3										
3 ST 4	**GvS**	**Gat van Stompe**	**53**	03.054	**5**	04.684	**53**	02.944	**5**	04.500
3 ST 4		nj 2007	**53**	02.944	**5**	04.684	**53**	03.054	**5**	04.500
3 ST 4			**53**	02.944	**5**	04.500	**53**	03.055	**5**	04.320
3 ST 4			**53**	03.054	**5**	04.500	**53**	02.945	**5**	04.320
3 ST 4										
3 ST 5	**GvSn**	**Gat van Stompe N**	**53**	04.554	**5**	06.565	**53**	04.554	**5**	06.565
3 ST 5		vj 2008	**53**	04.505	**5**	06.725	**53**	04.505	**5**	06.725
3 ST 5			**53**	04.600	**5**	06.805	**53**	04.406	**5**	06.645
3 ST 5			**53**	04.651	**5**	06.646	**53**	04.457	**5**	06.484
3 ST 5										
3 ST 6	**Tim**	**Timmekesplaat**	**53**	03.856	**5**	08.140	**53**	03.856	**5**	08.140
3 ST 6		nj 2008	**53**	03.856	**5**	07.958	**53**	03.856	**5**	07.958
3 ST 6			**53**	03.747	**5**	07.958	**53**	03.965	**5**	07.958
3 ST 6			**53**	03.747	**5**	08.141	**53**	03.965	**5**	08.141
3 ST 6										
3 ST 6	**SO**	**Omdraai**	**53**	04.921	**5**	12.546	**53**	04.999	**5**	12.324
3 ST 6		nj 2006	**53**	05.026	**5**	12.502	**53**	04.892	**5**	12.371
3 ST 6			**53**	05.053	**5**	12.678	**53**	04.921	**5**	12.546
3 ST 6			**53**	04.946	**5**	12.722	**53**	05.026	**5**	12.502
3 ST 6										
3 ST 7	**Waard**	**Waard**	**53**	04.141	**5**	11.296	**53**	04.141	**5**	11.296
3 ST 7		nj 2008	**53**	04.074	**5**	11.153	**53**	04.074	**5**	11.153
3 ST 7			**53**	04.159	**5**	11.041	**53**	03.988	**5**	11.264
3 ST 7			**53**	04.227	**5**	11.183	**53**	04.056	**5**	11.408

	PRODUS	Season and year	Closed for fisheries				Open for fisheries			
	Code	Location	Position (WGS84)				Position (WGS84)			
	Map	started	NB		OL		NB		OL	
3 ST 7										
4 AD 1	**VLn**	**Vlieter noord**	**53**	01.807	**5**	06.281	**53**	01.698	**5**	06.097
4 AD 1		nj 2007	**53**	01.698	**5**	06.281	**53**	01.807	**5**	06.097
4 AD 1			**53**	01.698	**5**	06.097	**53**	01.807	**5**	05.916
4 AD 1			**53**	01.807	**5**	06.097	**53**	01.698	**5**	05.916
4 AD 1										
4 AD 2	**VLz**	**Vlieter zuid**	**53**	01.383	**5**	06.817	**53**	01.275	**5**	06.999
4 AD 2		nj 2006	**53**	01.275	**5**	06.817	**53**	01.383	**5**	06.999
4 AD 2			**53**	01.275	**5**	06.999	**53**	01.383	**5**	07.180
4 AD 2			**53**	01.383	**5**	06.999	**53**	01.275	**5**	07.180
4 AD 2										
4 AD 3	**ADw**	**A'dijk west**	**53**	00.433	**5**	09.057	**53**	00.278	**5**	09.033
4 AD 3		nj 2006	**53**	00.362	**5**	08.916	**53**	00.348	**5**	09.172
4 AD 3			**53**	00.278	**5**	09.033	**53**	00.263	**5**	09.290
4 AD 3			**53**	00.348	**5**	09.172	**53**	00.195	**5**	09.149
4 AD 3										
4 AD 5	**AD10**	**Afsluitdijk - AD10**	**53**	00.081	**5**	10.047	**53**	00.098	**5**	09.789
4 AD 5		vj 2009	**53**	00.167	**5**	09.927	**53**	00.010	**5**	09.909
4 AD 5			**53**	00.236	**5**	10.069	**53**	00.081	**5**	10.047
4 AD 5			**53**	00.154	**5**	10.186	**53**	00.167	**5**	09.927
4 AD 5										
4 AD 6	**BZ**	**Breezanddijk**	**53**	02.181	**5**	12.957	**53**	02.157	**5**	13.214
4 AD 6		vj 2009	**53**	02.094	**5**	13.068	**53**	02.243	**5**	13.110
4 AD 6			**53**	02.029	**5**	12.919	**53**	02.181	**5**	12.957
4 AD 6			**53**	02.118	**5**	12.807	**53**	02.094	**5**	13.068
4 AD 6										
4 AD 7	**DB**	**Doove Balg**	**53**	03.155	**5**	12.135	**53**	03.022	**5**	12.003
4 AD 7		nj 2007	**53**	03.048	**5**	12.180	**53**	03.128	**5**	11.959
4 AD 7			**53**	03.022	**5**	12.003	**53**	03.100	**5**	11.782
4 AD 7			**53**	03.128	**5**	11.959	**53**	02.994	**5**	11.829
4 AD 7										
4 AD 8	**DBo**	**Doove Balg oost (DB23)**	**53**	04.087	**5**	16.429	**53**	03.935	**5**	16.405
4 AD 8		vj 2009	**53**	04.006	**5**	16.549	**53**	04.016	**5**	16.290
4 AD 8			**53**	04.075	**5**	16.686	**53**	04.087	**5**	16.429
4 AD 8			**53**	04.158	**5**	16.569	**53**	04.006	**5**	16.549
4 AD 8										
5 MR 1	**ZOR**	**Zuidoostrak**	**53**	07.740	**5**	14.741	**53**	07.717	**5**	14.477
5 MR 1		vj 2009	**53**	07.807	**5**	14.594	**53**	07.651	**5**	14.624
5 MR 1			**53**	07.889	**5**	14.700	**53**	07.740	**5**	14.741
5 MR 1			**53**	07.821	**5**	14.847	**53**	07.807	**5**	14.594
5 MR 1										
5 MR 2	**VVG**	**Verversgat**	**53**	07.628	**5**	17.896	**53**	07.628	**5**	17.896
5 MR 2		vj 2008	**53**	07.628	**5**	17.714	**53**	07.628	**5**	17.714
5 MR 2			**53**	07.738	**5**	17.714	**53**	07.520	**5**	17.714
5 MR 2			**53**	07.738	**5**	17.896	**53**	07.520	**5**	17.896
5 MR 2										
5 MR 3	**MRw**	**Molenrak west**	**53**	10.398	**5**	19.380	**53**	10.288	**5**	19.563
5 MR 3		nj 2006	**53**	10.398	**5**	19.563	**53**	10.288	**5**	19.380
5 MR 3			**53**	10.288	**5**	19.563	**53**	10.179	**5**	19.380

	PRODUS	Season and year	Closed for fisheries				Open for fisheries			
	Code	Location	Position (WGS84)				Position (WGS84)			
	Map	started	NB		OL		NB		OL	
5 MR 3			53	10.288	5	19.380	53	10.179	5	19.563
5 MR 3										
5 MR 4	**MRo**	**Molenrak oost**	53	09.942	5	21.500	53	10.048	5	21.318
5 MR 4		nj 2006	53	10.048	5	21.500	53	09.942	5	21.318
5 MR 4			53	10.048	5	21.681	53	09.942	5	21.500
5 MR 4			53	09.942	5	21.681	53	10.048	5	21.500
5 MR 4										
5 MR 5	**KW**	**Kornwerd - Boontjes**	53	05.508	5	19.504	53	05.419	5	19.287
5 MR 5		vj 2009	53	05.403	5	19.471	53	05.526	5	19.320
5 MR 5			53	05.387	5	19.650	53	05.508	5	19.504
5 MR 5			53	05.491	5	19.678	53	05.403	5	19.471
5 MR 5										
5 MR 6	**IN**	**Inschot**	53	10.407	5	12.768	53	10.284	5	12.919
5 MR 6		nj 2009	53	10.303	5	12.743	53	10.389	5	12.951
5 MR 6			53	10.284	5	12.919	53	10.372	5	13.126
5 MR 6			53	10.389	5	12.951	53	10.268	5	13.100
5 MR 6										
6 BS 1	**BSw**	**Blauwe Slenk west**	53	13.562	5	13.551	53	13.562	5	13.551
6 BS 1		vj 2008	53	13.668	5	13.551	53	13.668	5	13.551
6 BS 1			53	13.668	5	13.732	53	13.668	5	13.370
6 BS 1			53	13.562	5	13.732	53	13.562	5	13.370
6 BS 1										
6 BS 2	**BSo**	**Blauwe Slenk oost**	53	13.036	5	17.881	53	13.036	5	17.881
6 BS 2		vj 2008	53	13.103	5	18.013	53	13.103	5	18.013
6 BS 2			53	13.018	5	18.126	53	13.189	5	17.900
6 BS 2			53	12.949	5	17.981	53	13.121	5	17.760
6 BS 2										
6 BS 3	**BSn**	**Blauwe Slenk noord**	53	13.913	5	13.949	53	13.806	5	14.129
6 BS 3		nj 2009	53	13.806	5	13.949	53	13.913	5	14.129
6 BS 3			53	13.806	5	14.129	53	13.913	5	14.311
6 BS 3			53	13.913	5	14.129	53	13.806	5	14.311
6 BS 3										
6 BS 4	**BSp**	**Blauwe Slenk Pollendam**	53	11.554	5	18.598	53	11.701	5	18.522
6 BS 4		nj 2009	53	11.649	5	18.681	53	11.606	5	18.441
6 BS 4			53	11.597	5	18.845	53	11.554	5	18.598
6 BS 4			53	11.500	5	18.756	53	11.649	5	18.681
6 BS 4										
6 BS 5	**WM**	**Westmeep**	53	17.661	5	15.316	53	17.509	5	15.264
6 BS 5		nj 2009	53	17.569	5	15.416	53	17.602	5	15.164
6 BS 5			53	17.628	5	15.567	53	17.661	5	15.316
6 BS 5			53	17.721	5	15.463	53	17.569	5	15.416
6 BS 5										

Destroyed, moved or reserve locations

9 AD 4	**ADo**	**A.dijk oost**	53	01.620	5	11.459	53	01.729	5	11.276
9 AD 4		nj2006	53	01.729	5	11.459	53	01.620	5	11.276
9 AD 4		**vervallen**	53	01.729	5	11.639	53	01.620	5	11.459

	PRODUS	Season and year	Closed for fisheries				Open for fisheries			
	Code	**Location**	Position (WGS84)				Position (WGS84)			
	Map	started	**NB**		**OL**		**NB**		**OL**	
9 AD 4			**53**	01.620	**5**	11.639	**53**	01.729	**5**	11.459
9 AD 4										
9 TX 3	**TXo - 1**	**TXstroom oost**	**53**	04.000	**4**	56.317	**53**	03.900	**4**	56.498
9 TX 3		nj 2006	**53**	03.900	**4**	56.317	**53**	04.000	**4**	56.498
9 TX 3		**tot nj 2007**	**53**	03.900	**4**	56.498	**53**	04.000	**4**	56.681
9 TX 3		**vervangen door TXo-2**	**53**	04.000	**4**	56.498	**53**	03.900	**4**	56.681
9 TX 3										

Permanently closed locations

9 VL 1	**VL1**	**Vlieter 1**	**52**	59.318	**5**	05.851	**nvt**	**nvt**
9 VL 1		vj2009	**52**	59.318	**5**	06.034		
9 VL 1			**52**	59.207	**5**	06.034		
9 VL 1			**52**	59.207	**5**	05.851		
9 VL 1								
9 VL 2	**VL2**	**Vlieter 2**	**52**	59.045	**5**	04.855	**nvt**	**nvt**
9 VL 2		vj2009	**52**	59.045	**5**	05.038		
9 VL 2			**52**	58.934	**5**	05.038		
9 VL 2			**52**	58.934	**5**	04.855		
9 VL 2								
9 VL 3	**VL3**	**Vlieter 3**	**52**	59.301	**5**	04.368	**nvt**	**nvt**
9 VL 3		vj2009	**52**	59.301	**5**	04.550		
9 VL 3			**52**	59.190	**5**	04.550		
9 VL 3			**52**	59.190	**5**	04.368		
9 VL 3								
9 VL 4	**VL4**	**Vlieter 4**	**52**	59.536	**5**	04.855	**nvt**	**nvt**
9 VL 4		vj2009	**52**	59.536	**5**	05.038		
9 VL 4			**52**	59.426	**5**	05.038		
9 VL 4			**52**	59.426	**5**	04.855		
9 VL 4								