North Sea Wind Farms: NSW
Lot 1 Benthic Fauna. Final Report

Report to: Directorate - General of Public Works and Water Management. National Institute for Coastal and Marine Management / RIKZ

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19 February 2004

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Report: ZBB607.2-F-2004

Client: Directorate - General of Public Works and Water Management. National Institute for Coastal and Marine Management / RIKZ

Project Title: Dutch Wind Farms: NSW Lot 1 Benthic Fauna. Final Report

19 February 2004

Reference No: ZBB607.2-F-2004

For and on behalf of the Institute of Estuarine and Coastal Studies

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SUMMARY

In response to growing awareness of the causes and effects of climate change, the developed nations agreed at the 1997 Kyoto conference to reduce the emission of greenhouse gases through energy savings and a greater emphasis on renewable energy sources. As a signatory to the Kyoto Protocol the Netherlands is committed to reduce greenhouse gas emissions by 6% of 1990 levels by the year 2012, and by 2020 it is planned that 10% of Dutch energy consumption will be generated by renewable sources (Offshore Wind Energy, 2004). Wind energy is expected to contribute 16% of renewable sources by 2020 and thus represents an important component of the Netherlands energy strategy. Because of space limitations and planning complications the growth of land-based windfarms has been constrained and the development of offshore sites has therefore taken on a greater significance. Even after taking other uses (such as sand/gravel extraction, fishing and hydrocarbon exploration) into account, there is sufficient potential space in the Dutch Exclusive Economic Zone to generate 6000 MW, representing about 20% of the Netherlands' domestic demand. It is the intention of the Dutch government to facilitate the full exploitation of this resource but in harmony with other marine interests and environmental considerations.

The Near Shore Windfarm (NSW) was commissioned as part of the early stages of offshore wind development. Concieved as a demonstration project, NSW will be used to gain knowledge and experience for use in future projects. The windfarm will be situated about 10 km from the coast west of Egmond aan Zee, will cover an area of 25 km^2. It is projected to have a capacity of 100 MW generated by 36 turbines, and a lifespan of 20 years, after which it will be dismantled. There will be a 500 m safety exclusion perimeter zone which will be closed to all shipping.

Although wind generation is pollution-free, the environmental effects of construction and operation must be taken into account. The Dutch authorities have therefore commissioned an environmental assessment to address potential windfarm impacts on demersal and pelagic fish, marine mammals and birds and the benthic, or seafloor fauna. The benthic invertebrates (mainly worms, crabs and bivalve clams) are a vital link in the food chain, re-cyling organic material and making it available as a food source for fish and birds.

This report describes in detail the distribution of the invertebrates and the composition of the seafloor sediments in, and on which they live. Changes arising from windfarm construction may be detected by comparison with the baseline data presented here.

The study employed regularly spaced sampling sites within the proposed windfarm area, the safety zone and two reference areas situated approximately 15 km to the north and 20 km to the south of the windfarm. At each site the sediment and small, abundant species were sampled using a 0.068 m^2 box core. At some sites multiple samples were taken to obtain a measure of spatial variablilty. A similar array of sites was used to take larger (100 m^2), more deeply penetrating samples with a specially modified dredge. This was designed to sample the larger, more sparsely distributed animals.

This two-tiered sampling strategy using 126 box core sites and 51 dredge sites was successful in sampling the small common invertebrates as well as the less abundant burrowing animals.

- The sediments were sandy thoughout all areas with very little organic matter. They were coarser in the south.

- The survey found 115 invertebrate species with total density ranging from 0 to 1349 animals per square metre. Most species were those commonly encountered in high energy, shallow subtidal sands of the North East Atlantic and North Sea realm. The northern reference area had more species and a higher density of animals than the other areas.

- Rare species were represented by individuals normally found more abundantly in different habitats of the southern North Sea and their presence was interpreted as the result of random dispersal events.

- Many species exhibited a patchy distribution. Classification analysis of the species - abundance data revealed two main clusters (species assemblages) of box core samples and four clusters of dredge samples. In each case the clusters appeared to be defined by changes in relative abundance of common species rather than changes in species composition.

- The southern North Sea benthic fauna has been modified throughout a long history of intensive beam trawling. The exclusion area created by the windfarm will provide an opportunity to examine some of the effects of trawling and to study recovery rates using bivalve metrics.

It was recommended that the reference areas be maintained and sampled for comparison with baseline data. Future monitoring should be carried out by sampling at multiple sample sites for sediment characteristics and benthic invertebrates. Dredging should also be carried out to compare species data and collect bivalves for analysis.

1 INTRODUCTION

The expansion of sustainable energy sources is now a major consideration for industrialised countries and wind power (onshore and offshore) will provide an important contribution to this. The Dutch government has a policy to significantly increase the proportion of electricity generated from renewable sources and the construction of new offshore windfarms will be required to fulfil this plan.

Offshore wind generation produces “clean” energy without greenhouse gas emissions and can exploit the enormous potential of wind resources without causing major environmental damage. However, as with all man’s activities, there are some detrimental effects. These are mainly associated with the construction and cable laying phase where benthic communities will be eliminated by the turbine bases and cable installations. Further afield, fine sediment disturbed during construction, may settle out of the water column and smother the existing fauna, subtly altering the sediment characteristics and creating changes in future invertebrate recruitment patterns. Other negative effects, which apply mainly after construction, include changes in local hydrodynamics (which may modify benthic communities), bird roost disturbance and interference of flight paths by the turbines. Once constructed the turbine bases will provide new habitat for sessile marine invertebrates which would not otherwise be found in the area. These will concentrate organic deposits in the sediment around each turbine and may attract foraging fish as has been found elsewhere with offshore hydrocarbon platforms. Disturbance to birds and sea mammals may also continue through increased boat traffic during maintenance operations. Aesthetic considerations must also be taken into account.

A new windfarm is proposed for the region off Egmond aan Zee. NSW (Near Shore Windpark) will be situated about 10 km from the coast.

The University of Hull, Institute of Estuarine and Coastal Studies (IECS) was commissioned by the Directorate - General of Public Works and Water Management National Institute for Coastal and Marine Management (RIKZ) to design and carry out a survey to study the gross effects of construction on the invertebrates living on the seabed (Lot 1 as outlined in the Terms of Reference Document, Anon. 2002). The main aim of this work is to provide a baseline representation of animal communities and sediment types which can then be used in future monitoring programmes to detect windfarm effects and measure their extent. The knowledge so gained may also assist in the development of future offshore installations. To carry out these objectives the following types of information are required:

- distribution, abundance and biomass of common abundant seabed invertebrates
- distribution and abundance of more sparsely distributed animals
- distribution of sediment types

The survey was designed to produce these data in a manner consistent with previous BIOMON methods and in a way that will facilitate the tracking of any post-construction changes. Two sampling methods were needed to achieve this: a box core to sample the relatively abundant small invertebrates and sediments, and a specially designed benthic dredge to sample the more sparsely distributed (and larger) animals. Similar samples were also taken from two reference areas situated to the north and south of the proposed windfarm area. These will enable any changes in the immediate windfarm area to be compared with any general, unrelated changes in the southern North Sea.

The aims of this document are to succinctly summarise the rationale behind the survey design, describe the methods used to collect the information required as outlined above, and describe the findings of the survey within the context of previously published scientific surveys. Any knowledge gaps will be identified and recommendations for later monitoring will be given.

2 MATERIALS AND METHODS

2.1 Survey design

The development of the sampling strategy was governed by three prime considerations: the selection of appropriate reference areas, adequate spatial coverage and repeatability (Green, 1979).

Sediment characteristics in reference areas were chosen to correspond as closely as possible to those of the turbine area (Green, 1979) The main factor structuring benthic invertebrate distribution is thought to be sediment particle size (e.g. Snelgrove & Butman, 1994) and so the nature of the sediment was a prime consideration in the selection of reference areas.

The proposed Near Shore Windpark (NSW) lies in the Southern Bight of the North Sea about 10 km off the Dutch coast (Anon., 2002) opposite the town of Egmond aan Zee (see Figure 1). It covers an area of about 20 – 25 km^2 and will contain 36 turbines (Anon., 2002). The seabed here is a gently shelving, shallow (approximately 20 m) platform of fine to medium sands (Duineveld *et al*. 1990) and these conditions are believed to exist along the whole of the Dutch coast but with a trend to finer sediments to the north (Eisma, 1987; Duineveld *et al.* 1990). The main sources of information for seabed characteristics were British and Dutch admiralty charts and Holtmann *et al*. (1996). A more detailed picture of the sediments in the study region was supplied by RIKZ and this revealed some extensive patches of coarser sediment. These were superimposed upon the IECS computer charts and are indicated in Figure 1. This coarser material was not present in the proposed turbine area and was therefore avoided when positioning reference areas.

The NSW windfarm is sited in an area free from submarine pipelines and cables. Similar areas were sought for reference conditions so that they would also be free of any disturbances that these may attract (such as maintenance work or fishing activity). Depth was not considered to be an important controlling factor on the fauna in this area as differences are slight along the whole area of the coast. However, distance from shore may be significant in terms of invertebrate communities (Eisma, 1966).

Taking the above factors into consideration a northern reference area ("NSW Control North" abbreviated to NSWCN) was positioned about 15 km to the north and a southern reference area (NSWCS) placed about 20 km to the south. Both of these reference areas were the same distance offshore as the NSW site (NSW Turbines or NSWT). The boundary co-ordinates (WGS84 Projection) of these areas are given below:

NSWCN:

1	52.7416	4.44967
2	52.7368	4.49672
3	52.7044	4.49394
4	52.7082	4.44486

NSWT:

1	52.6309	4.35159
2	52.6351	4.37997
3	52.6257	4.39451
4	52.6394	4.41818
5	52.6046	4.49470

6	52.5738	4.48753
7	52.5730	4.43095

NSWCS:

1	52.4727	4.31754
2	52.4662	4.37387
3	52.4303	4.37139
4	52.4364	4.31321

One further factor came under consideration during the planning phase. This concerned the residual tidal current which flows parallel to the coast towards the German Bight (Eisma, 1987; Otto *et al.* 1990). There was concern that fine sediment raised during construction or from dredging activities at the nearby port of Ijmuiden may alter reference conditions north of the windfarm. This could result in confounding effects on statistical analyses and interpretation of changes. However, it was decided that NSWCN was required, in spite of this risk, to increase the chances of finding appropriate sediment characteristics and comparable animal communities, there being little historical information for this area. It was judged that the site would be too distant to be greatly affected by the relatively small volumes of fine material which may be mobilised in that direction.

Mean seasonal total suspended matter (TSM) is distributed in bands which are roughly parallel to the coastline (Suijlen & Duin, 2002). The positioning of reference sites accounts for this distribution so that all areas are subject to the same level of naturally occurring sediment inputs from the water column.

In the absence of specific fine scale information on invertebrate or sediment distribution it was decided to disperse sample locations evenly throughout the areas in a manner that would allow good spatial coverage and some statistical rigour without exceeding financial and time resources. Initial investigations revealed that the environment was homogeneous over the scale required for the present study (e.g. Creutzberg *et al.* 1984; Craeymeersch *et al*. 1997). A total of 68 sample locations (sites) in NSWT and 25 sites in each of the two reference areas resulted. For box core samples, most of the sites were to be unreplicated which, although giving an idea of the fauna present, would not allow for local variation at the site and would not be amenable to statistical comparisons. Therefore some locations were designated for replicated samples and these sites were distributed evenly throughout the respective areas. Five replicate cores would be taken at these sites.

In addition to these sites four pairs of sample sites were located around the windfarm area. This was in response to concerns about the possibility of increased fishing activity on the margins of the exclusion zone and the sites were added to provide baseline data for future monitoring. These are the Adjacent Waters sites (NSWAW) and can be seen in Figure 1. A summary of the disposition of sample sites is given in Table 1.

Dredge samples were planned for some of the sampling locations, again with the objective of obtaining an even spread of data over the three areas and the adjacent waters. These targeted sparsely distributed infauna and consisted of tows of 100 m to obtain adequate sample sizes. Their actual positions are shown in Figure 2. Note that 3 tows in NSWCS were aborted because of equipment failure (see Section 3.4.1).

During the planning phase the position of a mud channel or trench (of unknown origin) across the NSWT area was provided by RIKZ. It was decided that this feature should be avoided when taking

Table 1. Summary of samples taken

Sampling area	Number of unreplicated sites	Number of replicated sites	Total number of samples	Number of dredge samples
NSWCN	20	5	45	9
NSWT	58	10	108	25
NSWCS	20	5	45	9
NSWAW	0	8	40	8

dredge samples as they would probably be unrepresentative of the area. However, box cores would be deployed to determine the nature of the sediment and fauna. The band lacking dredge tracks which runs across NSWT indicates the position of the mud channel (Figure 2).

Because dredging will be prohibited in the windfarm area, the mean and maximum sizes of some of the larger infauna may be expected to increase when the communities are released from this disturbance. Wherever possible baseline data (length measurements) from the commonest bivalve molluscs would be collected for future comparison.

Repeatability was ensured by positioning all sites away from submarine cables or other obstructions. Within the NSWT site all locations were fixed between the projected turbine positions (about 500 m distant) so that the same site will be accessable by the monitoring organisation after consultation with the windfarm operator.

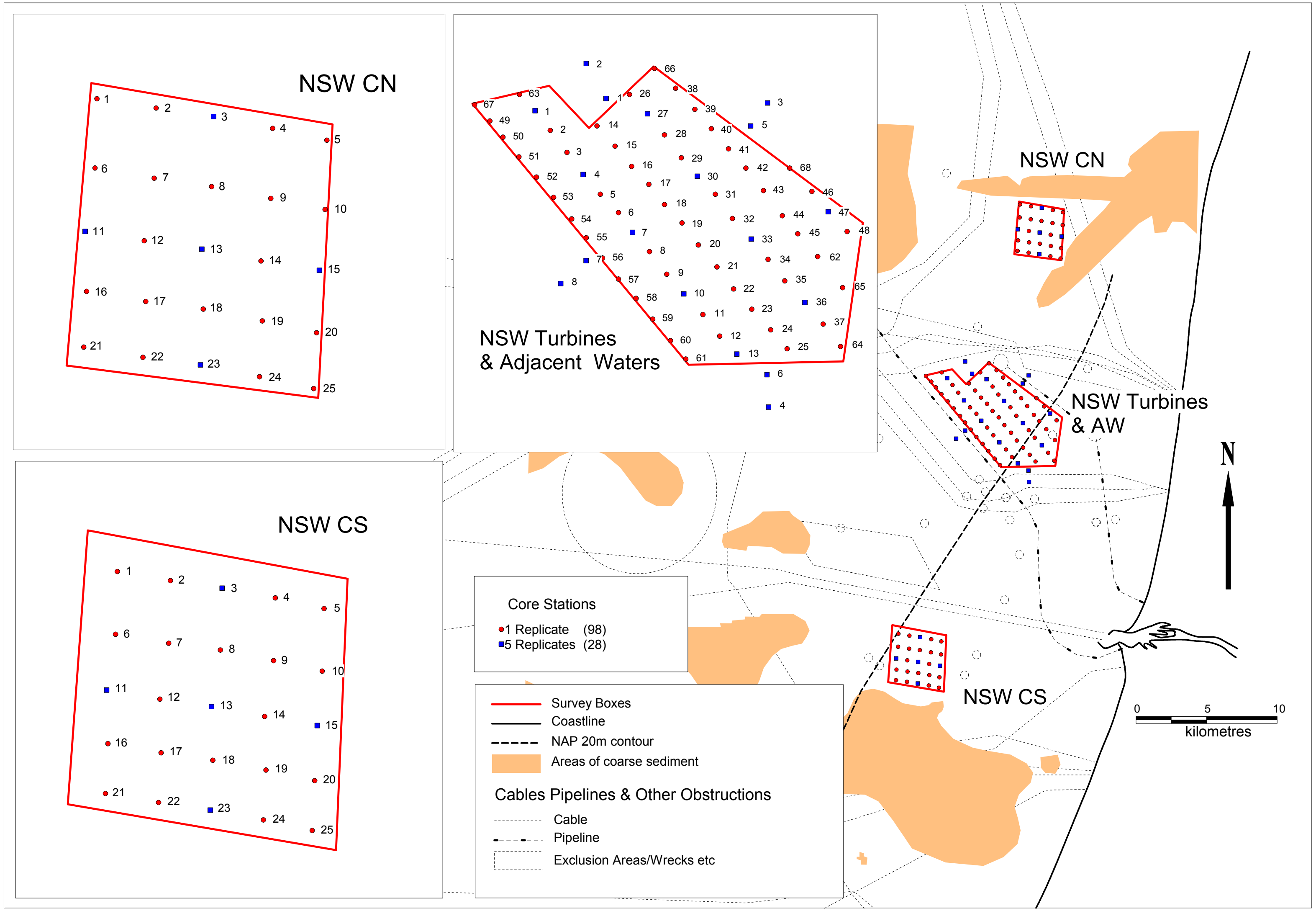


Figure 1. Box core sample locations showing replicated sites

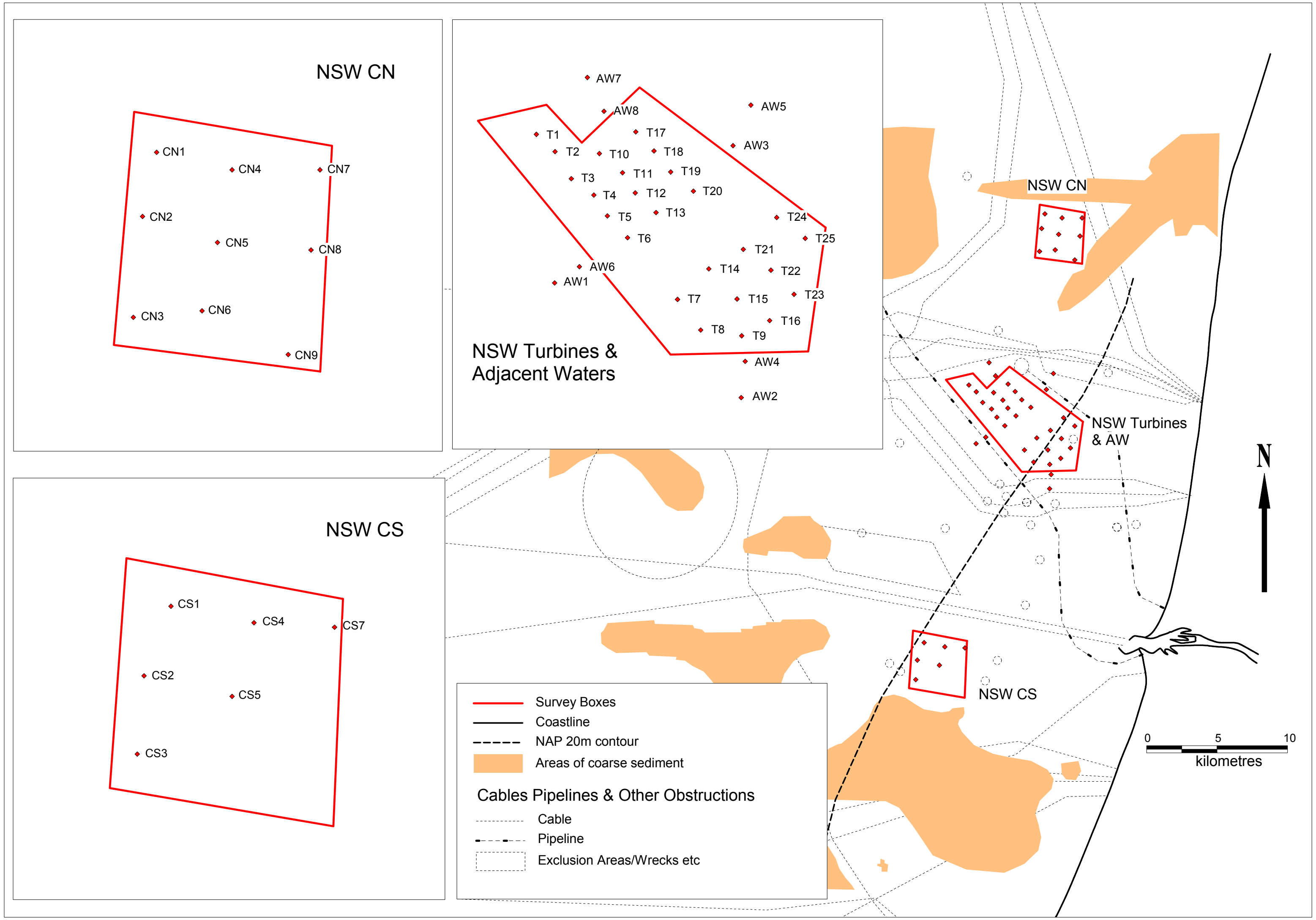


Figure 2. Actual dredge sample locations. Approximate position of mud channel in NSWT indicated by SW - NE band lacking samples

2.2 Sampling methods

A 0.068 m^2 Reineck box corer (Eleftheriou & Holme, 1984) was deployed for sampling the small invertebrates and a benthos dredge similar to the "Triple D" (Bergman & van Santbrink, 1994) was used for the fauna of low abundance.

The box corer (Figure 3) consists of a rectangular metal box (26 cm x 26 cm) fitted into a weighted tubular steel frame. When lowered to the seafloor the projecting box is driven into the sediment under the weight of the corer. When lifting tension is applied to the cable, a mechanism, triggered on contact with the sea bed, rotates a counterbalanced arm in such a way as to swing a cutting plate through the sediment and under the box before the sampler is lifted from the bed. The plate, which has a rubberised upper surface, sits flush against the lower edge of the box and seals the sample in the container during lifting back to the deck (see Eleftheriou & Holme, 1984 for further details and diagram). The box corer is normally considered superior to grabs (which operate by closing jaws to take a "bite" of sediment) in that the sample is relatively undisturbed when it arrives on the deck. However, as with most commonly used sampling equipment, the displacement of water as the corer reaches the seafloor causes a bow-wave which may displace any flocculent material including some of the fauna.

Figure 3. Box corer

The box corer was chosen because of its ability to retrieve relatively undisturbed cores and to provide continuity with previous studies conducted in this area (e.g. Duineveld *et al.* 1991; Daan & Mulder, 2002).

The corer was operated from the stern of the vessel and, when retrieved, was guided onto a supporting cradle by two deck hands in conjunction with the winch operator. Cores of poor integrity or with a sediment depth of less than 10 cm were rejected and a fresh attempt was made, otherwise the sample was emptied into a plastic crate and photographed. Sediment characteristics, visible fauna and any unusual features were recorded in the sampling log.

Three random subsample sediment cores (3.5 cm diameter to depth of sample) were taken from each box core sample except at replicated sites when only the first replicate was subsampled. These samples were placed in re-sealable labelled bags, frozen and stored for laboratory analysis.

Each sample was washed into a hopper and then sieved on board using a 1 mm mesh screen. Samples were fixed in 5% buffered formalin and stored in labelled, sealed plastic buckets with an internal punched-tape "security" label.

The dredge (Figure 4) was designed to be towed along the seabed and sample the sparsely distributed, deep burrowing fauna which could not be sampled with the box corer. The heavy steel frame consists of two "D" shaped side pieces with curved bases to act as runners or skis over the sandy ground.

Between the runners is an inclined (45˚), 1 m wide cutting plate set to project 15 cm below the frame. A 6 mm mesh, 5 m long net was closely fitted to the frame . As the dredge is hauled over the sediment the cutting plate lifts a 15 cm deep section of seabed over the frame and into the attached net.

The dredge was also lowered and retrieved over the stern. Once the dredge had reached the seabed sufficient cable was paid out, as the vessel slowly advanced, to haul it back towards the vessel over a 100 m track. Winching was carried out slowly and each track given a SW – NE axis. The cable was marked with heavy duty tape to ensure consistency and accuracy of dredge tow length.

Figure 4. Dredge with nets attached (left). Detail of cutting plate (right) showing wear (note: net partly removed)

Dredge samples were washed into a hopper and the fauna was extracted by hand. Fixing and storage were as described for core samples. Dredge samples were assigned a “D” suffix to differentiate from core samples.

The survey was conducted between 22 and 31 May 2003 on board the research and survey vessel M.V. *Maggie M*, operated by Danbrit Ship Management of Grimsby, U.K. The 29.5 m vessel was equipped with bow thruster, 3 tonne hydraulic crane and winch with pull of 16 tonnes. Position fixing was achieved using the onboard Sercel DGPS system with pre-loaded target points. Site positions are given in Appendix 1.

Throughout this report “region” refers to the whole region of the Dutch Continental Shelf in which all sampling took place, “area” refers to one of the sampling “boxes” (Turbine, Reference or Adjacent Waters) and “site” refers to the sampling locations within areas. Samples may or may not be replicated at each site (see Section 2.1) and replicates are indicated by lower case suffixes a to e (e.g. NSWAW5c).

2.3 Laboratory methods

2.3.1 Sediment characteristics

Sediment particle size data were determined using a combination of dry sieving (Buchanan, 1984) for the larger fraction (> 1.0 mm) and laser granulometry for the particles less than 1.0 mm. The smaller fraction was analysed using a recently calibrated Malvern Mastersizer 2000 laser diffractor. Grain size classification follows Folk (1980).

The organic matter content was estimated by placing a sub sample of thoroughly mixed sediment. into a small pre-weighed porcelain crucible and drying it at 80º C for 24 hours. This was then re-weighed to obtain dry weight. The sample was then placed in a Carbolite™ Muffle Furnace at a temperature of 480º C for 4 hours and allowed to cool in a desiccator before re-weighing. The difference between the two weights represents the weight of the organic carbon within the sediment. This was then expressed as a percentage of the dry weight.

For carbonate analysis the same sample was returned to the furnace at a temperature of 925º C for 4 hours. After cooling in a desiccator it was re-weighed. The difference between this weight and the weight after 480º C was multiplied by 1.36 (the difference between the molecular weights of CO_2 and CO_3) giving the weight of carbonate within the sample. This was then also expressed as a percentage of the dry weight. Carbonate data were supplied to RIKZ but are not considered further in this report.

2.3.2 Faunal samples

In the laboratory the fauna samples were re-sieved (1.0 mm for cores, 6.0 mm for dredges) in a fume cupboard to remove traces of formalin. Core samples were then washed into white plastic trays and examined under an illuminated magnifying lens to separate fauna from sediment. Dredge samples were re-sorted by hand if necessary. Taxa were identified to species level wherever possible (following Howson & Picton, 1997 for nomenclature) and enumerated. Where juvenile or damaged specimens could not be assigned with certainty to any species they were recorded at genus level and these have been treated as separate taxa in the calculation of indices. Taxa which could not be identified because of the preservation method used (e.g. Anthozoa, Nemertea) were recorded at Phylum or Class level (Daan & Mulder, 2002). Biomass was determined on a Mettler AB104-S microbalance by the blot dry method (Rumohr, 1999) and converted to Ash Free Dry Weight (AFDW) using conversion factors supplied by Netherlands Institute of Sea Research (NIOZ) and those published by Rumohr *et al* (1987) and Ricciardi & Bourget (1998). Bivalve lengths were converted to AFDW biomass using an equation of the form:

$W = aL^b$

where W is AFDW L is the length in millimetres and a and b are species specific constants supplied by NIOZ. Small molluscs, amphipods and cumaceans were assigned nominal individual dry weights of 0.2 to 0.5 mg (Daan & Mulder, 2000).

Where present in sufficient numbers bivalve lengths were measured to the nearest 1 mm using Vernier calipers. This proved feasible only for dredge material there being too few individuals per box core sample.

2.4 Statistical analyses

Density (individuals m^{-2}) and Ash Free Dry Weight (AFDW) biomass (g m^{-2}) were calculated for each box core sample. The following univariate measures were also computed: Hill's N_0 (which equates to sample species richness or total number of species present in the sample – Hill, 1973), Shannon diversity index (H') (using $\log_2$) (Shannon & Weaver, 1949) and Pielou's evenness (J') (Pielou, 1975).

Variables were tested for homogeneity of variance using the Levene statistic (Levene, 1960). Means were tested using ANOVA unless the assumption of equal variances was violated. In these cases the data were transformed using either $\log_{10}(n+1)$ or square root transformations. If transformation failed to produce homogeneous variances the Kruskal-Wallis distribution–free test was used. Percentage values were arcsine transformed before anaysis.

Differences between all possible pairs of means were further investigated using the Scheffé *post hoc,* or unplanned, multiple comparison procedure (Sokal & Rohlf, 1995) or Dunn's procedure, a nonparametric multiple comparison test for unplanned comparisons (Zar, 1999). These tests are more conservative than planned comparisons and are necessary because comparisons were not chosen independently of the sampling results (Sokal & Rohlf, 1995). Means are quoted with standard deviation (s.d.) as a measure of dispersion about the mean.

All analyses were performed with SPSS statistics software routines.

Classification analysis was used to investigate patterns in the fauna. All cluster analyses were conducted on untransformed data using the Bray - Curtis similarity measure (Bray & Curtis, 1957) and group average cluster mode using PRIMER™ software. At replicated sites mean abundances were used in the classification analysis (Duineveld *et al.* 1990).

Green (1979) highlights the importance of using data appropriate for the sampling device employed. Care was taken in this study not to confound analyses by including fauna that appeared in samples taken by an inappropriate sampling device. For box core samples, large crabs (*Liocarcinus* spp.), razor clams (*Ensis* spp.) and sea urchins (Echinoids) were discounted in the analysis (although identified and recorded in the full dataset). These large invertebrates constitute an extremely high proportion of the area covered by the box core and thier biomass would skew results for the rest of the fauna (Duineveld *et al*. 1990). Their size and distribution patterns are not appropriate for a box core, which is designed to operate on a smaller scale (Armonies, 2000). Furthermore, some individuals (e.g. Razor clams) burrow too deeply to be sampled by the box corer and may have been missed or were damaged by the cutting plate.

For similar reasons, only the larger, more sparsely distributed fauna such as crabs, bivalve clams, echinoderms and other large sessile or slow moving invertebrates were included in the analysis of dredge samples (as in Bergman & van Santbrink, 1994). The large mesh size of the dredge net precluded most of the polychaete and amphipod species sampled by the box corer. Species such as shrimps and mysids, with rapid escape responses were also unlikely to be captured by the slow moving, 1 m wide dredge. These were also discounted in the analysis (Craeymeersch *et al*. 1997).

Data were supplied in DONAR interface format for entry onto the RIKZ database.

3 RESULTS

3.1 Description of sampling areas

The Southern Bight is a shallow (20 - 30 m) shelf area of the southern North Sea bounded by the Deep Channel (which leads into the English Channel) to the west and the Oyster Grounds to the North (Daan & Mulder, 2002; van der Molen, 2002). Sea water input to the area is predominantly from the English Channel. Freshwater flows in from the Rhine and Meuse which disgorge approximately 90 km to the south. This forms a low salinity plume which moves northeast along the Dutch coast towards the Skagerrak. The Southern Bight is well mixed throughout the water column (Eisma, 1987). However, some salinity stratification may occur close to the Dutch coast during high river discharge events but this is not expected to affect the sampling areas (van der Giessen *et al*., 1990).

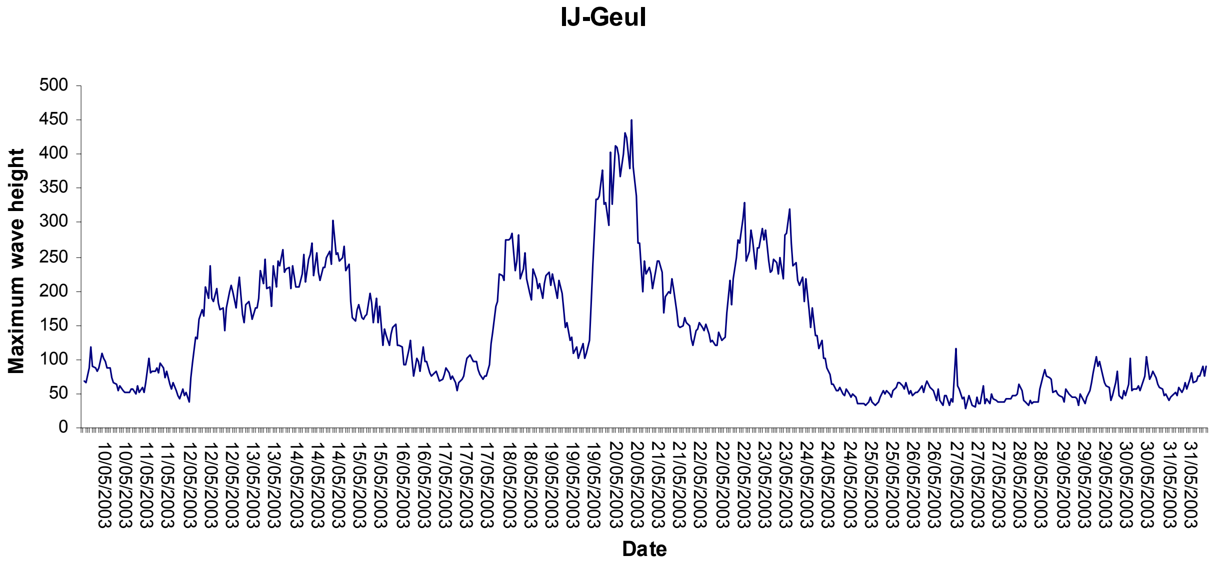
Tides are semi diurnal and residual surface tidal currents run northeast approximately parallel to the Dutch Coast. These are among the strongest in the North Sea (Eisma, 1987) and can reach 1.4 m sec^{-1} (van der Molen, 2002). A residual onshore movement (long-term average about 3 cm sec^{-1}) has been reported in this area for the lower part of the water column (van der Giessen *et al*., 1990). In calm conditions tidal currents dominate but during storms waves and wind-driven currents can be important. Winds may generate waves with a significant wave height of 9 m (Korevaar, 1990 cited in van der Molen, 2002). Such storm waves may produce sufficient orbital velocity to disturb sea-bed sediments down to considerable depths (van der Molen & de Swart, 2001; Otto *et al*., 1990). Washout of bottom features and erosional effects have been detected down to 45 m elsewhere in the North Sea (van der Molen, 2002).

Very little sand is supplied to the North Sea and most of the sedimentary processes now involve the re-working of existing sediments which were deposited during the last glaciation (Eisma, 1987). This process is mainly governed by tidal currents. According to van der Molen (2002) tides in the Southern Bight are strong enough to transport considerable quantities of sand close to the bed (within 1 m). In the southern North Sea this re-working can result in the formation of mobile sand waves which attain heights of 2 to 3 m in the area off Egmond aan Zee (McCave, 1971). Near bottom tidal currents, wind generated currents and (less frequently) storm waves all combine to modify sea floor sediments and thus create a physically stressed environment for marine invertebrates.

The relatively high current speed also affects the bottom characteristics by winnowing out fine-grained sedimentary and organic particles. Sediments therefore tend to be fine to medium sands (125 - 500 µm) with low organic carbon content. Species richness and abundance of infaunal and epifaunal animal communities are usually low in comparison with other areas of the North Sea such as the Oyster Grounds (Duineveld *et al*., 1990; Craeymeersch, *et al*. 1997).

3.2 Sampling conditions

Sampling was suspended on 22 May because of adverse weather conditions. No work was possible on 23 May as the sea state was unsafe for working. The rest of the period was dominated by calm conditions and sampling was carried out without further weather interruptions. Figures 5 and 6 give an indication of the wave climate in the area during and immediately preceding the sampling cruise. The data were taken from nearby wave measuring stations (IJ-geul IJ5 and IJ-geul munitiestorplaats 1: see www.actuelewaterdata.nl) and were supplied by RIKZ. Maximal wave height of 451 cm occurred at IJ-geul IJ5 on 20 May. Significant wave height (the average height of the highest one third of waves in a given area - Pond & Pickard, 1991) followed a similar pattern.



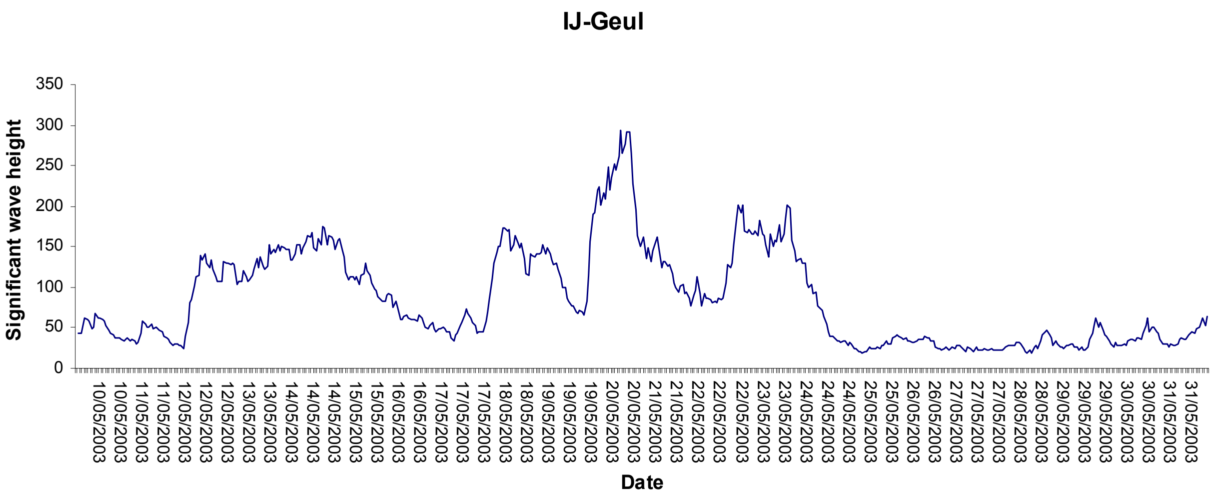


Figure 5. Wave climate data for IJ geul IJ5 wave measuring station. Maximum wave height (above) and significant wave height (below) expressed in cm. The survey was conducted between 22 and 31 May 2003.

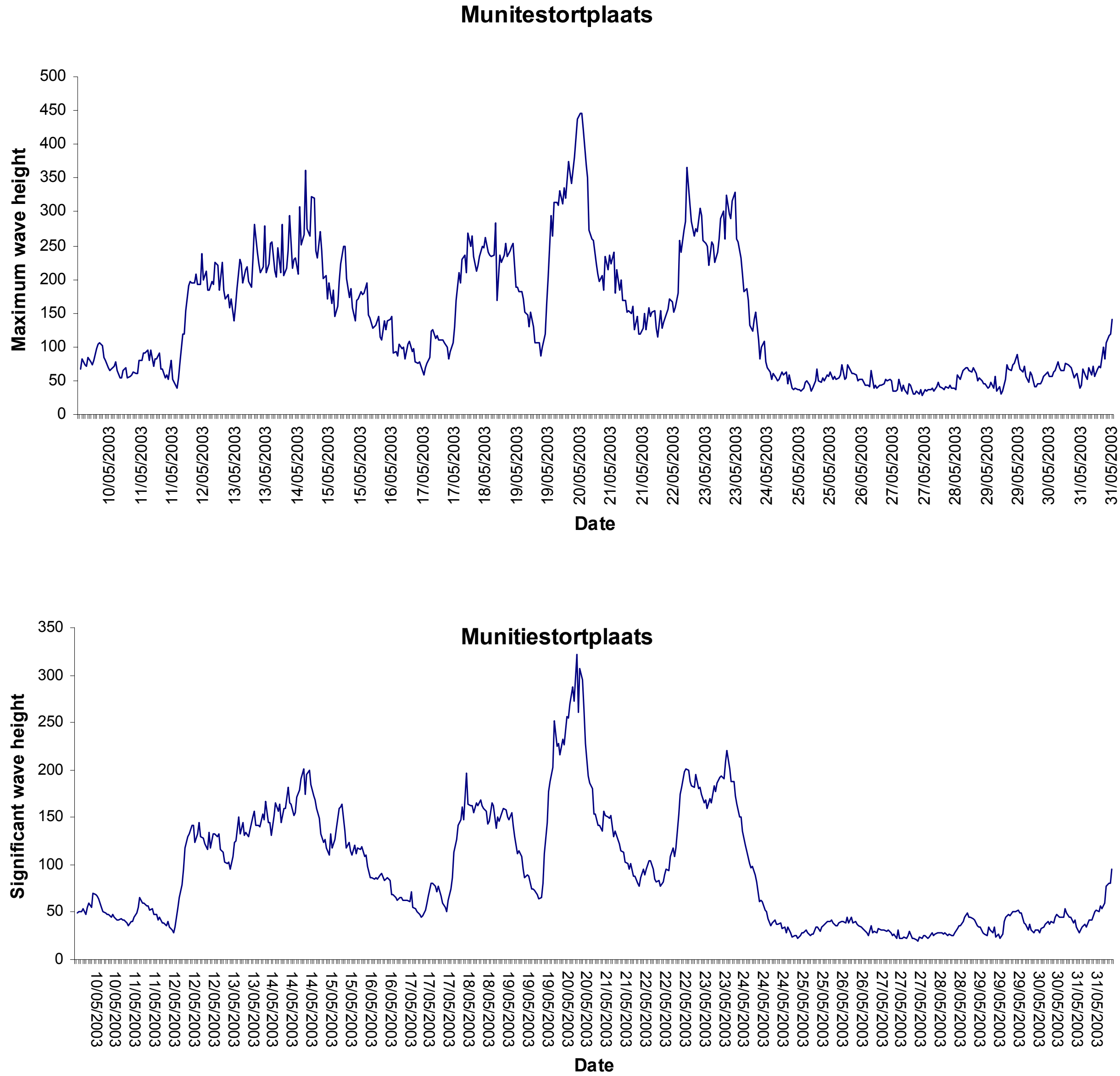


Figure 6. Wave climate data for IJ-geul munitiestorplaats 1 wave measuring station. Maximum wave height (above) and significant wave height (below) expressed in cm. The survey was conducted between 22 and 31 May 2003.

3.3 Box core samples

3.3.1 Physical variables - sampling areas

Depth at time of sampling ranged from 16.8 m at NSWT31 to 23.6 m at NSWCN06 the small range being indicative of the low relief of the seabed and resulting in low variance in depth data. Depth statistics are summarised in Table 2. Mean depth at NSWCS was significantly greater than at NSWT and NSWAW ($p < 0.05$).

Median grain size ranged from a minimum of 207 µm (fine sand) at NSWT34 to 1117 µm (very coarse sand) at NSWCS18. The latter reading was unusually high, the next highest being 660 µm at NSWCS23. The mean for all samples was 504 µm (s.d. = 122.8 µm which is classified as medium sand). NSWCS had the highest average median particle diameter (604 ± 123.4 µm) which was significantly greater than NSWCN and NSWT ($p < 0.05$) (Table 3). Median particle size at NSWAW was also significantly greater than that in NSWT ($p < 0.05$). See Figure 7 for variations in median grain size.

The coarser sediments were found in the southern reference area (NSWCS) where gravel grade material (> 2.0 mm) was detected in low proportions at five sites (NSWCS02, NSWCS03, NSWCS07, NSWCS12 and NSWCS16) (see Table 4 for summary). Only two sites in the northern reference area (NSWCN01 and NSWCN15), and one site in the turbine area (NSWT43) contained gravel sized sediment. The mean percentage gravel content at NSWCS was significantly higher than NSWT and NSWAW ($p < 0.05$) (see Table 4).

In all areas the sediment was predominantly medium sand and this is reflected in the very high mean percentage content of sand in each area (Table 5). NSWCS had the lowest mean value of 97.3% (± 4.99%). This was significantly lower than all other areas ($p < 0.05$).

Mud (< 63 µm) was not found in the Adjacent Waters or NSWCN samples but four sites in the turbine area contained mud grade particles (NSWT32, NSWT33, NSWT34 and NSWT21) ranging from 0.3% to 15.1% content. These sites form a small patch in the centre of the Turbine Area (see Figure 1 for locations). NSWCS had six sites (NSWCS02, NSWCS12, NSWCS16, NSWCS17, NSWCS21 and NSWCS24) with mud content ranging from 0.3% to 7.3%. Sites NSWCS12, NSWCS16, NSWCS17, and NSWCS21 form a discrete patch in the southwest corner of this reference area (refer to Figure 1 for site locations). Statistics for each area are summarized in Table 6 and a summary of sediment type is given in Figure 8.

There were no significant differences between the area means of organic matter content ($p = 0.40$; see Table 7) Values ranged from 0.2% at NSWAW01 to 1.5% at NSWT41. There was one exceptionally high reading of 4.1% at NSWT08 which was due to small particles of peat seen in the sample.

Table 2. Summary of sampling depth data (m) for box core samples. Horizontal bars connect means which are not significantly different ($p < 0.05$). Kruskal-Wallis test on untransformed data. Differences investigated using Dunn's procedure (Zar, 1999). n = 25 (NSWCS and NSWCN), n = 68 (NSWT), n = 8 (NSWAW).

	NSWAW	NSWT	NSWCN	NSWCS
Mean	19.0	19.8	20.4	20.8
Standard deviation	1.35	1.24	1.98	1.26
Maximum depth	21.5	22.5	23.6	23.4
Minimum depth	17.5	16.8	17.1	19.0

Table 3. Mean sediment grain size characteristics (median paticle size in µm) for each area. Horizontal bars connect means which are not significantly different ($p < 0.05$). Kruskal-Wallis test on untransformed data. Differences investigated using Dunn's procedure (Zar, 1999). n = 25 (NSWCS and NSWCN), n = 68 (NSWT), n = 8 (NSWAW).

	NSWT	NSWCN	NSWAW	NSWCS
Mean	466	489	557	604
Standard deviation	128.9	25.8	49.4	123.4
Maximum	655	547	628	1117
Minimum	207	447	490	409

Table 4. Mean gravel (> 2.0 mm) content (%) for each area. Horizontal bars connect means which are not significantly different ($p < 0.05$). Kruskal-Wallis test on untransformed data. Differences investigated using Dunn's procedure (Zar, 1999). n = 25 (NSWCS and NSWCN), n = 68 (NSWT), n = 8 (NSWAW).

	NSWAW	NSWT	NSWCN	NSWCS
Mean	0.0	0.1	0.5	1.4
Standard deviation	0.00	0.81	1.88	3.36
Maximum	0	7	9	14
Minimum	0	0	0	0

Table 5. Mean sand content (%) for each area. Horizontal bars connect means which are not significantly different ($p < 0.05$). Kruskal-Wallis test on untransformed data. Differences investigated using Dunn's procedure (Zar, 1999). n = 25 (NSWCS and NSWCN), n = 68 (NSWT), n = 8 (NSWAW).

	NSWCS	NSWT	NSWCN	NSWAW
Mean	97.3	99.4	99.5	100.0
Standard deviation	4.99	2.37	1.88	0.00
Maximum	100	100	100	100
Minimum	80	85	91	100

Table 6. Mean silt (< 63 µm) content (%) for each area. Horizontal bars connect means which are not significantly different ($p < 0.05$). Kruskal-Wallis test on untransformed data. Differences investigated using Dunn's procedure (Zar, 1999). n = 25 (NSWCS and NSWCN), n = 68 (NSWT), n = 8 (NSWAW).

	NSWAW	NSWCN	NSWT	NSWCS
Mean	0.0	0.0	0.5	1.0
Standard deviation	0.00	0.00	2.25	2.20
Maximum	0	0	15	7
Minimum	0	0	0	0

Table 7. Mean organic matter content (%) for each area. Horizontal bars connect means which are not significantly different (p = 0.610). ANOVA on untransformed data. n = 25 (NSWCN and NSWCS), n = 8 (NSWAW), n = 68 (NSWT).

	NSWAW	NSWCS	NSWCN	NSWT
Mean	0.35	0.40	0.44	0.49
Standard deviation	0.122	0.154	0.079	0.478
Maximum	0.62	0.77	0.60	4.06
Minimum	0.21	0.25	0.32	0.26

Figure 7. NSW windfarm and reference areas – sediment characteristics. Median grain size (µm). See Figure 1 for site numbers.

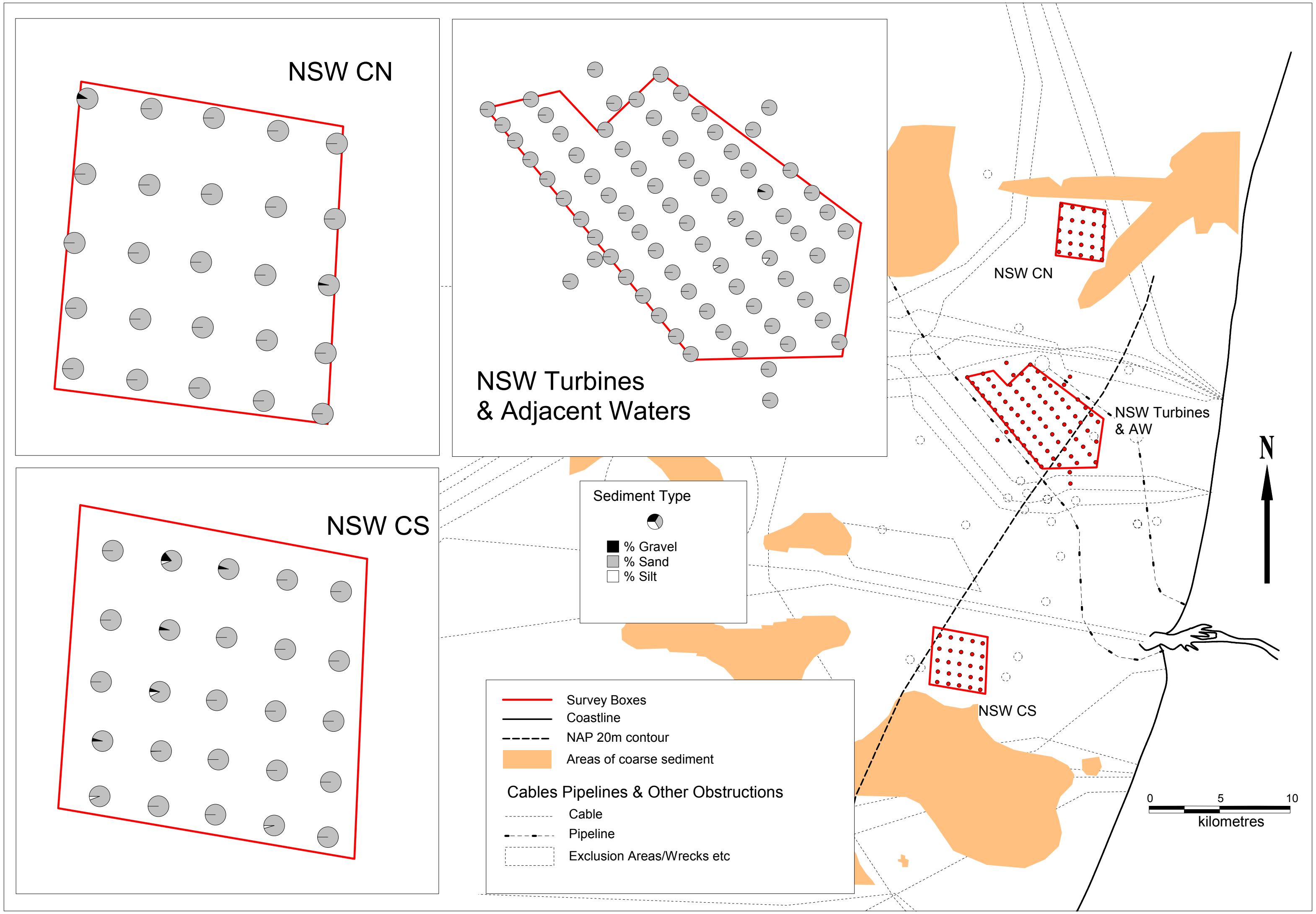


Figure 8. NSW windfarm and reference areas – sediment characteristics. Sediment type. See Figure 1 for site numbers

3.3.2 FAUNA - SAMPLING AREAS

Box core samples from NSWT and its associated reference areas yielded a total of 125 benthic invertebrate taxa. Most of these were polychaete worms (51 taxa) but there was also a diverse range of crustaceans (43 taxa) and a total of 17 bivalve mollusc taxa. The summary statistics of these samples are shown by area in Tables 8 to 12.

The greatest mean species richness was recorded at NSWCN and this was significantly higher than at NSWAW ($p < 0.05$ - Table 8). The maximum sample species richness (26) was recorded at NSWT45 (Table 8). Four samples in NSWCN (NSWCN14, NSWCN15a, NSWCN23c & NSWCN23d), two samples at NSWT (NSWT21, NSWT41) and one sample at NSWAW (NSWAW2a) contained no fauna. Species richness data are summarised in Figure 9.

Mean abundance was higher in the two reference areas than in the turbine area (see Table 9 and Figure 10) but the difference between means of NSWCS and NSWT was not significant. The mean of NSWCN was significantly higher than in any other area ($p < 0.05$). Maximum total invertebrate abundance of 7722 individuals m^{-2} was found in NSWCS12. The elevated abundance in NSWCS was due mainly to the prevalence of the tube-building worm *Lanice conchilega* (a mean of 422 individuals m^{-2}) and a much greater density of the spionid polychaete *Spiophanes bombyx* (mean = 533 individuals m^{-2} as opposed to 284 individuals m^{-2}, 267 individuals m^{-2} and 161 individuals m^{-2} at NSWT, NSWCS and NSWAW respectively).

The maximum Shannon diversity of 4.21 was recorded at NSWT47A and the minimum at NSWCS12. There were no significant differences between the means of this index (Table 10). Figure 12 summarizes variations in Shannon diversity at each site.

The greatest species evenness was found at NSWAW5E (J′ = 0.99). Samples at NSWCN had significantly lower mean J′ value than those of NSWT and NSWAW (Table 11). See Figure 13 for a summary of evennes statistics at each site.

Mean biomass (AFDW) was much greater in NSWCN than in any other area. This was attributable to high abundance of *Spisula subtrucata*. The mean of NSWCN was significantly higher than that of NSWCS and NSWAW (Table 12). Biomass for each site is summarised in Figure 11.

Table 8. Summary of sample species richness (Hill's N_0) statistics for box core samples. Horizontal bars connect means which are not significantly different ($p < 0.05$). ANOVA on untransformed data and differences investigated using the Scheffé *post hoc* test for unplanned contrasts among means. n = 45 (NSWCS and NSWCN), n = 108 (NSWT), n = 40 (NSWAW).

	NSWAW	NSWCS	NSWT	NSWCN
Total	73	71	86	77
Mean	10.2	11.4	11.8	14.1
Standard deviation	3.97	3.87	4.77	5.84
Maximum	19	21	26	23
Minimum	0	5	0	0

Table 9. Summary of total faunal abundance (individuals m^{-2}) for box core samples. Horizontal bars connect means which are not significantly different ($p < 0.05$). Kruskal-Wallis test on untransformed data. Differences investigated using Dunn's procedure (Zar, 1999). n = 45 (NSWCS and NSWCN), n = 108 (NSWT), n = 40 (NSWAW).

	NSWAW	NSWT	NSWCS	NSWCN
Mean	545.2	751.2	1039.2	1349.6
Standard deviation	384.54	641.17	1410.23	765.41
Maximum	1502	4282	7722	2857
Minimum	0	0	148	0

Table 10. Summary of Shannon diversity statistics for box core samples. Horizontal bars connect means which are not significantly different ($p = 0.331$). ANOVA on untransformed data. Samples without fauna omitted. n = 45 (NSWCS), n = 41 (NSWCN) n = 106 (NSWT), n = 39 (NSWAW).

	NSWCS	NSWAW	NSWT	NSWCN
Mean	2.52	2.59	2.67	2.68
Standard deviation	0.504	0.563	0.539	0.492
Maximum	3.32	3.46	4.21	3.41
Minimum	0.95	0.97	0.99	1.25

Table 11. Summary of Peilou's evenness (J′) statistics for box core samples. Horizontal bars connect means which are not significantly different ($p < 0.05$). ANOVA on untransformed data. Samples without fauna omitted. n = 45 (NSWCS and NSWCN), n = 108 (NSWT), n = 40 (NSWAW).

	NSWCN	NSWCS	NSWT	NSWAW
Mean	0.69	0.75	0.77	0.79
Standard deviation	0.098	0.159	0.129	0.141
Maximum	0.88	0.97	.097	0.99
Minimum	0.45	0.23	0.28	0.32

Table 12. Summary of total Ash Free Dry Weight (g) for box core samples. Horizontal bars connect means which are not significantly different ($p < 0.05$). Kruskal-Wallis test on untransformed data. Differencs investigated using Dunn's procedure (Zar, 1999). n = 45 (NSWCS and NSWCN), n = 108 (NSWT), n = 40 (NSWAW).

	NSWAW	NSWCS	NSWT	NSWCN
Mean	1.99	1.88	2.60	15.03
Standard deviation	4.825	1.764	4.201	32.298
Maximum	29.83	6.72	39.66	172.34
Minimum	0.00	0.08	0.00	0.00

The most abundant taxa in each area are listed in Table 13. The four areas were dominated by polychaete worms. *Spiophanes bombyx* was the most abundant in all areas except NSWCS which had higher mean abundance of *Lanice conchilega*. Other polychaete species were also important featuring prominently in all areas (*Nephtys cirrosa*, *Scoloplos armiger*). Amphipods were the most numerous crustaceans, *Urothoe poseidonis* being a conspicuous component of the fauna throughout the study.

The following taxa were present in all four areas:

Nemertea: Nemertea spp.

Polychaeta: *Malmgrenia glabra; Eteone longa; Anaitides lineata; Nephtys assimilis; Nephtys cirrosa; Nephtys hombergi; Scoloplos armiger; Scolelepis bonnieri; Spiophanes bombyx; Magelona filiformis; Magelona mirabilis; Magelona johnstoni; Chaetozone christiei; Notomastus latericeus; Lagis koreni; Lanice conchilega*

Crustacea: *Perioculodes longimanus; Pontocrates altamarinus; Pontocrates arcticus; Leucothoe incisa; Urothoe brevicornis; Urothoe poseidonis; Bathyporeia elegans; Bathyporeia guilliamsoniana; Bathyporeia ?nana; Megaluropus agilis; Diastylis bradyi*

Mollusca: *Polinices pulchellus; Tellimya ferruginosa; Spisula* spp (juveniles)*; Fabulina fabula; Donax vittatus*

Phoronida: *Phoronis* spp.

Echinodermata *Echinocardium cordatum*

Twenty-nine species were restricted to one area only and twenty-five species were represented by 1 or 2 individuals only. The following taxa were specific to one area only but were not singletons and appeared in more than one sample:

NSWAW: Polychaeta: *Chaetozone setosa* (2 samples)

Crustacea: *Pontocrates altamarinus* (10 samples)

NSWCN: Polychaeta: *Spio decorata* (4 samples)

Crustacea: *Iphinoe trispinosa* (2 samples); *Liocarcinus depurator* (2 samples)

NSWCS: Polychaeta: *Eumida sanguinea* (5 samples); *Travisia forbesii* (5 samples)

Mollusca: *Ensis americanus* (20 samples)

NSWT: Polychaeta: *Spio filicornis* (2 samples)

Crustacea: *Atylus swammerdamei* (2 samples)

Mollusca: *Ensis arcuatus* (4 samples); *Angulus tenuis* (2 samples)

Bivalves (*Fabulina fabula* and *Mysella bidentata*) ranked highly in abundance only in areas NSWT and NSWCN.

The commonest invertebrates found during this study are typical of sandy subtidal areas described by previous investigations. This habitat is often populated by species of polychaete worms such as *Nephtys* spp., *Scoloplos armiger, Spiophanes bombyx, Magelona* spp. *Travisia forbesii*, and *Lanice conchilega* (e.g. Heip & Craeymeersch, 1995). Amphipod (Crustacea) genera such as *Urothoe* spp. and *Bathyporeia* spp. are also typical for sandy ground as are the cumaceans (*Pseudocuma similis, Diastylis bradyi*) and burrowing crabs (*Thia scutellata*). Bivalves, such as *Spisula* spp. and *Donax vittatus,* and sea urchins (*Echinocardium* spp.) would also be expected in such areas and were found to be common throughout the study. A more detailed consideration of the compostion of the fauna is given in the discussion.

Biomass rankings are shown in Table 14. Although polychaetes still rank highly, the larger, but less frequently occurring animals such as bivalves (*Donax vittatus, Spisula elliptica, Fabulina fabula*) and burrowing crabs (*Thia scutellata*) attain greater rank than when compared by abundance. (Very large species which the box core is not designed to sample – *Liocarcinus holsatus, Ensis* spp. and *Echinocardium cordatum* - have been omitted from consideration here.) This is is a function of the average individual biomass of members of these species. This also explains why the small polychaete, *S. bombyx* is dominant numerically but does not rank highly in terms of its biomass.

In box cores *Nephtys* spp. were common and were significant contributors to total biomass. However, these worms appeared with lower frequency and abundance in NSWCN.

Table 13. Top ten most abundant taxa in each area. Mean = mean abundance (individuals m^{-2}), freq. = frequency of occurrence in samples (%).

NSWAW			NSWT			NSWCS			NSWCN		
	Mean	freq.		Mean	freq.		Mean	freq.		Mean	freq.
Spiophanes bombyx	161.5	90.0	*Spiophanes bombyx*	284.3	98.1	*Lanice conchilega*	422.0	95.6	*Spiophanes bombyx*	533.4	88.9
Nephtys cirrosa	97.7	97.5	*Urothoe poseidonis*	84.2	60.2	*Spiophanes bombyx*	266.7	91.1	*Lanice conchilega*	216.7	88.9
Urothoe poseidonis	79.4	55.0	*Nephtys cirrosa*	79.5	93.5	*Nephtys cirrosa*	66.7	82.2	*Urothoe poseidonis*	130.1	68.9
Terebellidae sp. juv	34.9	60.0	*Lanice conchilega*	61.7	81.5	*Ensis americanus*	34.3	44.4	*Spisula subtruncata*	73.6	57.8
Scoloplos armiger	31.2	60.0	*Scoloplos armiger*	27.9	67.6	*Lagis koreni*	24.2	24.4	Nemertea	42.2	68.9
Nemertea	15.9	52.5	*Eteone longa*	25.6	54.6	*Scoloplos armiger*	20.9	71.1	*Fabulina fabula*	40.2	60.0
Bathyporeia elegans	14.3	52.5	Nemertea	21.0	59.3	*Spio armata*	18.0	42.2	*Nephtys cirrosa*	32.4	46.7
Spio armata	9.2	45.0	*Fabulina fabula*	15.0	26.8	*Anaitides mucosa*	17.3	35.6	*Scoloplos armiger*	28.8	75.6
Eteone longa	7.4	35.0	*Bathyporeia elegans*	13.1	47.2	Nemertea	16.0	48.9	*Mysella bidentata*	28.5	37.8
Megaluroplus agilis	6.6	30.0	*Spio armata*	12.6	30.6	*Urothoe poseidonis*	15.1	33.3	*Nephtys hombergii*	20.9	62.2

Table 14. Top ten taxa (biomass) in each area. Mean = mean AFDW (g m^{-2}), freq = frequency of occurrence in samples (%).

NSW AW			NSW T			NSW CS			NSW CN		
	Mean	freq.		Mean	freq.		Mean	freq.		Mean	freq.
Spio armata	0.736	45.0	*Scoloplos armiger*	0.472	67.6	*Ophiura ophiura*	0.357	11.1	*Spisula subtruncata*	12.779	57.8
Nephtys cirrosa	0.466	97.5	*Nephtys cirrosa*	0.399	93.5	*Nephtys cirrosa*	0.269	82.2	*Anthozoa* spp.	0.510	17.8
Nepthys assimilis	0.139	2.5	*Fabulina fabula*	0.321	26.9	*Nepthys caeca*	0.247	8.9	*Fabulina fabula*	0.251	60.0
Ophiura ophiura	0.132	5.0	*Nephtys hombergii*	0.177	28.7	*Thia scutellata*	0.203	13.3	Nemertea	0.199	68.9
Donax vittatus	0.115	5.0	*Thia scutellata*	0.169	7.4	*Notomastus* sp.	0.176	24.4	*Nephtys cirrosa*	0.152	46.7
Scoloplos armiger	0.096	60.0	Nemertea	0.161	59.3	Nemertea	0.090	48.9	*Nephtys hombergii*	0.149	62.2
Nemertea	0.035	52.5	*Donax vittatus*	0.136	11.1	*Nephtys hombergii*	0.090	31.1	*Notomastus* sp.	0.142	28.9
Thia scutellata	0.034	2.5	*Nepthys caeca*	0.126	5.6	*Scoloplos armiger*	0.086	71.1	*Mactra stultorum*	0.139	2.2
Scolelepis bonnieri	0.025	22.5	*Spisula subtruncata*	0.122	14.8	*Lanice conchilega*	0.050	95.6	*Scoloplos armiger*	0.085	75.6
Urothoe poseidonis	0.024	55.0	*Notomastus* sp.	0.122	15.7	*Fabulina fabula*	0.046	24.4	*Donax vittatus*	0.079	4.4

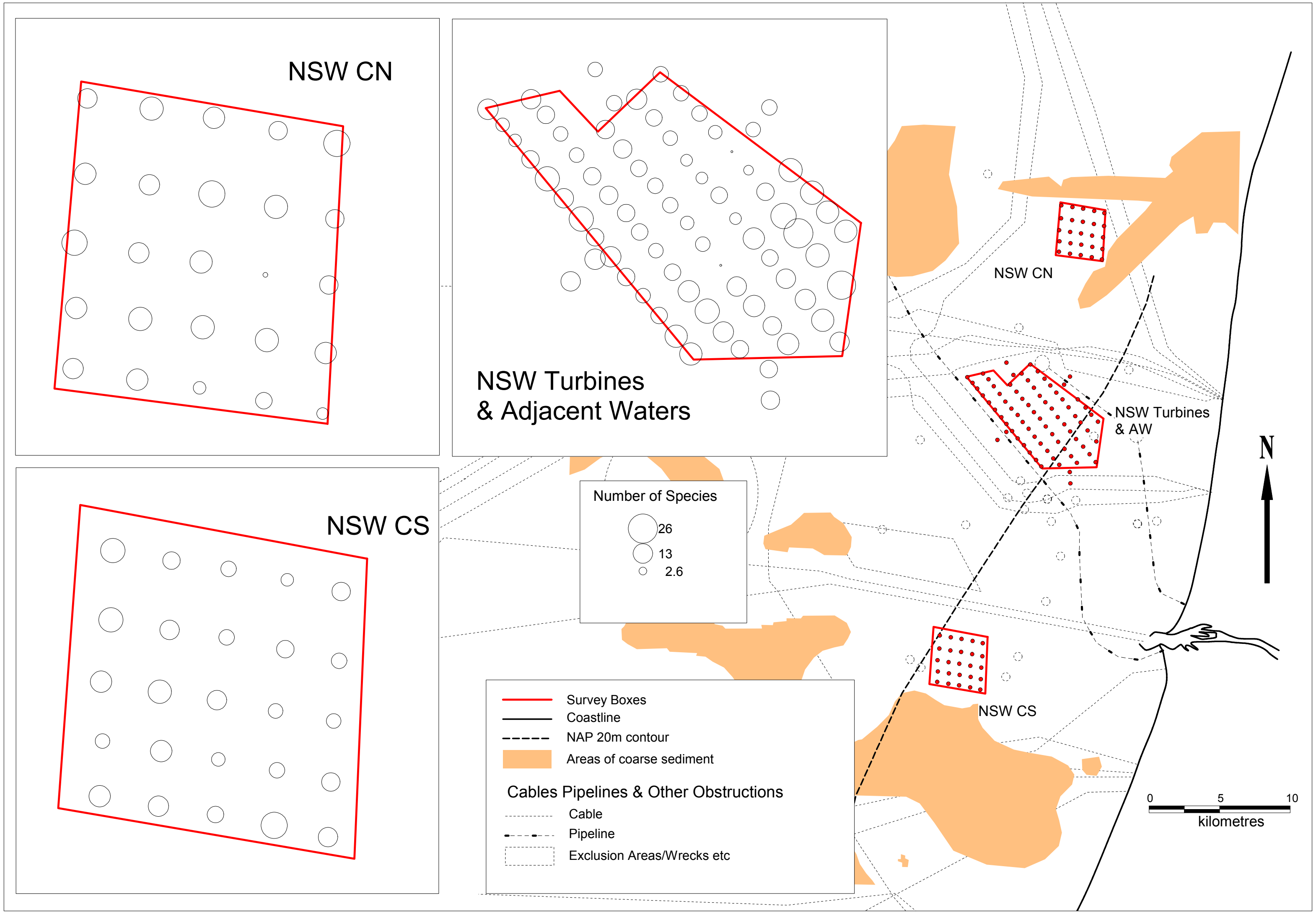


Figure 9. NSW windfarm and adjacent areas. Species richness (N_0). See Figure 1 for site numbers.

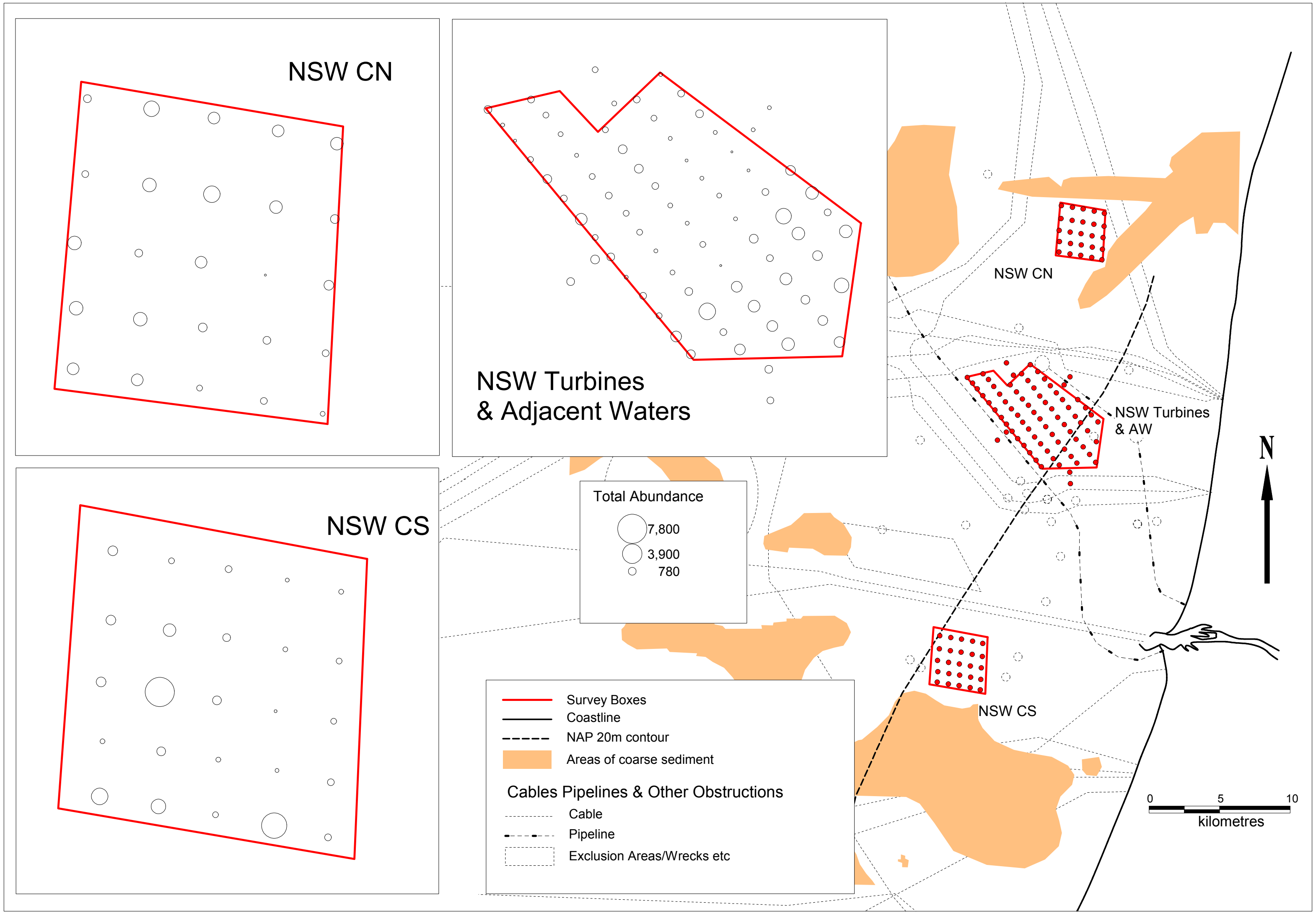


Figure 10. NSW windfarm and adjacent areas. Total abundance (individuals m^{-2}). See Figure 1 for site numbers.

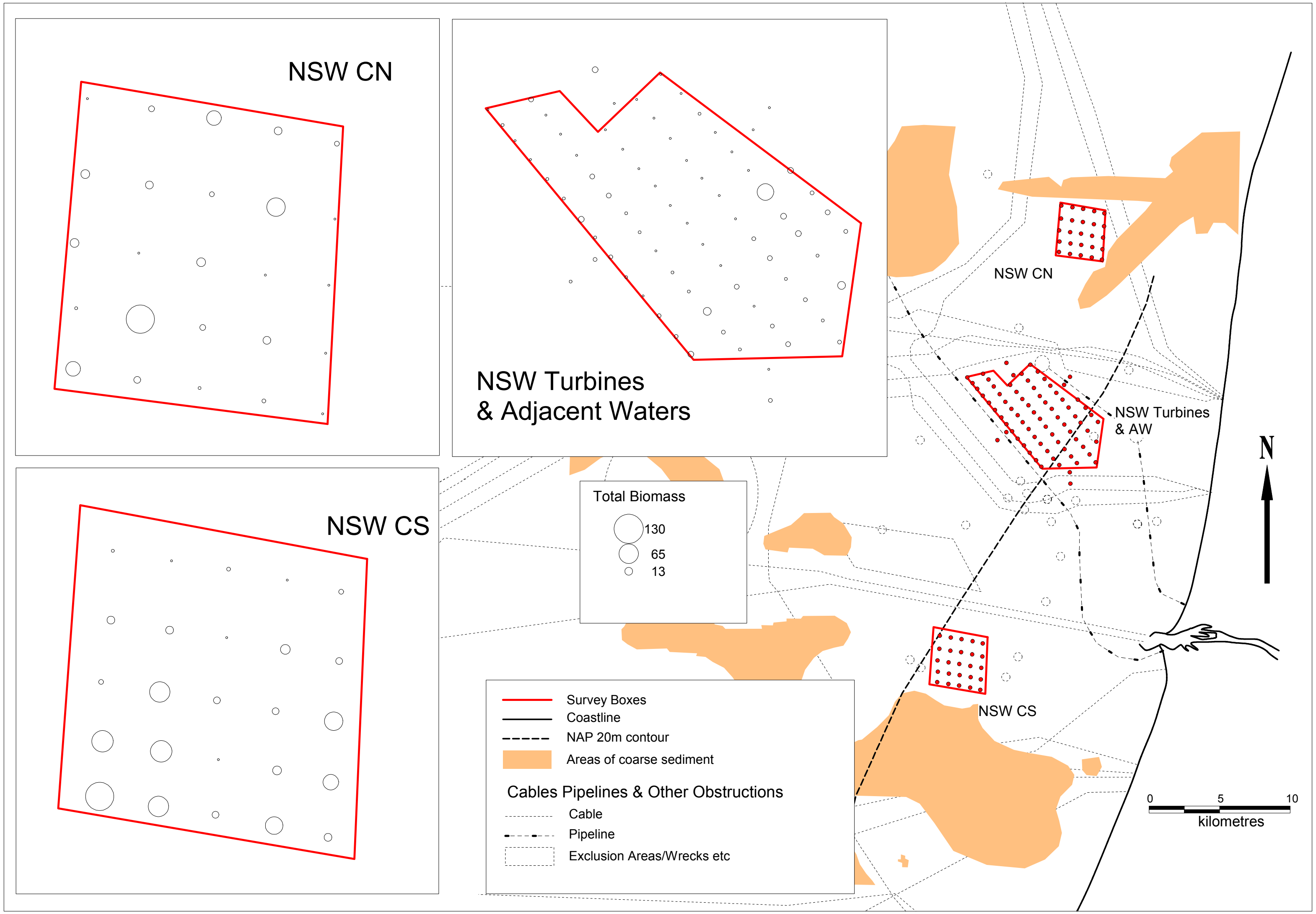


Figure 11. NSW windfarm and adjacent areas. Total biomass (g m^{-2}). See Figure 1 for site numbers.

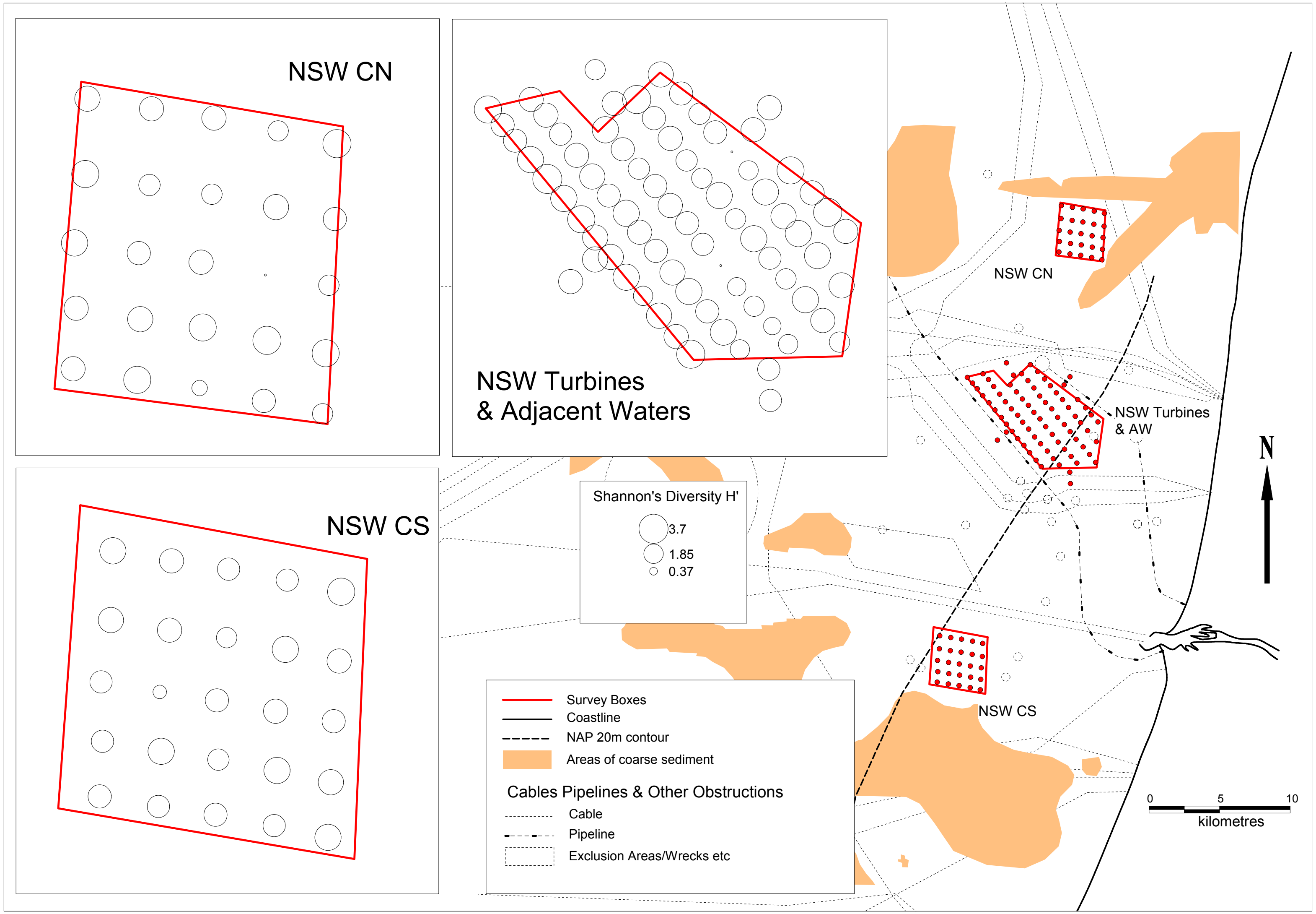


Figure 12. NSW windfarm and adjacent areas – Shannon diversity (H′). See Figure 1 for site numbers.

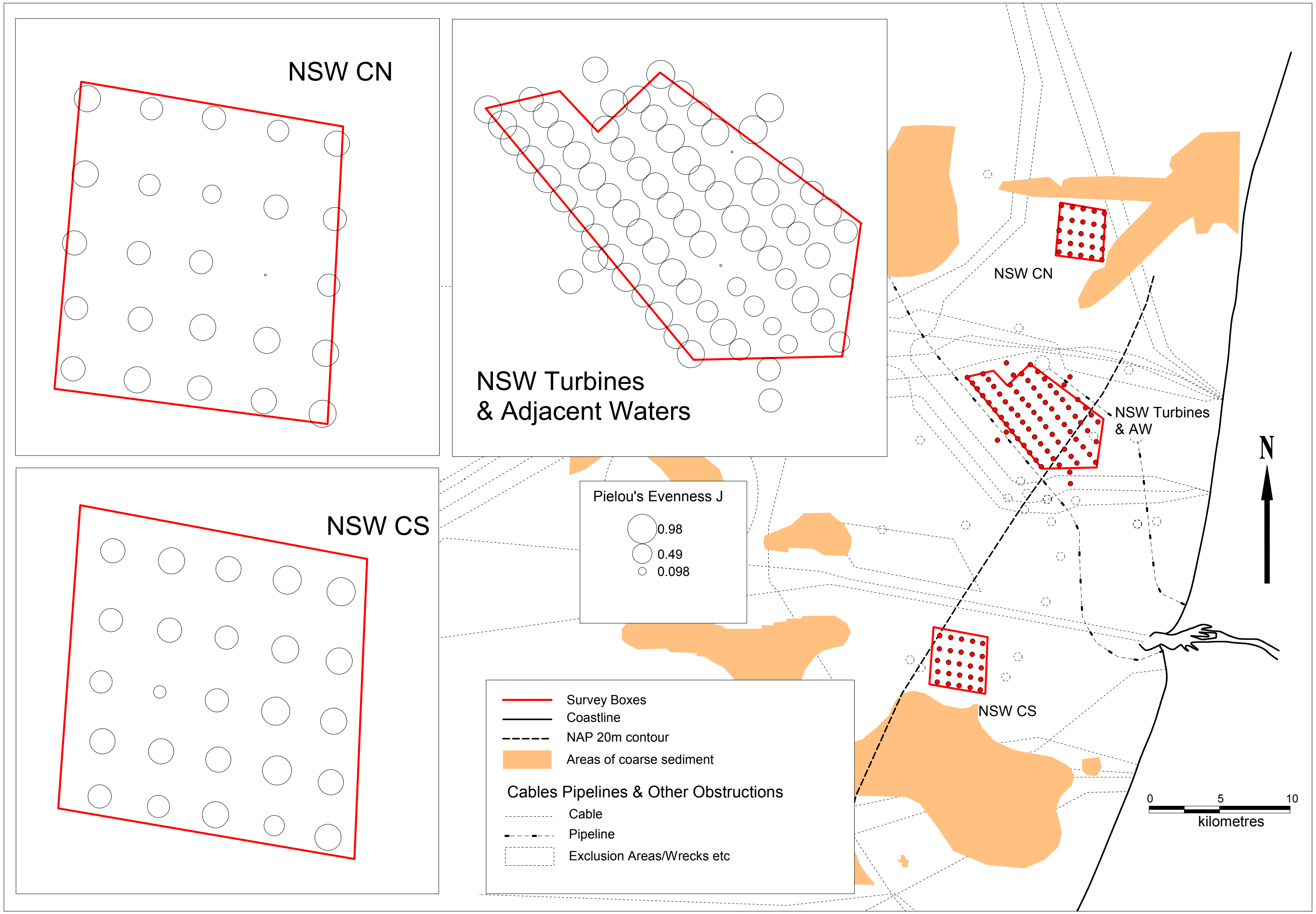


Figure 13. NSW windfarm and adjacent areas. Pielou's evenness (J′). See Figure 1 for site numbers.

3.3.3 Multivariate analysis

Two main groups of sites were resolved using classification analysis on abundance data. These clusters were defined at around 30% similarity (see Figure 14). Cluster 1 consisted of 65 sites (117 samples) and the majority of sites (30) were located in the turbine area (44% of all turbine area sites). NSWCN contributed 20 sites (80% of all NSWCN sites) and there were 11 NSWCS sites (44% of all sites from this area). NSWAW had 4 sites in each cluster.

Most sites in Cluster 2 (54 sites, 114 samples) were again from NSWT (35 or 51.5% of all NSWT sites) but the contribution of NSWCN sites was much lower (4 sites = 16% of all NSWCN sites). There were 11 NSWCS sites in this cluster (44% of all NSWCS sites).

Seven unreplicated sites (NSWT21, NSWT41, NSWT50, NSWCN14, NSWCS12, NSWCS16, NSWCS24) were not grouped in any of these clusters and are classified as “outliers”. No fauna was found at NSWT41 and NSWT21, and sites NSWCS16 and NSWT50 had very low abundance. NSWCN14 contained only Nemertea and NSWCS12 and NSWCS24 were characterised by an especially high abundance of *Lanice conchilega* (6750 individuals m^{-2} and 2956 individuals m^{-2} respectively). The distribution of clusters is shown in Figure 15.

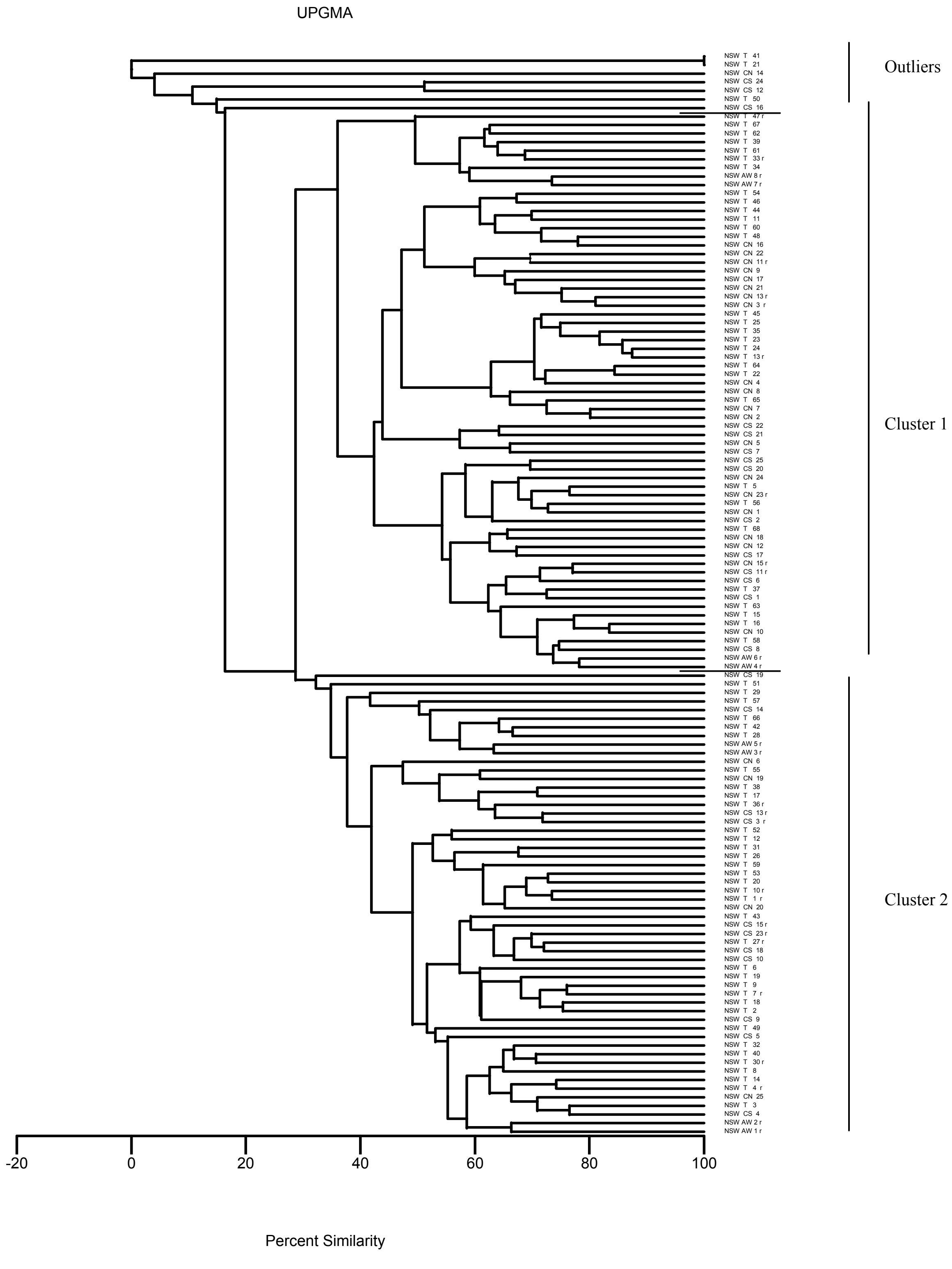


Figure 14. Classification analysis of core samples. Bray-Curtis similarity on untransformed data.

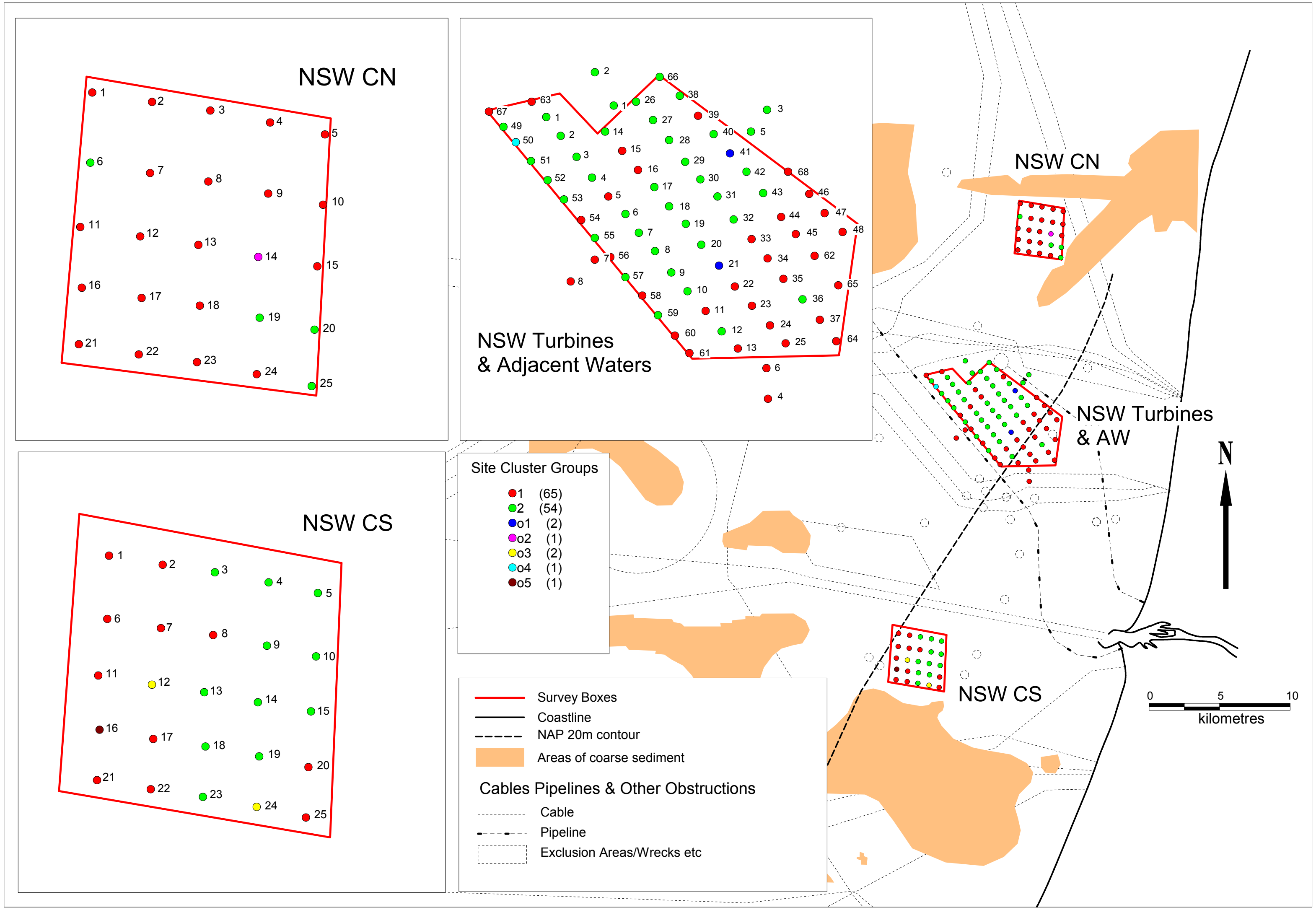


Figure 15. Box core sample groups 1 and 2 as identified by cluster analysis; o1 to o5 are outliers (see Figure 14).

3.3.4 Physical variables of derived sample clusters

There were no statistically significant differences between any measures of gravel, sand, silt and organic matter content (Table 15). However, depth at time of sampling was significantly shallower in Cluster 2 (although the difference between the means was only 1.1 m). There was also a significant difference between the means of the median particle size in each cluster, the sediment being coarser in Cluster 2. See Table 15 for details.

Table 15. Summary of physical variables of derived sample clusters. n = 65 (Cluster 1), n = 54 (Cluster 2). Values of p in bold face are statistically significant. s.d. = standard deviation.

	CLUSTER 1				CLUSTER 2				p
	Mean	s.d.	Max.	Min.	Mean	s.d.	Max.	Min.	
Depth (m)	20.5	1.40	24	18	19.4	1.39	24	17	**< 0.001**[a]
Median grain size (µm)	487	90.7	646	207	536	145.7	1117	252	**< 0.001**[b]
Gravel content (%)	0.5	2.21	14	0	0.2	1.16	7	0	0.473[c]
Sand content (%)	99.1	3.37	100	80	99.5	1.93	100	91	0.508[c]
Silt content (%)	0.4	2.09	15	0	0.1	1.06	8	0	0.155[b]
Organic matter (%)	0.44	0.118	0.90	0.25	0.45	0.519	4.06	0.21	0.395[a]

[a] - ANOVA on untransformed variates; [b]- Mann - Whitney test; [c] - ANOVA on arcsine transformed data

3.3.5 Fauna of derived sample clusters

Mean Shannon diversity (H′) did not differ between clusters ($p = 0.492$) but mean sample species richness (N_o), total abundance and biomass (AFDW) were significantly lower ($p < 0.001$) in Cluster 2 (Table 16) indicating a sparser fauna. Pielou's evenness measure (J′) was significantly higher in Cluster 2.

Both clusters were dominated numerically by *S. bombyx* although the mean abundance of this species was five times greater in Cluster 1 (Table 17). *S. bombyx, Urothoe poseidonis, Lanice conchilega, Nephtys cirrosa,* Nemertea spp., and *Eteone longa* were common in the top ranked taxa in both clusters. Bivalves (*Fabulina fabula* and *Spisula subtruncata*) were relatively more numerous in Cluster 1.

When ranked in order of biomass, less frequently encountered species with higher individual body mass assumed greater importance (Table 18). Cluster 1 was dominated by two bivalve species *Spisula subtruncata* and *Fabulina fabula*. *S. subtruncata* contributed a very high proportion of biomass and on average represented 18.9% of total sample biomass in this Cluster. This was mainly because of high abundances in the NSWCN samples.

Table 16. Summary of fauna variables of derived sample clusters. For species richness, abundance and AFDW n = 117 (Cluster 1) and n = 114 (Cluster 2). For derived univariate measures (Shannon and Pielou's evenness) samples were excluded when measures could not be computed (zero abundance): n = 114 (Cluster 1) and n = 113 (Cluster 2). Values of p in bold face are statistically significant. s.d. = standard deviation

	CLUSTER 1				CLUSTER 2				p
	Mean	s.d.	Max.	Min.	Mean	s.d.	Max.	Min.	
Species richness (N_o)	14.2	4.55	26	0	9.8	3.60	21	0	**< 0.001**[a]
Abundance (m^{-2})	1230	708.4	4282	0	458	317.7	2046	0	**< 0.001**[b]
Shannon (H′)	2.62	0.554	4.21	0.97	2.66	0.488	3.61	0.99	0.492[a]
Evenness (J′)	0.69	0.119	0.91	0.28	0.83	0.097	0.99	0.34	**< 0.001**[b]
AFDW (g m^2)	7.3	20.85	172.3	0.0	2.3	4.91	39.7	0.0	**< 0.001**[b]

[a] - ANOVA on untransformed variates; [b]- Mann - Whitney test.

In contrast Cluster 2 was dominated by polychaetes, especially *Scoloplos armiger* and *Nephtys cirrosa*. *S. subtruncata* was again the most important bivalve in terms of biomass (rank 6) but was accompanied by *Donax vittatus*.

Sixty-four percent of taxa were present in both clusters. The following taxa were specific to one cluster only but were not singletons and appeared in more than one sample:

Cluster 1

Polychaeta: *Sigalion mathildae* (6 samples); *Sthenelais boa* (7 samples); *Nephtys assimilis* (17 samples); *Spio decorata* (4 samples); *Spio filicornis* (2 samples); *Capitella capitata* (18 samples);

Crustacea: *Balanus* spp. (3 samples); *Synchelidium maculatum* (3 samples); *Iphinoe trispinosa* (2 samples)

Mollusca: *Abra alba* (6 samples)

Cluster 2

Polychaeta: *Mysta picta* (2 samples); *Nephtys longosetosa* (3 samples); *Ophelia borealis* (5 samples); *Travisia forbesii* (5 samples)

Crustacea: *Pseudocuma ?gilsoni* (3 samples)

Table 17. Top ten most abundant taxa (mean individuals m^{-2}) in box core sample clusters. *B.* = *Bathyporei*a. Frequency = proportion of samples in which species appeared

	Cluster 1			Cluster 2	
	Mean abundance	Frequency (%)		Mean abundance	Frequency (%)
Spiophanes bombyx	511.3	96.6	*Spiophanes bombyx*	102.6	93.0
Urothoe poseidonis	148.6	79.5	*Lanice conchilega*	93.7	72.8
Lanice conchilega	128.7	75.2	*Nephtys cirrosa*	80.0	97.4
Nephtys cirrosa	67.0	74.4	*Scoloplos armiger*	29.1	67.5
Nemertea	34.5	68.4	*Spio armata*	19.7	50.9
Fabulina fabula	32.4	58.1	Nemertea	12.6	48.2
Spisula subtruncata	31.6	34.2	*B. elegans*	12.4	41.2
Scoloplos armiger	26.9	72.6	*Urothoe poseidonis*	12.0	33.3
Eteone longa	25.7	58.1	*Eteone longa*	9.2	40.4
Nephtys hombergii	19.1	53.0	*B. guilliamsoniana*	6.4	30.7

Table 18. Top ten taxa ranked by biomass (AFDW g m^{-2}) in box core clusters.

	Cluster 1			Cluster 2	
	Mean abundance	Frequency (%)		Mean abundance	Frequency (%)
Spisula subtruncata	4.8959	34.2	*Scoloplos armiger*	0.4255	67.5
Fabulina fabula	0.4018	58.1	*Nephtys cirrosa*	0.4001	97.4
Nephtys cirrosa	0.3002	74.4	*Spio armata*	0.2595	50.0
Notomastus latericeus	0.2249	29.1	*Nepthys caeca*	0.2135	7.0
Nemertea	0.2015	68.4	*Thia scutellata*	0.2112	11.4
Anthozoa spp.	0.1960	7.7	*Spisula subtruncata*	0.1440	3.5
Ophiura ophiura	0.1631	6.8	*Donax vittatus*	0.1337	9.6
Nephtys hombergii	0.1521	53.0	*Nephtys hombergii*	0.1097	9.6
Scoloplos armiger	0.1190	72.6	*Ophiura ophiura*	0.0806	2.6
Nepthys assimilis	0.1159	17.1	Nemertea	0.0713	48.2

The spatial distribution of clusters can be seen in Figure 15. Cluster 1 dominated NSWCN and was concentrated in the offshore half of NSWCS. In the Turbine area most Cluster 1 samples were found in the nearshore, or southeastern, sector and in the four southernmost NSWAW sites. The remaining part of NSWT was dominated by Cluster 2 sites. Cluster 2 was represented sparsely in NSWCN but occupies the shoreward half of NSWCS. In NSWT the “outliers” (sites which did not fall into the two clusters) were due to low or zero abundance. These were situated within or adjacent to the area covered by Cluster 2 sites and may be associated with the lower abundance of that cluster. The outliers in NSWCS were sites dominated by sandmason worms (*Lanice conchilega*).

3.4 Dredge samples

3.4.1 FAUNA - SAMPLING AREAS

During the first day of field work the dredge net was snagged and torn on the vessel's stern plates. In view of time constraints and deteriorating weather it was decided to finish the sampling in NSWCS using a replacement 2 m beam trawl. This was of lighter construction than the dredge and was not fitted with a cutting plate, merely collecting fauna from the sediment surface.

The most abundant animals in these samples (NSWCS06D, NSWCS08D and NSWCS09D) were *Asterias rubens, Ophiura ophiura* and *Liocarcinus holsatus*. These species were common in the dredge samples from the same area. However, the 2 m trawl failed to sample any infaunal species such as *Echinocardium cordatum*, *Spisula subtruncata, Chamelea gallina* and *Thia scutellata* which were also abundant in nearby dredge samples. Although the use of this replacement trawl highlighted the efficiency of the dredge cutting plate in sampling the deep burrowing species, the data from these three sites were clearly not compatible with the rest of the samples and they have therefore been excluded from the following analyses. As a consequence of this, dredge data were missing from the southeast sector of the southern reference area. This contained six dredge sites as opposed to the nine which were originally planned.

A total of 46 taxa was identified in dredge samples from all areas. These were mostly crustaceans (16 taxa) and molluscs (24 taxa). The dredges in NSWT sampled over 2.5 times the volume of seafloor of the other areas and these 25 samples accumulated a total of 36 taxa in contrast to 26 and 29 taxa in NSWCS and NSWCN respectively. There were no significant differences between the means of sample species richness (N_o) (Table 19). However, the mean abundance of NSWCN dredges was significantly higher ($p < 0.05$) than all other areas (Table 20). This was due principally to very high populations of *Spisula subtruncata* which alone averaged 1777.6 ± 1472.26 individuals per 100 m^2.

The mean Shannon diversity index (H′) was significantly lower in NSWCN than in NSWT (Table 21) and NSWAW but did not differ from NSWCS ($p < 0.05$). Evenness (J′) was also lowest in NSWCN presumably because of the numerical dominance of *Spisula subtruncata* in these samples (Table 22). There were no differences between the means H′ or J′ in NSWCS, NSWT and NSWAW.

Table 19. Summary of sample species richness (Hill's N_0) statistics for dredge samples. Horizontal bars connect means which are not significantly different ($p < 0.05$). ANOVA on untransformed data. n = 9 (NSWCN), n = 6 (NSWCS), n = 8 (NSWAW), n = 25 (NSWT).

	NSWAW	NSWT	NSWCS	NSWCN
Total	27	36	26	29
Mean	12.5	14.3	14.5	16.0
Standard deviation	2.00	3.47	2.81	3.54
Maximum	16	21	18	23
Minimum	10	9	12	11

Table 20. Summary of total faunal abundance (individuals 100 m^{-2}) for dredge samples. Horizontal bars connect means which are not significantly different ($p < 0.05$). ANOVA on $\log_{10}(n+1)$ transformed data.

Differences between means investigated using the Scheffé *a posteriori* test. n = 9 (NSWCN), n = 6 (NSWCS), n = 8 (NSWAW), n = 25 (NSWT).

	NSWAW	NSWCS	NSWT	NSWCN
Mean	124.0	274.3	424.5	2208.0
Standard deviation	111.23	229.51	848.82	1776.98
Maximum	337	727	4314	5158
Minimum	38	88	35	89

Table 21. Summary of Shannon diversity (H′) statistics for dredge samples. Horizontal bars connect means which are not significantly different ($p < 0.05$). Kruskal-Wallis test on untransformed data. Differences between means investigated using Dunn's procedure (Zar, 1999). n = 9 (NSWCN), n = 6 (NSWCS), n = 8 (NSWAW), n = 25 (NSWT).

	NSWCN	NSWCS	NSWT	NSWAW
Mean	1.37	2.35	2.58	2.87
Standard deviation	0.795	0.554	0.487	0.220
Maximum	2.69	3.11	3.24	3.14
Minimum	0.57	1.72	1.59	2.58

Table 22. Summary of Peilou's evenness (J′) statistics for dredge samples. Horizontal bars connect means which are not significantly different ($p < 0.05$). ANOVA on untransformed data. Differences between means investigated using the Scheffé *a posteriori* test. n = 9 (NSWCN), n = 6 (NSWCS), n = 8 (NSWAW), n = 25 (NSWT).

	NSWCN	NSWCS	NSWT	NSWAW
Mean	0.34	0.62	0.69	0.79
Standard deviation	0.184	0.134	0.151	0.093
Maximum	0.67	0.75	0.93	0.93
Minimum	0.14	0.41	0.37	0.68

The following taxa were present in dredge samples in all four areas:

Anthozoa: Anthozoa spp.

Mollusca: *Polinices pulchellus; Spisula solida; Spisula subtruncata; Ensis ensis; Fabulina fabula; Donax vittatus; Chamelea gallina*

Crustacea: *Pagurus bernhardus; Corystes cassivelaunus; Thia scutellata; Liocarciuns arcuatus; L. depurator; L. holsatus*

Echinodermata: *Ophiura albida; Ophiura ophiura; Echinocardium cordatum*

Table 23 gives a more detailed summary of the most abundant species in each area. The dominance of *S. subtruncata* in NSWCN is clearly indicated, its mean abundance far exceeding any of the other common species in the region. Another major feature of the fauna in all areas is the co-occurrence of the brittlestars *Ophiura albida* and *O. ophiura*. both of which were ranked highly in all areas (*O. albida* on average the more abundant species).

Species restricted to one area were as follows (singletons unless otherwise indicated):

NSWCN	*Ebalia tumefacta* (2 individuals)
NSWCS	*Macropodia* sp. (juv.); *Liocarciuns marmoreus*
NSWAW	*Macropodia rostrata; Ensis siliqua*
NSWT	*Macoma balthica; Laevicardium crassum; Spisula elliptica* (4 individuals in 2 samples)

Further species were found with relatively low frequency and were absent from one or more areas. *Diogenes pugilator, Portumnus latipes*, and *Asterias rubens* were present only in NSWCS and NSWT. *Euspira catena*, *Abra alba* and *Venerupis senegalensis* occurred only in NSWCN and NSWT. *Mactra stultorum* and *Angulus tenuis* were absent from NSWCS, *Ensis americanus* was absent from NSWAW and *Ensis arcuatus* was absent from NSWCN.

The distribution of the main bivalve species is shown in Figures 16 - 18.

Table 23. Top ten most abundant (individuals 100 m^{-2}) taxa for dredge samples in each area. n = 9 (NSWCN), n = 6 (NSWCS), n = 8 (NSWAW), n = 25 (NSWT). freq. = frequency of occurrence.

NSWAW			NSWCN			NSWCS			NSWT		
	Mean	freq.		Mean	freq.		Mean	freq.		Mean	freq.
Donax vittatus	25.1	87.5	*Spisula subtruncata*	1777.6	100.0	*Echinocardium cordatum*	93.8	83.3	*Spisula subtruncata*	178.0	76.0
Ophiura albida	24.4	100.0	*Anthozoa spp.*	184.9	100.0	*Ophiura albida*	64.2	100.0	*Ophiura albida*	122.1	100.0
Ophiura ophiura	16.0	100.0	*Ophiura albida*	44.9	100.0	*Ophiura ophiura*	45.8	100.0	*Ophiura ophiura*	24.7	96.0
Spisula subtruncata	14.6	62.5	*Polinices pulchellus*	35.0	88.9	*Ensis sp. Indet*	19.5	100.0	*Donax vittatus*	20.9	92.0
Thia scutellata	8.6	87.5	*Fabulina fabula*	33.8	77.8	*Spisula subtruncata*	13.7	83.3	*Fabulina fabula*	15.8	48.0
Echinocardium cordatum	8.6	87.5	*Abra alba*	23.9	44.4	*Asterias rubens*	8.8	66.7	*Polinices pulchellus*	11.6	64.0
Fabulina fabula	7.4	25.0	*Ophiura ophiura*	15.6	88.9	*Liocarcinus holsatus*	5.0	100.0	*Chamelea gallina*	9.7	100.0
Chamelea gallina	5.3	87.5	*Ensis sp. Indet*	15.0	88.9	*Chamelea gallina*	3.2	66.7	*Ensis sp. Indet*	9.5	84.0
Ensis sp. Indet	3.1	100.0	*Tellinacea sp. Indet*	13.1	11.1	*Thia scutellata*	2.8	50.0	*Liocarcinus holsatus*	7.0	88.0
Juvenile Paguridae sp.	1.9	75.0	*Echinocardium cordatum*	12.2	100.0	*Ensis americanus*	2.8	50.0	*Thia scutellata*	6.1	80.0

Figure 16 Distribution (individuals 100 m^{-2}) of *Spisula solida* (above) and *S. subtruncata*.

Figure 17 Distribution (individuals 100 m^{-2}) of *Ensis ensis* (above) and *Fabulina fabula*.

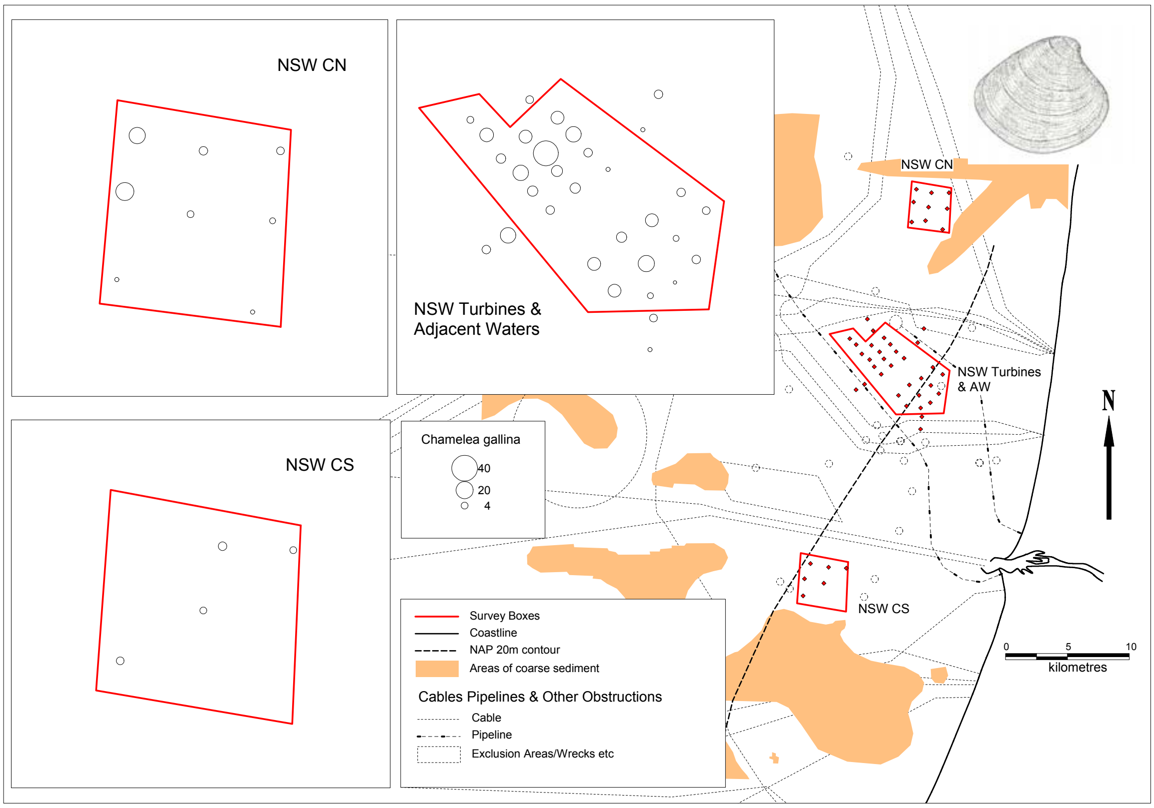


Figure 18. Distribution (individuals 100 m^{-2}) of *Donax vittatus* (above) and *Chamelea gallina*.

3.4.2 Multivariate analysis

Classification of samples using the Bray-Curtis similarity measure (Figure 19) produced four major clusters. Six NSWCN samples and one NSWT sample fell within the most distinctive cluster (Cluster 1D). Cluster 2D (10 samples) contained dredges from areas NSWCN and NSWT only, and Cluster 3D (12 samples) contained samples from NSWT and its satellite sites in NSWAW. Cluster 4D (18 sites) appreared to be a more diffuse collection of samples including data from all four areas. Within this cluster most of the NSWT sites formed a subgroup of 7 samples. NSWCS03D was not grouped with any cluster and is considered an “outlier”. Further discussion of these patterns is given below.

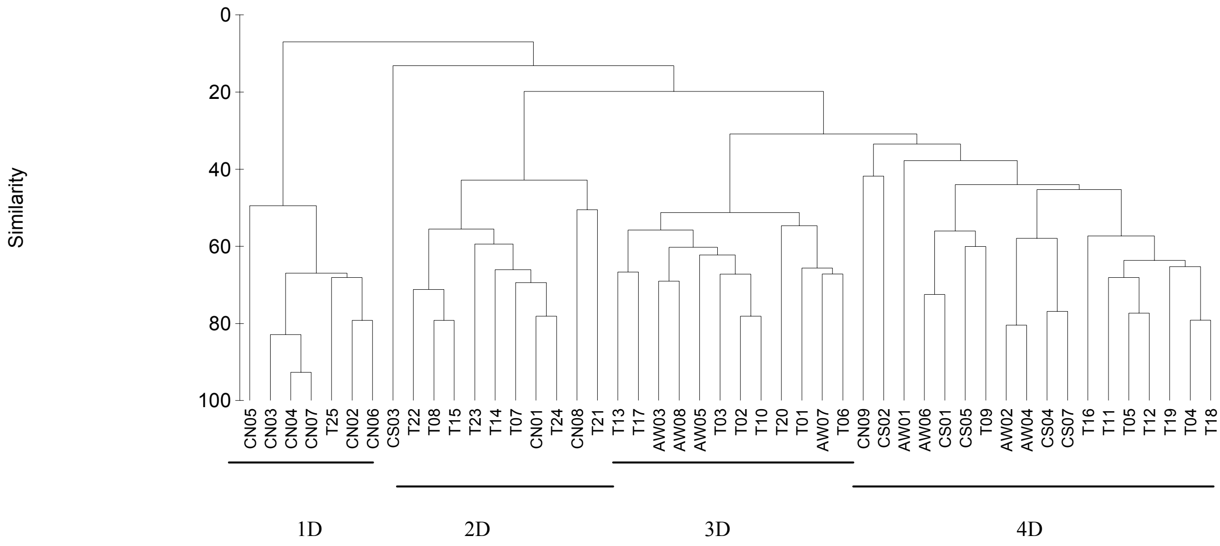


Figure 19. Dendrogram of dredge samples for all areas. Samples clustered using Bray-Curtis similarity measure. Sample clusters indicated below the x-axis.

3.4.3 Fauna - clusters

The highly distinct Cluster 1D was characterised by an extremely high mean total invertebrate abundance (Table 24). These samples were dominated by *Spisula subtruncata* whose mean abundance was 2598.7 ± 1044.59 individuals 100 m^{-2}. There was a large range of total abundance (35 individuals 100 m^{-2} in NSWT03D to 5158 individuals 100 m^{-2} in NSWCN02D) and all cluster means were significantly different from each other in this respect. Although Cluster 2D consisted of fewer samples than Clusters 1D and 3D, it contained the highest total number of species (33) and the highest mean species richness (N_o) per sample. Cluster 2D was significantly different from Clusters 3D and 4D, and Cluster 3D was also significantly different from Clusters 1D and 2D (Table 25).

The mean Shannon diversity measure (H′) was significantly reduced in Cluster 1 being less than half the value in any other cluster ($p < 0.05$) (Table 26). The difference between the means of clusters 2 and 3 was also significant ($p < 0.001$). Pielou’s evenness (J′) was also lowest in Cluster 1 ($p < 0.05$), due mostly to the dominance of *S. subtruncata*.

Table 24. Summary of total faunal abundance (100 individuals m^{-2}) for dredge samples. Horizontal bars connect means which are not significantly different ($p < 0.05$). ANOVA on $\log_{10}(n+1)$ transformed data. Differences between means investigated using the Scheffé *a posteriori* test. All pairwise differences were statistically significant ($p < 0.001$) n = 7 (Cluster 1), n = 10 (Cluster 2), n = 12 (Cluster 3), n = 18 (Cluster 4).

	Cluster 3	Cluster 4	Cluster 2	Cluster 1
Mean	57.6	158.2	607.9	3253.9
Standard deviation	16.17	73.80	222.65	1442.83
Maximum	91	337	1025	5158
Minimum	35	80	279	1142

Table 25. Summary of sample species richness (Hill's N_0) statistics for dredge samples. Horizontal bars connect means which are not significantly different ($p < 0.05$). ANOVA on untransformed data. Differences between means investigated using the Scheffé *a posteriori* test. n = 7 (Cluster 1), n = 10 (Cluster 2), n = 12 (Cluster 3), n = 18 (Cluster 4).

	Cluster 3	Cluster 4	Cluster 1	Cluster 2
Total	26	31	29	33
Mean	11.7	13.6	16.0	17.4
Standard deviation	1.87	2.09	2.71	3.81
Maximum	15	18	19	23
Minimum	9	10	11	11

Table 26. Summary of Shannon diversity (H′) statistics for dredge samples. Horizontal bars connect means which are not significantly different ($p < 0.05$). ANOVA on untransformed data. Differences between means investigated using the Scheffé *a posteriori* test. n = 7 (Cluster 1), n = 10 (Cluster 2), n = 12 (Cluster 3), n = 18 (Cluster 4).

	Cluster 1	Cluster 2	Cluster 4	Cluster 3
Mean	1.04	2.23	2.62	2.96
Standard deviation	0.449	0.400	0.416	0.284
Maximum	1.62	2.67	3.20	3.24
Minimum	0.57	1.38	1.62	2.53

Table 27. Summary of Peilou's evenness (J′) statistics for dredge samples. Horizontal bars connect means which are not significantly different ($p < 0.05$). ANOVA on untransformed data. Differences between means investigated using the Scheffé *a posteriori* test. All pairwise differences were statistically significant ($p < 0.001$) n = 7 (Cluster 1), n = 10 (Cluster 2), n = 12 (Cluster 3), n = 18 (Cluster 4).

	Cluster 1	Cluster 2	Cluster 4	Cluster 3
Mean	0.26	0.55	0.70	0.84
Standard deviation	0.102	0.096	0.088	0.074
Maximum	0.398	0.69	0.79	0.93
Minimum	0.143	0.39	0.49	.071

The following taxa were present in dredge samples from all four clusters:

Anthozoa:	Anthozoa spp.
Crustacea:	*Pagurus bernhardi; Corystes cassivelaunus; Thia scutellata; Liocarcinus depurator; L. holsatus*
Mollusca:	*Polinices pulchellus; Mactra stultorum; Spisula solida; S. subtruncata; Ensis ensis; Angulus tenuis; Donax vittatus; Chamelea gallina*
Echinodermata:	*Ophiura albida; O. ophiura; Echinocardium cordatum*

A summary of the mean abundances of the most commonly dredged animals in each cluster is given in Table 28. *Spisula subtruncata* dominated both Cluster 1D and Cluster 2D (to a much lesser degree in the Cluster 2D) but had lower relative abundance in Clusters 3D and 4D. Only the brittlestars (*Ophiura albida* and *O. ophiura*) appeared in the top ranking taxa in each cluster, *O. albida* the more abundant in each case. The high abundance of anthozoans was also a feature of Cluster 1.

Clusters 1 and 2 both contained high mean abundances of *Fabulina fabula* and *Polinices pulchellus* which were not highly ranked in the other two clusters. Cluster 3D was distinguished by the co-dominance of *Thia scutellata*, *Donax vittatus* and *Chamelea gallina*. Cluster 4 was dominated by brittlestars (see Table 28).

Of the rarer species the following taxa were specific to one cluster only but were not singletons and appeared in more than one sample:

Cluster 1	*Ebalia tumefacta* (1 sample - 2 individuals)
Cluster 3	*Spisula elliptica* (2 samples)

Singletons occurred in Cluster 2D (*Macoma balthica, Laevicardium crassum*) and Cluster 3D (*Macropodia rostrata* and *Ensis siliqua*). The remaining less frequently encountered species were absent from one or more clusters. *Diogenes pugilator* and *Liocarcinus arcuatus* were not recorded in Clusters 1D and 4D respectively. Anthozoa spp. *Euspira catena, Ensis americanus, Fabulina fabula, Abra alba* and *Venerupis senegalensis* were not found in samples from Cluster 3D. *Portumnus latipes* was present in Clusters 3D and 4D only. *Ensis arcuatus* and *Asterias rubens* were present in Clusters 2D and 4D only.

Within Cluster 4D a subgroup of NSWT samples can be identified (see Figure 19). These 7 samples contained 24 species (mean 13.4 ± 1.90 per sample) and a mean abundance of 134.9 ± 39.88 individuals 100 m^{-2}. *Ophiura albida, Donax vittatus, Ophiura ophiura*, and *Chamelea gallina* were the dominant taxa (100% occurrence) in order of mean abundance per sample.

NSWCS03D was a highly distinctive sample containing very high abundances of *Echinocardum cordatum* (513 individuals) and *Asterias rubens* (28 individuals). For both of these echinoderms this was by far the highest abundance recorded in any sample.

In Figure 20 the sites are designated on the chart according to cluster membership. Cluster 1D was confined almost solely to NSWCN. Only one nearshore sample from NSWT also fell into this group.

Cluster 2D had two sites in NSWCN but was otherwise confined to the easternmost, or shoreward sector of the turbine area. Cluster 3 was exclusively a turbine site grouping and occupied the offshore sector and the northernmost NSWAW sites.

Cluster 4D had representative samples in all areas (1 only in NSWCN) and was distributed in specific patches within each. All but one NSWCS site were found in this cluster. In NSWT and NSWAW it formed a coherent group of four samples in the southeast part of the area and in the centre of NSWT it formed a band running through the area between Cluster 3D sites. The neighbouring western NSWAW sites were also categorised in this cluster (see Figure 20).

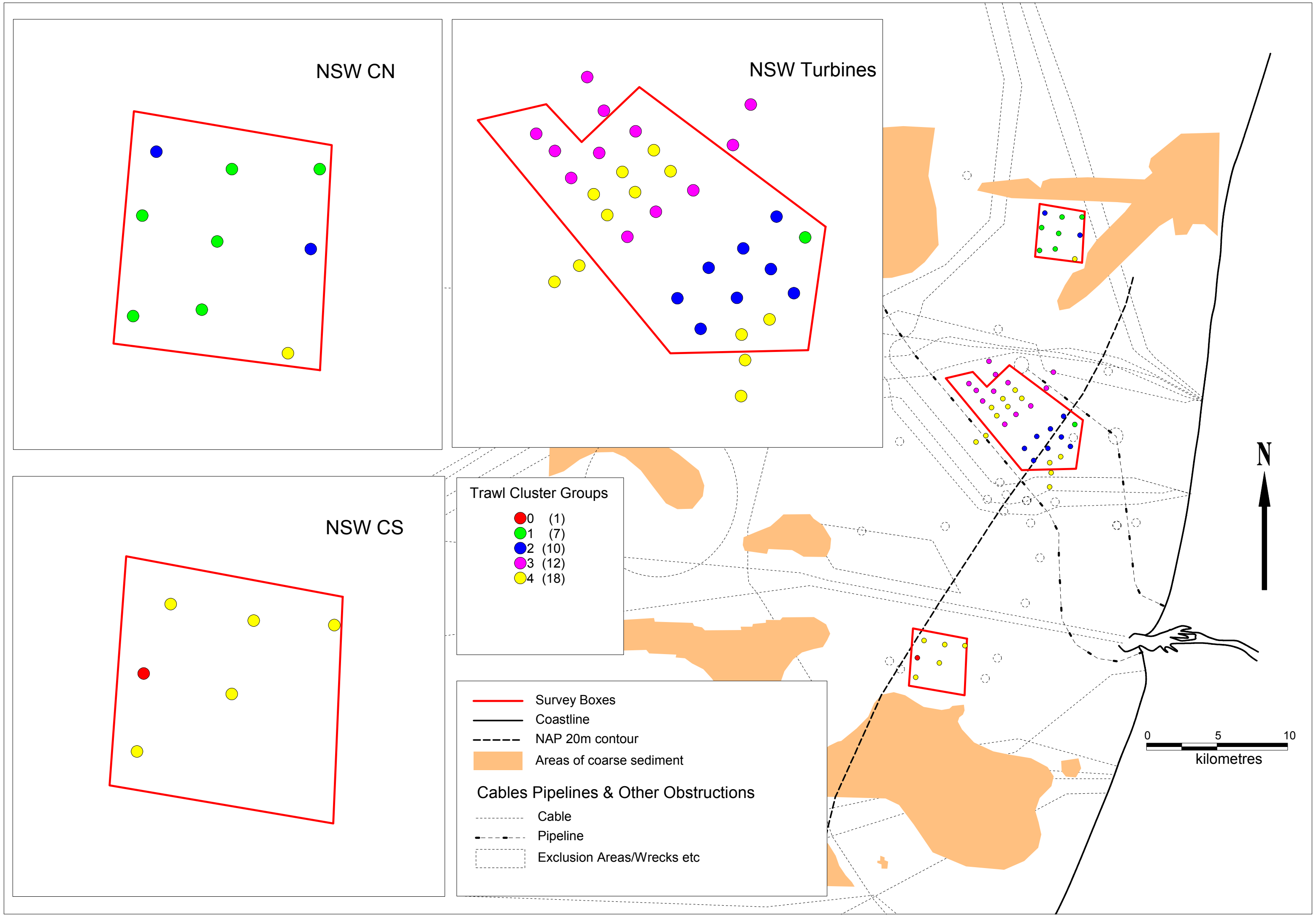


Figure 20. Dredge sites defined by cluster membership. See Figure 2 for site numbers.

Table 28. Top ten most abundant (individuals 100 m^{-2}) taxa for dredge samples in each cluster identified by multivariate analysis. n = 7 (Cluster 1), n = 10 (Cluster 2), n = 12 (Cluster 3), n = 18 (Cluster 4). freq. = frequency of occurrence.

Cluster 1			Cluster 2			Cluster 3			Cluster 4		
	Mean	freq.		Mean	freq.		Mean	freq.		Mean	freq.
Spisula subtruncata	2598.7	100.0	*Spisula subtruncata*	212.8	100.0	*Thia scutellata*	12.8	100.0	*Ophiura albida*	49.8	100.0
Anthozoa spp.	230.0	85.7	*Ophiura albida*	204.3	100.0	*Donax vittatus*	11.4	100.0	*Ophiura ophiura*	26.6	100.0
Ophiura albida	142.7	100.0	*Ophiura ophiura*	42.9	90.0	*Chamelea gallina*	6.4	91.7	*Donax vittatus*	23.1	83.3
Fabulina fabula	49.9	100.0	*Fabulina fabula*	34.5	90.0	*Ophiura albida*	5.6	100.0	*Spisula subtruncata*	17.2	88.9
Polinices pulchellus	46.3	100.0	*Polinices pulchellus*	26.1	90.0	*Ophiura ophiura*	5.6	100.0	*Chamelea gallina*	7.8	88.9
Abra alba	44.6	57.1	*Ensis sp. Indet*	19.0	90.0	*Ensis* sp. Indet	2.7	91.7	*Echinocardium cordatum*	6.4	77.8
Ophiura ophiura	22.0	85.7	*Liocarcinus holsatus*	14.7	100.0	*Echinocardium cordatum*	2.2	33.3	*Thia scutellata*	3.9	77.8
Ensis sp. Indet	21.1	85.7	*Donax vittatus*	13.8	80.0	*Spisula solida*	2.2	66.7	*Ensis* sp. Indet	3.8	88.9
Tellinacea spp.	16.9	14.3	*Chamelea gallina*	9.8	100.0	*Liocarcinus holsatus*	1.8	83.3	*Fabulina fabula*	3.6	33.3
Liocarcinus arcuatus	14.9	85.7	*Anthozoa* spp.	4.7	60.0	*Ensis ensis*	1.6	66.7	*Liocarcinus holsatus*	2.7	83.3

4 DISCUSSION

The objectives of this survey were to characterise the benthic invertebrate fauna in the proposed windfarm area and in two independent reference (or "control") areas. A two-tiered approach was adopted to examine the distribution of animals on two spatial scales. The small, more abundant animals were sampled using a small box core and processed on a 1.0 mm sieve. The larger species, or megafauna, which are more widespread in distribution, were sampled with a 1 m benthic dredge and sieved using a 6.0 mm mesh. Abiotic sediment variables were also measured during the survey so that any post constructional changes could be identified.

The general characteristics of the sea bed have been briefly described in Section 3.1. The Dutch continental shelf has very little relief in the region investigated and this is reflected in the extremely limited range of sampling depths recorded. Although there were statistically significant differences between areas and between clusters, the actual differences were slight and could be explained by changes in tidal height or swell. They are deemed to be of little biological significance to the faunas encountered in this study.

Sediments were coarsest (coarse sand) in the south (Table 3) and finer (medium sand) in the north. This was consistent with the previously documented gradation in particle size off the Dutch coast where sediments become progressively finer towards the German Bight (Creutzberg *et al*. 1984; Duineveld *et al*. 1990). Grain sizes in NSWCN, NSWT, NSWAW and NSWCS broadly corresponded with previously published findings.

The strength and frequency of tidal and wind generated currents ensure that fine particles and organic material are winnowed from the seabed and seldom accumulate (van der Molen & de Swart, 2001). Creutzberg *et al*. (1984) reported a mud content of less than 2% in their southern North Sea study and similar values are consistently found in the same region by regular monitoring surveys (e.g. Daan & Mulder, 2002). Comparable quantities of mud were found on rare occasions in this study and were probably of very limited significance in terms of animal distribution. Sedimentary organic material was detected in low proportions (less than 1% total weight - Table 7) and showed no difference between areas.

Grain size is often correlated with the distribution of animal communities but the mechanisms responsible for these associations are unclear (Snelgrove & Butman, 1994). The slight change from medium to coarse sand may be significant in altering species abundance patterns in the windfarm and reference areas (as described below) but no evidence for this effect can be provided by the current, purely descriptive study. Particle size is probably a surrogate for other conditions which affect faunal distribution (water movement, turbidity, organic content, pore space, mud content, chemical composition) (Eisma, 1987; Snelgrove & Butman, 1994).

Rare species identified by dredge sampling

As expected, many of the larger species collected by dredging did not occur in the full box core dataset. This highlights the difference in distribution patterns of the two size classes of benthos, and the advantages of conducting a comprehensive survey using more than one type of sampling equipment. Some species which were not found in box core samples, were nevertheless frequently encountered in dredge samples from all areas. These were the crabs *Liocarcinus arcuatus* and *L. holsatus* and the bivalve *Spisula solida*. These must be considered to be abundant in the region but so widely distributed that, by chance, none was sampled by the box corer.

Those species which were scarce in dredge samples and also absent from cores, may be categorised as truly rare in the survey region. Of these, the majority appear to be random occurrences of individuals usually associated with different habitat types. *Ebalia tumefacta, Macropodia rostrata, M. linarsi* and *Liocarcinus marmoreus* are crabs normally found on gravel or stony bottoms but which have nevertheless been recorded previously in the southern North Sea (Christiansen, 1969; Ingle, 1996). *Portumnus latipes* is a species of shallow sandy areas and is reported to be “rather common” off the Dutch coast by Christiansen (1969). However, it appears to be associated with intertidal and shallow nearshore habitats (Ingle, 1969; Wolff & Sandee, 1971) and so may also be regarded as an isolated, accidental occurrence. During this survey only 3 individuals were found, 2 in dredges at NSWT and 1 in a dredge in NSWCS.

The gastropod mollusc *Euspira (= Lunatia) catena* is uncommon on the Dutch continental shelf (Holtmann *et al*., 1996) and this was reflected in the current survey with only 11 individuals recovered in the NSWCN dredges and 3 in the windfarm area (NSWT). The other rare gastropod, *Crepidula fornicata*, found in one sample, prefers gravels where it can be extremely abundant (Graham, 1988).

Like the crabs, the rare bivalves caught in dredges could also be categorized as individuals normally found in different sediment types. *Laevicardium crassum* is usually sampled from areas of gravel and broken shell (Tebble, 1966), and *Macoma balthica* is a species of mud or muddy sand which is much more prevalent nearer the coast (Holtmann, *et al*., 1996). In both of these species only one individual was found in NSWT dredges. In contrast to these, the razor shell *Ensis siliqua* is often found in shallow water, sandy areas but was recorded infrequently by Holtmann *et al*. (1996) and was also rare in the current survey (1 individual in NSWAW).

Two relatively large species included in the box core analyses may also have been expected to occur in dredge samples. These were the burrowing mud shrimps (Thalassinidea) *Callianassa subterranea* and *Pestarella (= Callianassa) tyrrhena*. Both have been recorded previously in the region (Daan & Mulder, 2002; Ngoc-Ho, 2003) and *C. subterranea* was found in unusually high densities at a nearby station in the 2001 BIOMON survey (Daan & Mulder, 2002). In the North Sea Benthos Survey (Künitzer *et al*., 1992) *C subterranea* was found further north in the Oyster Ground area and was not recorded in the region investigated in the present survey. It should be noted that *C. subterranea* can burrow down to 60 cm and may be missed by most sampling gear (Atkinson, 1986; Witbaard & Duineveld, 1989; Dworschak, 2001).

Patterns in the fauna

The rare species described above occurred in such low abundance and had such sporadic distributions that they could not be considered as characteristic of this region. Furthermore, they were nearly always species associated with coarser sediments and so were probably the result of random dispersal events.

The populations of each area were more easily characterised in terms of the abundance of the more common species and their univariate sample statistics. In this way the fauna of NSWCN stood out as one of high abundance and high species richness. In core samples total abundance, species richness (N_o) and biomass were significantly higher than in other areas (see Section 3.3). This tendency was also seen in the dredge samples, which recorded highest total abundance and species richness. Median grain size in this area was 489 ± 25.8 µm. The commonest small species were *Spiophnes bombyx, Lanice conchilega* and *Urothoe poseidonis* and these were all more abundant in this area than elsewhere. *Spisula subtruncata* was extremely abundant here and was sampled frequently by both box core and dredge. Anthozoan spp. were also common in this area.

The windfarm area (NSWT) had the finest sediment (median of 466 ± 128.9 µm). Total invertebrate abundance was about half of that found in NSWCN (see Table 9 for details) but still dominated by *S. bombyx* and *U. poseidonis* with *Nephtys cirrosa* also an abundant species. *S. subtruncata* was the dominant bivalve but was much less abundant than in NSWCN. *Ophiura albida* was much more abundant in NSWT than in any other area.

The southern reference area (NSWCS) contained the coarsest sediments (median of 604 ± 123.4 µm) with the highest occurrence of gravel content. Total abundance was higher than NSWT (but not signifantly so). In this area the seabed was dominated by the tube dwelling polychaete *Lanice conchilega* with *S. bombyx* still very abundant. Of the larger fauna, *Echinocardium cordatum* was more abundant here than in any other area.

The adjacent water sites (NSWAW) were, relatively close to the windfarm area but had larger grain size. *S. bombyx, N. cirrosa* and *U. poseidonis* were the most abundant smaller species while *Donax vittatus* and *O. albida* were most abundant in dredge samples.

The sampling areas, as summarised above, were chosen without prior detailed knowledge of the fauna and their statistics mainly describe artificial assemblages. Natural assemblages may be identified by classification analysis, which re-orders the samples according to thier species-abundance similarities. The maps of box core and dredge clusters (Figures 15 and 20 respectively) show that there were spatially delineated communities of both small and large species. The box cores show that the fauna divided into two main categories. Cluster 1 contained high abundances of *Spiophanes bombyx, Urothoe poseidonis*, and *Lanice conchilega* and had significantly higher species richness and abundance than Cluster 2. The polychaete *Nephtys assimilis* was also frequent in Cluster 1 samples and completely absent for Cluster 2. Sediment particle size was significantly larger in Cluster 2 and this was dominated again by *Spiophanes bombyx* (but in lower abundance), *Lanice conchilega* and *Nephtys cirrosa*. Two polychaetes of the family Opheliidae were characteristic of this cluster (*Ophelia borealis* and *Travisia forbesii*) and these have been associated with coarser habitats by other studies (e.g. Duineveld *et al*. 1991).

Most of the sites in NSWCN were grouped in Cluster 1. These were also concentrated in the west of NSWCS and in the southeast section of NSWT showing that these were all areas of relatively high total abundance and species richness with a coarser sediment particle size. The difference between the mean particle sizes in Cluster 1 (487 ± 90.7 µm) and Cluster 2 (536 ± 145.7 µm) was only 49 µm. Whether this has any biological significance in determining the distribution of the adult fauna is not known.

The pattern was more complex when sampling on a larger scale, the dredge samples resolving into four clusters. Again, these showed spatial coherence forming discrete patches of samples, but there was little coincidence between these spatial patterns and those described by box core samples. NSWCN was again dominated by one cluster (Cluster 1D) but with dredge samples this was almost entirely restricted to NSWCN and was not important elsewhere. As stated earlier, this area was characterised by high total abundance at both sampling scales and this is reflected in the cluster analyses.

NSWT dredge sites fell into three main clusters and there was no strong similartiy between their arrangement and the patterns created by cluster analysis of the box core samples. The presence of a mud channel or trench had been indicated during the planning phase (see Section 2.1). This was reported to run across the area in a SW - NE orientation. None of the box cores positioned in the channel displayed any unusual features in terms of species composition or abundance nor did they exhibit any coherent behaviour in the cluster analysis. There was a patch of sites in and to the SE of the channel which contained some mud (Section 3.2.1) but this did not appear to have any effect on species composition and could not be attributed to a channel running through the area.

An area of samples containing small quantities of mud was also found in the southeast corner of NSWCS but these sites were not associated with any specific box core or dredge cluster. In the box core clusters there was evidence of separate faunal assemblages, those of Cluster 1 occupying the western section of this area and those of Cluster 2 occcupying the eastern half. This arrangement was not repeated in the dredge sample clusters.

The amount of organic material in the sediment did not vary significantly between area and did not provide information on the grouping of samples into clusters.

A history of earlier surveys in this area is given in Holtmann *et al.* 1996. An annual programme of sampling on the Dutch Continental Shelf is currently conducted by NIOZ (BIOMON programme). Some of these data were available for comparison with the current survey and statistics for the nearest stations are given in Table 29. These show abundances and species richness to be of the same magnitude as found in the NSW sites. Many of the smaller invertebrates have opportunistic life-history characteristics adapted to high enegy, shallow environments where natural physical disturbance may be strong and frequent (tidal currents, storms). They have short lifespans and their populations may fluctuate considerably in abundance (Craeymeersch *et al*. 2000; Duineveld *et al.* 1991). This can be seen in Table 29 where at OFF22, for instance, there was a reduction in abundance from 2502 animals m^{-2} in 1995 to 322 animals m^{-2} in 1996 caused mainly by a decrease in the population of *Spiophanes bombyx*. Fluctuations at OFF33 were even more pronounced, this station being anomalous in other respects, possibly being close to a wreck (Daan & Mulder, 2002). Densities of *Lanice conchilega* and *Spiophanes bombyx* appear to be particularly susceptible to large fluctuations in abundance (see graphs in Daan & Mulder, 2002). This gives an indication of the scale of temporal (and spatial) variablilty of invertebrate populations on the Dutch Continental Shelf.

Table 29. Summary statistics for BIOMON sites. A = total abundance (individuals m^{-2}), N_o = Sample species richness, H′ = Shannon diversity.

	1995			1996			1999			2001		
	A	N_o	H′	A	N_o	H′	A	N_o	H′	A	N_o	H′
OFF08	1463	17	2.94	761	19	3.97	2271	15	2.28	2053	21	3.07
OFF09	2663	20	3.42	644	15	3.21	564	12	3.06	564	13	3.32
OFF10	2019	17	2.56	1024	25	4.01	718	16	3.05	1642	19	2.92
OFF22	2502	21	1.92	322	12	3.39	257	8	2.63	500	10	2.64
OFF23	9422	24	2.22	2209	20	2.46	975	12	2.38	1014	16	3.13
OFF32	3862	15	1.46	775	16	3.16	423	21	3.09	654	12	2.65
OFF33	22164	35	2.30	1331	30	4.42	1103	23	3.78	1398	35	4.57

The North Sea Benthos Survey was carried out in April - May 1986 and covered a wide area of the North Sea (see Künitzer *et al*. 1992). In a classification analysis (TWINSPAN) of the NSBS data the stations in the region of the NSW windfarm were assigned to group Ia, a coarse sand assemblage (total abundance 805 ± 728 individuals m^{-2}) characterised by *Nephtys cirrosa, Echinocardium cordatum* and *Urothoe poseidonis* (see Figure 4 of Künitzer *et al*. 1992). Again these results are broadly in agreement with the findings of the current survey.

Effects of trawling

The Dutch sector of the North Sea is heavily exploited and the seafloor is often disturbed by man's activities, principally sand extraction and fishing. Beam trawling is now very intensive in this sector (Jennings *et al*. 2000) and long-term damage to the benthic ecosystem arises both because of the size of fishing gear now employed and the frequency of disturbance (Bergman & Hup, 1992). Heavy tickler chains are rigged in front of the net opening and scrape through the top few centimeters of sediment as the trawl is hauled over the seabed. These ticklers improve the efficiency of flatfish capture. Any invertebrate living on or just under the surface of the sediment is likely to be displaced, damaged or killed. Direct, *in situ* mortality of non-target organisms (i.e. benthic invertebrates) caused by the passage of a heavy, 12 m beam trawl (which weighs up to 8 tonnes in air - Kaiser & Spencer, 1996) can be extremely high. High - density aggregations of *Spisula subtruncata*, which lives near the surface of the sediment, may suffer up to 47% direct mortality from the passage of a 4 m trawl and *Fabulina fabula* has been reported to suffer 64% direct mortality following the use of a 12 m beam trawl (Bergman & van Santbrink, 2000). The shallow living *Donax vittatus* is reported to suffer 40% mortality (Hall, 1999). Animals which burrow deeply such as *Echinocardium cordatum* and *Ensis ensis* are less vulnerable to beam trawling as are the more robust bivalves such as *Chamelea gallina* (Bergman & van Santbrink, 2000). However, *E. cordatum* may still suffer up to 50% mortality (Hall, 1999) especially at times when it is near the sediment surface for spawning (Bergman & van Santbrink, 2000).

Sources of mortality and sub-lethal damage are not confined to the direct mechanical effects of trawling. On the seabed animals may be damaged or killed in the net or in trying to escape through the mesh (Bergman & Hup, 1992). If brought onto the trawler they may be killed or damaged in sorting the catch or while being discarded. Discards and injured animals left on the seafloor are highly susceptible to predators migrating in from the surrounding area. Brittlestars (e.g. *Ophiura ophiura*) and hermit crabs (e.g. *Diogenes pugilator*) are known to react extremely quickly to massed mortalities and may arrive in trawl tracks within 10 minutes of trawling (Feder, 1981; Chícharo *et al*. 2002). Even if unscathed, survival may depend on the speed in which displaced animals can re-bury (Chícharo *et al*. 2002) especially where predators are highly numerous. Trawl tracks may also attract scavengers such as *Asterias rubens* (Ramsay *et al*. 2000). Overall mortality rates inflicted by beam trawling vary from taxon to taxon but may reach 25% for infaunal polychaetes, 75% for hermit crabs, 40% for *Donax vittatus* and 50% for *Echinocardium cordatum* (Hall, 1999)

The rate at which disturbed communties can re-attain their pre-dredged state is not known. It will depend, *inter alia*, on the time of year the trawling took place, conditions on the modified seafloor and the colonizing capability of the component species (as adults or as larvae). To a certain extent this question is academic as beam trawling is now so intensive that some areas of the seabed may be trawled up to 7 times per year (Bergman & Hup, 1992). Bergman & van Santbrink (2000) state that "It is not uncommon for commercial trawlers to re-fish the same tracks within a few hours or days." Given this level of sustained physical disturbance in recent decades, it seems unlikely that any part of the seabed in the shallow North Sea is in pristine condition, most of the major changes to the natural fauna having occurred some years ago (Kaiser, 2000).

Trawling will be prohibited from the windfarm area and as a consequence of this, NSWT may effectively become a closed area (Lindeboom, 2000). Assuming that the erection of wind turbines will not significantly affect sediment granulometry or larval supply, the development of benthic communities should revert to an undisturbed state. This will not be the same as that which existed before the onset of intensive trawling (Hall, 1999) but it will provide a reference against which the persistent or "press" (*sensu* Bender *et al*. 1984) perturbation of beam trawling may be gauged.

Short-lived opportunistic species such as *Spiophanes bombyx* may be able to recover quickly after trawling or natural disturbance and would not by themselves provide useful comparative data between fished and unfished areas. Although it is possible that *S. bombyx* becomes more abundant in response to trawling natural variation is so high it would be difficult to differentiate natural and anthorpogenic effects (Craeymeersch *et al.* 2000). Longer lived species such as bivalves may, however, be more useful in this respect. *Donax vittatus* is known to live up to 7 years (Holtmann *et al*. 1996), *Chamelea gallina* for 10 years (Holtmann *et al*.1996), *Enis ensis* 7 years (Henderson & Richardson, 1994), *Fabulina fabula* 4 - 5 years (Holtmann *et al*. 1996) and *Spisula subtrucata* up to 2 years (Ambrogi & Ambrogi, 1987).

Although populations of these species may also fluctuate rapidly in abundance they do have certain potential advantages over opportunistic species as monitoring organisms in that i) once established they may remain in one area throughout their lifespan unless disturbed by trawling or storms; ii) they are known to be adversely affected by beam trawling (Bergman & van Santbrink, 2000); iii) growth can be easily and unambiguously measured; iv) they are important components of the ecosystem as prey species for flatfish (Lindeboom, 2000). Release from the persistent disturbance by beam trawls may result in bivalves living longer so that populations will contain a higher proportion of larger individuals than would be found in trawled areas. Populations of opportunistic species may decline in the absence of disturbance.

A further advantage in using bivalves is that their shells record evidence of previous sub-lethal disturbance (such as physical damage to the shell or growth impairment caused by disturbance or injury). These may be seen in preparations made from shell sections and could be used as an indicator of change in the disturbance regime (e.g. Kaiser *et al*. 2000; Richardson, 2001). Shells in the NSWT area would be expected to carry fewer signs of disturbance than those of the surrounding area. If this method is adopted the shells collected during the present survey will serve as a repository for comparison with future samples.

5 CONCLUSIONS AND RECOMMENDATIONS

- Most species found during this survey are typical of shallow, sub-tidal, sandy environments and broadly similar communities have been described by previous authors (e.g. Künitzer *et al*. 1992; Craeymeersch *et al*. 1997). The assemblages are relatively low in species richness with low biomass (Duineveld *et al*. 1990) and component species are adapted to a physically stressed, dynamic environment.

- Sediment grain size is reported to be stable in this area (Daan & Mulder, 2002) and the findings of this survey corresponded with previous published results. Tidal and wind induced currents can be strong and, as a consequence, organic matter and fine particulate material seldom accumulates.

- Most earlier studies have been conducted over much wider areas with less intensive sampling and the patterns descibed are therefore broad in scale (e.g. Kingston & Rachor, 1982; Künitzer *et al*. 1992; Craeymeersch *et al*. 1997). The survey design employed with this study has made it possible to draw a more detailed picture of species distribution patterns and these have been detailed in the two cluster analyses.

- Species show patchy distributions and probably also fluctuate widely over short time periods. Sources of variation include tidal/ storm disturbance, beam trawling and random variations in larval supply and survival.

- The effects of trawling (e.g. Bergman & Hup, 1992) are of particular interest here as all fishing will be prohibited in the windfarm area.

For future monitoring it is recommended that:

- The reference areas be maintained and sampled for comparison with baseline data.

- Box core sampling is conducted at the replicated sites only and that 5 replicates be taken at each site. This will increase the probablility of accurate estimations of relative abundance and improve the detection of rarer species. Changes in species composition (rather than changes in univariate community measures) will be the most relevant indication of environmental change.

- Particle size analysis should be carried out at each of the replicated sites. Changes in sediment grain size parameters may affect distribution of fauna.

- Megafauna should be sampled at all dredge sites using a “Triple D” dredge or equivalent. Changes in faunal composition may indicate windfarm effects.

- Common bivalve species should be measured and compared with baseline data to detect changes incurred by windfarm construction. Bivalves are predicted to suffer less trawling stress and grow to larger size in the exclusion area. No such changes would be expected in the reference areas. Effects of any concomitant changes in predatory fish populations should also be taken into account when analysing bivalve data.

- A more sensitive analysis may be considered by comparing microscopic features of shell damage and growth. Post-construction windfarm bivalves should display fewer signs of physical disturbance and growth interruption than bivalves from other areas and baseline conditions.

ACKNOWLEDGEMENTS

We wish to thank the skipper and crew of the *Maggie M* for their warm hospitality and hard work throughout the survey. NIOZ is gratefully acknowledged for supplying biomass conversion factors and wave data.

REFERENCES

Ambrogi, R. & Ambrogi, A. O. (1987) Temporal variations of secondary production in the marine bivalve *Spisula subtruncata* off the Po River delta (Italy). Est. Coastl. Shelf Sci. 25: 369 - 379

Anon. (2002) *Terms of Reference Procurement Base Line Studies North Sea Wind Farms. Directorate - General of Public Works and Water Management*. Unpublished 30 pp.

Armonies, W. (2000) On the spatial scale needed for benthos community monitoring in the coastal North Sea. J. Sea Res. 43: 121 - 133

Atkinson, R. J. A. (1986) Mud-burrowing megafauna of the Clyde Sea area Proc. Roy Soc. Edinburgh 90B: 351 - 361

Bender, E. A., Case, E. J. & Gilpin, M. E. (1984) Perturbation experiments in community ecology: theory and practice. Ecology 65: 1 - 13

Bergman, M. J. N. & van Santbrink, J. W. (1994). A new benthos dredge ('Triple D') for quantitative sampling of infauna species of low abundance. Neth. J. Sea Research 33: 129-133

Bergman, M. J. N. & van Santbrink, J. W. (2000). Fishing mortality of populations of megafauna in sandy sediments. In Kaiser, M. J. & de Groot, S. J. (eds.) *The effects of fishing on non-target species and habitats. Biological, conservation and socio-economic issues.* Blackwell Science Ltd., Oxford 399 pp.

Bergman, M. J. N. & Hup, M. (1992) Direct effects of beamtrawling on macrofauna in a sandy sediment in the southern North Sea. ICES J. Mar. Sci. 49: 5 - 11

Bray, J. R. & Curtis, J. T. (1957) An ordination of upland forest communities of southern Wisconsin. Ecol. Monogr. 27: 325 - 349

Buchanan, J. B. (1984) *Sediment Analysis* in Holme,N. A. & McIntyre, A. D. (eds.) *Methods for the study of marine benthos*. IBP Handbook 16. Blackwell Scientific Publications, Oxford

Chícaro, L. Chícaro, M. Gaspar, M., Regala, J. & Alves, F. (2002) Reburial time and indirect mortality of *Spisula solida* clams caused by dredging. Fish. Res. 59: 247 - 257

Christiansen, M. E. (1969) *Crustacea Decapoda Brachyura*. Marine Invertebrates of Scandinavia No. 2. Universitetsforlaget, Oslo 143 pp.

Craeymeersch, J.A. Heip, C. Buijs J. (1997) *Atlas of North Sea benthic infauna based on 1986 North Sea Benthos Survey.* ICES Coop. Res. Rep. 218. 86 pp.

Craeymeersch, J. A., Piet, G. J. Rijnsdorp, A. D. & Buijs, J. (2000) Distribution of macrofauna in relation to the micro-distribution of trawling effort. In Kaiser, M. J. & de Groot, S. J. (eds.) *The effects of fishing on non-target species and habitats. Biological, conservation and socio-economic issues.* Blackwell Science Ltd., Oxford 399 pp.

Creutzberg, F. Wapenaar, P. Duineveld, G. & Lopez Lopez, N. (1984) Distribution and density of the benthic fauna in the southern North Sea in relation to bottom characteristics and hydrographic conditions. Rapp. R.-v. Réun. Cons. int. Explor. Mer. 183: 101 - 110

Daan, R. & Mulder, M. (2002) *The macrobenthic fauna in the Dutch sector of the North Sea in 2001 and a comparison with previous data*. NIOZ Report 2002-1. Netherlands Institute of Sea Research (NIOZ), Den Burg, Texel, The Netherlands. 90 pp.

Duineveld,G. C. A., de Wilde, P. A. W. J. & Kok, A. (1990) A synopsis of the macrobenthic assemblages and benthic ETS activity in the Dutch sector of the North Sea. Neth. J. Sea Res. 26: 125 – 138

Duineveld, G. C. A., Künitzer, A., Niermann, U., de Wilde, P. A. W. J. & Gray, J. S. (1991) The macrobenthos of the North Sea. Neth. J. Sea Res. 28: 53-65

Dworschak, P. C. (2001) The burrows of *Callianassa tyrrhenea* (Petagna 1792) (Decapoda: Thalassinidea) P.S.Z.N. Mar. Ecol. 22: 155-166

Eisma, D (1966) The distribution of benthic marine molluscs off the main Dutch coast. Neth. J. Sea Res. 3: 107 - 163

Eisma, D. (1987) The North Sea: an overview. Phil. Trans. R. Soc. Lond. B 316: 461 – 485

Eleftheriou, A. & Holme, N. A. (1984) *Macrofauna techniques* in Holme, N. A. & McIntyre, A. D. (eds.) *Methods for the study of marine benthos*. IBP Handbook 16. Blackwell Scientific Publications, Oxford

Feder, H. M. (1981) Aspects of the feeding biology of the brittle star *Ophiura texturata*. Ophelia 20: 215 - 235

Folk, R. L. (1980) *Petrology of sedimentary rocks*. Hemphill Publishing Co. Austin, Texas

Graham, A. (1988) *Molluscs: Prosobranch and pyramidellid gastropods. Keys and notes for the identification of the species.* E. J. Brill/ Dr. W. Backhuys, Leiden for the Linnean Society of London. 662 pp.

Green, R.H. (1979) *Sampling design and statistical methods for environmental biologists*. John Wiley & Sons, New York. 257 pp.

Hall, S. J. (1999) *The effects of fishing on marine ecosysems and communities*. Blackwell Science Ltd. Oxford. 274 pp.

Heip, C. & Craeymeersch, J. A. (1995) Benthic community structure in the North Sea. Helgoländer Meeresunters. 49: 313 - 328

Henderson, S. M. & Richardson, C. A. (1994) A comparison of the age, growth - rate and burrowing behaviour of the razor clams *Ensis siliqua* and *Ensis ensis*. J. Mar. Biol. Assoc. U. K. 74: 939 - 954

Hill, M. O. (1973) Diversity and evenness: a unifying notation and its consequences. Ecology 54: 427-432

Holtmann, S. E., Groenewold, A. Schrader, K. H. M., Asjes, J., Craeymeersch, J. A. Duineveld, G. C. A. van Bostelen, A. J. & van der Meer, J. (1996) *Atlas of the zoobenthos of the Dutch continental shelf*. Ministry of Transport, Public Works and Water Management, North Sea Directorate, Rijswijk, 244 pp.

Howson, C. M. & Picton, B. E. (eds) (1997). *The species directory of the marine fauna and flora of the British Isles and surrounding seas.* Ulster Museum and the Marine Conservation Society, Belfast and Ross-on-Wye. Ulster Museum Publication No. 276

Ingle, R. W. (1996) *Shallow-water crabs. Keys and notes for the identification of the species*. Field Studies Council, Preston Montford, for the Linnean Society of London. 243 pp.

Jennings, S., Warr, K. J., Greenstreet, S. P. R. & Cotter, A. J. R. (2000) Spatial and temporal patterns in North Sea fishing effort In Kaiser, M. J. & de Groot, S. J. (eds.) T*he effects of fishing on non-target species and habitats. Biological, conservation and socio-economic issues.* Blackwell Science Ltd., Oxford 399 pp.

Kaiser, M. J. (2000) The implications of the effects fo fishing on non-target species and habitats. In Kaiser, M. J. & de Groot, S. J. (eds.) T*he effects of fishing on non-target species and habitats. Biological, conservation and socio-economic issues.* Blackwell Science Ltd., Oxford 399 pp.

Kaiser, M. J. Ramsay, K., Richardson, C. A., Spence, F. E. & Brand, A. R. (2000) Chronic fishing disturbance has changed shelf sea benthic community structure. J. Anim. Ecol. 69: 494 - 503

Kaiser, M. J. & Spencer, B. E. (1996) The effects of beam-trawl disturbance on infaunal communities in different habitats. J. Anim. Ecol. 65: 348 - 358

Korevaar, G. G. (1990) *North Sea climate: based on observations from ships and lightvessels*. Kluwer, Dordrecht, The Netherlands 137 pp.

Künitzer, A., Basford, D., Craeymeersch, J. A., Dewarumez, J. M., Dörjes, J, Duineveld, G. C. A., Eleftheriou, A., Heip, C., Herman, P., Kingston, P., Niermann, U. Rachor, E., Rumohr, H. & de Wilde, P. A. J. (1992) The benthic infauna of the North Sea: species distribution and assemblages. ICES J. Mar. Sci. 49: 127 - 143

Levene, H. (1960) Robust test for equality of variance in *Contributions to probability and statistics.* I. Olkin (ed.). Stanford University Press, Palo Alto. pp. 278 - 292

Lindeboom, H. J. (2000) The need for closed areas as conservation tools. In Kaiser, M. J. & de Groot, S. J. (eds.) T*he effects of fishing on non-target species and habitats. Biological, conservation and socio-economic issues.* Blackwell Science Ltd., Oxford 399 pp.

McCave, I. N. (1971) Sand waves in the North Sea off the coast of Holland. Marine Geology 10: 199 - 225

Ngoc-Ho, N. (2003) European and Mediterranean Thalassinidea (Crustacea, Decapoda). Zoosystema 25: 439-555

Offshore Wind Energy (2004) Website of Offshore Windenergy in Europe accessed 17 February 2004 www.offshorewindenergy.org

Otto, L., Zimmerman, J. T. F. , Furnes, G. K., Mork, M., Saetre, R. & Becker, G. (1990) Review of the physical oceanography of the North Sea. Neth. J. Sea Res. 26: 161 – 238

Pielou, E. C. (1975) *Ecological diversity*. Wiley, New York. 165 pp.

Pond, S. & Pickard, G. L. (1991) *Introductory dynamical oceanography*. Butterworth - Heinemann, Oxford. 329 pp.

Ramsay, K., Kaiser, M. J., Rijnsdorp, A. D., Craeymeersch, J. A. & Ellis, J. (2000) Impact of trawling on populations of the invertebrate scavenger *Asterias rubens*. In Kaiser, M. J. & de Groot, S. J. (eds.) *The effects of fishing on non-target species and habitats. Biological, conservation and socio-economic issues.* Blackwell Science Ltd., Oxford 399 pp.

Ricciardi, A. & Bourget, E. (1998). Weight to weight conversion factors for marine benthic invertebrates. Mar. Ecol. Prog. Ser. 163: 245-251

Richardson, C. A. (2001) Molluscs as archives of environmental change. Oceanogr. Mar. Biol. Ann. Rev. 39: 103 - 164

Rumohr, H. (1999) *Soft bottom macrofauna: collection, treatment, and quality assurance of samples*. ICES Techniques in Marine Environmental Sciences no. 27. ICES Copenhagen. 19 pp.

Rumohr, H., Brey, T. & Ankar, S. (1987). A compilation of biometric conversion factors for benthic invertebrates in the Baltic Sea. Baltic Marine Biology Publ. 9: 1-56

Shannon, C. E. & Weaver, W. (1949) *The mathematical theory of communication.* University of Illinois Press, Urbana, Illinois 117 pp.

Snelgrove, P. V. R. & Butman, C. A. (1994) Animal - sediment relationships revisited: cause versus effect. Oceanogr. Mar. Biol. Ann. Rev. 32: 111 - 177

Sokal, R. R. & Rohlf, F. J. (1995) *Biometry. The principles and practice of statistics in biological research.* W. H. Freeman & Co., New York 887 pp.

Suijlen, J. M. & Duin, R. N. M. (2002) *Atlas of near-surface Total Suspended Matter concentrations in the Dutch coastal zone of the North Sea*. Report RIKZ/2002.059. 46 pp.

Tebble, N. (1966) *British bivalve seashells. A handbook for identification*. British Museum (Natural History), London 212 pp.

van der Giessen, A., De Ruijter, W. P. M. & Borst, J. C. (1990) Three-dimensional current structure in the Dutch coastal zone. Neth. J. Sea Res. 25: 45 - 55

van der Molen, J. (2002) The influence of tides, wind and waves on the net sand transport in the North Sea. Continental Shelf Res. 22: 2739 - 2762

van der Molen, J. & de Swart, H. E. (2001) Holocene wave conditions and wave-induced sand transport in the southern North Sea. Cont. Shelf Res. 21: 1723 – 1749

van der Veer, H. W., Bergman, M. J. N. & Beukema, J. J. (1985) Dredging activities in the Dutch Wadden Sea: effects on macrobenthic infauna. Neth. J. Sea Res. 19: 183 - 190

Witbaard, R. Duineveld, G. C. A. (1989) Some aspects of the biology and ecology of the burrowing shrimp *Callianassa subterranea* (Montagu) (Thalassinidae) from the southern North Sea. Sarsia 74: 209 - 219

Wolff, W. J. & Sandee, A. J. J. (1971) Distribution and ecology of the Decapoda Reptantia of the estuarine area of the Rivers Rhine, Meuse and Scheldt. Neth. J. Sea Res. 197 - 226

Appendix 1

Site positions (WGS84)

(Dredge positions given are track starting points)

Area	Core Sample	Date	Deg	Min	Deg	Min	Depth (m)
NSWAW	1	29/05/03	52	37.94	4	24.04	18.0
NSWAW	2	29/05/03	52	38.41	4	23.61	19.1
NSWAW	3	29/05/03	52	37.88	4	27.59	18.1
NSWAW	4	29/05/03	52	33.82	4	27.61	18.2
NSWAW	5	29/05/03	52	37.57	4	27.22	17.5
NSWAW	6	29/05/03	52	34.25	4	27.57	19.3
NSWAW	7	30/05/03	52	35.77	4	23.61	20.3
NSWAW	8	30/05/03	52	35.47	4	23.05	21.5
NSWCN	1	28/05/03	52	44.39	4	27.05	23.6
NSWCN	2	28/05/03	52	44.32	4	27.74	22.8
NSWCN	3	28/05/03	52	44.26	4	28.41	21.8
NSWCN	4	30/05/03	52	44.18	4	29.10	21.2
NSWCN	5	30/05/03	52	44.09	4	29.74	20.2
NSWCN	6	30/05/03	52	43.90	4	27.02	23.6
NSWCN	7	30/05/03	52	43.82	4	27.72	22.1
NSWCN	8	30/05/03	52	43.76	4	28.39	21.3
NSWCN	9	30/05/03	52	43.68	4	29.08	20.2
NSWCN	10	30/05/03	52	43.60	4	29.72	19.3
NSWCN	11	30/05/03	52	43.45	4	26.91	23.4
NSWCN	12	30/05/03	52	43.38	4	27.60	18.0
NSWCN	13	30/05/03	52	43.32	4	28.27	22.4
NSWCN	14	30/05/03	52	43.24	4	28.97	19.2
NSWCN	15	30/05/03	52	43.17	4	29.65	18.5
NSWCN	16	30/05/03	52	43.02	4	26.93	22.1
NSWCN	17	30/05/03	52	42.95	4	27.62	20.7
NSWCN	18	30/05/03	52	42.89	4	28.29	19.5
NSWCN	19	30/05/03	52	42.81	4	28.98	17.1
NSWCN	20	30/05/03	52	42.73	4	29.62	18.3
NSWCN	21	30/05/03	52	42.62	4	26.89	21.2
NSWCN	22	30/05/03	52	42.55	4	27.58	20.2
NSWCN	23	30/05/03	52	42.50	4	28.26	18.9
NSWCN	24	30/05/03	52	42.41	4	28.95	17.9
NSWCN	25	30/05/03	52	42.33	4	29.58	17.6
NSWCS	1	22/05/03	52	28.03	4	19.44	20.5
NSWCS	2	22/05/03	52	27.96	4	20.13	21.0

Area	Core Sample	Date	Deg	Min	Deg	Min	Depth (m)
NSWCS	3	22/05/03	52	27.90	4	20.80	21.4
NSWCS	4	22/05/03	52	27.82	4	21.49	20.8
NSWCS	5	22/05/03	52	27.74	4	22.13	19.5
NSWCS	6	22/05/03	52	27.53	4	19.41	23.1
NSWCS	7	22/05/03	52	27.46	4	20.10	21.8
NSWCS	8	22/05/03	52	27.41	4	20.78	20.4
NSWCS	9	22/05/03	52	27.32	4	21.47	20.8
NSWCS	10	22/05/03	52	27.24	4	22.10	19.8
NSWCS	11	22/05/03	52	27.09	4	19.30	23.4
NSWCS	12	22/05/03	52	27.02	4	19.99	22.3
NSWCS	13	22/05/03	52	26.96	4	20.66	20.0
NSWCS	14	22/05/03	52	26.88	4	21.35	20.0
NSWCS	15	22/05/03	52	26.81	4	22.04	19.7
NSWCS	16	22/05/03	52	26.66	4	19.31	22.6
NSWCS	17	22/05/03	52	26.59	4	20.01	20.9
NSWCS	18	22/05/03	52	26.53	4	20.68	22.0
NSWCS	19	22/05/03	52	26.45	4	21.37	19.7
NSWCS	20	22/05/03	52	26.37	4	22.01	20.2
NSWCS	21	22/05/03	52	26.27	4	19.28	22.7
NSWCS	22	22/05/03	52	26.20	4	19.97	19.0
NSWCS	23	22/05/03	52	26.14	4	20.65	19.3
NSWCS	24	22/05/03	52	26.06	4	21.34	20.2
NSWCS	25	22/05/03	52	25.97	4	21.97	19.6
NSWT	1	29/05/03	52	37.78	4	22.48	20.1
NSWT	2	29/05/03	52	37.51	4	22.82	20.0
NSWT	3	29/05/03	52	37.22	4	23.19	19.0
NSWT	4	29/05/03	52	36.92	4	23.54	20.1
NSWT	5	30/05/03	52	36.66	4	23.92	20.2
NSWT	6	30/05/03	52	36.41	4	24.32	19.8
NSWT	7	30/05/03	52	36.15	4	24.62	19.2
NSWT	8	30/05/03	52	35.89	4	25.00	17.2
NSWT	9	30/05/03	52	35.59	4	25.38	17.1
NSWT	10	30/05/03	52	35.33	4	25.75	19.6
NSWT	11	30/05/03	52	35.05	4	26.17	21.0
NSWT	12	30/05/03	52	34.76	4	26.54	20.0
NSWT	13	30/05/03	52	34.52	4	26.91	19.1

Area	Core Sample	Date	Deg	Min	Deg	Min	Depth (m)
NSWT	14	29/05/03	52	37.57	4	23.84	19.1
NSWT	15	29/05/03	52	37.30	4	24.24	20.5
NSWT	16	29/05/03	52	37.03	4	24.61	21.2
NSWT	17	29/05/03	52	36.79	4	24.98	20.9
NSWT	18	29/05/03	52	36.52	4	25.32	20.4
NSWT	19	29/05/03	52	36.28	4	25.71	18.5
NSWT	20	29/05/03	52	35.98	4	26.07	21.9
NSWT	21	29/05/03	52	35.69	4	26.48	21.1
NSWT	22	29/05/03	52	35.39	4	26.84	21.8
NSWT	23	29/05/03	52	35.12	4	27.24	20.6
NSWT	24	29/05/03	52	34.85	4	27.66	19.8
NSWT	25	29/05/03	52	34.60	4	28.02	19.5
NSWT	26	29/05/03	52	37.99	4	24.56	18.3
NSWT	27	29/05/03	52	37.73	4	24.95	19.4
NSWT	28	29/05/03	52	37.45	4	25.33	19.4
NSWT	29	29/05/03	52	37.15	4	25.70	18.5
NSWT	30	29/05/03	52	36.90	4	26.05	17.4
NSWT	31	29/05/03	52	36.66	4	26.44	16.8
NSWT	32	29/05/03	52	36.34	4	26.82	18.7
NSWT	33	29/05/03	52	36.06	4	27.23	20.5
NSWT	34	29/05/03	52	35.79	4	27.60	19.7
NSWT	35	29/05/03	52	35.50	4	27.97	19.2
NSWT	36	29/05/03	52	35.21	4	28.41	18.8
NSWT	37	29/05/03	52	34.93	4	28.81	18.8
NSWT	38	29/05/03	52	38.08	4	25.57	19.6
NSWT	39	29/05/03	52	37.79	4	25.99	19.6
NSWT	40	29/05/03	52	37.54	4	26.35	19.0
NSWT	41	29/05/03	52	37.27	4	26.73	17.8
NSWT	42	29/05/03	52	37.01	4	27.11	18.4
NSWT	43	29/05/03	52	36.71	4	27.50	20.8
NSWT	44	29/05/03	52	36.37	4	27.91	20.7
NSWT	45	29/05/03	52	36.13	4	28.25	20.3
NSWT	46	29/05/03	52	36.70	4	28.56	21.1
NSWT	47	29/05/03	52	36.43	4	28.92	20.3
NSWT	48	29/05/03	52	36.16	4	29.33	20.0
NSWT	49	30/05/03	52	37.64	4	21.49	21.1

Area	Core Sample	Date	Deg	Min	Deg	Min	Depth (m)
NSWT	50	30/05/03	52	37.42	4	21.78	21.1
NSWT	51	30/05/03	52	37.16	4	22.13	20.8
NSWT	52	30/05/03	52	36.89	4	22.52	21.1
NSWT	53	30/05/03	52	36.62	4	22.89	19.6
NSWT	54	30/05/03	52	36.33	4	23.29	22.1
NSWT	55	30/05/03	52	36.08	4	23.61	21.2
NSWT	56	30/05/03	52	35.81	4	23.97	20.1
NSWT	57	30/05/03	52	35.53	4	24.32	18.7
NSWT	58	30/05/03	52	35.27	4	24.70	18.0
NSWT	59	30/05/03	52	34.99	4	25.07	20.6
NSWT	60	30/05/03	52	34.70	4	25.46	21.2
NSWT	61	30/05/03	52	34.46	4	25.79	20.2
NSWT	62	29/05/03	52	35.83	4	28.69	19.8
NSWT	63	29/05/03	52	37.99	4	22.14	20.6
NSWT	64	29/05/03	52	34.63	4	29.19	18.3
NSWT	65	29/05/03	52	35.41	4	29.24	19.2
NSWT	66	29/05/03	52	38.34	4	25.11	19.0
NSWT	67	30/05/03	52	37.85	4	21.16	22.5
NSWT	68	29/05/03	52	37.01	4	28.07	21.5

Area	Dredge Sample	Date	Deg	Min	Deg	Min	Depth (m)	Bearing
NSWAW	1	27/05/03	4	23.000	52	35.450	22.2	220
NSWAW	2	27/05/03	4	27.600	52	33.740	17.5	035
NSWAW	3	27/05/03	4	27.398	52	37.498	18.0	045
NSWAW	4	27/05/03	4	27.697	52	34.279	18.0	050
NSWAW	5	27/05/03	4	27.839	52	38.103	18.6	043
NSWAW	6	27/05/03	4	23.610	52	35.692	21.7	235
NSWAW	7	27/05/03	4	23.806	52	38.516	19.7	222
NSWAW	8	27/05/03	4	24.217	52	38.012	18.6	218
NSWCN	1	28/05/03	4	27.303	52	44.150	22.2	228
NSWCN	2	28/05/03	4	27.102	52	43.598	22.7	049
NSWCN	3	28/05/03	4	26.971	52	42.730	21.0	227
NSWCN	4	28/05/03	4	28.380	52	44.000	21.3	040
NSWCN	5	28/05/03	4	28.170	52	43.375	20.3	219
NSWCN	6	28/05/03	4	27.950	52	42.786	19.5	237

Area	Dredge Sample	Date	Deg	Min	Deg	Min	Depth (m)	Bearing
NSWCN	7	28/05/03	4	29.632	52	44.000	19.8	225
NSWCN	8	28/05/03	4	29.505	52	43.310	18.8	219
NSWCN	9	28/05/03	4	29.179	52	42.410	18.2	226
NSWCS	1	24/05/03	4	19.748	52	27.905	22.1	210
NSWCS	2	24/05/03	4	19.325	52	27.245	23.9	210
NSWCS	3	24/05/03	4	19.220	52	26.503	22.2	210
NSWCS	4	24/05/03	4	21.042	52	27.748	20.6	210
NSWCS	5	24/05/03	4	20.700	52	27.050	20.1	211
NSWCS	6	24/05/03	4	20.647	52	26.400	20.0	210
NSWCS	7	24/05/03	4	22.300	52	27.705	20.1	210
NSWCS	8	24/05/03	4	21.800	52	27.001	19.2	200
NSWCS	9	24/05/03	4	21.715	52	26.210	20.3	210
NSWT	1	27/05/03	4	22.550	52	37.667	19.9	240
NSWT	2	27/05/03	4	23.010	52	37.410	19.2	235
NSWT	3	27/05/03	4	23.410	52	37.005	19.3	219
NSWT	4	27/05/03	4	23.967	52	36.760	21.4	238
NSWT	5	27/05/03	4	24.300	52	36.450	21.1	227
NSWT	6	27/05/03	4	24.796	52	36.124	19.8	220
NSWT	7	27/05/03	4	26.029	52	35.204	22.0	035
NSWT	8	27/05/03	4	26.602	52	34.747	20.3	230
NSWT	9	27/05/03	4	27.611	52	34.661	18.7	050
NSWT	10	27/05/03	4	24.103	52	37.380	20.1	230
NSWT	11	27/05/03	4	24.672	52	37.095	21.1	218
NSWT	12	27/05/03	4	24.987	52	36.793	20.0	227
NSWT	13	27/05/03	4	25.500	52	36.500	19.0	219
NSWT	14	27/05/03	4	26.800	52	35.660	21.6	040
NSWT	15	27/05/03	4	27.496	52	35.210	19.4	220
NSWT	16	27/05/03	4	28.300	52	34.889	18.7	050
NSWT	17	27/05/03	4	24.998	52	37.704	20.1	040
NSWT	18	27/05/03	4	25.448	52	37.420	20.1	039
NSWT	19	27/05/03	4	25.860	52	37.105	20.0	049
NSWT	20	27/05/03	4	26.420	52	36.820	18.6	230
NSWT	21	27/05/03	4	27.651	52	35.950	21.2	050
NSWT	22	27/05/03	4	28.334	52	35.640	20.2	230
NSWT	23	27/05/03	4	28.900	52	35.280	18.6	030

Area	**Dredge Sample**	**Date**	**Deg**	**Min**	**Deg**	**Min**	**Depth (m)**	**Bearing**
NSWT	24	27/05/03	4	28.473	52	36.426	21.1	030
NSWT	25	27/05/03	4	29.180	52	36.116	19.5	210

Note: The above dredge sample codes are those used by IECS during the analysis. Some of these were not compatible with DONAR and were re-named for entering into the database:

IECS name	New DONAR name
NSWT5	NSWT6
NSWT8	NSWT12
NSWT12	NSWT17
NSWT17	NSWT27
NSWCN3	NSWCN21

Appendix 2

Species list

Cnidaria

Anthozoa spp.

Nemertea

Nemertea spp.

Annelida: Polychaeta

Malmgrenia (Harmothoe) glabra (Malmgren, 1865)

Malmgrenia (Harmothoe) marphysae McIntosh, 1876

Sigalion mathildae Audouin & Milne-Edwards in Cuvier, 1830

Sigalion squamosus Chiaje, 1830

Sthenelais boa (Johnston, 1839)

Eteone longa (Fabricius, 1780)

Mysta picta (Quatrefages, 1866)

Anaitides groenlandica (Oersted, 1842)

Anaitides lineata (Claparède, 1870)

Anaitides mucosa (Oersted, 1843)

Anaitides rosea (McIntosh, 1877)

Eumida bahusiensis Bergstrom, 1914

Eumida sanguinea (Oersted, 1843)

Streptosyllis websteri Southern, 1914

Nereis longissima Johnston, 1840

Nephtys assimilis Oersted, 1843

Nephtys caeca (Fabricius, 1780)

Nephtys cirrosa Ehlers, 1868

Nephtys hombergii Savigny, 1818

Nephtys longosetosa Oersted, 1843

Scoloplos armiger (O F Müller, 1776)

Poecilochaetus serpens Allen, 1904

Malacoceros fuliginosus (Claparède, 1868)

Scolelepis (Scolelepis) bonnieri (Mesnil, 1896)

Scolelepis (Parascolelepis) tridentata (Southern, 1914)

Spio armata Thulin, 1957

Spio decorata Bobretzky, 1870

Spio filicornis (O F Müller, 1766)

Spiophanes bombyx (Claparède, 1870)

Magelona filiformis Wilson, 1959

Magelona mirabilis (Johnston, 1865)

Magelona johnstoni Fiege, Licher & Mackie, 2000

Chaetozone setosa Malmgren, 1867

Chaetozone christiei Chambers, 2000

Capitella capitata (Fabricius, 1780)

Notomastus latericeus M Sars, 1851

Ophelia borealis Quatrefages, 1866

Travisia forbesii Johnston, 1840

Owenia fusiformis Chiaje, 1842

Lagis koreni (Malmgren, 1866)

Lanice conchilega (Pallas, 1766)

Annelida: Oligochaeta

Grania spp.

Arthropoda: Crustacea

Gastrosaccus spinifer (Goës, 1864)

Perioculodes longimanus (Bate & Westwood, 1868)

Pontocrates altamarinus (Bate & Westwood, 1862)

Pontocrates arcticus G O Sars, 1893

Pontocrates arenarius (Bate, 1858)

Synchelidium maculatum Stebbing, 1906

Leucothoe incisa Robertson, 1892

Stenothoe marina (Bate, 1856)

Urothoe brevicornis Bate, 1862

Urothoe poseidonis Reibisch, 1905

Atylus falcatus Metzger, 1871

Atylus swammerdamei (H Milne-Edwards, 1830)

Bathyporeia elegans Watkin, 1938

Bathyporeia guilliamsoniana (Bate, 1856)

Bathyporeia nana Toulmond, 1966

Megaluropus agilis Hoek, 1889

Microprotopus maculatus Norman, 1867

Pariambus typicus (Kröyer, 1845)

Leptognathia gracilis (Kröyer, 1842)

Tanaissus lilljeborgi Stebbing, 1891

Iphinoe trispinosa (Goodsir, 1843)

Pseudocuma gilsoni Bacescu, 1950

Pseudocuma longicornis (Bate, 1858)

*Pseudocuma simili*s G O Sars, 1900

Diastylis bradyi Norman, 1879

Crangon crangon (Linnaeus, 1758)

Crangon trispinosus (Hailstone, 1835)

Callianassa subterranea (Montagu, 1808)

Pestarella (= Callianassa) tyrrhena (Petagna, 1792)

Diogenes pugilator pugilator (Roux, 1829)

Pagurus bernhardus (Linnaeus, 1758)

Ebalia tumefacta (Montagu, 1808)

Macropodia linarsi Forest & Alvarez, 1964)

Macropodia rostrata (Linnaeus, 1761)

Corystes cassivelaunus (Pennant, 1777)

Thia scutellata (Fabricius, 1793)

Liocarcinus arcuatus (Leach, 1814)

Liocarcinus depurator (Linnaeus, 1758)

Liocarcinus holsatus (Fabricius, 1798)

Liocarciuns marmoreus (Leach, 1814)

Portumnus latipes (Pennant, 1777)

Pinnotheres pisum (Linnaeus, 1767)

Mollusca: Gastropoda

Crepidula fornicata (Linnaeus, 1758)

Polinices pulchellus (Risso, 1826)

Euspira catena (da Costa, 1778)

Mollusca: Bivalvia

Tellimya ferruginosa (Montagu, 1808)

Mysella bidentata (Montagu, 1803)

Laevicardium crassum (Gmelin, 1791)

Mactra stultorum (Linnaeus, 1758)

Spisula elliptica (Brown, 1827)

Spisula solida (Linnaeus, 1758)

Spisula subtruncata (da Costa, 1778)

Ensis americanus (Gould in Binney, 1870)

Ensis arcuatus (Jeffreys, 1865)

Ensis ensis (Linnaeus, 1758)

Ensis siliqua (Linnaeus, 1758)

Angulus tenuis (da Costa, 1778)

Fabulina fabula (Gmelin, 1791)

Macoma balthica (Linnaeus, 1758)

Donax vittatus (da Costa, 1778)

Abra alba (W Wood, 1802)

Chamelea gallina (Linnaeus, 1758)

Venerupis senegalensis (Gmelin, 1791)

Phoronida

Phoronis spp.

Echinodermata

Asterias rubens Linnaeus, 1758

Ophiura albida Forbes, 1839

Ophiura ophiura (Linnaeus, 1758)

Echinocardium cordatum (Pennant, 1777)

Appendix 3

Bivalve measurement data

(s.d. = standard deviation)

Area	#	Species	mean	sd	max	min	n
NSWAW	1	*Chamelea gallina*	24.67	4.8	31	19	6
NSWAW	4	*Chamelea gallina*	19.00	6.2	27	13	5
NSWAW	5	*Chamelea gallina*	24.25	3.7	29	20	4
NSWAW	6	*Chamelea gallina*	24.05	4.1	30	17	20
NSWAW	8	*Chamelea gallina*	19.60	7.9	29	8	5
NSWAW	1	*Donax vittatus*	22.67	4.0	28	12	33
NSWAW	5	*Donax vittatus*	21.57	4.7	26	14	7
NSWAW	6	*Donax vittatus*	23.94	2.5	31	17	35
NSWAW	7	*Donax vittatus*	22.52	5.8	33	13	23
NSWAW	8	*Donax vittatus*	20.14	5.9	31	15	7
NSWAW	1	*Fabulina fabula*	16.47	3.6	21	11	17
NSWAW	1	*Spisula subtruncata*	16.24	1.9	19	11	25
NSWAW	6	*Spisula subtruncata*	17.13	2.0	24	14	31
NSWCN	1	*Chamelea gallina*	23.40	4.9	30	15	15
NSWCN	2	*Chamelea gallina*	25.00	2.8	27	23	2
NSWCN	7	*Chamelea gallina*	21.50	8.1	29	14	4
NSWCN	1	*Donax vittatus*	24.00	1.4	26	23	4
NSWCN	9	*Donax vittatus*	24.60	1.1	26	23	5
NSWCN	1	*Fabulina fabula*	15.72	2.8	21	11	32
NSWCN	2	*Fabulina fabula*	19.90	2.6	23	12	21
NSWCN	3	*Fabulina fabula*	19.33	2.6	22	12	21
NSWCN	1	*Spisula subtruncata*	15.61	3.8	30	11	90
NSWCN	2	*Spisula subtruncata*	27.39	4.1	32	15	44
NSWCN	3	*Spisula subtruncata*	24.45	5.6	33	11	101
NSWCN	5	*Spisula subtruncata*	21.94	5.6	30	11	51
NSWCN	6	*Spisula subtruncata*	22.49	5.5	31	15	49
NSWCN	7	*Spisula subtruncata*	20.10	4.8	32	14	186
NSWCN	8	*Spisula subtruncata*	28.02	2.0	32	24	54
NSWCN	9	*Spisula subtruncata*	26.12	4.0	30	15	43
NSWCS	3	*Chamelea gallina*	21.40	3.0	26	18	5
NSWCS	4	*Chamelea gallina*	21.60	4.6	27	16	5
NSWCS	4	*Ensis ensis*	97.00	5.7	101	93	2
NSWCS	3	*Ensis (arcuatus)*	87.30	11.8	118	75	10
NSWCS	7	*Ensis americanus*	201.88	315.0	981	81	8

Area	#	Species	mean	sd	max	min	n
NSWCS	3	*Fabulina fabula*	18.00	1.4	19	17	2
NSWCS	1	*Spisula subtruncata*	16.38	2.7	21	8	48
NSWCS	2	*Spisula subtruncata*	17.20	1.1	20	16	20
NSWCS	3	*Spisula subtruncata*	16.86	1.7	19	14	7
NSWT	2	*Chamelea gallina*	22.69	4.7	32	15	13
NSWT	4	*Chamelea gallina*	23.75	3.2	29	17	16
NSWT	5	*Chamelea gallina*	23.63	3.0	29	20	8
NSWT	7	*Chamelea gallina*	24.67	2.4	28	21	9
NSWT	8	*Chamelea gallina*	21.36	3.4	26	16	11
NSWT	9	*Chamelea gallina*	18.33	4.9	24	15	3
NSWT	10	*Chamelea gallina*	22.67	4.7	30	14	12
NSWT	11	*Chamelea gallina*	23.03	3.2	31	17	34
NSWT	12	*Chamelea gallina*	26.56	2.6	31	24	9
NSWT	13	*Chamelea gallina*	23.25	4.2	30	18	8
NSWT	14	*Chamelea gallina*	22.40	5.9	27	12	5
NSWT	19	*Chamelea gallina*	23.00	3.3	27	19	6
NSWT	21	*Chamelea gallina*	20.25	6.0	26	11	8
NSWT	23	*Chamelea gallina*	20.80	0.4	21	20	5
NSWT	24	*Chamelea gallina*	21.67	9.5	29	11	3
NSWT	2	*Donax vittatus*	26.45	1.8	30	25	11
NSWT	4	*Donax vittatus*	20.97	4.6	30	12	38
NSWT	5	*Donax vittatus*	20.93	4.6	30	14	40
NSWT	6	*Donax vittatus*	25.21	1.7	28	21	14
NSWT	8	*Donax vittatus*	21.79	3.1	25	13	14
NSWT	9	*Donax vittatus*	21.43	3.2	24	15	7
NSWT	10	*Donax vittatus*	21.83	6.0	27	11	12
NSWT	11	*Donax vittatus*	20.26	4.6	28	12	46
NSWT	12	*Donax vittatus*	23.94	1.7	27	20	34
NSWT	13	*Donax vittatus*	24.17	4.5	30	16	6
NSWT	15	*Donax vittatus*	23.89	1.7	27	19	37
NSWT	16	*Donax vittatus*	22.85	3.9	28	15	13
NSWT	18	*Donax vittatus*	21.28	4.5	27	14	40
NSWT	19	*Donax vittatus*	23.38	3.7	30	14	29
NSWT	22	*Donax vittatus*	23.18	1.4	26	21	11
NSWT	23	*Donax vittatus*	22.00	1.2	24	20	9

Area	#	Species	mean	sd	max	min	n
NSWT	1	*Ensis ensis*	98.00	5.3	104	94	3
NSWT	5	*Ensis ensis*	94.50	3.5	97	92	2
NSWT	8	*Fabulina fabula*	17.00	1.8	19	14	9
NSWT	14	*Fabulina fabula*	17.44	2.9	21	12	16
NSWT	21	*Fabulina fabula*	18.90	3.1	27	12	20
NSWT	22	*Fabulina fabula*	15.00	4.0	23	11	13
NSWT	24	*Fabulina fabula*	18.40	2.0	21	15	20
NSWT	10	*Spisula solida*	23.50	2.4	26	21	6
NSWT	4	*Spisula subtruncata*	18.13	2.4	23	16	8
NSWT	5	*Spisula subtruncata*	16.57	1.1	18	15	7
NSWT	7	*Spisula subtruncata*	17.81	1.5	21	15	47
NSWT	8	*Spisula subtruncata*	16.14	2.4	23	11	42
NSWT	9	*Spisula subtruncata*	16.67	4.4	25	13	6
NSWT	11	*Spisula subtruncata*	19.46	3.7	25	14	13
NSWT	12	*Spisula subtruncata*	17.29	3.4	25	15	14
NSWT	14	*Spisula subtruncata*	17.85	2.9	30	14	40
NSWT	15	*Spisula subtruncata*	16.23	3.2	25	12	44
NSWT	16	*Spisula subtruncata*	21.57	5.6	29	13	14
NSWT	18	*Spisula subtruncata*	16.77	3.5	26	12	13
NSWT	21	*Spisula subtruncata*	17.00	2.3	26	14	35
NSWT	22	*Spisula subtruncata*	16.58	3.2	24	12	31
NSWT	23	*Spisula subtruncata*	16.97	2.7	27	12	67
NSWT	24	*Spisula subtruncata*	16.94	2.8	27	13	62