ECOREGION **General advice**
SUBJECT **OSPAR request on spatial design of a regional monitoring programme for contaminants in sediments**

Advice summary

This is an update of the advice given in 2012 on spatial design of a regional monitoring programme for contaminants in sediments. Advice is provided on preferred types of sediment, sampling depths, ship time considerations, and the selection of areas where monitoring will be most effective.

The following approach for sediment monitoring designs on a regional scale is advised:

1. Identify areas of sediment with ≥20% fines[1].
2. Create sampling strata containing only areas with ≥20% fines.
3. Use existing data to estimate mean concentrations and variability in the sampling strata.
4. Undertake a power analysis to determine the number of samples required in each stratum.
5. Aggregate individual stratum assessments to the regional scale by using the weighted mean of the individual stratum means, using stratum area as the weighting factor.
6. Refine the design in the light of the additional data obtained above (e.g. the location of strata, and the number of samples required per strata).
7. Statistically compare the aggregated values with the assessment criteria to determine compliance with good environmental status (GES) as expressed in the Marine Strategy Framework Directive (MSFD).

ICES advises that OSPAR coordinates regional sampling programmes based on the approach outlined. ICES is of the opinion that this sampling design allows assessment of compliance with the MSFD GES for the European regional seas.

Request

Spatial design of a regional monitoring programme for contaminants in sediments (OSPAR 2011/2)

To develop guidance on the design of a regional monitoring programme for contaminants in sediments which can explain whether good environmental status has been achieved on a larger regional scale (e.g. sub-Regions of the OSPAR Regions) within the period 2010-2020, with the major effort in 2014-2020. The guidance should address:

a. the selection of areas where monitoring makes most sense, i.e.;

(i) depths that are sensible to monitor (does it make sense to monitor below 1000 m? 500 m? 200 m? 100 m?);
(ii) sediment types that are sensible to use and the implication for possible spatial coverage;
(iii) ship time considerations;
(iv) time from changes in inputs to response in the sediment can be detected;

b. the required spatial resolution of sampling within these areas.

The guidance should be divided into coastal and open water (i.e. beyond 12 nautical mile limit) and take into account the need to distinguish between point source monitoring and diffuse sources.

ICES advice

ICES interpreted the request as referring to the requirements of the Marine Strategy Framework Directive (MSFD) in the OSPAR regions. The request is particularly challenging, as the details of the definitions of good environmental status (GES) for MSFD purposes are not yet clear. In the case of contaminants in sediments for MSFD Descriptor 8, it will be necessary to define indicators and targets whereby contaminants are at a level not giving rise to pollution effects. OSPAR environmental assessment criteria (EACs) have a similar role in OSPAR’s Coordinated Environmental Monitoring Programme (CEMP) assessments. It has been OSPAR practice in recent years, including the Quality Status

[1] defined as being ≥20% silt-clay or fine fractions (< 63 µm).

Report (QSR) 2010 process, to make comparisons of concentrations of contaminants in fine-grained material (with or without normalization) with EACs and based on that, to draw conclusions regarding environmental quality status. This practice has proved particularly effective in OSPAR regions 1 (Arctic waters), 2 (Greater North Sea), and 3 (Celtic seas).

ICES advises that the assessment of compliance with GES for Descriptor 8 should be similar to that undertaken for concentrations of contaminants in sediment in the OSPAR CEMP assessment process, i.e. using fine-grained sediments. This advice addresses the preferred types of sediment, sampling depths, ship time considerations, and the selection of areas where monitoring will be most effective.

ICES notes that the current assessment tools OSPAR EACs or US effects range low (ERLs) are based on toxicity information and make no distinction between sediment type (mud/sand/gravel) or bulk composition (aluminium or total organic carbon (TOC) concentrations). Taking this as the current best approach to assess the contaminant-specific burden in sediment against the GES, a monitoring concept that makes use of strata based on hydrographical and sedimentological factors, which represent the general features of the assessed region, appeared to be the most suitable. The current OSPAR assessment criteria system is used to assess contaminant data from non-normalized concentrations in total sediment samples.

The use of non-normalized concentrations for GES compliance assessment is contrary to the methods used to investigate temporal trends in concentrations, for example in the OSPAR CEMP. Normalization, by sieving or calculating ratios to geochemical normalizers, has a strong theoretical basis as a method to reduce variances in field data. However, such ratios include the variance from two measurements – those of the contaminant and those of the normalizer. The analytical components of these variances, particularly in sediments containing low proportions of fines, or in groups of samples of similar grain size distributions, can be sufficiently great to result in variances of the ratios that are greater than those of the non-normalized concentrations. This is clearly unsatisfactory, and ICES stresses the need to continuously improve the quality of analytical data for both contaminants and normalizers so that the theoretical benefits of normalization can be achieved.

ERLs/EACs are defined for non-normalized concentrations in whole sediments. Therefore, in the context of a spatial monitoring plan for assessing GES, non-normalized concentrations in whole sediments should be used. In this context, it is important to note that the recommended monitoring strategy is intended to be suitable for a spatial assessment in relation to the MSFD. It is not intended to answer questions about the relevance of specific contaminant sources or pathways.

Contaminants in sediments are mainly associated with the fine-grained fraction (i.e. < 63 µm). As a result, for an area influenced by the same sources, finer sediments will have higher contaminant concentrations than coarser ones. ICES current advice is to focus the monitoring, for the purposes of quality status assessment, on the fine-grained sediments (defined as being ≥20% silt-clay) or fine fractions (< 63 µm). This is in line with current practice in temporal trend monitoring in the OSPAR CEMP. Concentrating on areas of fine sediment will increase the statistical power to detect spatial and long-term temporal changes, and also has the benefit of reducing sampling effort (ship time) to the most suitable areas.

The prior specification of appropriate sampling depths is not a major factor in sampling programme design, other than that sampling depths should remain practical. In general, sampling at large depths (e.g. in excess of 500 m) should not be necessary unless there are indications of potentially significant anthropogenic contamination.

ICES noted that OSPAR has already used a division between coastal and offshore waters (12 nm) in the QSR 2010 (OSPAR, 2010) assessment process. At the regional level, reporting on GES compliance will be on a broad scale. Therefore, at this level, it is unlikely that such a division will be appropriate in the context of the MSFD. In designing sampling programmes, ICES considers that rather than having an artificial division between coastal and offshore (e.g. 12 nm) regions it is more appropriate to divide OSPAR regions into sampling strata based upon environmental characteristics (e.g. sediment type, sediment dynamics) and existing knowledge on the influence of point sources and riverine discharges. This will enable a greater integration between the assessment methods used in the Water Framework Directive (WFD) and the MSFD.

Summary of the approach for meeting the requirements of Descriptor 8 of the MSFD for contaminants in marine sediments on a regional scale (ICES, 2013a):

1. Identify areas of sediment with ≥20% fines.
2. Create sampling strata containing only areas with ≥20% fines.
3. Use existing data to estimate mean concentrations and variability in the sampling strata.
4. Undertake a power analysis to determine the number of samples required in each stratum.

5. Aggregate individual stratum assessments to the regional scale, by using the weighted mean of the individual stratum means, using stratum area as the weighting factor.
6. Refine the design in the light of the additional data obtained above (e.g. the location of strata, and the number of samples required per strata).
7. Statistically compare the aggregated values with the assessment criteria to determine compliance with GES.

Link with temporal trend monitoring

ICES remains of the opinion that the best sampling approach for temporal trend analysis of contaminants in sediments is to annually determine their concentrations in the fine fractions and/or normalize concentrations to a co-factor to reflect the physico-chemical composition of fine-grained sediment. The frequency of spatial surveys can be lower than that for the yearly temporal trend monitoring. The environmental status assessment cycle for MSFD is six years, requiring a spatial survey of contaminant concentrations at least once per assessment cycle. It is advisable to coordinate the efforts for the two processes by e.g. collecting and analysing samples side by side.

Additional comments regarding passive sampling

ICES considers passive sampling (sorption to introduced substrates), in combination with passive dosing, to be a promising alternative in assessing hydrophobic contaminants. Passive sampling is used to determine the chemical activity of environmental contaminants (sometimes described as “pollutant pressure”) through measuring their freely dissolved concentrations (C_{free}). Since C_{free} of hydrophobic compounds is proportional to concentrations in biota (C_{biota}), it is directly linked to bioavailability and thus toxicity, requiring no normalization for global comparability, and being a more relevant metric for environmental assessments than the “total” concentrations in water or sediments that do not relate well to toxicity, even if normalized, e.g. for amorphous organic carbon (ICES, 2013b).

The uniformity of the approach allows comparison of this pressure in sediments from different regions. Furthermore, through passive dosing, the passive sampling material can be used to expose test organisms to known (in laboratory experiments) or unknown (collected in the field) doses of contaminants. Ideally, the contaminant pressure observed through passive sampling should be linked to its toxicity through passive dosing. The latter could, on the one hand, inform about the toxicity of the actual mixtures present in the environment and, on the other hand, allow development of an assessment scale for known contaminants through laboratory experiments. As such, it would be ideally suited to evaluate the environmental status of large areas such as the OSPAR regions.

Recent studies with passive samplers have emphasized the role of the concentrations of hydrophobic contaminants in sediment pore waters in determining the availability of contaminants to sediment biota, and the apparent toxicity of sediment samples (see also ICES, 2013b). The sand fraction of sediments generally acts as an inert diluent of the fine-grained material and TOC which carries the bulk of the contaminant burden. There is a clear case for more widespread use of passive sampling in the assessment of sediment quality with respect to the availability of contaminants to biota. However, while the use of whole sediment concentrations (e.g. in the form of ERLs or EACs) of hydrophobic contaminants therefore has theoretical weaknesses, there is a general lack of assessment criteria based upon the free concentrations of these contaminants in pore water, or in the overlying waters. Such assessment criteria are needed before quality assessments based on passive sampling data can deliver to their full potential. Linkages between biological effects and freely dissolved concentrations of hydrophobic contaminants are generally not available in toxicological databases, at least partly because classical measurement or dosing methods do not address free concentrations. A potential way forward is to develop toxicity criteria related to (lipid normalized) concentrations of the contaminants of interest in test biota. These could then be linked to freely dissolved concentrations in the water through partitioning theory. ICES recommends to progress work in this field, also taking into account developments in relation to the implementation of the Water Framework Directive (WFD).

Southern North Sea case study

In developing this advice ICES undertook a series of case studies. Because of the availability of data in the ICES database, the southern North Sea was studied in detail as described below.

Concentration data for a subset of contaminants (Cd, Pb, benzo[*a*]pyrene (BaP), fluoranthene (Flu), and CB153) and supporting parameters (Al, organic carbon, and silt/clay content) were extracted from the ICES database for the southern North Sea for the period 2006–2011. International data on sediment grain size distributions were merged to produce one map showing silt/clay content greater than or equal to 20% (Figure 1.5.6.8.1) from which areas of fine-grained sediments could be identified. Six major areas (target zones) of muddy sediment were identified as suitable strata for further analysis: Oyster Grounds, German Bight, Weisse Bank, North Frisian coast, Wadden Sea, and Flemish Banks (Figure 1.5.6.8.2).

Concentration data from sampling sites within the target zones were collated (Table 1.5.6.8.1) and used to explore the relationship between number of samples and the statistical power to detect differences. In practice, the coefficients of variation will be both contaminant and stratum specific. In particular, they will generally increase with the size of the stratum and are likely to be greater in coastal strata where there are more localized influences. For sampling design purposes, the data suggest a coefficient of variation of about 35% and 75% for metals and organics respectively, perhaps increasing to about 40% and 100% in coastal areas.

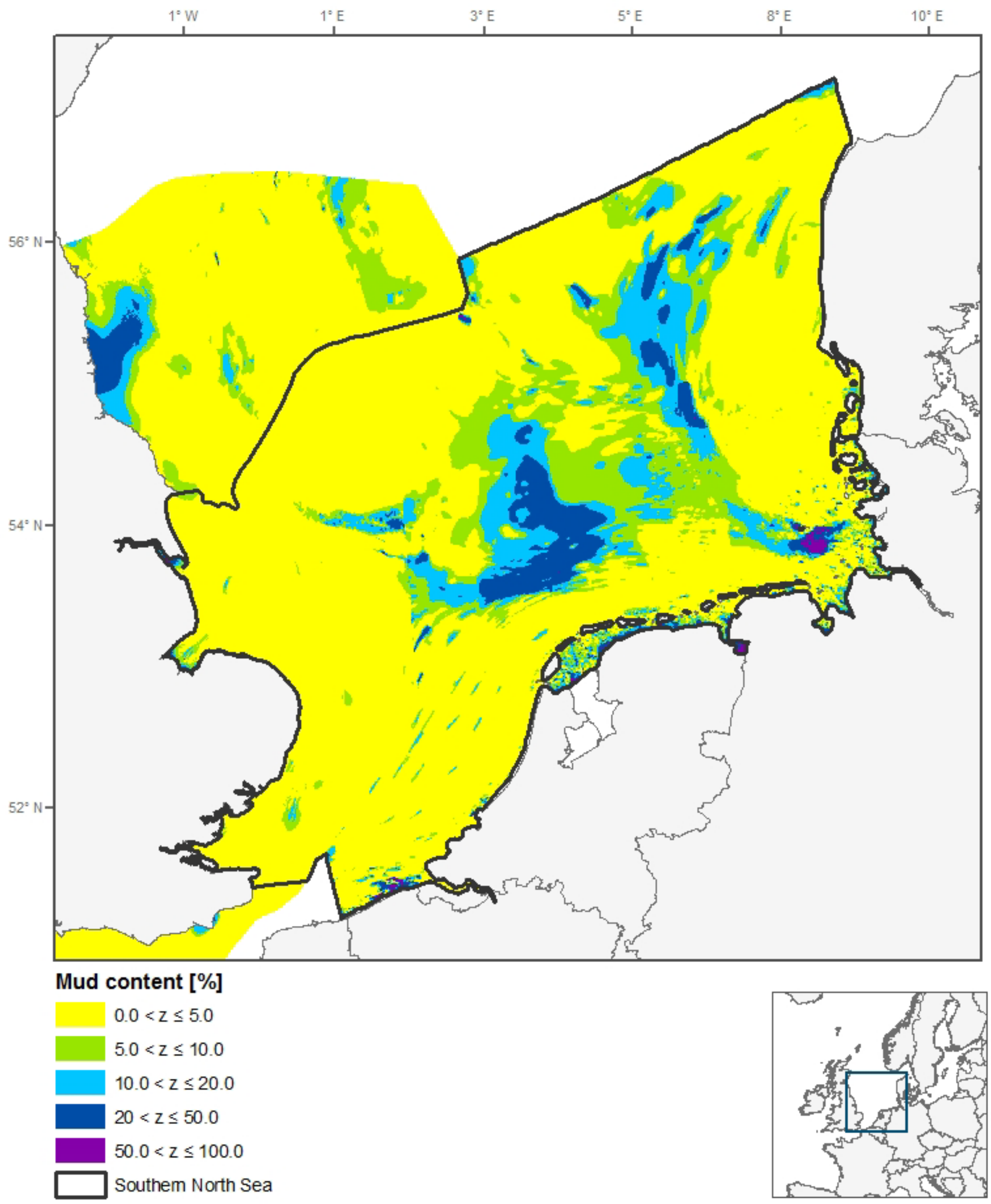

Figure 1.5.6.8.1 Merged mud map (Defra seabed integrity (west side) and BSH/Smile consult GmbH (east side) (ICES, 2013a).

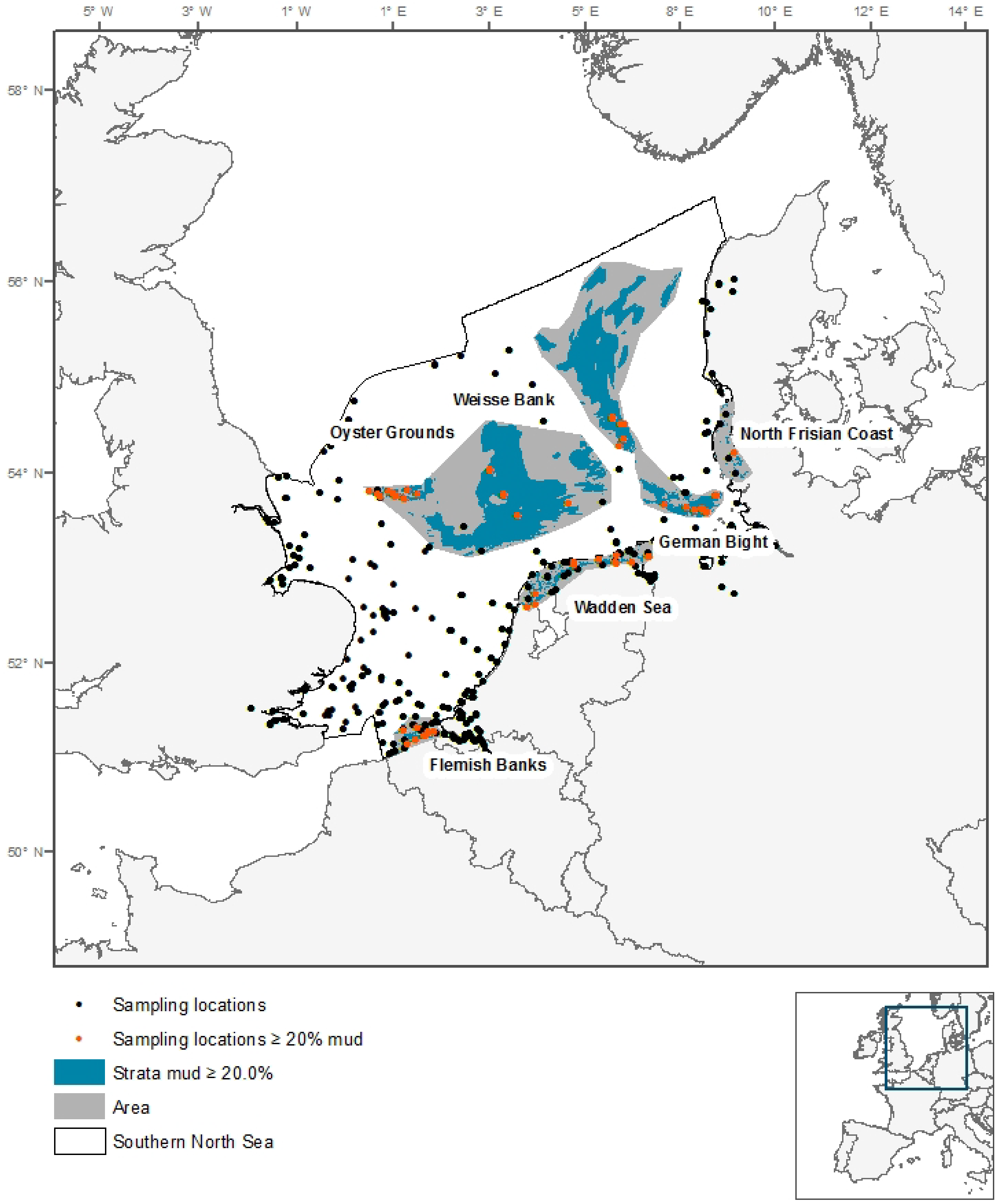

Figure 1.5.6.8.2 The six selected strata (target zones) and sampling points extracted from ICES database – red sampling locations in muddy areas.

Table 1.5.6.8.1 The number of locations sampled each year for each contaminant/stratum combination, the mean concentrations, and the coefficients of variation in concentration. (Combinations with less than two locations sampled each year are omitted.) The corresponding ERL or EAC is also shown.

		Oyster Ground	Weisse Bank	German Bight	Wadden	Flemish Banks	ERL / EAC
Cd	n	2	15	6	6	4	
(mg/kg)	mean	0.03	0.05	0.28	0.14	0.09	1.2
(%)	cv	7	30	52	38	33	
Pb	n	2	17	6	6	4	
(mg/kg)	mean	14	21	25	15	9	47
(%)	cv	33	13	19	43	26	
Flu	n	2	2	3	6	2	
(μg/kg)	mean	32	28	59	37	10	600
(%)	cv	37	59	76	125	57	
BaP	n	2	2	3	6	2	
(μg/kg)	mean	21	16	25	16	10	430
(%)	cv	32	68	75	86	141	
CB153	n		2	3	6	4	
(μg/kg)	mean		0.10	0.78	0.49	0.40	40
(%)	cv		81	72	62	114	

Probably the simplest form of sampling design, given the stratification of the region, is to conduct simple random sampling within each stratum (i.e. random stratified sampling). To have 90% power for rejecting the null hypothesis, $\mu \geq AC$, in an individual stratum when $\mu = AC / 2$[2], or 90% power when $\mu = 3\ AC / 4$ in the southern North Sea, the data suggest that five samples per stratum would be required for metals, and between ten and fifteen samples per stratum for organics (ICES, 2013a). Since the MSFD will require assessment of both metals and organics, this means taking between ten and fifteen samples per stratum, and hence between 60 and 90 samples for the whole southern North Sea.

Based on this design, the status of the whole southern North Sea could be assessed in several ways. One option would be to use the individual assessments for each stratum, perhaps insisting that the southern North Sea can have acceptable status only if each stratum has acceptable status. An alternative would be to use the data from each stratum to estimate the mean concentration across the (muddy parts of the) whole southern North Sea and to compare this to the AC. The overall mean would be a weighted average of the stratum means, where the weights are proportional to the area of the strata (and would thus be dominated by any large areas of mud). The power of this assessment would be greater than the power of an individual stratum assessment, because more samples would be involved. For example, suppose there are six strata, all of equal area, all with a mean concentration of μ, and all sampled with 15 samples, and suppose the within-stratum coefficient of variation is 100%. Then, in an individual stratum, we would have 90% power for rejecting the null hypothesis when $\mu = AC / 2$, and in the southern North Sea, we would have 90% power when $\mu = 3\ AC / 4$.

The design above could be easily refined as more data become available. For example, stratum-specific coefficients of variation could be used to reduce sampling effort in more homogeneous strata. Also, sampling effort could be reduced in those strata where concentrations are expected to be 'very low' (i.e. well below AC / 2). Finally, if some strata have strong spatial gradients (more likely in nearshore strata) they could be further stratified to reduce sampling effort/increase power.

This approach to sampling design and data assessment was also applied to coastal sediments of Spain and France and led to similar conclusions, indicating broad applicability of the recommended approach (ICES, 2013a).

[2] Here, μ is the true mean concentration and AC is the assessment concentration.

Sources

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