Advisory Committee on the Marine Environment

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REPORT OF THE JOINT MEETING OF THE WORKING GROUP ON ENVIRONMENTAL ASSESSMENT AND MONITORING STRATEGIES AND THE WORKING GROUP ON STATISTICAL ASPECTS OF ENVIRONMENTAL MONITORING

Aberdeen, United Kingdom

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International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

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1 OPENING OF THE MEETING

The Chairman, Rob Fryer, opened the meeting at 09.00 hrs on 1 April 1995. He welcomed the members of both working groups.

2 ADOPTION OF THE AGENDA AND ORGANIZATION OF WORK

The agenda for the meeting is attached as Annex 1. The list of participants is attached as Annex 2.

3 TASKS FOR THE MEETING

The tasks for the meeting are listed in the agenda (Annex 1).

4 (ACME) OSPARCOM AND HELCOM REQUESTS FOR ADVICE ON SETTING TARGETS FOR TREND DETECTION AND MEASURING POWER

Both OSPARCOM and HELCOM have expressed the desire to assess the power of their temporal monitoring programmes, and to devise new programmes so that quantified objectives such as those of Section 9.2 in Anon. (1995) will have an adequate power of being achieved.

The basic theory for calculating power for perhaps the simplest objective of wishing to be, e.g., 90% certain that a given linear trend will be found to be statistically significant different from zero when R animals are collected and separately analysed in each of T years is described in Fryer and Nicholson (1993). They consider the simple case which assumes that a linear trend is present and is tested from a regression analysis of the annual mean log-concentration on year.

The power is a function of

$$\delta = b^2 \frac{(T-1)T(T+1)}{12\psi^2}$$

where b is the change per year on a log scale, T is the number of years and ψ is the total standard deviation of an estimated yearly mean log concentration, given by

$$\psi^2 = \sigma_y^2 + \frac{\sigma_w^2}{R} + \varepsilon_y^2 + \frac{\varepsilon_w^2}{R}$$

where the components of variance correspond to between- and within-year sampling variability and between- and within-year analytical variability, respectively. If good estimates of these are available, the power can then be calculated for given values of R, T and b. If costs of analysis, sample preparation and collection are available, then costs may also be calculated.

The group agreed that it would be helpful if a paper giving a simple presentation of the theory to calculate the power of a temporal trend monitoring programme, with appropriate formulae, and look-up tables, could be prepared and submitted to the 1995 ICES Annual Science Conference.

Term of reference a) refers to OSPAR 4.1 in which:

ICES is requested to advise on realistic (in terms of cost benefit relations) statistical requirements for establishing temporal trends for nutrients, inorganic and organic contaminants. What, for example, are the monitoring requirements in terms of sampling frequency, accuracy of measurements and minimum duration of the programme for establishing, with a 90% probability, a temporal trend of 5% per year for hydrographic regions with either low, medium or high natural variability?

Although the objectives are clear, and both the power and the target trend are explicitly stated, there is no single answer to this request, since there are many combinations of sampling frequency, analytical accuracy and duration that would achieve a 90% power of detecting a 5% change.

It has not been possible to explore quantitatively all the combinations of matrix, contaminant and location implicit in term of reference a). However, the discussion of variance components and power above is applicable to all the combinations of interest. It is appropriate that programmes are individually assessed by laboratories or coordinating bodies, so that improved estimates of the statistical performance of the programme can be obtained.

At this stage, it is more appropriate, and possibly more useful, to explore the effect of varying the variance components, T and R, to identify those factors to which the power is most sensitive. As an example of the principles outlined above, we will use published data for mercury in fish and shellfish to show how appropriate values of the variance components could be obtained and used.

We will use the estimates of the components of sampling variability from ICES (1989, 1991) and from OSPARCOM assessment reports to generate a distribution showing the range of values. About 90 values were obtained. These were divided into three approximately equal groups corresponding to High, Medium and Low levels of variability, and the median value from each group was calculated.

Estimates of the analytical components of variability were taken from the report of the ICES Seventh Intercalibration on Metals in Fish Tissue (Berman and Boyko, 1992). Again, the medians from each of three groups corresponding to levels of High, Medium and Low levels of variability were computed.

The median values of the standard deviations on a log scale are given in the following table:

	s_y	s_w	e_y	e_w
Low	0.08	0.22	0.09	0.04
Medium	0.26	0.28	0.13	0.05
High	0.52	0.42	0.24	0.10

Taking these values and b=0.05 it is now possible to explore the interaction between R, T and the corresponding power (from δ as described in Fryer and Nicholson, 1993). The graphical aids described in Nicholson and Fryer (1994) and in Fryer *et al.* (1995) may be useful for doing this. The dialogue between statisticians and planners may be very beneficial at this stage.

For example, we could examine how changes in R affect the value of T required to detect a 5% trend with 90% power within each of the Low, Medium and High groups. This is show in the following table for R=1, 5, 25 and infinity:

R	inf	12	25	5	1
Low	12	12	12	14	18
Medium	17	17	18	18	22
High	25	25	>25	>25	>25

We see that increasing R beyond 25 provides little improvement; decreasing R to a single animal has some effect in the regions of Low and Medium levels of variability.

Similarly, we could explore the effect of combining Low, Medium and High levels of sampling variability with Low, Medium and High levels of analytical variability. The following table shows the number of years for which a 5% trend on a log scale would be detected with a 90% power with R=25:

Sampling/Analytical	Low	Medium	High
Low	10	12	16
Medium	17	18	20
High	25	>25	>25

As might be expected, we see that in areas with high levels of sampling variation, increasing analytical variation, has progressively less effect.

Note that:

- A specific and rather simple objective has been used for demonstration here.

- Only one type of statistical design has been considered, and others might lead to improved power. For example, sampling on more than one occasion each year might be beneficial. (The consequences of sampling twice a year or every other year could be also be investigated.) Another example might be splitting analyses between a number of laboratories to reduce between-year analytical noise.

- The analytical variances are only loosely connected with the environmental variances in that they were estimated using data from a small number of laboratories over a short time period.

- The analytical variances are poorly estimated on few data.

5 THE POWER OF MONITORING PROGRAMMES IN MAPPING SPATIAL DISTRIBUTIONS OF CONTAMINANTS IN SEDIMENTS AND BIOTA (ACME)

The power of a monitoring programme is only meaningful when the programme is designed to test some null hypothesis. The power is then the probability of rejecting the null hypothesis about the environment, given that some specified change to the environment has occurred.

For example, consider a temporal trend monitoring programme to investigate if there are any changes in concentration levels. The null hypothesis is that there is no change, and the power of the programme is the probability of detecting some specific change, should it occur.

Power does not apply to mapping, because there is no hypothesis to be tested. However, it is possible to consider the 'precision' of a map; i.e., the precision with which concentration is estimated at all points within an area. Further, given an area to be mapped, and the variogram, it is often possible to design a survey to estimate the concentration at all points within the area to a specified precision (see Section 7).

Plausible objectives for spatial monitoring programmes are discussed in ICES (1995) and, in relation to sediments, in Section 7. Power **is** relevant to some of these objectives. For example, in a programme to detect 'areas of special concern', one can consider the power of the programme to detect an 'area of special concern' of a certain size (see Section 7).

The group noted that mapping the spatial distribution of contaminants in biota is only sensible when the structure of the data is stable over the time period of the survey; e.g., the distance moved by individual fish is insignificant compared with the total area.

The group also noted that there should be a clear distinction between data collected at a number of sites because they are of special interest, and those which can be used in some way to make inferences about the spatial distribution of contaminants in some specified area. For example, corresponding to the first case, data may have been collected at sites known to have elevated concentrations, and it would clearly be inappropriate to use these data to estimate the average concentration in the area from which the sites were selected. When data are tabulated or distributed without reference to how they were collected, a misleading and incorrect interpretation of them is all too easy to make.

Spatial data should be referred to in a clear statement about the area sampled and the method by which sampling sites were selected.

6 TEMPORAL TREND MONITORING OBJECTIVES (ACME)

A draft TIMES document on the formulation of detailed objectives for temporal trend monitoring purposes was not available. However, the group was pleased to note that the guidance on objectives in ICES (1994) has been adopted by OSPARCOM and HELCOM. The group also noted that this guidance has been refined in ICES (1995).

A sub-group was formed to discuss the issue. The sub-group thought the texts on temporal monitoring objectives from ICES (1994) and ICES (1995) should be combined in a TIMES document.

The sub-group noted that:

- To design an effective programme requires estimates of the relevant variance components. It is important to realize that, although pilot studies to obtain such estimates take time and money, this initial investment will have long-term benefits, because the programme should then achieve its objectives. As a programme evolves, improved estimates of the variance components become available and the programme design can be improved accordingly.

- Different parts of a large monitoring programme have different objectives and different components of variance; it is important to get away from the notion that the same sampling design (numbers of samples, sampling frequency, etc.) will be appropriate for all parts of the monitoring programme.

- There are objectives for temporal monitoring programmes other than those discussed in ICES (1994) and ICES (1995). For example, to provide a baseline for detecting incidents; to provide a baseline trend (e.g., due to natural environmental fluctuations) for comparison with trends in other areas.

- It is important that objectives are phrased in terms of the practical and environmentally meaningful changes that can be observed.

- It should be possible to specify in some detail the variance components that would need to be estimated to effectively design a temporal monitoring study of a new contaminant (e.g., PAHs) in a new species (dab). For example, knowledge of the small-scale spatial and temporal variability may offer the potential for reducing the between-year variation.

- It is unlikely that costs will be evenly distributed throughout a programme. In particular, costs could be high at the start of a programme, if data must be collected to design the programme effectively, e.g., if variance components have to be estimated.

- Trends could also be assessed from direct observations of biological indicators, such as maturation rates, growth rates, survival of oyster larvae. Some of these pose new statistical questions, and WGSAEM should be aware that these may be the subject of future studies.

- Available biological knowledge should be used in designing sampling schemes, for instance, to avoid sampling in seasons with large natural variability due to spawning. The use of physical covariables to reduce residual variance in time trend data should be explored.

The group noted that the plans emerging from SIME for the components of the new OSPARCOM JAMP included the following:

a) studies of temporal trends in mercury, cadmium and lead in mussels and sediments;

b) the spatial distribution and effects of TBT;

c) temporal trends of PCBs in fish liver (with shellfish or fish muscle as alternatives);

d) the spatial distribution of non-*ortho* and mono-*ortho* substituted CBs;

e) spatial distribution of PAHs in sediment (with mussels as an alternative).

The programme therefore includes both temporal trend studies and spatial distribution studies. The group considered that the statistical advice already available should enable informed decisions to be made on how to design temporal trend studies. There is clearly a need to further develop comparable guidance on objectives and statistical methodology for spatial distribution programmes, particularly for some of the objectives of the JAMP programme.

7 PLAUSIBLE OBJECTIVES FOR SEDIMENT MONITORING PROGRAMMES AND STATISTICAL METHODS TO ADDRESS THESE PROBLEMS (ACME)

A sub-group was formed to discuss plausible objectives for sediment monitoring programmes. The sub-group identified six plausible objectives, and for each, listed the information that the statistician would require from the geochemist in order to design the programme.

1) To estimate the concentration at all points in an area with a certain precision. The procedure will involve sampling followed by interpolation.

a) The geochemist will tell the statistician the area, the financial and logistic resources available and the desired precision. If possible, the geochemist will also provide information leading to a better estimate of the variogram: analytical variability, ideas of micro-scale distributions or spatial extent of the observed phenomenon. Note that defining the precision is another way of defining the resolution of the map.

2) To estimate a parameter or parameters (e.g., mean, median, 95 percentile) to describe a population within an area with a specified precision.

a) The geochemist will tell the statistician the available resources and desired precision, and if possible, provide an estimate of the variance in the data.

3) To locate all areas of special concern of a certain size in an area, with a specified probability of success (i.e., with a specified power).

a) The geochemist will tell the statistician the size and shape of the area of special concern and the desired probability of success. (NB normal mapping, as in (1) above, may not show areas of special concern.)

4) To determine a specified change in a parameter (as in (2) above) with a specified precision over a specified time.

a) The geochemist will tell the statistician the size of the change, the precision and the time period.

5) To determine a specified change in the spatial extent of an area with a specified precision over a specified time. For example, in the case of a disposal site, the boundary could be where the sediment has more than 2% carbon.

a) The geochemist will tell the s tatistician what constitutes the area, the precision and time.

6) The theory for assessing temporal changes in maps (e.g., changes in structure) is not yet well developed (although work is underway, see the ICES (1995)) and therefore it is not considered here.

7) It is important that geochemists develop their understanding of precision in terms of geochemical variation.

8 OTHER BUSINESS

The group noted that there were two possible types of joint meeting between WGSAEM and WGEAMS. The first facilitated exchange of views and discussion and is best accommodated by a short meeting either before or after the main meetings. The second would be more like the Workshop of the ICES Sub-Group on Temporal Trend Monitoring Programmes for Contaminants in Biota held in February 1994, to facilitate the development of new methodologies; this would be best achieved by a separate workshop held away from the main meetings.

9 ACTION LIST

1) To draft a TIMES document on detailed objectives for temporal trend monitoring programmes. (Rob, Mike, Ian).

2) To prepare a paper giving a simple presentation of the theory to calculate the power of a temporal trend monitoring programme, with appropriate formulae, and look-up tables, for submission to the ICES Annual Science Conference. (Mike, Rob)

10 RECOMMENDATIONS

The joint meeting of WGSAEM and WGEAMS recommends that

1) ACME should note that the review of any large monitoring programme should evolve as follows:

   a) evaluation of the current programme;
   b) clarifying and quantifying objectives;
   c) reappraisal of current performance;
   d) identification and development of new strategies;
   e) where appropriate, a phased introduction of new strategies replacing the old.

2) ACME should adopt the principles outlined in Section 7 for the setting of objectives for sediment monitoring programmes.

3) A joint meeting of WGSAEM and WGEAMS should take place over two days in Spring 1996, starting midweek, in Stockholm, in March/April 1996 under the chairmanship of Rob Fryer, to

   a) review the draft TIMES document on detailed objectives for temporal trend monitoring programmes;

   b) review progress on setting objectives for, and the design of, spatial monitoring programmes.

11 CLOSING OF THE MEETING

The Chairman thanked all the members for their enthusiasm and industry, and Ian Davies for organizing the sticky toffee pudding, and closed the meeting at 13:20 on 2 April 1995.

12 REFERENCES

Berman, S.S., and Boyko, V.J. 1992. ICES Seventh Round Intercalibration for Trace Metals in Biological Tissue ICES 7/TM/BT (Part 2). ICES Cooperative Research Report, No. 189.

Fryer R.J., and Nicholson M.D. 1993. The power of a contaminant programme to detect linear trends and incidents. *ICES J. mar. Sci.*, 50: 161–168.

Fryer R.J., Nicholson, M.D., and Ross, C. 1995. Yet more graphical aids for designing contaminant monitoring programmes. Annex 10. Report of the Working Group on Statistical Aspects of Environmental Monitoring. CM 1995/D:2.

ICES. 1989. Statistical analysis of the ICES Cooperative Monitoring Programme data on contaminants in fish muscle tissue (1975-1985) for determination of temporal trends. ICES Cooperative Research Report, No. 162.

ICES. 1991. Statistical analysis of the ICES Cooperative Monitoring Programme data on contaminants in fish liver tissue and *Mytilus edulis* (1978-1988) for determination of temporal trends. ICES Cooperative Research Report, No. 176.

ICES. 1994. Report of the Sub-Group on Temporal Trend Monitoring Programmes for Contaminants in Biota. ICES CM 1994/ENV:8.

ICES. 1995. Report of the Working Group on Statistical Aspects of Environmental Monitoring. ICES CM 1995/D:2.

Nicholson, M.D., and Fryer, R.J. 1994. Graphical aids for designing contaminant monitoring programmes. Annex 4. Report of the Working Group on Statistical Aspects of Environmental Monitoring. ICES CM 1994/ENV:6.

ANNEX 1

TERMS OF REFERENCE

The terms of reference for the joint meeting (C.Res.1994/2:7:9) were to:

a) advise on the most appropriate means of monitoring to identify temporal trends under different hydrographic conditions, taking into account statistical requirements and comments from the North Sea Status Report (OSPAR 4.1[1]);

b) discuss the approach proposed by WGSAEM for assessing the power of monitoring programmes in mapping spatial distributions of contaminants in sediments and biota, making use of, *inter alia*, the ICES/HELCOM Sediment Baseline Study, and the ICES/NSTF North Sea data sets;

c) review a draft TIMES document on the formulation of objectives for temporal trend monitoring studies to be prepared jointly by members from the two Groups intersessionally;

d) exchange views on plausible objectives for sediment monitoring programmes and statistical methods to address problems.

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[1] ICES is requested to advise on realistic (in terms of cost benefit relations) statistical requirements for establishing temporal trends for nutrients, inorganic and organic contaminants. What, for example, are the monitoring requirements in terms of sampling frequency, accuracy of measurements and minimum duration of the programme for establishing, with a 90% probability, a temporal trend of 5% per year for hydrographic regions with either low, medium or high natural variability? It should also be considered how different conditions might influence the choice of the matrix to be sampled (water, SPM, sediment, biota).

ANNEX 2

Joint Meeting of the
Working Group on Environmental Assessment and Monitoring
and the
Working Group on the Statistical Aspects of Environmental Monitoring

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