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Fish disease surveys in environmental monitoring: the role of ICES

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Diseases of wild marine fish have been studied on a regular basis by many ICES Member Countries for more than two decades. Disease surveys are often integrated with other types of biological and chemical investigations as part of national and international monitoring programmes aiming at an assessment of the health of the marine environment, in particular in relation to the impact of human activities. Since the early 1980s, ICES has played an active role in the initiation and coordination of fish disease surveys and has contributed considerably to the development of standardized methodologies. A fish disease data bank has been established within the ICES Environmental Data Centre, consisting of disease prevalence data on key fish species and diseases and accompanying information submitted by ICES Member Countries. Quality assurance procedures have been implemented at all stages, from sampling of fish to submission of data to ICES. Current ICES activities have focused on the development and application of statistical techniques for an assessment of disease data with regard to the presence of spatial and temporal trends in the North Sea and Western Baltic Sea. In a more holistic approach, analyses have been carried out combining the disease data with oceanographic, nutrient, contaminant, and fishery data extracted from the ICES data banks in order to improve the knowledge about the complex cause–effect relationships. The present paper describes the history and present state of fish disease surveys coordinated by ICES and provides information on their strengths and limitations and on the discussion of cause–effect relationships between contaminants and diseases. Examples are given illustrating recent developments in the analysis of ICES fish disease data and some future perspectives for environmental monitoring.

Keywords: fish disease surveys, marine pollution.

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Introduction

Grossly visible fish diseases and parasites have attracted the interest of naturalists and scientists for centuries, and there are numerous anecdotal reports in the earlier literature describing conspicuous anomalies such as skeletal deformities, bone tumours, skin lesions, and parasites of wild fish, in most cases caught by fishermen (Sindermann, 1970; Roberts, 1982; Watermann and Kranz, 1992).

The first systematic studies were related to diseases of commercial importance to freshwater aquaculture, e.g., bacterial furunculosis and vibriosis (Roberts, 1982). Reports on diseases of wild marine fish in relation to pollution were published beginning in the late 1960s when North American scientists found coincidences between disease prevalence and levels of anthropogenic contaminants in estuaries and other coastal areas impacted by urban and industrial effluents. In these studies, a large number of infectious and non-infectious fish diseases considered to be associated with marine pollution were identified, such as fin rot/erosion, skin ulcerations, skeletal deformities, and skin and liver tumours (reviews have been published, for in-stance, by Sindermann, 1979, 1984, 1989, 1993; Mix, 1986; Malins *et al.*, 1988; Overstreet, 1988; Vethaak and ap Rheinallt, 1992).

In Europe, particularly Sindermann's reviews of pollution-associated diseases and abnormalities of fish and shell-fish received much attention and stimulated systematic research/monitoring activities which commenced in the 1970s. In the beginning, these were focused on the southern North Sea and the Irish Sea, but were extended to larger geographical areas in the following years, including the central and northern North Sea, the English Channel, the Baltic Sea, and even areas outside the North Sea, such as waters around the Orkney and Shetlands Islands and Iceland (for a review, see Vethaak and ap Rheinallt, 1992; Lang and Dethlefsen, 1996; Dethlefsen *et al.*, 1996).

Results of these studies have been reviewed continuously by ICES working groups and at various ICES Statutory Meetings and Annual Science Conferences. Particularly in the beginning, controversies arose regarding the cause–effect relationships between contaminants and fish diseases and the usefulness of fish disease surveys as part of national and international programmes for monitoring and assessing biological effects of contaminants in marine organisms.

Today, it is generally accepted that studies of externally visible fish diseases and contaminant-associated liver anomalies may provide information on the occurrence of environmental stress and are, therefore, considered an important component of monitoring programmes. Consequently, many ICES Member Countries conduct more or less regular fish disease surveys, most of which apply standardized methodologies which have been developed through various ICES activities starting in the early 1980s.

The present paper describes the history and present state of fish disease surveys coordinated by ICES and provides information on their strengths and limitations. The debates of the late 1970s and 1980s in ICES on cause–effect relationships between marine pollution and fish diseases and on the usefulness of fish disease monitoring are highlighted. Developments within ICES in the 1990s are described, leading to the establishment of fully standardized methodologies for fish disease surveys and data reporting, and to a fish disease data bank as part of the ICES Environmental Data Centre. Recent activities are outlined that aim at a statistical analysis of the ICES fish disease data in order to study variation in the temporal and spatial distribution of fish diseases and to improve knowledge on the relationship between fish diseases and environmental factors, including contaminants.

On the role of ICES

Three major objectives of ICES can be highlighted in the context of fish disease surveys. First, ICES has always been a forum for planning marine scientific research and for discussing its results in an open and occasionally confrontational way. This was also, and in certain periods even particularly, the case with diseases of marine fish in relation to marine pollution. Second, ICES has from its inception played a major role as coordinator of science and as adviser for identifying and applying appropriate monitoring and assessment strategies. This can also be shown using fish disease surveys as an example. Third, ICES holds a number of multidisciplinary databases, enabling holistic assessments to be made on the status of the marine environment and the health of its inhabitants. The importance of this issue will certainly increase in the future since ICES increasingly provides advice on the quality of the marine environment to international regulatory bodies. Again, ICES activities related to fish disease surveys can be taken as an example of this third aspect.

The history of fish disease surveys in ICES

ICES has been involved in the initiation and coordination of fish disease surveys in relation to pollution since the 1970s when there was a growing awareness and concern about the occurrence of adverse biological effects of contaminants in the ICES area. In 1975, the ICES Working Group on Pollution Baseline and Monitoring Studies in the Oslo Commission and ICNAF Area recommended the formation of a subgroup to review the present state of knowledge of the effects of marine pollution on living resources and to examine the experimental demonstration and measurement of these effects, and their interpretation and evaluation in field and monitoring situations (ICES, 1978).

Whilst in the report of this subgroup, the term "fish diseases" did not even occur and only very few "morphological effects" (skeletal deformities, tumours, gill damage) were considered to be useful parameters for biological effects monitoring programmes, it was only a few years later, at the 1979 ICES Workshop on Biological Effects of Marine Pollution and the Problems of Monitoring held in Beaufort, North Carolina, USA (McIntyre and Pearce, 1980), that a number of fish and shellfish diseases were classified as potentially valuable tools for pollution monitoring, and detailed guidelines for the design of fish disease studies were developed (Sindermann *et al.*, 1980). This workshop constituted an important milestone since it prepared the way for further ICES activities in this field. The results of the workshop were reviewed by the ICES Advisory Committee on Marine Pollution (ACMP) which stated that the workshop provided a firm scientific basis for biological effects monitoring (ICES, 1980, 1981).

In 1982, the ACMP discussed a report containing results of observations on the occurrence of tumours, fin rot, and skeletal anomalies made by ICES Member Countries on request from the ICES Working Group on Marine Pollution Baseline and Monitoring Studies in the North Atlantic (WGMPNA) (ICES, 1983). The report covered 12 fish species and many thousands of individual specimens from the Baltic Sea, North Sea, Irish Sea, and off the east coast of Canada and the USA and revealed considerable spatial differences in the prevalence of certain grossly visible diseases. This was the beginning of the ICES coordinated fish disease surveys and also the beginning of a structured disease data submission to ICES. Member Countries had been requested not only to undertake observations on pathobiology in relation to the environment, but also to report their results annually and to submit data to the ICES Secretariat on a special data reporting form.

From that time on, wild fish disease data obtained by Member Countries during their national fish disease monitoring surveys were reviewed regularly in ICES. This was mainly done by the ICES Working Group on Pathology and Diseases of Marine Organisms (WGPDMO). The WGPDMO was established in 1976 as the ICES Working Group on the Pathology of Molluscs and Crustacea of Economic Importance, but widened its scope shortly thereafter to include the consideration of fish diseases. At the end of the 1970s, the WGPDMO started to focus on the relationship between contaminants and wild fish diseases, an issue that has since constituted one of the major activities of the Working Group.

Standardization and intercalibration of methodologies for fish disease surveys in ICES

When results of the first coordinated surveys on wild fish diseases were discussed in ICES in the early 1980s, it became apparent that there was a lack of intercalibration and standardization of methodologies applied by Member Countries and that reported results appeared to lack comparability. Therefore, the ACMP recommended in 1982 that a practical workshop be arranged on methods to be used in fish disease surveys in relation to pollution, and that it preferably should be held at sea during a fish disease survey cruise (ICES, 1983). This recommendation was taken up by the WGPDMO, and plans for a workshop were developed. It was decided that the final aim of the workshop would be to produce a paper including proposals for standardized methodologies to be employed in forthcoming fish disease surveys.

The workshop was held in January 1984 on board the RV "Anton Dohrn", with 14 scientists from 11 ICES Member Countries participating, and practical work was carried out at stations in the southern and central North Sea (Dethlefsen *et al.*, 1986). This workshop was followed by two other sea-going ICES fish disease workshops in 1988 and 1994. The 1988 workshop was held on board the RV "Argos" and covered stations in the Kattegat (ICES, 1989), and the 1994 workshop was held on board the RV "Walther Herwig III" in the Baltic Sea with the Baltic Marine Biologists (BMB) as co-sponsor (Lang and Mellergaard, 1999).

The workshops and their results helped greatly to establish intercalibrated and standardized methodologies for fish disease surveys and to develop practical guidelines for an integrated international programme to determine long-term trends in prevalence levels of gross fish diseases, particularly externally visible diseases. The guidelines focused on minimum sampling requirements, target fish species for disease studies, types and intensity of diseases to be monitored, sampling stations and areas, and measurements accompanying disease work (Dethlefsen *et al.*, 1986; ICES, 1989; Lang and Mellergaard; 1999). Whilst these first guidelines covered externally visible diseases, the WGPDMO developed guidelines for macroscopic and microscopic inspection of flatfish livers for the occurrence of neoplastic lesions at a later stage. Attempts at further intercalibration and standardization of methodologies for studies on liver pathology of flatfish were a major issue of the 1996 ICES Special Meeting on the Use of Liver Pathology of Flatfish for Monitoring Biological Effects of Contaminants (ICES, 1997).

Other major ICES activities related to fish disease surveys were the ICES/IOC Workshop on Biological Effects of Contaminants in the North Sea (Vethaak *et al.*, 1992) and the publication of a training guide for the identification of common diseases and parasites of fish in the North Atlantic (Bucke *et al.*, 1996). In addition, diseases of marine finfish and shellfish are being described in the *ICES Identification Leaflets for Diseases and Parasites of Fish and Shellfish*, a publication series prepared under the guidance of the WGPDMO that at present encompasses more than 50 titles.

The ICES fish disease database

Further steps in the coordination and standardization of fish disease surveys were the establishment of an ICES fish disease database as part of the ICES Environmental Data Centre and the description of procedures for reporting and submission of disease data to ICES by Member Countries. Again, the WGPDMO and its offspring, the Sub-Group/Study Group on Statistical Analysis of Fish Disease Data in Marine Stocks (SGFDDS), established in 1992, took the lead and elaborated, in close collaboration with the ICES Secretariat, a fish disease data reporting format and a disease data entry programme for incorporation of disease data into the ICES Environmental Data Centre, both facilitating compatibility with other ICES environmental data (e.g., contaminants in biota, water and sediments, hydrography).

The ICES fish disease data submitted by Member Countries comprise information from studies on the occurrence of externally visible diseases and macroscopic liver lesions in the common dab (*Limanda limanda*) and the European flounder (*Platichthys flesus*) from the North Sea and adjacent areas, including the Baltic Sea, Irish Sea, and the English Channel. In addition, reference data are available from pristine areas, such as waters around Iceland. In total, data on length, sex, and health status of almost 500 000 individual specimens, some from as early as 1981, have been submitted to ICES, as well as information on sampling characteristics (Wosniok *et al.*, 1999).

Assessment of ICES fish disease data

Activities of the WGPDMO and SGFDDS in the 1990s were related to the statistical analysis of the ICES fish disease data. In 1998, a comprehensive report providing information on statistical methodologies suitable for the analysis of disease monitoring data and on spatial and temporal trends in the prevalence of diseases of dab and flounder from the North Sea and Baltic Sea was prepared and reviewed by the ICES Advisory Committee on the Marine Environment (ACME) (Wosniok *et al.*, 1999). The report provided information on temporal and spatial trends in the prevalence of diseases of dab (lymphocystis, epidermal hyperplasia/papilloma, skin ulcerations) and flounder (lymphocystis, skin ulcerations) from the North Sea and Baltic Sea for the period 1981–1997.

Major conclusions from the report were that marked spatial differences occurred with respect to the absolute levels and the temporal changes in the disease prevalence, the latter including seasonal effects. For the period since 1992, a test for statistical significance in the temporal changes was employed, and areas with either significantly increasing, decreasing, or stable trends were identified. With the exception of only a few areas, stable or decreasing trends in the prevalence dominated in both the North Sea and the Baltic Sea and for both fish species. However, a few areas of concern were identified which were characterized by significantly increasing disease prevalence. For skin ulcerations in dab, these cases were located in the central and western North Sea, and for epidermal hyperplasia/papilloma, in the German Bight. In some areas, variations in prevalence of lymphocystis and epidermal hyperplasia/papilloma followed the same temporal pattern, indicating the presence of some underlying mechanisms affecting the development of the two diseases in the same way.

Although the report provided useful information on the distribution of diseases, it did not permit any conclusions on causes of the observed trends. As a consequent next step, the ICES disease data were combined with other types of data available in the ICES Oceanography Data Centre and the ICES Fishery Data Banks for a more holistic data analysis, with the aim of improving knowledge about possible cause–effect relationships. As a first step, an overview report on data available in the ICES data banks which may be used for a holistic analysis was prepared by the WGPDMO. Additionally, the WGPDMO carried out a pilot study for which a selected subset of suitable data was extracted from the ICES databases in order to assess the practicability and perspectives of a future holistic data analysis. For the pilot study, data from an area in the southeastern North Sea, including the German Bight, were used consisting of information on the prevalence of diseases in dab and a number of factors suspected as playing a role in the disease aetiology and pathogenesis (water temperature and salinity, concentrations of nutrients in sea water, contaminants in sediments, water, and biota, and data on catch per unit effort as an index of fish density) (Lang and Wosniok, 2000; Wosniok *et al.*, 2000).

The results of the case study revealed a close relationship between the disease prevalence and some of the factors included in the analysis. In a univariate analysis based on logistic models, water temperature was the parameter with the strongest impact, and the prevalence of all three diseases considered was highly and positively correlated with temperature. Catch per unit effort as an index of fish density also showed a significant relationship with the prevalence of all diseases. However, a positive relationship was only found for lymphocystis and epidermal hyperplasia/papilloma, while skin ulcerations were negatively correlated. For other factors, such as contaminants in sediment, water, and biota, relationships were only detected with single diseases and without any consistent trends that might reflect more clearly the impact of contaminants. A multivariate analysis resulted in complex relationships between the disease prevalence and potentially explanatory factors considered, which can be taken as an indication of the complex and multifactorial aetiology of the diseases considered in the analysis (Lang and Wosniok, 2000; Wosniok *et al.*, 2000).

A major restriction for a data analysis covering larger geographical areas and time spans was the lack of sufficient data in the ICES data banks, particularly on contaminants in sediments, water, and biota. ICES has, therefore, repeatedly encouraged its Member Countries to submit relevant data which are known to be held in national databases (ICES, 1999, 2000; Wosniok *et al.*, 2000).

It is intended that future activities related to a holistic analysis of ICES fish disease data involve areas other than the North Sea and also other fish species. A prerequisite, however, would be an extended data set involving more contaminant data and also fishery data (e.g., fishing effort) in order to obtain a better view of the effects of contaminants and fishery activities on the diseases (ICES, 1999, 2000).

Present status of fish disease monitoring in the ICES Area

In many ICES Member Countries, surveys of the prevalence and spatial distribution of diseases of wild marine fish continue to be a component of national research/monitoring programmes for the assessment of biological effects of contaminants. Whilst mainly externally visible diseases were investigated in the beginning of these studies, the gross and histological examination for neoplastic and putative pre-neoplastic liver lesions has increasingly been included during the past decade.

In North America, most activities in previous years were carried out in the United States. These studies were focused on coastal areas with bottom-dwelling fishes

Table 1. Present status of fish disease monitoring programmes carried out by European ICES Member Countries in the North Sea and adjacent waters.

Belgium	Belgian continental shelf and southwestern North Sea; dab, plaice, flounder, sole, cod, whiting; externally visible diseases and parasites; in dab liver nodules/tumours
Denmark	No regular fish disease monitoring (the former extensive fish disease monitoring has been completely stopped only recently)
France	No regular fish disease monitoring
Germany	Whole North Sea, English Channel, Irish Sea; dab, plaice, cod, whiting, haddock, saithe; externally visible diseases and parasites; in dab liver nodules/tumours and histopathology
Iceland	No regular fish disease monitoring
Ireland	No regular fish disease monitoring
The Netherlands	Dutch coastal waters; dab and flounder; externally visible diseases; in dab and flounder liver nodules/tumours and histopathology
Norway	No regular fish disease monitoring
Portugal	No regular fish disease monitoring
Spain	No regular fish disease monitoring
UK–England	Central and western North Sea, English Channel, Irish Sea; dab, flounder, cod; externally visible diseases and parasites; in flatfish liver nodules/tumours and histopathology
UK–Scotland	Northwestern North Sea; dab, cod, haddock; externally visible diseases and parasites; in dab liver nodules/tumours

such as English sole (*Pleuronectes vetulus*), starry flounder (*Platichthys stellatus*), and white croaker (*Genyonemus lineatus*) along the Pacific Coast and winter flounder (*Pleuronectes americanus*) on the northeast Atlantic coast as main bio-indicator species (Myers *et al.*, 1994a). Since the 1980s, these studies have mainly been addressing the links between contaminants and the occurrence of neoplastic and non-neoplastic liver lesions and related biomarkers (Malins *et al.*, 1988; Murchelano and Wolke, 1991; Myers *et al.*, 1991, 1994a, 1994b; McCain *et al.*, 1992; Moore and Stegeman, 1994). Studies on externally visible diseases have been carried out only sporadically since that time and were not incorporated in regular monitoring programmes.

In Canada, a number of multidisciplinary research programmes on diseases in estuarine fishes of the St Lawrence, Miramichi, and St Maurice rivers, mostly in relation to pulp and paper mill effluents, have been carried out, including fish species such as American eel (*Anguilla rostrata*), mummichog (*Fundulus heteroclitus*), and white sucker (*Catostomus commersoni*) (C. Couillard, personal communication). Again, these studies were not part of regular monitoring activities.

In the European ICES Area, studies in the North Sea on the occurrence of externally visible fish diseases (e.g., lymphocystis, epidermal hyperplasia/papilloma, skin ulcer disease) and, since the late 1980s, liver nodules/tumours of the common dab, have, in particular, been part of national long-term monitoring programmes carried out by all bordering countries since the end of the 1970s. Common diseases of dab and other abundant fish species occurring in the North Sea and adjacent areas have been described, for instance, by Bucke *et al.* (1996), and the literature on epidemiological data has been thoroughly reviewed by Vethaak and ap Rheinallt (1992). Whilst, in the beginning, these programmes were restricted to coastal areas, they have been extended to offshore regions in the entire North Sea since the 1980s. Externally visible diseases of dab were also included in the list of biological effects techniques applied in the framework of the former Monitoring Master Plan (MMP) of the North Sea Task Force

Table 2. Present status of fish disease monitoring programmes carried out by ICES Member Countries in the Baltic Sea.

Denmark	No regular fish disease monitoring
Estonia	Gulf of Finland; flounder; externally visible diseases and parasites; liver nodules/tumours
Finland	No regular fish disease monitoring
Germany	Whole southwestern Baltic Sea; cod, flounder, plaice, dab, whiting; externally visible diseases and parasites; in flounder and dab liver nodules/tumours and histopathology
Latvia	Latvian waters; flounder, cod, herring, pike, pikeperch, roach
Poland	Polish fishery zone; cod, flounder, herring, sprat
Russia	No regular fish disease monitoring
Sweden	No regular fish disease monitoring

(NSTF) (North Sea Task Force, 1993). In coastal areas of the North Sea, Dutch and German studies have also been investigating diseases and parasites of the European flounder (Köhler, 1990; Möller, 1990; Anders and Möller, 1991; Vethaak, 1992; Lang, 1994; Wahl *et al.*, 1995; Vethaak and Jol, 1996; Vethaak and Wester, 1996). Other fish species frequently included in disease monitoring programmes in the North Sea are cod (*Gadus morhua*), whiting (*Merlangius merlangus*), haddock (*Melanogrammus aeglefinus*), and plaice (*Pleuronectes platessa*).

In Table 1, the present status of fish disease monitoring programmes carried out by European ICES Member Coun-tries in the North Sea and adjacent waters is listed. Only those programmes are mentioned which pertain to the assessment of contaminant effects and which are carried out on a regular basis. Apart from these, there have always been a large number of more scientifically orientated and temporally restricted research projects, partly initiated by ICES, investigating contaminant-induced biological effects associated with pathology and disease.

Studies on the occurrence of fish diseases are also components of national research/monitoring programmes in the Baltic Sea. The major target fish species of larger-scale studies are European flounder and cod. In addition, species such as fourhorn sculpin (*Myoxocephalus quadricornis*), herring (*Clupea harengus*), sprat (*Sprattus sprattus*), perch (*Perca fluviatilis*), ruffe (*Gymnocephalus cernua*), and pike (*Esox lucius*) have been investigated on a more local basis. Current reviews of flounder diseases and parasites in the Baltic Sea are given by Bylund and Lönnström (1994), Lang *et al.* (1999), and Køie (1999). Dethlefsen and Lang (1994), Draganik *et al.* (1994), and Mellergaard and Lang (1999) described the abundance and spatial distribution of cod diseases in the Western Baltic Sea. Bengtsson (1988), Bengtsson *et al.* (1988), Mayer *et al.* (1988), and Bengtsson (1991) described pollution-associated skeletal deformities of fourhorn sculpin, and Lindesjöö (1992) examined diseases of perch, ruffe, and pike related to pulp mill effluents. Information on Baltic Sea countries with regular wild fish disease monitoring programmes related to contaminant effects is given in Table 2. Additionally, there have been a number of research projects in Baltic Sea countries focusing on various aspects of contaminant-induced biological effects including pathology and diseases.

The extent of fish disease monitoring programmes in a number of ICES Member Countries has been considerably reduced during the past several years. This trend has been pointed out with regret by ICES working groups and committees. Examples are: 1) Denmark and Sweden, which completely terminated their formerly intensive efforts in the North Sea and Kattegat and the Kattegat and Baltic Sea, respectively; 2) The Netherlands, where the former programme which had covered stations throughout large areas of the North Sea, is now restricted to a few stations in Dutch coastal waters; and 3) Scotland, where the number of sampling sites has also been reduced considerably. Also in the United States, some long-term monitoring programmes have been suspended owing to a lack of funding.

During past years, a number of fish disease monitoring programmes conducted in ICES Member Countries have increasingly been integrated with other monitoring activities, e.g., chemical monitoring and a more biomarker-type biological effects monitoring. Furthermore, oceanographic, demographic, and other relevant data are increasingly incorporated in the disease data assessments. It is hoped that this kind of integrated approach will be more effective with respect to the identification of potential cause–effect relationships.

Controversies and debates on the causes of fish diseases

When early results of studies of the link between fish diseases and marine pollution were reported to various ICES bodies and were presented at the ICES Statutory Meetings/Annual Science Conferences, their conclusions were often debated and heated discussions frequently occurred. This was most evident in the 1980s when the discussion on the quality of the marine environment and the extent to which man impacts it, e.g., by allowing toxic contaminants to enter the sea – even in an independent scientific organization such as ICES – was polarized and often of a purely political nature rather than being based on scientific knowledge. Since one of the few biological markers indicating biological effects of contaminants at that time was the prevalence and spatial distribution of marine fish diseases, the discussion in ICES on possible adverse environmental effects of contaminants centred around this issue. The sometimes heated discussion on this issue is reflected in the reports of various ICES working groups and committees, as well as in a great number of scientific publications (e.g., Sindermann, 1979; Möller, 1985; Dethlefsen *et al.*, 1987; Vethaak and ap Rheinallt, 1992; Bucke, 1993; ICES, 1995).

Two major questions were raised and answered quite differently, depending on the personal attitude of the scientists: 1) does pollution cause diseases among aquatic life forms? and 2) can fish pathology be used to monitor the biological effects of marine pollution? The major reasons for disagreement were that only in a very few cases could unanimous scientific evidence be provided for a causal link between environmental contaminants and an increased prevalence of fish diseases. These cases were restricted to a few heavily contaminated coastal areas and only a few diseases (liver tumours and precursor stages, skeletal deformations, fin rot/erosion). The majority of studies, however, failed to provide indisputable evidence. At best, they provided circumstantial evidence by indicating correlations between contaminant levels in water, sediments, or biota and disease prevalence.

A special case stimulating discussions in ICES (and among the public) on the relationship between contaminants and fish diseases was the observation of the elevated prevalence of epidermal hyperplasia/papilloma in dab from dumping sites for wastes from the titanium dioxide production in the German Bight and off the coast of The Netherlands compared with surrounding areas (Dethlefsen *et al.*, 1987; Vethaak and Van der Meer, 1991). Whereas Dethlefsen *et al.* (1987) found clear correlations between the disease prevalence and chemical factors in the German Bight, Vethaak and Van der Meer (1991) failed to show any links. The discussion of the possible causes of increased prevalence lasted for a couple of years and statements given were quite polarized and ranged from "natural causes" to "caused by contaminants".

The discussion on the usefulness of fish disease studies for monitoring purposes was again intensified when it was decided during the second half of the 1990s to revise the former Joint Monitoring Programme (JMP) of the Oslo and Paris Convention and to implement the Joint Assessment and Monitoring Programme (JAMP). A major improvement of the JAMP was to replace the purely chemical monitoring with an integrated programme comprising both chemical and biological effects monitoring. In order to identify suitable biological effects techniques to be incorporated in such a programme, ICES was requested by the Oslo and Paris Commission (OSPARCOM) to assess the usefulness of biological effects techniques, including studies on externally visible fish diseases, for monitoring purposes, and to recommend techniques for incorporation in general and contaminant-specific monitoring programmes. After some struggles, it was finally decided to incorporate studies on externally visible diseases of dab in the plans for general biological effects monitoring, but not into the plans for contaminant-specific monitoring. For the latter, however, studies on histopathological liver changes were incorporated in the list of biomarker studies considered to be useful.

Today, the multifactorial aetiology of disease is generally accepted. Most wild fish diseases monitored in past decades are caused by pathogens (viruses, bacteria). However, other endogenous or exogenous factors may be required before the disease develops. One of these factors can be environmental pollution, which may either affect the immune system of the fish in a way that increases its susceptibility to disease, or may alter the number and virulence of pathogens. In addition, contaminants may also cause specific and/or nonspecific changes at various levels of biological organization (molecule, subcellular units, cells, tissues, organs) leading to disease without involving pathogens (e.g., exposure to heavy metals and carcinogenic contaminants such as PAHs and/or PCBs may lead to skeletal deformities and neoplastic liver changes, respectively).

It is furthermore agreed that, given the complexity of biological systems and the variety of factors potentially influencing the development of diseases, an integrated multidisciplinary approach, involving physical, chemical, and biological measurements is needed to identify or quantify aetiological factors with a major impact on disease pathogenesis. The current epidemiological methods used in most field studies *per se* cannot provide scientific proof of clear cause–effect relationships between specific diseases and pollutants (Dethlefsen, 1988; Sindermann, 1989, 1993). According to Dethlefsen (1990), methods used can only describe coincidences between (known) contaminants and biological effects, but cannot provide unequivocal scientific proof. At best, circumstantial evidence can be gathered, the degree (probability) of which depends on the degree of statistical correlation. Scientists involved in such studies will always have to be prepared for the fact that any of

Table 3. Strengths and limitations of fish disease monitoring.

Strengths	Limitations
Diseases are an overt and integrative biological endpoint of physiological changes at different levels of biological organization affecting the organism's homeostasis that are associated with environmental change.	Most diseases (particularly infectious) have a complex multifactorial aetiology, potentially involving the impact of anthropogenic and/or natural variations of host, pathogens, and environmental characteristics.
In concert with more specific early-warning biological effects techniques, e.g., biomarkers of contaminant exposure and contaminant-induced damage, fish diseases can be used more specifically as indicators of effects of contaminants.	Changes in prevalence of wild fish diseases are often a non-specific indicator of environmental change, the causes of which are difficult to identify.
Significant changes in disease prevalence are a biologically and ecologically relevant warning sign for adverse environmental changes, since diseases may affect growth, reproduction, and survival of affected individuals and may, therefore, have implications on the population level.	The elucidation of cause–effect relationships between contaminants and changes in disease prevalence requires a multidisciplinary monitoring strategy, involving the measurement of a wide range of potentially explanatory host-specific (e.g., age, length, gender, population density, status of the immune system, migration patterns), disease-specific (aetiology, pathogenesis, transmission pathways, seasonal effects, natural background levels, effects on hosts) and site-specific factors (e.g., community structure, contaminant levels in different compartments, bioavailability of contaminants, fishing pressure, hydrography).
Data on the prevalence and spatial distribution of diseases (including parasites) of commercial fish species are of direct use for quality controls of fish as a food resource for human consumption.	
Fish disease monitoring is cost-effective since it can be carried out directly on board research or even commercial vessels, possibly in combination with stock assessment surveys, without involving subsequent laboratory work (except histopathology).	Owing to the complexity of the relationship between the environment and the pathogenesis of diseases and owing to the great effort needed to identify cause–effect relationships related to contaminant effects, results from wild fish disease monitoring can, at best, provide circumstantial evidence for the existence of such a relationship, rather than indisputable scientific proof.
Externally visible target diseases identified are, with a certain degree of training, easy to recognize.	
A large number of fish and large geographical areas can be screened and results are immediately available.	
Methodologies for fish disease surveys have been established and repeatedly intercalibrated.	
Standard procedures for data submission and validation, statistical analysis, and data presentation have recently been developed by ICES.	
A large ICES database with long-term fish disease data from the North Sea and adjacent areas submitted by ICES Member Countries has been built up and can be used as baseline information for future monitoring programmes.	

their statements and conclusions on the presence or absence of a cause–effect relationship will be disputed according to the personal beliefs of other scientists and non-scientists.

Conclusions and prospects for future fish disease monitoring programmes

Thanks to ICES activities, regular fish disease surveys carried out by Member Countries have been standardized to a large extent, and methodologies applied have been intercalibrated repeatedly. Procedures involved in data collection, reporting, and assessment are conducted according to agreed quality assurance protocols, and disease prevalence data generated and submitted to the ICES Environmental Data Centre can be considered to be of high quality. The analysis of ICES disease data started only a few years ago, and much still needs to be done in order to improve our knowledge on cause–effect relationships between the variation in disease prevalence and environmental factors, including contaminants.

Based on the experience in and the results of ICES coordinated programmes, some conclusions as to the strengths and limitations of wild fish disease surveys can be drawn (see Table 3). One of the major advantages fish disease surveys offer is that diseases are ecologically relevant and integrative endpoints of chronic exposure to stressors, including contaminants. According to Kinne (1984), disease tends to reduce the energy available for sustaining essential functions and structures, the resistance to concomitantly effective stressors (natural and man-made), the capabilities for defence and escape, and the potential for competition and counteracting additional disease-causing entities. Therefore, a high prevalence of diseases might have serious implications for fish populations in terms of growth, reproduction, and survival. However, the occurrence of significant changes in the prevalence of gross fish diseases can be considered a nonspecific and more general indicator of chronic rather than acute (environmental) stress, and it has been speculated that they might, therefore, be an integrative indicator of the complex changes typically occurring under field conditions rather than a specific marker of effects of single factors. Therefore, the identification of causes for observed changes in disease prevalence is difficult, and scientific proof of a link between contaminants and fish diseases is hard to achieve. Nevertheless, fish disease surveys should continue to be part of national and international environmental monitoring programmes since they can provide valuable information on changes in environmental health and may act as an "alarm bell".

The monitoring of fish diseases alone, however, is not sufficient to assess the effects of contaminants on the marine environment. The same is, of course, true for any other biological effects technique used in isolation. There can be no doubt that monitoring programmes using only single biological indicators of environmental effects would not be successful. What is needed is an integrated monitoring approach such as that recommended by ICES (ICES, 1995) comprising a combination of techniques measuring the presence and fate of contaminants in the environment, the exposure of organisms and bioavailability of contaminants, early toxicological effects, responses on the organism level, and responses on the population/community level. These monitoring components can be supplemented by experimental studies (bioassays, toxicity experiments) investigating the toxic potential of marine compartments (e.g., sediments, water, surface microlayer) and mechanisms involved in toxicity.

Whatever environmental monitoring strategies are being applied, they should always be accompanied by research activities in order to provide scientific background data required for the interpretation of monitoring data and to improve monitoring strategies and techniques, as appropriate. ICES should and certainly will continue to play a major role in the identification of environmental research needed and in the initiation and coordination of appropriate research and monitoring programmes.

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