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An historical perspective on ICES studies of diseases of marine and diadromous animals

James E. Stewart and Alasdair H. McVicar

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Before 1950, many of today's familiar diseases of fish and shellfish were unidentified. Much of our current knowledge has been generated as a result of commercial practices of holding captive animals live for sale to consumers and increasingly from the attempts to culture many fish and invertebrate species. The formal and substantive entry of ICES into the diseases field is associated with the increasing importance of mariculture in Member Countries. This resulted in the formation of the Working Group on Introductions and Transfers of Marine Organisms (WGITMO) in 1969, the Working Group on Pathology and Diseases of Marine Organisms (WGPDMO) in 1976, and the Mariculture Committee in 1978. The activities of WGITMO over the past 30 years resulted in a Code of Practice for Introductions and Transfers which, if followed assiduously by Member Countries and others, should markedly reduce or virtually eliminate problems arising from deliberate introductions and transfers. Currently, attention is focused on introduction problems stemming from release of ballast waters. The WGPDMO has concentrated on three major topics: 1) diseases associated with culture operations, 2) assessment of the impact of diseases on natural populations, especially those fished commercially, and 3) fundamental approaches to determine whether diseases of wild fish can be used to trace contaminants and assess pollution (biological effects monitoring), with pioneering work in development, standardization, and calibration of methods. In all of these activities, there has been a logical progression in the development of the field of pathobiology in which ICES has played a major role in developing more relevant approaches to diseases of marine and diadromous animals.

Keywords: biological effects monitoring, mariculture, marine animal diseases, pathobiology, population assessments.

James E. Stewart: Department of Fisheries and Oceans, Bedford Institute of Oceanography, PO Box 1006, Dartmouth, Nova Scotia, Canada B2Y 4A2; tel: +1 902 426 8145; fax: +1 902 426 7827; e-mail: stewartje@mar.dfo-mpo.gc.ca. Alasdair H. McVicar: Marine Laboratory, PO Box 101, Victoria Road, Aberdeen AB11 9DB, Scotland, UK.

Introduction

Kinne (1984a) defined disease as "a demonstrable negative deviation from the normal state (health) of a living organism....negative implies an impairment, quantifiable in terms of a reduction in the ecological potential (e.g., survival, growth, reproduction, energy procurement, stress endurance, competition)". Kinne was insistent that the study of marine ecology should include a focus on diseases of the species being studied. He deplored the fact that ecologists have neglected to consider the health status of the objects of their studies whose natural population sizes are limited by varying combinations of food, predation, reproduction, age, and disease. In addition, an intense interest has recently developed focused on the role viruses might play in the control of populations of bacteria and algae in the aquatic environment. Given these statements and concerns, it is interesting to note that the resolution and general acceptance of the germ theory of infectious diseases coincided with the considerations leading to the formation of ICES. It is noteworthy that some of the important principles of resistance to infection actually stemmed from studies of aquatic animals.

Development of the field

From ancient times, varying beliefs and hypotheses had postulated that many diseases were contagious and propagated by self-perpetuating agents transferred from affected hosts. Although much of this folklore was an

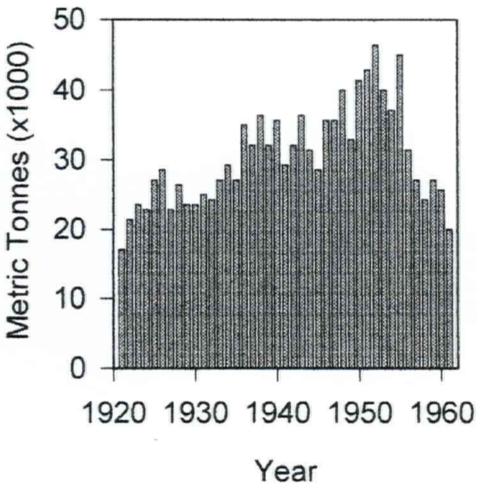

Figure 1. Annual landings of Atlantic herring in the southern Gulf of St. Lawrence illustrating reductions resulting from the 1954–1956 *Ichthyophonus* epizootic (redrawn from Sindermann, 1963).

amalgam of fact and fancy, it gave rise to practical approaches which reveal a surprisingly sophisticated understanding of microbiological principles. These took the form of quarantine measures imposed upon ships and people to prevent the spread of devastating epidemic diseases such as plague and cholera, the development of industries based upon fermentation, i.e., wine and vinegar-making, baking, and the techniques employed in cheese-making, to list a few.

This immense body of practical knowledge was followed by the observations of "animalcules" (microorganisms) in the 1680s by the man who was the first microscopist, bacteriologist, and protozoologist, Anton van Leeuwenhoek. Milestones in laying the foundations for recognition of the true causes of infectious disease included the proof by Bassi in 1835 and 1836 that *mal del segno* in silkworms was contagious and caused by a fungus (now named *Beauveria bassiana*) (cited by Steinhaus, 1969) and later studies described by Dubos (1950). Despite this rather clear general understanding of contagion and microbiological processes, it was not until the anthrax studies of Koch and Pasteur in the 1870s that the germ theory of disease was widely accepted, initiating over the next two decades "the golden age of bacteriology". From the ICES point of view, the studies by Metchnikoff in the late 19th and early 20th centuries greatly expanded work on marine and terrestrial invertebrates, and these aquatic studies, in fact, contributed materially to conclusions about the resistance factor, phagocytosis, for which he and Paul Ehrlich were awarded, in 1908, one of the early Nobel Prizes (Goetz, 1988).

The discovery that microbial agents were the primary cause of infectious diseases led to a heavy emphasis on the infant science of bacteriology. It was recognized and maintained by some at that time, however, that the known facts did not fully explain the course and mechanisms of epidemics which often appeared unpredictable and capricious. It was soon found that these adjectives applied just as much to epizootics among aquatic species.

Involvement of ICES

Studies on diseases of marine organisms have been more constrained than for terrestrial diseases and, by the 1970s, the situation was strikingly similar to that for terrestrial organisms toward the end of the "golden era of bacteriology". In many cases, the microbial cause was known, and in others, the microbial cause based upon associations was suspected, but not proven. Understanding of the defence systems of aquatic animals against disease-causing agents has lagged behind that of higher animals. While fish had been shown to possess immune systems similar to higher vertebrates, the systems were believed to be more primitive in poikilothermic animals. Invertebrates, it was believed, did not have actual immune systems, but rather collections of general defence or resistance factors that could be mobilized and act in concert to meet the immediate threat of invasion by a foreign agent, but could not be stimulated to provide a qualitative or quantitative defence which lasted after the disappearance of the threat. This premise is still held to be true for all aquatic invertebrates, with the relatively recent exception of the Crustacea.

Constraints of importance to the development of the studies of diseases of marine animals include the marine environment, which alone adds enormously to the complexity and the long list of species of concern. In addition, the lack of the infrastructure in training and research that the parallel terrestrial fields have enjoyed has restricted the basic microbial findings on cause and effect from being taken further to broadly based and sophisticated levels and applied to individuals, the community, and populations.

Although, on occasion, ICES had been involved in minor ways with diseases (for example, with sealworm in cod), it was not until mariculture became of interest to a number of Member Countries that the study of diseases of marine organisms received formal recognition and support. In so doing, ICES was able to provide some of the missing infrastructure which has been of such importance to the development of the terrestrial disease field.

To give some perspective, at the beginning of the 1970s, mariculture was increasing in importance to ICES Countries. In 1970, the production of cultured species in Member Countries was largely in molluscan shellfish (mussels and oysters), of which several hundred thousand t were produced annually. Atlantic salmon production was of the order of 1000 t, which had increased to around 5000 t by 1978. By 1998, farmed

Table 1. Representative diseases and pathological occurrences in marine and anadromous species in ICES Member Countries (prepared from WGPDMO annual reports and ICES annual reports and updated from Stewart, 1991a).

Agent or sign	Host species	General location	Time of year
Vibrio anguillarum	Atlantic salmon, rainbow trout, cod, halibut, char, turbot	N. Europe	Summer and fall
V. ordali	Rainbow trout, salmon	W. Atlantic	Summer and fall
Cold water disease (*V. salmonicida*)	Atlantic salmon, rainbow trout	N. Europe	Year round
Bacterial kidney disease (*Renibacterium salmoninarum*)	Atlantic + Pasific salmon, rainbow trout	Atlantic and Pacific	Year round
Furunculosis (*Aeromonas salmonicida*)	Atlantic + Pasific salmon	Atlantic and Pacific	Summer and fall
Enteric redmouth (*Yersinia ruckerii*)	Rainbow trout	Atlantic and Pacific	Summer to fall
Pancreas disease (viral)	Atlantic salmon	Atlantic	Spring to fall
Infectious salmon anemia (viral)	Atlantic salmon	Atlantic	
Myxobacteriosis	Atlantic salmon	Atlantic	Winter
Infectious Pancreatic Necrosis (viral)	Salmonids	Atlantic and Pacific	Fry period
Ichthyophonus	*Pleuronectes platessa*, haddock, herring	Atlantic	
Pseudobranch swelling	Cod	Atlantic	
Skin ulcers (*Hyperplasia papilloma*)	*Limanda limanda*	Atlantic	
Lymphocystis	*Limanda limanda*	Atlantic	
Gaffkemia (*Aerococcus viridans*)	Lobster (*Homarus*)	Atlantic	Spring to fall
Bonamia ostreae	*Ostrea edulis*	Europe	Year round
MSX "Dermo" disease (*Haplosporidium nelsoni*)	*Crassostrea virginica*	Atlantic	Year round
Perkinsus marinus	*Crassostrea virginica*	Atlantic	Spring
Marteila refringens	*O. edulis, Mytilus edulis, Crassostrea gigas*	Atlantic	Year round
Protozoan (Denman Island Disease) *Mikrocytos mackini*	*C. gigas*	N. Pacific	Jan–May
Fatal Inflammatory Bacteremia	*C. gigas*	N. Pacific	Jan–Oct
Macro parasites	All species of finfish and shellfish	Atlantic and Pacific	
Sea lice (*Lepeophtheirus salmonis*)	Atlantic salmon	Atlantic	Year round
Gyrodactylis salaris	Atlantic salmon	E. Atlantic, Baltic, Norway	
Anguillicola crassus, A. novaezelandiae	Eel (*Anguilla anguilla*)	Europe	

Atlantic salmon production in the ICES Area was 538 011 t, a 100-fold increase in 20 years. The worldwide production of farmed Atlantic salmon in 1998 was 710 342 t, approximately 295 times the nominal catch of wild Atlantic salmon in the North Atlantic (ICES, 2000a). Currently, the annual total production of cultured species in Member Countries is approximately 1 million t, composed of salmonids, molluscan shellfish, eels, and various marine fish species.

Over the same period, the decline of many stocks of commercially fished species was becoming an increasingly serious problem, and any factor which might threaten the well-being of stocks was of concern. In addition to the direct effects of infectious diseases, there was also widespread interest in whether effects of pollution could be assessed in natural populations. The possibility of using various infectious diseases and pathological anomalies as indicators of pollution began to receive considerable attention. Finally, it was already apparent that certain species were threatened by diseases which had been introduced inadvertently along with desired species and others had been transported through such media as ship's bottoms, bilge water, and ballast-water discharges. Given the scale of the demands and the scattered nature of the slender resources in the individual countries devoted to these studies, it was obvious that only by pooling resources of Member Countries could significant progress be made in time periods realistic enough to be useful.

The role played by ICES in the field of marine diseases has been tied primarily to the three subordinate bodies listed below in order of their formation:

1) Working Group on the Introduction of Non-Indigenous Marine Organisms, which was brought into being by passage of a Council Resolution (C.Res. 1969/2:10), and later renamed the Working Group on Introductions and Transfers of Marine Organisms (WGITMO) (C.Res.1980 /2:18).
2) Working Group on Pathology of Molluscs and Crustaceans of Economic Importance (C. Res. 1976/2:12). Later, with the inclusion of marine fish, it was expanded and renamed the Working Group on Pathology and Diseases of Marine Organisms (WGPDMO) (C.Res.1977/2:9).

3) Mariculture Committee, which was established at the 1977 Statutory Meeting and met for the first time at the 1978 Statutory Meeting.

In discussing the work of these several bodies, the authors have deliberately avoided singling out individuals. We believe it is important to emphasize that the considerable progress made has been largely a result of team approaches rather than individual efforts. As a consequence, we have only named the Chairs to aid in identifying the periods and enterprises being discussed. The extensive lists of contributors and participants can be found in the annual reports and various publications resulting from the work of these bodies.

Working Group on Introductions and Transfers of Marine Organisms

This group's function has been extremely important to the spread and control of diseases, although its central activities were not focused specifically on disease.

The original Working Group (WG) was formed as a direct result of a paper presented to the Fisheries Improvement Committee at the 1969 Statutory Meeting by A. C. Simpson entitled "The benefits and dangers in the introduction of fish and shellfish in the ICES Area from other parts of the world" (Simpson, 1969). The WG established, at national expense, with representatives from each Member Country, and chaired by H. A. Cole (United Kingdom), had a remit "to consider the principles which might govern the introduction and acclimatization of non-indigenous marine organisms, especially shellfish and anadromous and catadromous fish species" (ICES, 1972).

The WG met in London in 1970 and 1971 and drafted a report (ICES, 1972) that described the various pertinent national laws and other governing procedures current in responding Member Countries. Based on a listing of the widespread deliberate and accidental introductions, an evaluation was made of any resulting harmful effects, including those from inadvertent introductions of pests and infectious disease agents. The report noted that, although many deliberate introductions had been important and beneficial, too many had harmful results. Also, although a number of the non-related organisms and parasites had been introduced accidentally with the deliberate introductions, the greatest number of accidental transfers had been made by ships. It was concluded that legislation governing the introduction of non-indigenous species was diverse and mostly inadequate. To guard against this, a recommendation was made that each Member Country should implement control over indigenous pests and diseases and that international control would be most effective when these national controls were adequately developed.

The report (ICES, 1972) made two important and far-reaching recommendations:

1) Member Countries should be requested to provide additional information annually on introductions and transfers, progress reports, and details of any further planned introductions.
2) An Advisory Committee of ICES should be set up to collate and disseminate the information received and to advise on all questions relating to the introduction of new species, with the aim of establishing an International Code of Practice (details of what should be included in both national legislation and a Code of Practice were supplied).

This advice led directly to the formation of the Advisory Committee on Marine Pollution.

In 1979 (C.Res.1978/2:28), the WG was reconvened, with C. J. Sindermann (United States) as Chair until 1990, to assess plans for intended introductions and to comment on the proposals of the WG on Pathology and Diseases of Marine Organisms to amend the existing Code of Practice to reduce the risks of adverse effects arising from the introduction of non-indigenous marine species.

Beginning in 1979, the WG produced a succession of reports concerned primarily with introductions and transfers of all species, but also with the stated central aim of preventing the introduction of macroparasites and microbial agents of disease. The main instrument for countering these problems was entitled "The 1994 Code of Practice on Introductions and Transfers of Marine Organisms" (ICES, 1994a). In this form, the preamble to the Code of Practice read:

> The introduction and/or transfer of marine organisms, including genetically modified organisms, carries the risk of introducing not only pests and disease agents but also many other species. Both intentional and unintentional introductions may have undesirable ecological and genetic effects in the receiving ecosystem, as well as potential economic impacts. This Code of Practice provides recommendations for dealing with new intentional introductions, and also recommends procedures for species which are part of existing commercial practice, in order to reduce the risks of adverse effects that could arise from such movements.

The five relevant reports which led to this final form of the Code of Practice are ICES (1972, 1982, 1984), Turner (1988), ICES (1994a), plus a status report (Munro *et al.*, 1999). ICES (1994a) was subsequently printed as a monograph in a slightly amended bilingual English/French version in September 1995; see: www.ices.dk/pubs/itmo.pdf.

The 1994 Code of Practice recommended procedures for countries which have sought Council advice and received approval for a new introduction are:

a) A brood stock should be established in a quarantine situation approved by the country of receipt, in sufficient time to allow adequate evaluation of the stock's health status.
b) The F1 progeny should be placed on a limited scale into open waters to assess ecological interactions with native species.

c) All effluents from hatcheries or establishments used for quarantine purposes in recipient countries should be sterilized in an approved manner (which should include the killing of all living organisms present in the effluents).
d) A continuing study should be made of the introduced species in its new environment, and progress reports submitted to the International Council for the Exploration of the Sea (ICES, 1994a).

The WG reported initially to the Fisheries Improvement Committee and then, in 1978, to the Mariculture Committee. In 1993, it began reporting to the newly formed Advisory Committee on the Marine Environment (the body which, with a broadened mandate and enlarged membership, replaced the Advisory Committee on Marine Pollution). J. T. Carleton (United States) served as WG Chair from 1990 to 2000, during which time many of the Group's activities were involved with introductions and transfers which may occur as a result of ballast water carriage and release (Carleton, 1998). The current Chair is S. Gollasch (Germany).

Working Group on Pathology and Diseases of Marine Organisms

Interest generated by increased mariculture activities in Member Countries and information on a variety of relevant formal and informal sessions on marine animal diseases sparked the interest of ICES. These included:

1) the "Consultation on an International Convention for the Control of Major Communicable Fish Diseases" held in Aviemore, UK, in 1974;
2) a report in 1976 that the United Nations Food and Agriculture Organization (FAO) body, the European Inland Fisheries Advisory Commission (EIFAC), wished to cooperate more closely with ICES in the field of aquaculture, notably in the area of fish diseases and fish nutrition; and
3) an informal meeting on the pathology of oysters held in France in 1976 in which specialists from several Member Countries took part.

The WG, with C. Maurin (France) as Chair, was formed in 1976 in the face of concern that molluscs and crustaceans were becoming increasingly affected by diseases and that both natural stocks and cultured animals might be endangered, as was currently feared for flat oysters on the French coast. The remit of the WG was:

- assess the present situation and research on current epizootics of molluscs and Crustacea;
- consider disease control measures;
- prepare disease identification sheets; and
- make recommendations for the reduction of economic impacts of diseases of molluscs and crustaceans.

As mentioned earlier, the role of the WG was expanded the following year to include marine fish. Subsequently, its mandate was modified from year to year to reflect the particular concerns of the day. In general, the overall thrust remained basically the same, i.e., to maintain a "watching brief" on new disease trends in wild and cultured marine organisms, to evaluate and develop approaches to assess and control the impact of disease on marine resources, and to investigate the role pathology and disease may have in providing early warnings of environmental pollution. The WG has met annually since its formation and has been chaired by C. Maurin (France) (1976), E. Egidius (Norway) (1984), B. J. Hill (United Kingdom) (1989), A. H. McVicar (United Kingdom) (1992), and currently S. Mellergaard (Denmark) (1997) (the year given indicates the beginning of that person's term). The WG reported in 1977 to the Shellfish and Benthos Committee and the Fisheries Improvement Committee; subsequently, it has reported to the Mariculture Committee. The main output from WGPDMO has been in the form of:

a) the annual WG meeting reports, which cover the most significant elements and events in ICES involvement in marine diseases, generated directly by the WG;
b) *Fiches*, published in both French and English, currently entitled *ICES Identification Leaflets for Diseases and Parasites of Fish and Shellfish / Fiches d'Identification des Maladies et Parasites des Poissons, Crustacés et Mollusques* and edited by C. J. Sindermann in 1981–1985, C. J. Sindermann and C. Maurin in 1986–1989, G. Olivier in 1989–1997, and S. E. McGladdery beginning in 1997, with 56 Fiches published to date; and
c) reports of special topic meetings, including Stewart (1983), Dethlefsen *et al.* (1986), ICES (1989, 1994a, 1994b), Bucke *et al.* (1996), Hutchinson (1997), and ICES (1998, 1999a, 1999b, 1999c).

Mariculture Committee

As mariculture had become more important in Member Countries, the Council established a Working Group on Mariculture at the 1974 Statutory Meeting (C.Res. 1974/2:12). After meeting in each of the ensuing three years, it was succeeded by the Mariculture Committee established by the Council in 1977, with the following terms of reference:

The Mariculture Committee shall keep under review and coordinate investigations relating to culture of marine organisms, including transplantation and introduction of new species.

The Council noted that, as the Mariculture Committee was in many respects a continuation of the Working Group on Mariculture, the WG Chair, K. Tiews (Federal Republic of Germany), should be asked to act as Chair of the new committee for the coming year. At its inaugural meeting in 1978, Professor Tiews paid tribute to E. Egidius and Dag Møller, both of Norway, as two aquaculturists who were instrumental in beginning the efforts, four years earlier, which led to the establishment of the Mariculture Committee. Professor Tiews was elected Chair for the next three years.

Upon its formation, the Mariculture Committee, along with its other functions, performed as the oversight body for work on diseases of marine organisms. The Committee has been chaired subsequently by D. Møller (Norway) (1981), J. E. Stewart (Canada) (1984), H. Rosenthal (Federal Republic of Germany) (1987), H. Ackefors (Sweden) (1990), R. H. Cook (Canada) (1993), M. Héral (France) (1996), and A. Calabrese (United States) (1999) (the year given indicates the year of that person's election).

Discussion

The partial, but representative, list of diseases considered by ICES over the last 20–30 years (Table 1) illustrates the diversity of infections and conditions, which range from low pathogenicity (necessary for environmental monitoring studies) through relatively mild interferences with health and well-being to those causing mass mortalities. It is not possible here to discuss more than a few to illustrate salient features. Comprehensive accounts of the wide spectrum of diseases affecting aquatic species can be found in such works as Kinne (1980, 1983, 1984a, 1985, 1990), Roberts (1982, 1989), Sindermann (1970, 1990), Couch and Fournie (1993), and Inglis *et al.* (1993), among others. Any publications list, however, will be incomplete as new conditions continue to be described.

Introductions and transfers

An illustration of what can happen when protocols such as those in the Code of Practice of the WG on Introductions and Transfers of Marine Organisms are not available or not applied is revealed by several past introductions.

The fungal disease "Krebspest" was seen first in Italy in 1860 (Unestam, 1973). It is caused by the fungus *Aphanomyces astaci*, which, since that date, has progressively eliminated the valued crayfish *Astacus astacus* from most of Europe. The fungus is part of the normal microflora of the American crayfish *Pacifastacus*, in which it does not cause a disease. It is believed to have been transferred by the introduction of American crayfish to Europe where infections of *Astacus* are always fatal. Thus, the introduction and spread of this fungus has eliminated an important fishery and food item as well as a vital member of the ecological community from virtually all of continental Europe.

The destructive salmonid disease, furunculosis, caused by the bacterium *Aeromonas salmonicida*, now appears to be endemic in virtually all salmonid areas, on occasion causing major losses in hatcheries and massive mortalities among both wild and cultured salmonids. Although impossible to prove now, it is considered to have been introduced to previously unaffected areas via transfers of trout and salmon. Arguments have been developed on both sides of the Atlantic purporting to show each side of the Atlantic had received the disease from the other (Stewart, 1991b).

More recently, the spread of the disease bonamiasis has been well documented. This disease of the flat oyster (*Ostrea edulis*) is caused by the protozoan parasite *Bonamia ostreae*, and is readily transmitted directly (oyster to oyster). Within six months of its introduction to dense, but uninfected populations, it caused mortalities estimated as high as 80% (Balouet *et al.*, 1983; Elston *et al.*, 1986). According to Elston *et al.*, infected *O. edulis* spat from Elkhorn Slough, California, was the primary source for the spread of the disease to other parts of North America and its later introduction to Europe. First recognized in Brittany in 1979 (Comps *et al.*, 1980), it spread to the Netherlands, Spain, Ireland, and the United Kingdom (reviewed by Stewart, 1991b) and was reported (ICES, 1995a) to have now reached Portugal and the Mediterranean. A map of the current distribution of *B. ostrea* is presented in the 2000 report of WGPDMO (ICES, 2000b). The economic consequences of bonamiasis have been extremely serious. An attempted countermeasure, i.e., reduction of the host density on natural beds, has not so far shown any major success in limiting the impact on the cultivation of the flat oyster and in halting its further spread.

Recently, the salmon parasite *Gyrodactylus salaris* is considered likely to have been introduced into wild fish in Norway through aquaculture. It is regarded as a major threat since, in some areas, it is having a serious detrimental effect on wild salmon stocks (ICES, 1995b). It was recommended in the 1996 WGPDMO report (ICES, 1996) that whatever measures are available should be employed to limit its distribution.

These several examples serve to show the problems which inadvertent and unforeseen introductions can impose. They also underscore the importance and value of knowing what agents are carried by organisms for which transfers are planned and by those species which are routinely transferred live as regular items of commerce. The main principles of the ICES Code of Practice on the Introductions and Transfers of Marine Organisms now also appear in the Office International des Epizooties (OIE) Fish Diseases Commission International Aquatic Animal Health Code covering all aquatic animals on a worldwide basis (OIE, 1997).

Impacts on wild stocks

The best-documented epidemic disease of marine fish is that caused by *Ichthyophonus* (a lower protistan parasite, previously considered to be a fungus). As summa-

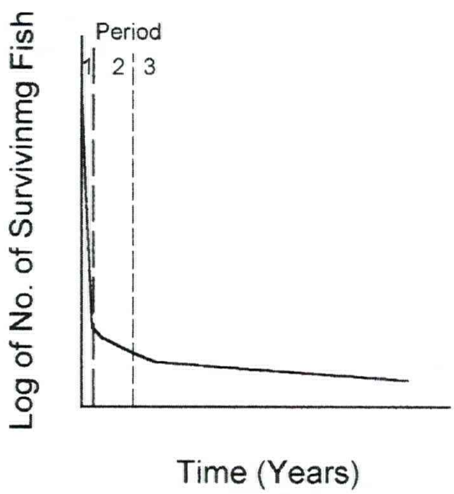

Figure 2. Hypothetical survival curve of one year class of fish. Period 1, eggs and larval fish; period 2, pre-recruit fish; period 3, fish stocks (redrawn from Munro *et al.*, 1983).

rized by Sindermann (1990), *Ichthyophonus* is an introduced, but controllable, pathogen in trout hatcheries worldwide, a long-recognized pathogen of wild salmonids in Western Europe, and a pathogen of many other marine and freshwater fish, with more than 80 species of fish having been found to be infected by the parasite. Over half a century of sporadic study in Europe, North America, Japan, and elsewhere has provided ample evidence that *I. hoferi* is one of the most serious pathogens of marine or freshwater fish and can result in widespread mortalities. Epizootics of the disease are characteristic in herring (*Clupea harengus*) of the western North Atlantic. Six such outbreaks have been reported since 1898. Drastic reduction in herring abundance due to disease has been documented, and the postulation made that outbreaks of this disease may be an important limiting factor to population growth of herring in the western North Atlantic. The impact attributed to the 1954–1956 epizootic on the stocks of herring in the southern Gulf of St Lawrence is shown in Figure 1. It was estimated that up to half of the stock was killed by the disease (Sindermann, 1963).

Although *Ichthyophonus* has been recognized in European marine fish stocks since at least 1900, it was not identified as causing significant mortalities until McVicar (1979, 1981, 1988) indicated a calculated annual mortality of 55% in the fishable plaice stock off the north of Scotland (from a 9.4% prevalence). A high infection prevalence level of 85% in haddock in the same area occurred without associated marked pathology and indicated that this species largely tolerated the infection.

The first records of *Ichthyophonus* infecting European stocks of herring were made in the late summer of 1991 in the Skagerrak and Kattegat when mass mortalities occurred and large quantities of dead herring were visible on the sea surface and washed up on the beaches (Rahimian and Thulin, 1996). In the subsequent two years, observations of the disease in herring stocks extended into the northern North Sea, along the Norwegian coast, to the Barents Sea, and to the Norwegian Sea southeast of Iceland. Two special ICES meetings were held on the epizootic in 1991 and 1993 to standardize methodology and to update and analyse information on the prevalence and impact of the *Ichthyophonus* on herring stocks. The following herring stocks were identified as significantly infected: 1) Norwegian spring spawners, 2) part of the northern North Sea stock, and 3) the Kattegat / western Baltic Sea stock. Preliminary attempts to calculate the resulting mortality levels in the several herring stocks (Patterson, 1993; Hagström and Patterson, 1993) indicated that the annual mortality in North Sea herring caused by *Ichthyophonus* could be as high as 16%, but no changes in stocks definitely attributable to the disease could be detected from stock assessment data. As a consequence, it was recommended that sampling to obtain data on infection rates should be intensified, analysis of commercial catches should be extended, available data on *Ichthyophonus* should be summarized, and experimental work should be carried out on the pathogenicity of the fungus (ICES, 1994b). WGPDMO now includes an assessment of the available data on *Ichthyophonus* prevalence in its annual report to ICES.

This case history of *Ichthyophonus* infections reveals a number of opportunities and problems arising in the studies of the epidemiology of infectious diseases in commercially fished stocks. The opportunities exist largely in the area of generating consistent data that would enable an early recognition of any future epizootics and of having reasonable estimates of population size. The problems relate mainly to devising appropriate means to gauge the impact the disease has on the population.

The important central role of disease as a component of natural mortality was considered by Munro *et al.* (1983) in response to a specific request made by the convener of the special ICES Meeting on "Diseases of Commercially Important Marine Fish and Shellfish" held in Copenhagen in 1980. As an aid to understanding, these authors used a hypothetical survival curve through three different developmental stages of one year class of common demersal or pelagic fish (Figure 2):

1) In the first period after hatch of eggs, larval survival was largely dependent upon their finding a favourable food situation, and the majority were destined to die whether or not disease was a factor influencing the outcome.
2) In the second pre-recruit period, distribution patterns are largely determined by feeding, and most fish would be in good condition, but immunologically naive. Pre-recruit surveys indicate a rapid depletion in numbers, e.g., up to 10–15% per day. Infections carried by predators could contribute to

epidemic density-dependent diseases which may be difficult to detect because of diminished predator avoidance in diseased individuals. In this period, the presence of disease agents coupled with evidence of pathology and higher-than-expected population declines provide the best indicators of a disease impact on the fish stock.

3) In period three (fished stocks), the fish may have already survived several disease encounters and may still be experiencing persistent infections. Determination of the contribution disease makes to the widely variable level of natural mortality among fished populations may be complicated by compression of any disease-related mortalities into one or another of the life phases, i.e., long migrations, spawning concentrations, post spawning recoveries, or migrations with little feeding en route.

Munro *et al.* (1983) concluded that, if the study of disease in wild fish was to progress beyond qualitative descriptions and classification of pathogens to quantifying effects on host populations, the methods of data collection would have to be amplified and demonstrate effects of disease on the populations. As has been endorsed repeatedly in many subsequent WG reports, the approaches identified which should assume greater importance were:

1) determining specific disease prevalence ratios and their comparison with catch data on the survival of healthy and infected fish;
2) establishing factors to convert prevalence ratios to mortality rates, e.g., by using intensity of infection (as defined earlier), field observation and from infected fish held in captivity;
3) determining recovery rates of tagged diseased and healthy fish;
4) from experimental prey–predator situations comparing rates of predation on healthy and diseased prey;
5) improving detection of disease from greater emphasis on pathological features other than gross pathology.

Biological effects monitoring

The development, by WGPDMO, of the concept of using fish disease as an index of environmental quality was described by McVicar (1997). The 1996 Report of the Oslo and Paris Commission recognized that fish disease studies meet the general criteria for biological effects monitoring and, as a result, the approach was included as part of the Joint Assessment and Monitoring Programme (JAMP).

The methodologies for diagnosing specific infections, pathological signs of disease, or contaminant effects are under constant development by many individuals. These have been intensively compared, standardized, and applied under controlled field conditions on the several ICES sea-going workshops: RV "Anton Dohrn", 1984 (Dethlefsen *et al.*, 1986); UF "Argos", 1988 (ICES, 1989); and RV "Walther Herwig III", 1994 (ICES, 1999c). These cruises have been invaluable for developing and ensuring compatibility in methodology, an essential component underpinning the development of the ICES fish disease database. In addition, they provided hands-on training which has been applied in conjunction with assessment cruises, in "biological effects monitoring", and codified in the *ICES Techniques in Marine Environmental Sciences* series.

As superficial signs of pathology may not be as reliable as internal signs, a "Special Meeting on the Use of Liver Pathology of Flatfish for Monitoring Biological Effects of Contaminants" was held in 1996. This recommended that five new categories of relevant liver lesions should be added to the existing list of diseases of dab and flounder in the ICES Fish Disease Data Entry Program / Fish Disease Reporting Format and that ICES Member Countries should submit data on these categories of liver lesions (ICES, 1999b).

In 1991, under the WGPDMO a group was formed to capitalize on the developing ICES fish disease database. Named the Sub-Group on Statistical Analysis of Fish Disease Data in Marine Stocks, it met annually, with the exception of 1995, through to 1996 when it was replaced by a Study Group with the same subject name. In 1992 J. Thulin (Sweden) acted as Chair, followed by A. D. Vethaak (The Netherlands), who also chaired the Study Group at its only meeting, held in 1997. The Group's activities were part of the pioneering ICES work to develop methodologies for the statistical analysis of fish disease data collected for measuring general biological effects of contaminants. In 1998, the fish disease database of the ICES Environmental Data Centre comprised information on single fish (length, sex, diseases) for some 400 000 dab and almost 26 000 flounder for the period 1981–1997. Major tasks were:

to establish standardized procedures for the submission of fish disease data to the ICES Environmental Data Centre (the former ICES Environmental Databank) by ICES Member Countries; and to develop methods for and carry out a statistical analysis of the fish disease prevalence data submitted to the ICES Environmental Data Centre.

The database has been subjected to development and statistical assessment each year. For example, the aim of the 1997 analysis was to identify location-specific temporal trends in the prevalence of lymphocystis, epidermal hyperplasia/papilloma and skin ulcers in dab and lymphocystis and skin ulcers in flounder, as well as to compare trends at different geographical locations. From the results of the analyses, there was clear evidence of significant and consistent temporal trends in disease prevalences, although the direction of these trends was not uniform in all areas (ICES, 1999a).

WGPDMO concluded that identifying the possible causes for observed spatial and temporal trends in disease prevalence was still not possible because of the unavailability of physical and biological data currently stored in the ICES data banks (ICES, 1999a). Despite these shortcomings, the development of standardized and intercalibrated survey methods, examinations, data reporting, data storage, and analysis has transformed the field from one of qualitative descriptions of individual happenings to a sophisticated quantitative tool. This has very real potential for acting as an "early warning alarm bell" of change in specific localities or general areas of the sea, thereby enabling the intensive focusing of resources (hydrographic, sediment analyses, toxicological, pollution, stock assessment, chemistry) to improve understanding and to seek to extend the list of proven cause-and-effect relationships. Although the applications to date have been confined largely to flatfish, the utility and value of the methods and approach on a wider scale, applied in general to population dynamics as well as the consequences of pollution, are evident.

Culture

The ICES concern with diseases of cultured species is of a more detailed and immediately commercial nature, but it is correct to state that it too has progressed from the particular to more systematic approaches. In brief, the problems which have periodically afflicted molluscan shellfish culture have been approached through eradication of infected stocks and their replacement by clean seed stock or through use of strains or species which have shown some degree of resistance to the specific condition or disease. For example, in the case of bonamiasis, the main approach for managed beds has been to reduce the density and handling of the affected stocks, as density appears to be critical in the maintenance of the infection; handling of the individual oysters markedly worsens the condition. These measures coupled with provision of seed stock free of *Bonamia ostreae* may be having some beneficial effects in reducing the depredations of this disease, although the long-term prognosis is uncertain.

In finfish, using salmonids, especially *Salmo salar*, as an example, the serious problems over the years seem to have stemmed first from *Vibrio* sp. infections along with furunculosis and bacterial kidney disease. The diseases caused by the *Vibrio* sp. were dealt with successfully by the fairly rapid development and application of effective vaccines. Furunculosis was a longer-term problem which required a multifaceted approach initially involving antibiotics, selection of provably clean seed stock (brood stock and smolts), and ultimately the development of several vaccines. As with many approaches to disease management, the effectiveness of these is closely linked to aspects of improved husbandry. Bacterial kidney disease (BKD) was dealt with in a manner similar to that for furunculosis, with the exception of vaccines. To date, no BKD vaccine of proven effectiveness has been developed.

As major problems, these diseases have been superseded by sea lice (*Lepeophtheirus salmonis*) and the virally induced infectious salmon anaemia. Sea lice have proven to be a major bugbear in Norway, Scotland, Ireland, and Canada causing serious losses in both numbers and quality. The lice infestations have been treated with "cleaner fish" (e.g., wrasse) and chemotherapeutants (e.g., organophosphates). Currently, a more environmentally sanguine approach has evolved, namely, fallowing. This involves removing the farmed, host salmonids (and therefore their sea lice) for varying periods and then restocking the areas with unaffected smolts. Infectious salmon anaemia has been a problem from the mid-1980s for Norwegian salmon farming and of the late 1990s for Canadian and Scottish salmon farming. The disease has also recently been reported from Faroes salmon farming (Anon., 2000). Coping with the problem has involved withdrawal of infected stocks, salvage of products, improved husbandry, altered slaughter practices (retention of all wastes), attempts to immunize the fish with new, rapidly developed vaccines, and improved management practices for affected areas in general (Stewart, 1998).

Much more emphasis is now being placed on meeting environmental requirements for culture, development, and application of appropriate husbandry, early diagnosis of diseases, and immunological developments leading to vaccines rather than an immediate recourse to chemotherapeutic approaches. The consequent improvement in local environments, greater commercial success because of improved husbandry with lowered costs, and reduction of problems such as antibiotic resistance and other chemical problems are all rewards for improved practices in which the ICES scientists have played major roles. The experience of working together under the auspices of ICES has meant that background (pre-publication) information and practices are made available more rapidly and readily and work on solutions proceeds on a more shared basis than would have occurred in earlier times.

Farmed salmonid / wild salmonid interactions

Mariculture is a relatively recent phenomenon in the ICES Area, and it is almost inevitable with any new development that there will be associated local changes that may involve many aspects including scenic issues, access, pollution, disease transfer, and interference with local wildlife. Shellfish farming has attracted the least critical comment. In contrast, the very rapid growth of sea-cage salmon farming in several countries has been associated with considerable controversy. While much of the debate centres on contaminant and genetic issues, disease has not been excluded. The ICES Special Workshop on Interactions between Salmon Lice and Salmonids (ICES, 1998) drew together active researchers on sea lice topics to collate available data, address possible areas of cause-and-effect relationships, and identify topics where future research effort should be directed. Wider issues of possible environmental contamination and genetic interactions between wild and farmed salmon, in addition to disease implications, were addressed by the ICES/North Atlantic Salmon Conservation Organization (NASCO) meeting held in Bath, UK (Hutchinson, 1997).

Summary and prospects

The work of the several ICES working/study groups has progressed and expanded considerably with the years, changing from concerns with qualitative descriptions of pathogens, particular diseases of cultured species, local wild stock kills, and introductions, to more systematic approaches and generalized concerns. The gradual development of the relatively sophisticated systems approach to determining disease prevalence and impacts in the wild and biological effects of contaminants are cases in point. In addition, the studies on the list of diseases given in Table 1 benefit greatly from discussion, comparisons of results, and further planning. Joint enterprises have often been undertaken with others in ICES Member Countries through interaction within working groups, between working groups, and with outside agencies such as the OIE and EIFAC. These cooperative ventures have materially advanced the way in which diseases of cultured animals have been dealt with.

As a direct result of the work in ICES on aquatic animal diseases coupled with the increasing efforts of others worldwide over the past 30 years, it is apparent that significant progress has been made in keeping with the four reasons given by Sindermann (1990) for studying diseases of marine species. These, in somewhat altered form, are:

1) to understand the role and significance of disease as a major density-dependent factor in the population biology of marine species;
2) to understand the effects of disease in marine aquaculture, and to develop methods to reduce those effects;
3) to understand the relationships of coastal/estuarine pollution and aquatic diseases, and to explore the use of these diseases and abnormalities as indicators of environmental degradation and potential human risks; and
4) to understand the relationships between parasites and diseases of marine species and human health in those instances where such a relationship seems to exist.

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