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Changes in the North Sea Ecosystem and Their Causes: Århus 1975 Revisited

Introduction

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Århus 1975 was revisited by 70 marine scientists from eight Member Countries of ICES from 11 to 14 July 1995. We say "revisited" because an ICES Symposium on "North Sea Fish Stocks – Recent Changes and Their Causes" was convened by Professor Gotthilf Hempel in the same surroundings at the University of Århus exactly 20 years earlier. The Conveners of the 1995 Symposium were Dr Niels Daan (The Netherlands) and Dr Katherine Richardson (Denmark), supported by Steering Committee members Professor Franciscus Colijn (Germany), Dr John R. G. Hislop (United Kingdom), Dr Britta Pedersen (Denmark), Professor John G. Pope (United Kingdom), and Dr Fredric Serchuk (United States).

The evolution that the ICES role has undergone during the intervening period is evident. The 1995 Symposium addressed changes in all aspects of the ecosystem and of human activities rather than focusing solely on fish and fisheries as the earlier Symposium had done. A total of 35 papers and 20 posters were presented during seven sessions, and 36 of these presentations appear as written contributions in this volume.

During recent decades, changes have been observed over a wide range of biota from phytoplankton to birds, and we tried to relate almost everything to anything. Our intention was to keep the Symposium small to give the best possible conditions for active scientific exchange, and we believe that the relatively small size of the audience contributed to the stimulating discussions we experienced. The Symposium was, in our eyes, a success if only because hydrographers, ecologists, chemists, biologists, and fisheries scientists were, for once, not just talking among themselves but to each other. The event was truly "interdisciplinary".

The overwhelming problem

The 1975 Symposium was held shortly after a period of dramatic changes in fish stocks. Although these changes were the topic of much discussion and debate, no definite conclusions about their likely causes were reached. Twenty years later, we must admit that our conclusions, at least at first glance, resemble those found in Hempel's summary. Few unequivocal examples of cause-and-effect relationships with respect to changes in the marine ecosytem have been identified. The extensions of time-series data have, however, made it easier to recognize the changes that have occurred, and in many cases, to reduce the number of likely agents for change.

Observations made in the sea do not result from Latin Square experiments and, often, several potentially important factors may be acting simultaneously in eliciting a response in the ecosystem. Thus, while we are usually restricted to correlative studies in our hunt for causes, there is often an embarrassment of possible factors to consider. Of course, as scientists, we must consider all of the possible explanations for an observed phenomenon. However, after having tried 20 different parameters, confidence in significance levels should be less than if the result came from a single trial. The actual situation is even worse. If 20 scientists try out a single factor independently, one lucky person may find a significant result by mere chance – and probably get it published (scientific literature is unmistakably biased towards positive results!). Therefore, significant correlations should formally be regarded as providing plausible hypotheses rather than evidence. They require new and independent data sets to stand the test of time. However, even then, correlative studies remain always subject to fallacy. This may sound like a first-year primer in statistics, but what it all adds up to is that it is extremely difficult to identify cause and effect with respect to changes in the marine ecosystem. More often than not, new information indicates that the interactions within the system are even more complicated than we thought on the basis of our early data sets. The paradox is that the more data we collect, the less we appear to know!

Underlying all anthropogenic influences on the environment are the natural changes in the physical environment. We live in a world that changes on all time scales. The Symposium logo reminds us that not so long ago in geological time (10 000 years) the southern North Sea was not even a muddy puddle. As a consequence, variation appears to increase as time series become longer. This is inevitable. Such changes are of little interest to managers because there is nothing they can do about them. However, both from a scientific and from a management point of view it is extremely important to be able to distinguish between natural and "man-made" variation.

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Data archaeology

In order to examine cause and effect in relation to changes in the marine ecosystem, reliable time series are indispensable. During the previous ICES Symposium, the importance of monitoring was stressed, and in the intervening period a variety of carefully planned surveys have been initiated. Many of the studies presented here emphasize the understanding that can be achieved through regular surveys. In the light of this, it is disquieting that a number of Member Countries have elected to stop the collection of some important time-series data. In particular, several of the long-term hydrographic stations have been abandoned (e.g. Laane *et al.*) or are in danger of being abandoned. There is also good news. A vital existing resource has been detected: the data archived by our predecessors! An encouraging feature of this Symposium has been the "rehabilitation" of several old data series. We can only advance into the future one year at a time, but our series may, in some cases, be extended backwards in time very quickly. The purpose that these old data collections may ultimately serve will not always be the one they were set up to serve. Captain Dannevig might be surprised at the uses to which we are putting his beach-seine survey off southern Norway. Many of the old time series we have may turn out to be priceless; they should be put in a museum alongside the crown jewels and illuminated manuscripts!

There were several examples presented at the Symposium of time series extended backwards by some 50 years based on unpublished or published but formerly not fully utilized information (Pope and Macer; Rijnsdorp and Millner). These analyses provide an extremely valuable perspective over a much longer time span than exists from the routine ICES assessments. For instance, these data indicate that cod, haddock, whiting, and plaice were experiencing very high exploitation rates already prior to World War II. In addition, the longer data series allow new perspectives in assessing the sustainability of a fishery.

Our interpretation of what has happened within the marine ecosystem can be enhanced by utilizing appropriately archived information. The electronic tools available to us allow uses of these data that their originators could only dream about. We, ICES, should think hard about establishing study groups charged to dig out, store, and interpret old data sets. The trials with demersal fish suggest that this might be a good starting point.

Archiving historic series is a non-trivial task that we should address seriously. This is a duty of the "silicon age" and we had better do it urgently, particularly while there is still folk memory available to tell us: how these data were collected, where the data are, and what parts of the data cannot be trusted. Maybe we should even go as far as to equip an old sailing smack from the museum and repeat the hauls done almost a hundred years ago in order to examine changes that may have occurred during the last century.

"Natural" variations

Hydrographers have a long history of bringing together existing data from different sources in integrated databases. The North-West European Shelf Programme (Van Leussen *et al.*) is aimed at a comprehensive description of changes and trends in measured variables as well as in modelled fluxes. The first step is quality control of the original data. But even after we are satisfied that data are correct, a simple parameter, for example, dissolved inorganic phosphate concentration, does not lead to spatially coherent results because we do not yet understand the local physical, chemical, and biological processes well enough (Laane *et al.*).

For a sailor, water is water but the weather can be rough. For a hydrographer, all waters are different. The North Sea does not provide a homogeneous environment but varies at all time and space scales. Twenty-five years of weekly sea surface temperature anomaly patterns do not reveal a clear climatic trend but they do reveal regional differences, which are subject to climatic fluctuations with a periodicity that is also observed in the atmospheric circulation over the North Atlantic (Becker and Pauly). A closer look suggests that, with the exception of the central North Sea, air–sea exchange processes as well as advection of heat from the North Atlantic dominate the observed temperature fluctuations. Owing to advection, decadal oceanic variability is communicated to the northern North Sea through the Fair Isle Current and the East Shetland Atlantic Inflow (Turrell *et al.*). The negative Great Salinity Anomaly in the late 1970s has become a cold issue but, in the early 1990s, a long-term positive salinity and temperature anomaly is observed in most time series, including the Skagerrak (Danielssen *et al.*).

Have there been changes observed in biota that reflect the abiotic environment and that may be considered natural? This was, of course, one of the central themes of the Symposium. Based on laboratory observations, biologists are convinced that temperature affects growth of many organisms in nature. Surprisingly, no temperature signal has been observed in the growth of plaice (Rijnsdorp and Van Leeuwen) or sole (Millner), despite the fact that these species encounter extreme temperature conditions in estuaries during their juvenile phase. To complicate matters, growth rates in different sole stocks were significantly correlated, suggesting a common environmental factor that has not yet been identified (Millner *et al.*). Also, the intriguing synchronized growth patterns observed in individuals of the bivalve *Arctica islandica* in the northern North Sea are not correlated with temperature but must be explained by some other environmental factor (Witbaard).

Temperature may also affect survival and, therefore, recruitment. However, the contributions rarely indicate a clear relationship between seawater temperature and species abundance, with two exceptions:

(1) Lusitanian (Mediterranean or "southern") species are most abundant in the southern North Sea during warm years and periods (Corten and Van de Kamp; Greve *et al.*; Heessen; Rogers and Millner). However, it is not clear whether or not temperature is the controlling factor here as enhanced immigration may be caused more by wind-forcing through the Channel than by the temperature itself (Corten and Van de Kamp). These immigrations result, of course, in sudden jumps in diversity indices, which have little to do with maintaining biodiversity *per se*!
(2) Severe winters are associated with a strong signal in benthos abundance in estuaries – high mortalities of adults followed by enhanced settlement of juveniles – and act as a synchronizing factor over large space scales (Beukema *et al.*). Monitoring such species in reference areas as well as in areas that are suspected of being affected by anthropogenic factors might give important clues as to causes and effects, if the synchronization proves to be disrupted. There is also circumstantial evidence that extremely strong year classes of cod, plaice, and sole are often produced during severe winters. However, severe winters do not always result in strong year classes of these species.

In both cases mentioned above, the actual controlling processes are still unclear. One major research planning problem is that winter conditions cannot be predicted. It is only after the event that we realize what data should have been collected to elucidate the processes induced by a specific weather pattern. Perhaps it would be a good idea to develop some kind of "emergency" plan that could be taken out of the cupboard as soon as estuaries start freezing. At the time of writing this overview, it is evident that we have lost yet another chance to study the influence of a severe winter during the winter of 1995/1996!

A more general observation that can be made on the basis of the contributions is that if environmental conditions affect population size and structure, the causes are multifactorial (e.g. Frid *et al.*; Philippart *et al.*; Rijnsdorp and Van Leeuwen; Rogers and Millner). The processes involved appear to be so complex that it may even be unlikely that one factor can be singled out as controlling the population dynamics of a species. This is, of course, equally relevant when considering anthropogenic influences on populations. The finding of a highly significant correlation should probably make one wonder whether it might be a spurious one (Heessen and Daan).

In this context, it must be realized that survey data sets often contain information on tens of species where a number of different parameters may have been measured at many locations (e.g. Greve *et al.*; Basford *et al.*). Thus, in order to carry out meaningful statistical tests, we have *a priori* to be selective, systematic, and rigorous with respect to the treatment of the data. It is often easy to think of a plausible explanation for an observed effect after a significant correlation is found. This problem must be considered in advance if it is to be possible to draw firm conclusions.

In principle, state variables (such as population size) represent integrated effects over time rather than reflecting the immediate response to environmental signals. Process variables (e.g. reproduction, growth, mortality, etc.), on the other hand, would represent more suitable indicators. However, information on rates of change is often lacking, because these are more difficult to measure than state variables.

Fisheries

Hislop addresses the "gadoid outburst" – a topic which occupied many minds during the previous Symposium. The change during the 1960s from a system dominated by pelagic species to one dominated by demersal species was largely reversed during the 1980s. At face value, a negative relationship between these two components is certainly suggested. Gadoids appear to be gradually on the way down. The herring stock recovered strongly, but recently it has been going downhill. Although the true North Sea mackerel stock has failed to recover, the North Sea is now invaded annually by Western mackerel for the greater part of the year. However, details of timing in the trends leave considerable doubt regarding a possible causal interaction between gadoids and pelagic species. Hislop argues that the causes of the gadoid outburst are complex and may include intraspecific recruitment cycles, influenced by predation as well as by the abiotic environment.

Serchuk *et al.* provide a review of the population dynamics of the commercially important fish stocks during the past 30 years and of the recent management advice. Fisheries represent the only human activity impinging on the North Sea ecosystem where there is overwhelming evidence of the quantitative impact on individual stocks. Exploitation levels have continued to increase and, taken as a whole, the North Sea is more heavily fished than ever before. Given the poor state of many of the stocks relative to the Minimum Biologically Acceptable Levels defined for spawning stock biomass, it can only be concluded that the Total Allowable Catch regime imposed by the European Union and Norway has not been effective in constraining fishing mortality. Several stocks (cod, herring, plaice) appear to be staggering dangerously close to the verge of a collapse. This is not a new observation but it does highlight the urgent need to investigate alternative management systems.

Although most commercial fish stocks are in a state of gradual decline, many non-commercial stocks appear to be thriving or are stable (Heessen and Daan; Heessen). This is true even for the starry ray (*Raja radiata*), although ray species are generally suspected of being sensitive to exploitation. However, many other ray species have disappeared from large areas, and the thornback ray (*Raja clavata*) survives mainly in one stronghold off the English coast (Walker and Heessen).

Eutrophication

From nutrients to phytoplankton is only one step. Nevertheless, the relationship between nutrients and phytoplankton is not straightforward. Estimates of gross annual primary production off the Dutch coast (based on extensive data on chlorophyll concentrations, light attenuation estimates, and solar irradiance) do not follow the pattern seen in phosphate loading of the River Rhine. Bot and Colijn argue that the effect of a reduced availability of nutrients in recent years is compensated by the higher transparency of the water. This work highlights the problem of cause-and-effect studies, because if eutrophication cannot be shown to affect primary production, one might not expect to see clear effects further up the food chain.

Nielsen and Richardson did find a positive relationship between yield from fisheries and nutrient input to the Kattegat. However, these authors are careful not to draw too firm a conclusion regarding cause and effect because other factors have changed over the same period. Boddeke suggests that the area for profitable shrimp fisheries has contracted as a result of the recent clean-up programme for phosphate discharge into the Rhine. Also, he argues that the expansion of the mussel fisheries in the Wadden Sea coincided with increasing levels of eutrophication and, if there is a causal relationship, we may expect future reductions in the mussel fishery. On the positive side, Boddeke and Vingerhoed attribute the first signs of a possible revival of an anchovy fishery to the increased transparency of estuarine waters in connection with reduced nutrient inputs.

Growth in plaice (Rijnsdorp and Van Leeuwen) and sole (Millner) is correlated with phosphate run-off, but also to beam-trawl effort (thought to increase food availability) and fish density. Although the influence of eutrophication on the ecosystem is not straightforward, it does seem likely that eutrophication can affect the potential yield of some stocks.

Oil and gas

The hydrocarbon industries have expanded tremendously (De Groot) since the first exploratory holes were drilled in 1961, particularly after large oil and gas fields were found. Today, the interlinked platforms in some North Sea areas look, at night, very similar to industrial complexes in some of the home ports of our research vessels. In addition, thousands of kilometres of pipeline run over the seabed. The impact of all these activities (including seismic surveying, drilling, construction, and gas flaring) on the marine ecosystem is not well understood, but the available evidence suggests that it is relatively minor. The best-documented impact relates to the production of oil-based drilling muds (Daan and Mulder). Mapping of their effects on benthic communities indicates that short-term effects may be found up to 1000 m from a discharge site. Within a radius of 500 m, hydrocarbon concentrations remained far higher than background levels even eight years after the cessation of drilling activities, and long-term effects on biota were observed. In contrast, the recently applied water-based mud discharges had no measurable effect, not even within a radius of 25 m from the discharge site.

The construction associated with oil extraction may actually have a positive effect by providing new habitats for a variety of species and attracting others in much the same way as shipwrecks do. Since fishing is not allowed within a radius of 500 m from platforms, these areas have become virtually "protected". Extraction of marine aggregates also constitutes a threat to marine habitats. However, because of the costs involved, to date these activities have been restricted to coastal regions close to major harbours (De Groot).

Contaminants

Measuring the total load of contaminants entering or present in the North Sea presents an almost infinite task. Moreover, the behaviour of individual substances in relation to physical and biochemical processes varies enormously. In practice, it turns out to be very difficult to trace the apparent reductions in the input of, for instance, heavy metals to the measured levels in marine organisms (Pedersen), probably because of lack of understanding of the effects of biological covariables. Nevertheless, remedial programmes in heavily contaminated estuaries have resulted in an improvement in the benthos (Hall *et al.*).

The possible synergistic effects of different contaminants pose a particular problem. The response of individuals or populations may not simply be the sum of the responses to each substance individually. In addition, other factors than contaminants may be involved in eliciting responses that correlate with contaminant input. For instance, prevalences of malformations in fish embryos appear to be correlated not only with the presence of contaminants, but also with water temperature (Dethlefsen and Von Westernhagen). With the exception of imposex in whelks and, possibly, reproduction in seals, there are very few clear cases of populations of North Sea marine biota having been or being seriously affected by contamination.

Ecosystem effects

We have great difficulties in coming to grips with an appropriate description of integrated changes at the ecosystem level without falling back on examples of changes in individual species. In fact, the ecosystem concept is very much like the concept of the hereafter: everyone understands what is meant by it but no one can define exactly what it is. Defining appropriate quantitative parameters that describe ecosystem characteristics in a meaningful and interpretable way is a big challenge. In this context, it must be realized that, by definition, every change in the ecosystem is truly multifactorial because all elements are causally interlinked. Prey are the reason that predators can feed and predators are the reason that prey die. Sensible cause-and-effect studies should, therefore, be restricted to global ecosystem responses to external disturbing factors. However, even that creates problems because the disturbing factors depend on the ecosystem response: climate change affects hydrography but hydrography, in turn, affects local climate; fisheries affect the relative abundance of species but the relative abundance of species determines the nature of the fisheries.

It is not surprising that progress in this field of elucidating ecosystem interactions is slow. Nevertheless, progress is being made in the investigation of community metrics of fauna assemblages in relation to external factors (Rogers and Millner; Rijnsdorp *et al.*). Multivariate statistics are also potentially useful here (Philippart *et al.*; Frid and Huliselan). However, owing to the multifactorial nature of ecosystem interactions, very extensive time-series data are required before firm conclusions can be drawn.

A very promising approach to examining ecosystem changes was presented by Rice and Gislason, who compared diversity and size spectra in trawl surveys and in a multispecies North Sea model in order to investigate whether the model mimicked the observations in the sea. Their comparative approach allows empirical tests of our understanding of the system, which can be used as a basis for predicting the effects of possible management measures to control the fisheries. The size-spectra approach seems particularly suitable for estimating ecosystem effects of fishing because higher mortalities lead to erosion of the larger size groups.

Some final remarks

One major change observed over the last 20 years does not relate to the North Sea but to science itself: the development of models. For example, multispecies fisheries modelling, which was in its infancy at the previous meeting, has evolved into a standard assessment tool. Modelling of hydrographic and plankton processes has also developed to an immense degree. Although there is still a way to go before we can render these models comprehensible, their development represents a real scientific leap forward. Nevertheless, a few cautionary remarks are appropriate here. It is important that model builders hold enough data in reserve for testing after having used the rest for internal parameter tuning. We also need to develop tests for examining the ability of complex models to describe nature: does the "blob" of larvae in the model, for example, really look like the "blob" in the sea?

To back up correlative approaches, more process-oriented studies are urgently needed in order to understand more clearly what is going on. Such studies are, generally, laborious and costly, requiring interdisciplinary and international cooperation. They may also need new technologies and new interpretative models. However, the realization of such programmes is extremely difficult in this era of de-nationalized research institutes, budget cuts, and contract research.

Finally, at a time when both scientists and the public, in general, are concerned about the deterioration of our environment, it was certainly comforting to hear from Witbaard that he found individuals of *Arctica islandica*, which have been quietly sitting on the bottom of the North Sea filtering their way through all the changes occurring ever since the turn of the century. The mere presence of these organisms is proof that the North Sea is not an underwater desert. Similarly, there is no scientific evidence that the marine ecosystem is on the verge of collapse. However, this is not to say that we need not be concerned about the state of the North Sea environment. Fisheries put so much pressure on the system that they may no longer be considered sustainable, and contamination remains a continuous threat.

Let us end this summary with a prediction: while our appreciation of cause-and-effect responses will certainly increase in the coming years, another Århus Symposium in 20 years' time will still not totally resolve all the remaining questions about causes of the changes that have been or will be observed in the North Sea ecosystem.

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