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Stock structure and management structure: an ongoing challenge for ICES

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Research during the early years of ICES contributed greatly to the understanding of stock structure of marine finfish and invertebrates. More recently, ICES has been a key player in the evolution of modern fisheries-management approaches. Attention to stock structure, which was a major research theme during the early years of ICES, appears to have given way in recent decades to considerations of consistency in management in support of an increasingly complex system of monitoring, evaluating, and regulating fisheries. For several stocks, there has been, and remains, a mismatch between population structure and management structure. This mismatch has plagued fisheries science and management – and may have led to changes in stock structure (including erosion of spawning components) of some species. A new emphasis on consideration of biodiversity and a precautionary approach to management is raising the importance of stock-structure consideration, and this represents a substantial research challenge for ICES as it begins its second century.

Keywords: biodiversity, fisheries management, ICES, intraspecific diversity, management units, populations, stock structure.

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Introduction

Research early in the first century of ICES contributed greatly to the understanding of marine fish stock structure (Sinclair and Smith, 2002; Stephenson and Clark, 2002). This was an issue when ICES was established, it was an active element in the early programs of ICES, and it became one of the greatest scientific achievements of ICES. Later in that century, ICES became a key player in the evolution of modern fisheries-management approaches, developing a major emphasis on stock assessment, peer review, and provision of management advice. The common approaches to evaluation and management of marine finfish and invertebrate stocks assume discrete populations. It has long been recognized, however, that this assumption is complicated to some degree by migration and mixing between management units and by complexity of spawning components within management units. Further, definition of management units has often included operational considerations including historical consistency, resolution of statistical data collection, and political boundaries. In this paper, I discuss ICES research on this topic, suggesting that stock structure remains one of the greatest challenges for ICES as it begins its second century.

ICES and the notion that fish form populations

Sinclair and Smith (2002) have reviewed the development of "population thinking" which took place in fisheries science between about 1878 and 1930. The decade prior to the formation of ICES had seen the publication of Heincke's work on the life history of herring that spawned in the Baltic near Kiel (Heincke, 1878, 1882, 1898). This work challenged, and would eventually undermine, the extant concept summarized within the "Polar migration theory" – changing the emphasis from the species to the population. Much of the development of that change in thinking took place within the newly formed ICES.

There was considerable debate at the time of the formation of ICES about stock structure. This is well summarized by Sinclair and Solemdal (1988):

> He [Heincke] initiated his work in the early 1870s within the context of the herring overfishing debate in the Baltic. There were two schools of thought. Based on the work of the Swedish natural historian Nilsson, it was believed that there were many local forms of herring in the Baltic, each form having a limited distributional area with short seasonal migrations. Under

this interpretation there was considerable scope for overfishing, even with the simple harvesting technology of the time. The second school of thought, championed by the Danish scientist Henrik Krøyer, favoured the traditional interpretation based on Anderson's 'migration' theory, with local overfishing being impossible. The public debate was heated, but unresolved based on the methodologies used at the time to identify the putative local forms.

> Heincke approached the issue by carrying out a detailed life history study of two herring spawning components off Kiel – the spring and autumn spawners. He sampled spawning fish, the early larval stages, the postlarvae and the juveniles of the two components.…He concluded, using primitive multivariate statistics, that the two herring spawning groups were separate races of the same species, and that the racial differences of herring become expressed during the transition from the larval stage to the definitive (juvenile) stage.
>
> He hypothesised that the migrations of herring races were based on both reproductive and feeding instincts. The time and location of spawning was selected in relation to seasonal plankton dynamics and the transport of larvae.

Heincke's thinking regarding herring was incorporated in the discussions in Stockholm and Kristiania which led up to the formation of the original ICES program. Appendix 4 to the Kristiania meeting (Brandt *et al.*, 1901, translated by C. Hammer) suggests a logical continuation of research focusing on herring stock structure:

> The herring which occurs in the entire area of investigation should be the subject of especially intense international investigations. From these are especially important insights to be expected about most diverse questions of marine biology. In addition, there are already a great number of in depth pre-investigations on the herring, which partly have methodological character, which allow now for a firm and very detailed work program.

Brandt *et al.* (1901) went on to point out that herring fall into "scientifically distinguishable local forms or subforms" and proposed research in many areas to determine:

1. "Detailed description of the bodily properties of the herring sub-forms in the area…" and
2. "Record of the spawning places of the local herring forms…"

Racial investigations were indeed included in the work of the famous Committee A chaired by Hjort. The topic was one that seems to have been of personal interest to Hjort, and it received considerable attention in early reports of the Committee. Hjort (1914) generalized the findings of Heincke on herring to other commercial species, and clearly identified the significance of "population thinking" to fisheries management.

Schmidt, in a series of papers from 1917 to 1930 (Schmidt, 1917, 1922, 1930), reported results of racial investigations of cod, herring, eel, and eel pout, concluding that differences observed between populations are, at least in part, genetically based, and that population complexity/richness varies among species.

In 1928, there was a special meeting on "Racial investigations of fish" at which a dozen papers were presented, including :

- Lea's "Herring scales as a certificate of origin" (Lea, 1929);
- Ehrenbaum's "Racial investigations of food-fishes especially herring," which included a section of biometrical "Methods and rules of investigation" (Ehrenbaum, 1929);
- Schmidt's publication referring to a series of investigations and publications of the Carlsberg lab that were "both statistical and experimental" (Schmidt, 1929); and
- A revealing comment by Brunelli, that "we believe that Prof. Ehrenbaum will agree to coordinate the biometric and genetic methods," indicating the intent to apply biometrical methods widely (Brunelli, 1929).

By the mid-1940s, with the addition of tagging studies, biological structure was being elucidated for many stocks. Hjort, in what I think is a very interesting summary of the "ideas, problems and results" of ICES which appeared in Volume 115 of the *Rapports et Proces-Verbaux* (Hjort, 1945), summarized the situation:

> there gradually arose the important conceptions connected with the words 'population' and 'stock', which denote a group of individuals distinct from all others both geographically and biologically.

…and after describing Peterson's marking studies:

> this in its turn led on to using all the ideas and research methods that in the theory of human population had developed into the science called 'population statistics'.

There was clearly a shift in thinking that took place between about 1880 and 1930 (Sinclair, 1997; Sinclair and Smith, 2002). Although the development of the notion that fish form stocks actually began before the formation of ICES, it was a major point in the discussions surrounding the formation of ICES, and it was developed within ICES. Because of this work within ICES, the biological stock was recognized as the appropriate unit of study, and methods were worked out for the discrimination of stocks. This was a major achievement for ICES in its first century.

ICES and an evolving advisory/ management system

ICES was, from the very beginning, a practical organization that worked explicitly to be relevant to fisheries management. This is amply demonstrated in the preambles of both proposed workplans discussed at the meetings in Stockholm (Anon., 1899) and Kristiania (Anon., 1901):

> Considering that rational exploitation of the sea should rest as far as possible on scientific enquiry, and considering that international cooperation is the best way of arriving at satisfactory results in this direction, especially if in the execution of the investigations it be left constantly in view that their primary object is to promote and improve the fisheries through international agreements, this International Conference resolved to recommend to the states concerned the following scheme of investigations which should be carried out for a period of at least five years.

ICES would never have the authority to manage, but would evolve as an intergovernmental science organization providing advice. This would have some great benefits, as the organization could, arguably, focus on science. However, I suggest that as ICES developed its role in fisheries management – an aspect that was to dominate the second half of the century – the demands and complexity of the evolving fisheries-management system posed some difficulties in relation to the definition of stock management units.

Fisheries management (worldwide) evolved quickly over a few decades during the late 20th century into a substantial entity. The "modern fishery management experiment" was characterized by increasingly complex regulatory measures aimed at restricting ever more sophisticated and efficient fishing fleets with spiralling regulations (Stephenson and Lane, 1995). ICES evolved to take a leadership role in the development of methods and concepts for the evaluation of populations. Griffith (1999) described the "steady evolutionary trend" in stock assessment and forecasting, including what he termed the ICES "quantification era" during the 1960s and 1970s:

> …by the 1960s widespread quantification and forecasting of fish stocks had been made possible. This achievement was the product of a steady evolutionary trend, founded mainly on the work of Hjort, Heincke, Einar Lea and others…followed by E. S. Russell and Michael Graham in the 1930s, Ray Beverton and Sydney Holt in the 1940s and 1950s, and John Gulland and others in the 1960s. (The first exposition of the mainstay of fish stock assessment methodology, the Virtual Population Analysis, is tucked away as an annex, written by John Gulland, attached to the 1965 report of the North-East Arctic Fisheries Working Group.) These developments enabled ICES, during the 1960s, to set up the first fully analytical Fish Stock Assessment Working Groups.

ICES became very involved with an advisory process providing the basis for effort restrictions, technical measures, quotas, etc. in an increasingly elaborate management system. This is demonstrated, for example, in the rapid growth in assessment working groups and reports synthesized in reports of the ICES Liaison Committee (e.g., ICES, 1978) and early reports of the Advisory Committee on Fishery Management (ACFM) (e.g., ICES, 1979), compared with recent years (e.g., ICES, 2000). Over a 25-year period, the ICES advisory process evolved to provide annual assessments and advice for over 100 stock units, and ICES became recognized as a world leader in the evaluation of stock status and in the provision of scientific advice in support of fisheries management (Caddy, 1999).

While the assessment and advisory aspects were progressing in the latter half of the last century, development of the stock concept within ICES (and indeed elsewhere) did not progress much further. There was, of course, continued development of stock identification techniques (including genetics), a large number of applications of stock identification techniques and tagging to groups of fish, and a steady stream of papers describing attributes [e.g., Special Meeting on Herring "Races" in 1956 (Bückmann, 1958). However, there does not seem to have been a coordinated effort, major initiative, or major conference on stock structure, and certainly no conceptual development to rival that of the early period. Further elucidation of stock structure, and even some of the existing knowledge regarding stock structure, was, I suggest, pushed aside with the emphasis on attempts to assess and manage fisheries.

This change in approach came about quite logically and rationally. The management units were set up considering what was known about stock structure and mixing at the time (not bisecting major areas of concentration), but also considering practical aspects of the scale of statistical data from fisheries, political jurisdiction of management, and consistency among species. Although there were changes to management units in response to some obvious discoveries (from tagging, for example), as soon as management areas were established, there was a tendency to forget about the complexities of stock structure.

Stock assessments and advice were not strictly based on biological populations, but rather on practical stock units that were a compromise between biological structure, statistical availability, and management requirements. ICES was attempting to implement the assessment and management process on a number of units and in a suite of areas that did not match the criteria of biological populations developed earlier; in some cases, the underlying biological basis of biological populations that it had developed was ignored. There was a mismatch between biological scale and management scale in several stocks.

The problem of the mismatch between biological and management units is evident from the beginning of ICES. The first meeting of the "statistical section", chaired by Hoek (Hoek and Kyle, 1905), took place in July 1905. It was a meeting of "those interested in statistical matters" to discuss plans to compile and publish statistics, which were an important component of the basis both for ICES advice and for the development of management. The problem of the scale of assessment and management is apparent in opinions by D'Arcy Thompson "that such a method of dividing up the international area was not the most suitable for showing the distribution of fishes" (he much preferred a system of "squares..."), and by Henking who "thought that the method of subdividing the North Sea according to fishing-grounds was preferable on the whole, and doubted whether the contour lines of depths were sufficiently definite to form the basis of such a subdivision as proposed" (Hoek and Kyle, 1905).

The tension between the use of fishing grounds and statistical areas is one that has developed repeatedly in fisheries assessment and management (including the Gulf of Maine, T. Smith, pers. comm.). In the context of this paper, the interesting point is the relatively common occurrence of mismatch between stock structure and management structure.

As has also happened elsewhere in the world (Smedbol and Stephenson, 2001), ICES ended up trying to support an assessment and management structure in which the biological and management scales were not matched.

Current discrepancy between population and management unit definitions

A review of the 1999 ACFM advice (ICES, 2000) yields a substantial number of situations in which there is explicit reference in the advice to a mismatch between population structure and the management unit (approximately 50 out of about 150 stock units). A number of examples are summarized in Table 1. In many cases (e.g., most *Nephrops* stocks), the total allowable catch (TAC) has been recommended for a larger area than that of the biological stock. There are situations where, for practical reasons, separate, but similar, species are managed under the same TAC (including anglerfishes, megrims, horse mackerels), and even one case (anglerfish in Divisions VIIIc and IXa) where two species are included in the same assessment. Of more concern, in the context of this paper, however, are situations in which there are obvious problems in the biological stock unit definition. In some cases, there is clear uncertainty about stock structure. A good example is redfish in Subareas V, VI, XII, and XIV (ICES, 2000):

> There are indications that *S. marinus* includes a genetically distinct component 'giant' *S. marinus* with a different depth distribution...The stock structure of *S. mentella* is complex and uncertain, but there are indications that there may be at least 'oceanic', 'pelagic deep-sea' and 'deep-sea' stocks or stock components. ...Thus the redfish fisheries...operate on several stocks.

Research continues to clarify the genetic relationships among the various forms, but regardless of future advances in that area, the morphological similarities among species and forms, and the continuous distributions among them will continue to present difficulties for assessment and management of these resources.

Of equal or greater concern, I suggest, are cases where the advice alludes to subunits within a stock that are treated in the assessment as a single unit. This is evident from statements in the advice for blue whiting, mackerel, haddock (Divisions VIIb-k), sand eel, and very clearly in most herring assessments (ICES, 2000):

> This stock complex also includes Downs herring... which has shown independent trends in exploitation rate and recruitment but cannot be assessed separately.
>
> The assessment is uncertain due to the complexity of the stock structure in the area, ...

In at least one case, there is evidence of erosion of stock structure (ICES, 2000):

> There were two spawning components of herring in the Irish Sea (Manx and Mourne). At present these are treated as one stock for assessment and management purposes. The Mourne component is no longer a significant part of the stock.

The compilation in Table 1 focuses on the problems of stock structure. There have been, of course, significant attempts to resolve complexities of stock structure and the mismatch between stock structure and management units. In the case of the interaction between Iceland and Greenland cod, for example (ICES, 2000):

> In years of high recruitment a larval drift to Greenland is often observed...and in some years an immigration of adult cod from Greenland has taken place, which have been taken into account in the assessment.

There is an ongoing evaluation and redefinition of stock boundaries as evidence becomes available [e.g., the combination of units of saithe in Subareas IV and VI and Division IIIa. (ICES, 2000)], but there remains evidence of stock complexity that is not recognized and not safeguarded.

Stock structure is an increasingly important strategic issue for ICES

Stock structure was, from the beginning, and remains, an issue for ICES. This is evident, for example, in the following two statements concerning herring stock structure made in ICES reports almost a century apart. Brandt *et al.* (1901), in Supplement 4 to the Kristiania program, wrote:

> There are two special points to be considered. For the first, the majority of the herring fleets are coastal fisheries, and secondly, that the herring as a species, as scientifically undoubted, is falling into scientifically distinguishable local forms or subforms...Further investigation of the natural history of herring must take account of and be based on the important fact of

Table 1. Examples of the mismatch between population structure and management unit definition in the 1999 Report of the ICES Advisory Committee on Fishery Management (ACFM), Parts 1 and 2 (ICES, 2000).

Species/Stock	Page	Text in ACFM Report
Nephrops	1:8–10	"Functional units" are different than management units. "TACs are set for areas areas which are often larger than the management areas considered appropriate."
Norwegian Coastal cod	1:24	"Norwegian Coastal cod is managed as part of the Norwegian North-East Arctic cod fishery. An expected yield of 40 000 t from the Norwegian Coastal cod has been added annually since the mid-seventies to the Norwegian quota for North-East Arctic cod."
Greenland cod (ICES Subarea XIV and NAFO Subarea 1)	1:92	Recognition of several stocks, only some of which are regulated: "In Greenland waters there are inshore fjord stocks and offshore stocks." "The offshore component is since 1990 severely depleted without any signs of recovery.... Recruitment to the inshore component has been poor ...the inshore stock is still declining." "Only the offshore catches...are subject to a TAC... The inshore fishery is unregulated."
Redfish in Subareas V, VI, XII and XIV	1:123-124	"There are indications that *S. marinus* includes a generically distinct component 'giant' *S. marinus* with a different depth distribution. ...The stock structure of *S. mentella* is complex and uncertain, but there are indications that there may be at least 'oceanic', 'pelagic deep-sea' and 'deep-sea' stocks or stock components.... Thus the redfish fisheries ...operate on several stocks." "Research continues to clarify the genetic relationships among the various forms, but regardless of future advances in that area, the morphological similarities among species and forms, and the continuous distributions among them will continue to present difficulties for assessment and management of these resources."
Pelagic *Sebastes mentella* in the Irminger Sea	1:137	"There are indications that the pelagic deep-sea and oceanic *S. mentella* types in the Irminger Sea represent separate genetic stocks. Management measures to ensure that the individual stock components will not be overexploited in the pelagic fishery in the Irminger Sea are required. Recommended TAC can possibly be split between the stock components."
Faroe Bank cod (Subdivision Vb_2)	1:166	"Since 1996 the vessels are allowed to fish both on the Plateau and on Faroe Bank during the same trip, making it difficult to assign landings to area...to protect the productive capacity of each individual unit, then it is necessary to monitor and regulate the catch removed from each stock."
Whiting in Division IIIa (Skagerrak-Kattegat)	1:194	"It is likely that this stock is linked to the North Sea stock..." "Recent TACs are not restrictive. Given the probable linkage to the North Sea stock, which is currently low, this is of concern."
Herring in Subdivisions 22–24 and Division IIIa (spring-spawners)	1:213	"...the TAC for herring applies to several herring stocks..." "The TAC comprises both the autumn- and spring-spawning stocks in the area. The spring spawners are also fished in the Baltic, under the overall IBSFC herring TAC..." "A considerable part of the landings of juvenile herring in Division IIIa originates from the North Sea stock."
Saithe in Subarea IV (North Sea), Division IIIa (Skagerrak), and Subarea VI (West of Scotland and Rockall)	1:257	"These saithe were previously assessed as two separate stocks. This is the first combined assessment..."
Herring in Subarea IV, Division VIId, and Division IIIa (autumn spawners)	1:282	"This stock complex also includes Downs herring...which has shown independent trends in exploitation rate and recruitment but cannot be assessed separately."
North Sea horse mackerel (*Trachurus trachurus*) [Division IIIa (eastern part), Divisions IVb,c, VIId]	1:297	"This stock migrates out of the North Sea to areas where it mixes with the Western horse mackerel. The present agreed TAC area...does not correspond to the distribution area of the stock."

Sandeel in Subarea IV	1:307	"Sandeels are largely stationary after settlement and…must be considered as a complex of local populations." "Management of fisheries should try to prevent local depletion…"
Sandeel in the Shetland area	1:315	"The sandeel population at Shetland is not a unit stock, but forms part of a larger complex of sub-populations."
Nephrops in Division IVa, rectangles 44–48 E6-E7 + 4 4 E8 (Management Area F)	1:321	"It should be noted that this Management Area includes two FUs [Functional Units] and that a TAC set for the entire area will not necessarily result in balanced exploitation between the two FUs."
Stocks in the Eastern English Channel (Division VIId)	1:350	"Pelagic species …herring (Downs herring), horse mackerel, mackerel, and sprat… are subject to TACs set over larger areas. There are no separate estimates of the state of the stocks in this area."
Plaice in Division VIId (Eastern English Channel)	1:357	"The TAC is set for Divisions VIId and VIIe combined."
Megrim in Subarea VI (West of Scotland and Rockall)	1:390	"The megrim in Subarea VI consists of two species, *Lepidorhombus whiffiagonis and L. boscii."*
Anglerfish in Subarea IV (North Sea) and Subarea VI (West of Scotland and Rockall)	1:394	"Two species occur, *Lophius piscatorius* and *L. budegassa*, although catches are almost exclusively of the former."
Clyde herring (Division VIa)	1:404	"An assessment…is complicated by the mixture of a spring-spawning component and autumn-spawners from adjacent areas. Nothing is currently known about the proportions of these two components in the catches or in the stock."
Irish Sea herring (Division VIIa)	2:31	"There were two spawning components of herring in the Irish Sea (Manx and Mourne). At present these are treated as one stock for assessment and management purposes. The Mourne component is no longer a significant part of the stock."
Nephrops in Division VIIa, North of 53°N (Management Area J)	2:36	"There are two Functional Units in this Management Area." "…this Management Area is within a much larger TAC area…a single TAC set for the whole Subarea, will not necessarily result in balanced exploitation…"
Whiting in Divisions VIIe–k	2:52	"The assessment area was expanded in 1997 to cover Divisions VIIe-k. The TAC for whiting which is for all of Sub-area VII (excluding Division VIIa) includes this assessment and that for Division VIId."
Plaice in Division VIIe (Western English Channel)	2:71	"The TAC…is set for Divisions VIId,e combined, so the results from this assess ment need to be considered along with those for the much larger Division VIId stock. Given that the Division VIId component dominates the TAC, a catch control is unlikely to constrain fishing mortality on this stock." "This [tagging] suggests there is both a resident stock and one which migrates to the North Sea after spawning in the Channel."
Sole in Division VIIe (Western English Channel)	2:78	"Adult sole in the Western Channel may recruit from local nurseries and from those in the eastern Channel, but there is no evidence for subsequent emigration from the Western Channel. Coupled with the localised spawning areas in the western Channel, this suggests that adult sole there are largely isolated from those found in northern Biscay, the eastern Celtic Sea and the eastern Channel."
Celtic Sea and Division VIIj herring	2:91	"The fishery exploits a stock which is considered to consist of two spawning components (autumn and winter)." "There are serious potential threats to some of the more important spawning beds…"
Megrim (*L. whiffiagonis*) in Subarea VII and Divisions VIIa,b,d,e	2:99	The TAC includes two megrim species. "Taking into account a 5% contribution of *L. boscii* in the landings, the equivalent TAC for the two species combined would be …"
Stocks in Divisions VIIb,c,h–k (West of Ireland)	2:124	"These groups of fish may be only components of larger stock complexes. …it is still not clear if these stocks should be assessed with the stocks in the Celtic Sea or with the stocks off the West of Scotland."

Haddock in Divisions VIIb–k	2:127	"Catches of haddock are recorded along the entire western seaboard of the British Isles, with concentrations off the west coast of Scotland, off the NW coast of Ireland .... The extent of mixing between these areas is not presently known." "This stock is presently managed by means of a TAC set for the whole of areas VII, VIII, IX and X."
Herring in Divisions VIa (South) and VIIb,c	2:130	"The fishery now exploits a mixture of autumn- and winter/spring-spawning fish. The winter/spring component is distributed in the northern part of the area and does not appear to have suffered the serious decline of the autumn-spawning component." "Traditional fisheries in this area were based on the winter/spring component and the stock composition may now be reverting to its earlier form." "The most recent assessment...was carried out on both 'components' separately and on the overall catch data."
Nephrops in Divisions VIIb,c,j,k (Management Area L)	2:136	"It should be noted that this Management Area includes four FUs [Functional Units] and that a TAC set for the entire area will not necessarily result in balanced exploitation between the units. At present, this Management Area is within a much larger TAC area where the problem referred to will be even greater."
Megrim (*L. boscii* and *L. whiffiagonis*) in Divisions VIIIc and IXa	2:147	"The TAC covers both megrim species (*L. boscii* and *L. whiffiagonis*)..."
Anglerfish in Divisions VIIIc and IXa (*L. piscatorius* and *L. budegassa*)	2:157	The TAC is "for both species combined". "Given that [the] two species are not usually sorted in the landings... an assessment with both species combined was carried out."
Southern horse mackerel (*Trachurus trachurus*) (Divisions VIIIc and IXa)	2:161	The TAC includes several *Trachurus* species. "ICES recommends that the TAC for this stock should only apply to *Trachurus trachurus* and that other species of horse mackerel be excluded."
Sardine in Divisions VIIc and IXa	2:167	"It is not possible presently to distinguish whether the observed change in distribution is due to a migration...or due to local depletion of independent population units."
Anchovy in Division IXa	2:179	"The differences of the length distributions between Subdivision IXa South...and Subdivision IXa North suggest that the populations inhabiting these areas may have different biological characteristics. Furthermore, mean lengths at age are different between the Southern and Northern areas, which supports the suggestion that populations inhabiting these areas must have different dynamics."
Nephrops in Division IXa (Management Area Q)	2:186	"It should be noted that this Management Area includes five FUs [Functional Units], and that a TAC set for the entire area will not necessarily result in a sufficient reduction in fishing mortality in the two critical FUs..."
Sardine in Divisions VIIIc and IXa	2:192	"The basis for the current assumptions about stock identity was reviewed...the updated information...did not [provide] conclusive evidence to redefine the actual stock unit. Therefore it was decided to continue to assess the Iberian sardine as a single stock unit..."
Mackerel	2:202	"ICES currently uses the term **'North East Atlantic Mackerel'** to define the mackerel present in the area extending from ICES Division IX in the south to Division IIa in the north, including mackerel in the North Sea and Division IIIa. The spawning grounds of mackerel from this area are widely spread, and only the area in the North Sea is sufficiently discrete to be clearly identified as a separate spawning component. ... Since it is at present impossible to allocate catches to the stocks previously considered by ICES they are at present, for practical reasons, considered as one stock." "In order to be able to keep track of the development of the spawning biomasses in the different spawning areas, the North East Atlantic mackerel stock is divided into three area components..."
Western horse mackerel (*Trachurus trachurus*) (Divisions IIa, IVa, Vb, VIa, VIIa–c,e–k, VIIIa,b,d,e)	2:219	There is a discrepancy between the assessment and management units. "ICES also recommends that the TAC for this stock should apply to all areas in which Western horse mackerel are fished..."

Blue whiting combined stock (Subareas I-IX, XII and XIV)	2:229	"The blue whiting is widely distributed… It consists of several populations with genetic 'leakage' between them, but it is treated as one stock as it so far has not been possible to define an unambiguous border between populations."
Baltic herring	2:242	"Herring in the Baltic is assessed as five stocks. This is to be regarded as a compromise between using the larger number of stocks/populations that have been identified on biological grounds and the practical constraints such as in what units catch figures are available and possibilities for correctly allocating individual fish to particular stocks."
Herring in Subdivisions 22-24 and Division IIIa (spring-spawners)	2:250	"In the Baltic the TAC for herring applies to several herring stocks including the component of this stock in Sub-divisions 22-24… ICES reiterates its previous advice that the herring TAC for the Baltic should be split and individual TACs applied on the stocks…"
Herring in Subdivisions 25-29 (including Gulf of Riga) and 32	2:254	"The assessment is uncertain due to the complexity of the stock structure in the area, …"
Baltic salmon	2:311	"There are 40-50 rivers in the Baltic with significant wild salmon smolt production. Reared fish are released in many of these rivers, which makes it difficult to assess whether the salmon populations are self sustaining or not. Many rivers have been dammed and spawning and nursery areas have been completely or partially destroyed." "The overall management objective of IBSFC to increase the production of wild Baltic salmon is to attain at least 50% of the natural production capacity of each river…by 2010…"
Baltic Sea trout	2:329	"Currently approximately 250 rivers in the Baltic support wild populations of sea trout. There are no estimates of the original number of sea trout populations… Several of these populations are probably overexploited to the extent that they now mainly exist as non-migratory brown trout."
Baltic cod	2:345	"The Bornholm Basin, the Gdansk Deep and the Gotland Basin cod are the principal spawning areas of the eastern Baltic cod stock.…oxygen conditions in the eastern spawning areas are unfavourable for egg survival and development during stagnation periods. … The size and distribution of the spawning stock component…in the various areas has changed over time."
Atlantic salmon in the North Atlantic area	2:368	"There are over 1500 rivers supporting salmon in the NEAC area, but for most of these there is no information on the status of stocks."
	2:370	"ICES considers that river/stock-specific conservation limits and stock-specific exploitation rates are most appropriate…" There are "uncertainties about the most appropriate stock groupings…"

> the existence of the different local forms, it must take into acount the fact that the Heimatgebiete (home area…areas from which the fish stem and to where they will inevitably return) of these local forms have to be addressed separately…

Almost a century later, in response to a special request from Estonia to reconsider the stock components of an aggregated Baltic herring assessment, ICES stated (ICES, 1999) that the current assessment structure was:

> a compromise between using the larger number of stocks/populations that have been identified on biological grounds and the practical constraints such as in what units catch figures are available and possibilities for correctly allocating individual fish to particular stocks. While it is important to maintain all spawning components, the migration and mixing of stocks…makes it very difficult to separately assess the individual populations.

The mismatch between the scale of biological stock structure and the scale of management consideration in fisheries is not only true of the ICES Area, but is also a general phenomenon worldwide. Common stock assessment techniques and management strategies assume discrete populations – but this is often not the case. It has long been recognized that some management units contain stock complexes and that the boundaries of management areas are confounded by migration, mixing, and political and administrative considerations and do not always match biological population structure. The concern is that a fishing mortality rate that is considered appropriate for an entire area could be very inappropriate if applied to a subunit and could lead to progressive erosion of spawning groups within a complex (e.g., Frank and Brickman, 2000; Smedbol and Stephenson, 2001). The net result is an inability to ensure protection of the stock components for the overall management area even under moderate levels of exploitation.

There have been changes in the distribution of some species, including marked reduction in area and fragmentation of distribution (Smedbol and Stephenson, 2001). The ecological significance of such spatial changes is unclear. It is not known, for example, to what degree changes in distribution represent extirpation (local removal of a portion of a single population that would presumably be easily reversible) or more permanent and serious loss of a discrete subunit of the population (perhaps extinction).

There has been increasing interest in stock identification at scales smaller than have been considered previously. This has been so for a variety of reasons including the recent failures of current fisheries management, increasing interest in the broad topic of biodiversity, improved techniques to demonstrate differences between groups/populations, increasing focus on a complete suite of impacts of fishing, and a progressive movement to a more cautious approach to management (Stephenson, 1999).

I suggest that, in managing fisheries, there has been insufficient attention to biological stock structure. In many cases, management is not of single, simple populations, but rather of complex populations containing components which are susceptible to overfishing and erosion, even under management measures (such as TACs) thought to be appropriate to the overall management unit (Stephenson, 1999). In other words, there is additional structure and other attributes of populations that are distinct on temporal and spatial scales of relevance to management. There is a need for increased consideration of aspects of intraspecific diversity (Stephenson, 1999; Stephenson and Kenchington, 2000; Smedbol and Stephenson, 2001).

Not all species, of course, have such a rich stock structure, and there have been ongoing attempts to match biological and management scales. But it is a fact that there is a gradient of stock complexity and that several species exhibit a complex stock structure that is not being considered adequately in assessment and management. Failure to match the biological and management scales could lead to failures of assessment, or management, or both.

There is uncertainty in several species regarding the degree of discreteness of spawning components, the value of specific genes and genetic variations, the number of sub-populations necessary for ensuring stock viability in all conditions, and how fishing affects genetic resources. While there has been considerable discussion concerning the complexity of populations within the field of terrestrial ecology [e.g., development and debate of the concept of "metapopulations" and consideration of the appropriate scale of management (Hanski and Gilpin, 1997)], there has been insufficient discussion of this type in the marine fisheries literature. There has certainly been little discussion, until recently, of the need to have management measures to protect the diverse populations within the management areas. This is an area of potential development within the ICES research and assessment community. Stock structure and complexity are fundamental aspects of "biodiversity" and of a precautionary approach to management, which are listed as priorities in the recent ICES Strategic Plan (ICES, 2002). The notion that fish species form stocks remains an important and exciting strategic issue for ICES.

Conclusions

ICES contributed greatly during its early years to the notion that fish form stocks (populations). This was an issue when ICES was established, was an active element in the early ICES programs, and became one of the greatest scientific achievements of ICES. The issue of stock structure was largely neglected within ICES during the recent half century as the organization became preoccupied with the provision of advice to an increasingly demanding advisory/management system. There are at present some major problems surrounding attempts to manage fish, arising in part from the discrepancy between the biological stock/population and management unit definitions. Stock structure is an increasingly important strategic issue for ICES in the future owing to changing international standards and views on management.

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