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The role of ICES herring investigations in shaping fisheries science and management

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Herring fisheries have been important for centuries, especially to the nations bordering the eastern Atlantic Ocean and Baltic Sea. As a result of this economic importance, herring was an important consideration during the formation of ICES, and herring research was a dominant theme at ICES throughout most of the 20th century. This paper summarizes the evolution of the herring research initiative at ICES and emphasizes major advances in fisheries science and management that have been based largely on herring investigations associated with ICES. These include the development of the population/stock concept, age determination (including year-class strength and prediction), development of hydroacoustic methods, hypotheses on population structure and the regulation of abundance, and the link between fisheries dynamics and hydrography. This historical view indicates that the first century of ICES was characterized by strong science around practical questions of economic importance and involving international cooperation. ICES seems to have been able to attract outstanding scientific collaborators, strong scientific leadership, and scientific debate. Based on the herring case study, it is clear that scientific developments within ICES have been among the most influential in the world in fisheries science and fisheries management.

Keywords: fisheries management, fisheries research, fisheries science, herring, ICES, science history.

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Introduction

During the 20th century, the first century of the International Council for the Exploration of the Sea (ICES), there were profound developments in concepts and techniques of fisheries science and management. ICES was involved with much of this development, and it is of interest to reflect, as was done at the symposium reported in this volume, on the achievements – how they occurred, what has worked and what has not, and what lessons may prove useful for the future.

We have chosen, in this paper, to take a rather different approach to the historical analysis from those of most other papers in this volume by focusing on the impact of major developments and observations based primarily on studies of one species – herring. While it might be argued that this approach is narrow and defies the recent trend to holistic or integrated consideration, we suggest the approach has considerable merit given the prominence of herring fisheries and herring research throughout most of the period being investigated.

In a review presented at the opening of the Alaska Herring Symposium in February 2000, Stephenson (2001) claimed that work on herring and its fisheries (Atlantic, Baltic, and Pacific herring), more than that of any other fish, had shaped the development of fisheries biology and fisheries management. We hypothesize that the same may be said of herring research within ICES. Herring, because of its importance to the economies of ICES Member Countries, has been the subject of considerable study, such study has involved important personalities, and the results have been influential in the development of fisheries science and management. Further, we suggest that some reflection on historical herring research reminds us of some basic characteristics of fisheries research – including the persistence of several major themes and recurrent interest in ideas, some of which were generated more than a century ago.

Herring was an important consideration during the formation of ICES

The importance of herring to the economics and culture of coastal communities in Europe is well documented. The *Oxford Companion to Food* (Davidson, 1999) states that herring is "of all fish probably the one which has most influence on the economic and political history of Europe". Herring have supported important fisheries for centuries. The Helsinki herring market, for example, has taken place each October for over 200 years very near the site of the ICES History Symposium. Data series of some Swedish (Bohuslän) and Norwegian herring fisheries, for which records go back some 500 years (Csirke, 1988), are among the longest for any fisheries worldwide.

It was inevitable that the historical economic importance of herring led to a great deal of attention and interest. Prior to the 20th century, there was interest in explaining the variability in catches which had so much impact on social and economic affairs of some nations. Herring fisheries, which were prominent in the lives of coastal communities, had to cope with large variations in catches that were caused by large variations in abundance, and this fuelled concern, speculation, documentation, and eventually scientific study. Towards the end of the 19th century, the mechanization of fish capture led to the expansion of fisheries (both in size and distribution) and to the depletion of stocks. Interest in marine science had flourished in the 19th century, and scientists naturally became interested and involved in the study of practical fisheries problems. At the same time, governments became persuaded to support fisheries research and to support research among nations (Cushing, 1988; Smith, 1994; Stephenson, 2001).

An investigation of the records of the meetings surrounding the formation of ICES confirms this context and gives an indication of the particular relevance of three factors: 1) the need for international cooperation, 2) an interest in the study of practical problems, and 3) concern for commercially important species including herring.

The proposed work plans for the new organization, which was to become ICES, discussed at the meetings in Stockholm (June 1899) and Kristiania (May 1901), were influential in shaping the early work, structure, and function of ICES. Appendix 4 to the Kristiania meeting provided the rationale for the logical focus on herring (Brandt *et al.*, 1901, translated by C. Hammer):

> 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 and 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.* went on to discuss the fact that herring fisheries were coastal and that herring fall into "scientifically distinguishable local forms or sub-forms" and proposed that research should occur in many areas to determine:

1. Detailed description of the bodily properties of the herring sub-forms in the area,
2. Record of the spawning places of the local herring forms,
3. Study of the early life history, by fishing of the herring fry (larvae) from hatching until the fish have reached adult form,
4. Investigations of the growth and other biological characteristics of herring, and
5. Investigation of the migrations of the adult and fertile herring schools, with studies of the feeding and links with physical conditions.

Comments attributed to Johan Hjort at the inaugural meeting of ICES in Copenhagen (May 1902) recommended that the new organization should concentrate on a few practical problems of great practical interest – the most important of which were (Went, 1972):

1. The migrations of the herring and the cod and the influence of these migrations on the fisheries… and also the biology of these and other allied fishes, and
2. The question of overfishing.

This clearly influential suggestion resulted in the Council proposal of July 1902 (Herwig, 1902):

> to undertake at once the investigation of the two following problems which specially concern the countries interested in the fisheries of the North Sea, Skagerrak, Kattegat and the neighbouring seas:
> a) the migrations of the most important food-fishes of the North Sea, especially the herring and cod; and
> b) the question of overfishing…

Herring was prominent in ICES programs throughout the last century

An examination of the progression of major themes in the evolution of herring research generally (on Pacific, Baltic, and Atlantic herring) since 1875 (Stephenson, 2001) indicates that herring research seems to have been influenced by three general factors:

1) It has reflected, and contributed to, general developments in fisheries research and management (including, for example, migration patterns as the explanation of fluctuations in catch, existence of separate populations/stocks, concept of overfishing, stock assessment methodologies, and acoustic methods).
2) It has reflected issues and changes in the use and demand for herring (including practical aspects of management of herring fisheries and use of herring in animal/livestock/aquaculture feed).

3) It has responded to unique/local issues and perturbations.

Herring remained a prominent species of interest almost throughout the first century of ICES history. The degree and type of attention changed as topics of interest regarding herring evolved in the Atlantic, Baltic, and Pacific and as the ICES approach to science evolved (Griffith, 1999), but there is a reasonably complete lineage of progressive study of herring throughout the first century of ICES.

Herring became an explicit species of focus in the original ICES Committee A (Committee on Migration of Food Fishes) convened by Johan Hjort of Norway. The original terms of reference for the Committee, emerging from the Kristiania program proposal, specified study of herring and cod. The administrative report of the first year (Hoek, 1903) showed a quick start to the beginnings of a herring program:

> For the extremely important questions centred round the migrations of herring, the first things to be determined are how far the herring shoals vary their habitat at different periods of the year... Special experiments are to be made for this purpose on the 'boundaries of the herring fishery regions, and with the assistance of the statistics a picture should be constructed of the distribution of herring shoals within the region under observation'.

In spite of this early start, there was little attention to herring, it seems, in the first five years of the ICES scientific program. Committee B (Overfishing) quickly evolved to focus on flatfishes and trawl fisheries (Hoek, 1904) because of the value of the plaice fishery at the time and the suspicion that steam trawlers were a cause of overfishing. Committee C (Baltic) developed a plan to address salmon, trout, eels, sprats, cod, flounder, and effects of seals (Went, 1972). Even the reports of the earliest years of Committee A indicate an initial emphasis on cod, but the recognition for greater emphasis on herring. The administrative report for 1904–1905 (Hoek, 1905), for example, stated about Committee A:

> The Committee has continued its researches on the biology of cod and other gadoids... It was resolved at this meeting that these investigations should be continued until the spring of 1907, and then that they should also embrace, as far as possible, the natural history and race-differences etc. of the herring.

The Committee's recommendations accepted by the Council that year included (Herwig, 1905):

> Migrations of herring
>
> I. The Committee recommends, that greater attention should from now onwards be paid to the natural history of the herring and that regular investigations should be instituted in the various countries on this point.
>
> II. In each of the participating countries some fixed regions or stations should be chosen, at which regular observations should be made on the occurrence of the herring shoals, on the spawning places and periods of the herring, on the occurrence of the herring fry etc.; hydrographical investigations should be carried on simultaneously. At these stations also material should be collected for exact anatomical investigations.
>
> III. A portion of the material collected should be studied in accordance with the recent methods for the investigation of races.

Considerable herring research was being undertaken in Norway, where herring was an important fishery (Schwach, 2002). Hjort was personally interested and involved in sampling the Norwegian herring fishery and in research into various aspects of herring biology including age composition and larval distribution. It is obvious that Hjort provided considerable impetus to the work of Committee A, which continued to evolve with herring as a focus. In 1909, for example, Hjort "reported on herring and mackerel and gave an outline of the work done in Norway which had been devoted mainly to improvements in the methods and attempts to find some relation between hydrographical and biological phenomena. Eventually a sub-committee was appointed to deal with herrings and the sum of 3,000 kroner was eventually placed at the disposal of Hjort to enable the work to be carried out. A plan for collection of sets of herring scales was also drawn up" (Went, 1972).

Included in the appendices to the report that year is Hjort's "Proposal for organisation of the international investigations of the herring fisheries" (Hjort, 1909). Building on recent results, he was looking to resolve a number of issues:

> I and my assistants have endeavoured during the past year to improve the methods of age determination with a view to ensuring a more systematic and comprehensive investigation of the different kinds of herrings, and I have also at the same time considered a more definite plan for the investigation of the whole question of herring fisheries.

There was an emphasis on the two most prominent (and eventually most influential) questions of age determination and stock structure (Hjort, 1909):

> I stated in the above mentioned circular...while referring to the publications on the subject by Hjalmar Broch and Knut Dahl, that it could likewise be shown that the herring family was especially well adapted for age determination, and that moreover investigation of the scales rendered it possible to distinguish between the different races; the spring-spawning herrings in particular being distinguishable from those that spawned in the autumn. Generally speaking it was found 'that a combined determination of the following characters: age, length, development of the genital organs, as also (from the scales) whether the specimen had been spawned in the spring or in autumn together characterized different races in relation to one another in an excellent manner'.

But Hjort's plan for the work within ICES was even more comprehensive and had several objectives span-

ning distribution, abundance, growth, fisheries statistics, and the link with hydrography (Hjort, 1909). ICES reports of the few years following 1910 showed increasing accounts of results from the international herring investigations. The issue of the link between hydrographical conditions and fisheries was emphasized in a proposal by the Hydrographical Section for fine-scale observations by a vessel anchored in the North Sea in the summer of 1911 (Went, 1972):

> It was proposed to make three-hourly hydrographical observations, plankton investigations, including sampling at the same time as the herring fishery and in the water layers where herrings are found, and to undertake fishing operations with drift nets and long lines.

Hjort and Einar Lea seem to have been prolific in reports, papers, and presentations, as exemplified by the publication of "Fluctuations in the Great Fisheries of Northern Europe Viewed in the Light of Biological Research" (Hjort, 1914), with the first two chapters devoted to herring.

In 1913, the Council saw fit to establish a Herring Committee. The administrative report for that year (ICES, 1915) set out the rationale:

> The study of the herring, which is the most important of all the European food-fishes, has for two reasons been taken up by the international council. The first reason is, that the biology of this fish, with the questions of growth, migrations, races, variations in frequency of the young from year to year, etc. needs new and extensive treatment. The second reason is the appearance of the herring trawl in the North Sea fishing industry and the question regarding the influence of this trawl upon the herring stock itself and upon the young of several other important food fishes.

The Committee elected Hjort as Chair and, in 1914, developed an expanded program of international herring investigations. In addition to the issues identified by Committee A five years earlier, the Herring Committee proposed studies of catches by different gear, studies of early life history stages, and the investigation of the food of herring of all sizes.

There was a gap in the meetings of the Herring Committee from 1915 to 1919 due to World War I, but research continued in some areas. Committee meetings resumed in 1920, at which time Hjort (1920) presented results from his visit to Canada in 1914 during which he discovered that "in Canadian, as in European waters, herrings from different localities show marked differences in their rate of growth, and in the predominance of certain yearclasses, which persisted from year to year. Thus the Canadian herrings could be divided into so many 'kinds' or races, according to these characters."

At this meeting, Hjort also expressed regret at having to sever connection with the herring work as he was no longer Director of Fisheries Research in Norway and had no direct responsibility in this field (Went, 1972).

Lea became convener of the Herring Committee. The Committee appears to have been preoccupied during this period by the dispute (primarily) between Lea and Thompson over the validity of age determination using scales – a dispute that seems to have lasted until 1923 (Ruud, 1971). Went referred to this event as "one of the first serious rifts in the Council since its inception" (Went, 1972), but pointed out, "This event shows how useful the Council could be in providing a forum for discussion of important problems."

The report for 1925 referred to the lack of a herring report, presumably due to the illness of Lea, who had been appointed reporter for that species (Went, 1972). The same year marked the elimination of the Herring Committee in a reorganization that introduced area-based committees.

Annual reports indicated that herring work continued under the relevant area committees such as, North-eastern Area (Hjort, 1929a) and Southern North Sea (Mielck, 1930), but it is clear that international coordination and momentum were maintained by occasional meetings of herring "experts". Meetings were held, for example, in Lowestoft in 1930, 1932, and 1935. Went's (1972) account of the 1935 meeting is amusing:

> A meeting of herring experts was arranged for 16 and 17 October 1935 in the Fisheries Laboratory in Lowestoft when all the "big names" in herring research in Europe were present. Here I impose a personal note. As I was due shortly afterwards to enter Hjort's laboratory in Oslo it was suggested I should attend the Lowestoft meeting to get an introduction to fisheries research. And a good introduction it was for all these people were kindness itself to a beginner – to a young student. The report of this meeting (held under F. M. Davis' chairmanship) was a valuable one and so were the ten printed papers which accompanied it.

After World War II, the Council extended its area of operations to correspond to an increased membership, and reorganized the committee structure and programs (Pettersson, 1920). This led to a number of thematic meetings dealing with topics of special or common interest; some of these had considerable herring content. The 1928 special meeting on "Racial Investigations of Fish" (Maurice, 1928) contained several herring papers including Lea's "The herring's scale as a certificate of origin". Eight of the 20 papers in the 1929 meeting on "Fluctuations in the Abundance of the Various Year-Classes of Food Fishes" (Hjort, 1929b) dealt with herring.

World War II resulted in a serious disruption of ICES activities at a time when the problem of overfishing was becoming more apparent. Herring issues were important enough that the first post-war special meeting of the Council was a special meeting of herring experts, held at Charlottenlund in October 1945 (Went, 1972). This was followed quickly by another meeting of herring experts (Aberdeen) in June 1946 and a special meeting on "herring problems" in Stockholm in August 1946. These meetings led to a standardization of measure-

ments for sampling, a recommendation for investigation of racial characters through rearing experiments, reiteration of the need for hydrographical investigations on spawning grounds, and the publication of monthly charts of distribution of herring ("Hodgson's Atlas of Herring").

Interestingly, herring issues were not prominent in the Overfishing Conference held in London in 1946 or in the special meeting on "The Effect of the War on the Stocks of Commercial Fishes" held in 1947.

A major meeting of herring experts (chaired by R. S. Clark) took place prior to the Annual Meeting in Edinburgh in 1949. Went (1972) offered the opinion that "this was an important meeting because it was time that scientists concerned with herring research should have taken stock of their position". It was at this meeting that Hardy (1950) proposed again that herring should be the subject of the key program at ICES, providing as logic:

> my belief that it is through herring investigations that marine science can…make its greatest contribution to the needs of the fisheries and at the same time make the most rapid progress in the development of fundamental oceanographical knowledge.

Hardy's proposal was based on the belief that fisheries science required a multidisciplinary approach, and that a focused initiative on herring had the greatest potential for advancing marine ecology (Hardy, 1950):

> Herring research is so many-sided, it embraces aspects of meteorology, physical and chemical hydrology, and plankton studies of all kinds in addition to the biology of the fish itself. It is because this field of work is so wide that I believe, with the driving urge to benefit the herring fisheries, more progress can be made in future oceanography, centered around this uniting and exciting theme, than can be made by any other means of attack…The herring being directly dependent upon the plankton, and the plankton upon its physical and chemical environment, we have here a chain of cause and effect which can be investigated link by link until the whole is complete…. I want to plead for a program of intensive herring research – including particularly plankton and hydrological research in relation to the herring fisheries – not simply for its economic end… but because I believe it can best produce the ecological structure round which all the rest of the ecology of our waters may eventually crystalize and fall into place.

In the published preface, Fridriksson (1950) pointed to the development of a coordinated herring initiative within ICES, stating: "since the end of World War II, a great amount of effort has been devoted to herring research, and several special meetings have been held. The trend has been to conform to a more or less common plan in order to attack the major problems in the biology of this fish."

An outcome of this meeting was the formation, again, of a Herring Committee (actually the special Herring Sub-Committee of the Atlantic Committee), with Fridriksson as the first Chair. So, as ICES passed the halfway mark of its first century, it had again established a Herring Committee which was to continue as a specific "herring" initiative for 16 years and as a strong element of the later Pelagic Fish Committee until the end of the century.

It is clear from the records of the Consultative Committee of 1949 and the first meeting of the Herring Committee in 1950 that the Herring Sub-Committee was to have a broad mandate, including promoting tagging experiments, compilation of information on herring distribution and stock changes from each country, preparation of a manual (handbook) of activities, and even promotion of closer contact between biologists and hydrographers.

The late 1940s and early 1950s witnessed the emergence of widespread interest in hydroacoustics. In 1950, the Herring Sub-Committee approved a request by the Consultative Committee that the "Chairman of the Herring Committee should collect the requirements for echo sounders and ASDIC for the location of fish shoals into a document to be made available to manufacturers, who would then be supplied with copies of requirements and invited to supply further information". This report was prepared by W. C. Hodgson in 1954. During the same period, there was further development of the link between herring and hydrography. A 1951 Special Scientific Meeting on Fisheries Hydrography (Chair: C. E. Lucas) included papers on migrations of Atlanto-Scandian and Scottish herring in relation to hydrography.

A Special Scientific Meeting on Herring Tagging Techniques and Results, chaired by W. C. Hodgson and held in Paris in 1954 (Hodgson, 1954), concluded that there was a practical need to consider herring fisheries in terms of larger geographical groups rather than small units. Results of tagging to that point indicated that groups of herring that had been referred to individually on the basis of long-recognized areas of aggregation and spawning (e.g., Dogger Bank, Sandettie, East Anglian) were connected at times with fish from other areas (Fladen Ground, Skagerrak, and northeast of Scotland) in various fisheries of the North Sea for which there was growing management concern.

In 1956, there were two relevant special meetings, one a Special Scientific Meeting on "Herring of the Southern North Sea" owing to concern about declining stock status (Chair: O. Aasen), and the other a "Special Scientific Meeting on Herring 'Races'" (Chair: A. Bückmann).

In 1961, ICES convened a Herring Symposium to appraise the knowledge of population dynamics of Atlantic herring, examine the current state of the fisheries and exploited stocks, and look at short- and longer-term changes in stock size and composition in three broad ICES areas: near-northern seas, distant-northern seas, and Baltic (Parrish, 1963). Among the broad range of topics addressed was continued emphasis on the need to standardize methods, the need to computerize data, and

a call for attention to problems of recruitment in the North Sea and Atlanto-Scandian herring fisheries.

One recommendation of the 1961 Symposium was for an international study of biological and ecological questions in relation to a small, self-contained herring population (Parrish, 1963). This became the Working Group on the International Herring Research Scheme. Members of the Working Group attempted to establish intensive studies of herring in an enclosed fjord, but interest was limited to only several nations, and the Working Group ceased after about seven years.

The ICES herring work of the 1960s, chaired by B. B. Parrish, G. Hempel, and J. J. Zijlstra, appears to have been characterized by the need to handle increasing amounts of information related to fisheries for which there was increasing fishing and mounting concern. Many of the data necessary for biological and fishery assessments were missing from data submissions by various nations, which compromised comprehensive stock assessment. There were annual calls for the need to standardize and coordinate data collection, for international cooperation and pooling of data, and concern for the state of major fisheries including the North Sea and Atlanto-Scandian stocks. A standardized method for assessing herring length, maturity, and age was proposed in 1962. There were regular discussions of the type and amount of hydrographic information that might be useful in explaining fluctuations in abundance and distribution. From 1967 onward, there was no longer a specific Herring Committee, but herring issues remained prominent in the broader Pelagic Fish Committee.

A 1968 ICES Symposium on "The Biology of Early Stages and Recruitment Mechanisms in Herring" addressed the causes of population fluctuations and the diminished sizes of some populations (Saville, 1971).

The 1970s (Pelagic Fish Committee Chairs: K. Popp Madsen, A. Saville, and J. Jakobsson) were marked by the collapse of the major ICES herring fisheries. Responses by ICES included a major increase in stock assessments and fishery evaluation (exemplified by developments within the ICES Liaison Committee) and a major symposium ("The Assessment and Management of Pelagic Fish Stocks") held in Aberdeen in 1978 (Saville, 1980). Sætersdal (1980) reviewed the chronology of management of the ICES herring fisheries to demonstrate the rapid evolution of the biological advice for management at the time:

> Historically, the collapse of the Atlanto-Scandian herring stock was the first serious one in the Northeast Atlantic…This dramatic event seems, however, to have attracted surprisingly little attention from the scientific community at the time [the late 1960s] …Only in 1971 was the situation considered very serious, and not until 1975 was a complete ban recommended… The stock events were partly recorded by the scientists (probably more fully by the fishermen), but their significance was not realized.

This decade saw the rapid development of assessment working groups and of the advisory structure that had been started in the late 1960s. Research efforts encouraged by ICES were directed largely at improving the basis for stock assessment, including standardized approaches to surveys (especially larval herring surveys), which were being used as indices of abundance, improved biological sampling, and standardized treatment of fishery data.

During the 1980s and 1990s, the majority of herring work was undertaken in relation to major stock assessments and was contributed through relevant assessment working groups. Herring assessments were being undertaken by several working groups, notably the Herring Assessment Working Group for the Area South of 62°N (which included the North Sea herring assessment). Reports of "scientific" studies were contributed to annual meetings of the relevant science committee (especially the Pelagic Fish Committee).

Important contributions of ICES herring studies to the development of fisheries, fisheries science, and fisheries management

Stephenson (2001) has proposed that herring research (Atlantic, Pacific, and Baltic) has contributed substantially to a number of major developments in fisheries science and management. Developments include the polar migration theory, development of population thinking, age determination (year-class strength and prediction), hydroacoustic estimation of fish abundance, hypotheses on population structure (and regulation of abundance), fisheries/environment interactions, and advances in fisheries management. ICES studies have been key to most of these.

Population thinking

Just prior to the formation of ICES, Friedrich Heincke published a series of papers on herring (Heincke, 1878, 1882, 1898) that effectively undermined the prevailing polar migration theory. The early meetings of ICES offered a forum for further development of population thinking, resulting in a shift from the species to the population as the appropriate unit of study. The work of Hjort (synthesized in his 1914 paper) generalized the findings of Heincke on herring to other commercially important species and clearly identified the significance of "population thinking" to fisheries management. Sinclair and Solemdal (1988), Sinclair (1988, 1997), and Sinclair and Smith (2002) chronicle this development and its importance to fisheries biology generally. During this period, research on the interannual variability in abundance and on intraspecific variability in body

form led to a major conceptual shift – from consideration of species as types (later known as the essentialist species concept) to consideration of the species made up of groups of populations (component populations). This development, based largely on herring, represents a major scientific advance involving ICES.

Age determination, year-class strength, and prediction

Studies of age structure in herring populations in the early 1900s represent the second major ICES advancement in fisheries science based on herring. This development, featuring Johan Hjort and colleagues in Bergen, is summarized in the account of Smith (1988):

> In an evening lecture during the ICES meeting in 1907 the chairman of the Migration Committee, Hjort, suggested a new approach to determining the status of fish stocks (Hjort, 1908) that would eventually lead to understanding one reason catches vary. Hjort proposed adopting the approaches of the science of 'vital statistics', i.e. human demography. One of the key tools of vital statistics was the study of the age distribution of human populations, and that, Hjort asserted, was what should be done for fish.
>
> ....Although not completely proven, Hjort felt that for herring the rings in the scales were most likely to be useful, and suggested that an international project to collect and analyse these scales be undertaken. Only by an international effort would the committee obtain a comprehensive understanding of the vital statistics of that species.
>
> Hjort's suggestion was not universally supported by ICES, and it was not until 1909 that he succeeded in getting a small programme called 'special ichthyometric and biostatistics' approved.

Hjort and colleagues persisted and, over several years, assembled data on numbers of herring and cod at each age as reflected in scale rings. Hjort (1914) noted that the relative number of fish in successive ages varied for both species, suggesting that the size of fish populations may be determined at a very young age, and that there was an opportunity to predict the probable future course from year to year.

The 1920s saw examination of year-class strength in prominent fisheries including haddock (Thompson) and the East Anglian herring fishery (Hodgson). For the first few years, Hodgson failed to see the great year-to-year differences in year-class strength on which Hjort had based his conclusion, but with the recruitment of the very strong 1924 year class in 1927, Hodgson was able to "take the plunge" (Smith, 1994) into prediction of stock abundance in the fishery. In the words of Hodgson (1957):

> The year 1929 was an important one in the history of herring research, for it was then that the first attempt was made to forecast a fishery. The experience of seven years of sampling the 'East Anglian fishery made it appear quite certain that once a rich year-class came into the fishery it remained in the shoals until it was completely fished out at the age of eleven, so...[we] decided to...tell the Trade what they might expect from the fishery that was about to start in a few weeks time'.

These studies contributed greatly to the understanding of why catches vary, and formed the basis for the age-structured analyses which are prevalent today. This represented one of the most significant advancements in fisheries biology, and one that took place within ICES.

Hydroacoustic estimation of fish abundance

Herring, a schooling, pelagic species, was the logical candidate for detection using hydroacoustic techniques that had been developed primarily for military purposes. Interest in hydroacoustics was first to find fish, but then in quantitative estimation of abundance and surveys. From an historical standpoint, the most important early work with the echosounder was that carried out by Skipper Ronald Balls when fishing for herring in the North Sea during the 1930s (Thomasson, 1981). Balls, a drifter skipper, undertook pioneering work using a Marconi 424 echosounder during fishing operations on his own vessel "Violet and Rose". He kept detailed records of his observations which he published, among other places, in the ICES *Journal du Conseil* (e.g., Balls, 1948). Balls reported that the echometer worked with "steadily increasing efficiency" for locating herring in 400 nights on the summer fishing grounds, but not well in the East Anglian autumn fishery, suggesting "that some change in local conditions on the two fishing grounds is the cause".

There was a great deal of interest in and encouragement of hydroacoustics within ICES. The field developed greatly over the last half of the century, and acoustic surveys are now used as the basis for several major stock assessments. ICES has continued to be a prime forum for the development of acoustic survey methodology (see Fernandes *et al.*, 2002) and for progress in the use of hydroacoustics in stock assessments.

Hypotheses on population structure and regulation of abundance

In fisheries, the factors contributing to population structure, recruitment variability, and regulation of abundance have been (and still are) a popular topic of research. Herring studies involving scientists active in ICES have contributed to the notions of a critical period (Hjort, 1914) and to the further development and elaboration of this in Cushing's "match/mismatch" hypothesis (Cushing, 1975). The major recent advancement in this field is also linked explicitly to herring in the ICES

Area. In the "herring hypothesis" of Iles and Sinclair (1982), observations on herring distribution and abundance are linked to physical oceanographic conditions, as follows:

> The number of herring stocks and the geographic location of their respective spawning sites are determined by the number, location and extent of geographically stable larval retention areas.

Sinclair (1988) extended and generalized the herring hypothesis in his "member/vagrant" hypothesis in an attempt to account for a wide range of sexually reproducing populations.

Research on herring in the ICES Area continues to contribute to the issue of the structure of fish populations, for example, the discussion about the exact nature of herring populations and the relevance of the scale of the population to intraspecific biodiversity and to management (McQuinn, 1997; Stephenson, 1999; Stephenson and Kenchington, 2000).

Linking fisheries dynamics and hydrography

Hydrography has had a "central role" in ICES throughout its first century (Griffith, 1999), and there has long been an interest in linking hydrographical conditions to various aspects of fish distribution, recruitment, and fisheries dynamics. Hjort (1909), for example, expressed the hope that:

> Hydrographical investigations should render it possible, at any rate after continued operations lasting over a series of years, to ascertain the influence exerted by ocean currents upon the fluctuations that occur in the quantities of herrings in the different fisheries.

While this has not been fully realized, there has been progress through ICES herring work in at least two aspects that have helped advance fisheries science generally.

Fluctuations, including collapse, of the major herring fisheries assessed by ICES have emphasized the interaction of fishery and environment in determining abundance. Diagnoses of the major herring stock collapses have pointed not only to the obvious impact of high rates of fishing mortality, but to periods of poor recruitment undoubtedly linked to oceanographic conditions (Stephenson, 1997). While the mechanisms of linkage remain elusive, ICES has provided a forum, particularly in recent years, for synthesis and debate concerning fish/environment interactions. The herring stocks in the ICES Area provide some of the most extensive time-series and data sets for exploration of these links. The recent synthesis of historical data on Norwegian spring-spawning herring (Toresen and Østvedt, 2000), for example, demonstrates a clear relationship between water temperature and the fluctuations of herring abundance prior to the period of extensive fishing.

Herring work within the ICES community has also contributed to a major advancement in the modelling of the interaction of larval fish and hydrography. Katherine Richardson (pers. comm.) has suggested that this was prompted in large part by development of oceanographic interest in "mesoscale" processes including shelf-sea fronts in the mid-1970s (e.g., Simpson and Hunter, 1974) and the herring "retention" hypothesis of Iles and Sinclair (1982). Dispersion and dynamics of herring larvae in relation to hydrography became the topic of a number of innovative studies (summarized by Heath, 1992), including the first published three-dimensional hydrodynamic model of the advection of fish larvae (Bartsch *et al.*, 1989).

Advances in fishery management

The historical importance of herring fisheries, combined with the rather extensive research effort on herring, has meant that herring fisheries (Atlantic and Pacific) have been the subject of some of the earliest management restrictions, and have been featured in the development of modern fisheries management (Stephenson, 2001). The collapse of major herring fisheries in the ICES Area in the 1970s was "undoubtedly the most striking phenomenon in the history of European fisheries" (Jakobsson, 1985) and contributed to the rapid evolution of fisheries management. ICES provided the forum for development of the biological basis for management and has been at the forefront of advances in fisheries assessment and management worldwide. Herring fisheries (Icelandic herring, Norwegian spring-spawning herring, North Sea herring) were among the earliest experiences in rebuilding strategies, (Sætersdal, 1980; Jakobsson, 1985), and have continued to be key case studies in the development of assessment methods and management approaches (well documented in the record of the ICES Advisory Committee on Fishery Management; e.g., ICES, 2001).

Observations, lessons, conclusions, and expectations for the future

Issues concerning herring were prominent in the development of the scientific program of ICES when it was established a century ago, and ICES has had a nearly continuous line of herring investigations for a century. A number of the significant "evolutionary markers" in the development of ICES over the century (Griffith, 1999) were advancements based on herring research.

During the 20th century, herring studies were key in early coordinated international programs. There were a number of significant symposia devoted to herring, and herring studies formed the basis for several major developments in fisheries, fisheries science, and management worldwide. With the exception of the Polar Migration Theory put forward by Johann Anderson, which predates ICES, all of the major herring developments were

made through, or in conjunction with, ICES herring projects.

From our review of the herring studies within ICES over the past century we offer the following general observations:

- Research has often been driven by an almost continuous sense of urgency to solve practical problems.
- There has usually been the need to prioritize and to select the most relevant of several important practical research questions.
- Herring has been a prominent species of research throughout the history of ICES research.
- The major questions of interest within ICES have, since the beginning, been multidisciplinary in nature.
- ICES has attracted the constant attention of outstanding scientists. It has been a forum for relevant research and a place to synthesize scientific thinking.
- ICES has promoted international collaboration and international scientific debate in spite, at times, of severe political differences.
- ICES has managed to facilitate a sustained program of scientific effort for a century in spite of an unstable landscape including wars, political changes, and changes in society and science.
- Based on the herring case study, it is clear that scientific developments within ICES have been among the most influential in the world in fisheries science and fisheries management.

The positive attributes of scientific investigation within ICES during its first century would seem to have been:

- strong science, around practical questions of economic importance, involving international cooperation; and
- outstanding scientific collaborators, strong scientific leadership, and scientific debate.

It is interesting to note that several topics were investigated for most, if not all, of the first century of ICES. It is somewhat sobering to note that a number of research questions posed a century ago when ICES was established remain unresolved today. While there has been great progress, the elements of Hjort's 1909 workplan (distribution, abundance, and growth of various races of herring; statistical documentation of fishery fluctuations; and link with hydrography) would be a reasonable starting point for a research plan even today. The issue of stock structure (among others), which seemed important at the inception of ICES and was the subject of intensive study at various times, remains an important strategic issue for ICES to this day (Stephenson, 2002).

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