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From fisheries research to fisheries science, 1900–1940. The Bergen and the ICES scenes: tracing the footsteps of Johan Hjort[1]

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The period 1900–1914 has been termed the golden age of Norwegian fishery investigations. The advances made in those years can largely be ascribed to the work of Johan Hjort, who was the leader of the Directorate of Fisheries in Norway and an active participant in the affairs of ICES from the beginning. The research programmes carried out by Hjort and his collaborators were directed at all stages of fishes and their environment. Surveys covering wide ocean areas provided information on hydrography and plankton as well as on the distribution of eggs, larvae, and juvenile and adult fish, and sampling schemes of commercial catches produced knowledge on the size and age distribution of the catches and stocks. In ICES, Hjort argued strongly for age sampling of commercial catches on the largest possible scale so that stock age compositions instead of commercial size classes could be established for the purpose of predicting fishable biomass. He also indicated that such data could be used in a way similar to that applied for human populations. D'Arcy W. Thompson, who used commercial size classes in his analyses, opposed Hjort's views for a long time, declaring that the method of age determination was not proven and that the number of rings in herring scales was subject to individual variations. This was probably the first serious rift in ICES since its inception and a reason why stock age structure studies did not become a routine tool in ICES before the 1930s. Hjort and his group in Bergen functioned as the leading fishery research institution in Europe until World War I and, with his stock age composition concept, Hjort was at the point of achieving deeper insights into the complexities of exploited fish stocks. In the 1930s, British scientists developed theories on the effects of fishing on the stocks partly based on Hjort's earlier findings and suggestions.

Keywords: history, ICES, Johan Hjort, research surveys, stock age compositions, theory of fishing.

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Introduction

A few years after the Norwegian Parliament had created a new government organization in 1900, the Directorate of Fisheries in Bergen, this institution developed into a centre for comprehensive programmes of investigations of the basis of fisheries, fish stocks, and their physical environment. The investigations were directed mainly at problems in the great Norwegian fisheries for Arctic cod and Norwegian spring-spawning herring, but were soon expanded to other stocks. The results proved to be of great general interest.

The period 1900–1914 has been termed the golden age of Norwegian fishery investigations (Rollefsen, 1962). To an unusual degree, the advances made in this golden age can be ascribed to the innovative ideas and dynamic personality of one scientist, Johan Hjort (Schwach, 2002). European fishery research at that time went through an important process of internationalization, and Hjort became a central figure in that process. His activities thus parallel the main events in the early development of both Norwegian and European fishery research, as well as those of the creation and early history of ICES.

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Hjort was the leader of the Directorate of Fisheries in Bergen from 1900 until 1916. He was a keen supporter of ICES and an active participant in its affairs throughout the whole period 1900–1940. The present paper is a brief description of his efforts and influence in fisheries science in Norway and ICES in three main fields:

1) the utilization of research surveys to describe the life history of fish stocks;
2) his struggle to establish an ICES database of stock age compositions, i.e., catch-at-age figures for stocks; and
3) his contribution to the understanding of the effects of fishing and the formulation of a theory of fishing.

Early objectives and programmes of the Bergen institution

Research surveys

In his proposition to the Home Office in 1899 for building a research steamer for Norwegian fishery research, Hjort's main argument was the need to extend fishery research beyond coastal waters (Hjort, 1899). There was hardly any information on the location of the large masses of cod and herring after they left the coast following spawning. There was a clear need for an expansion of the Norwegian fisheries, which were still mainly coastal, and the potential was indicated by the growth in the previous decade of the trawler fleets of Great Britain and Germany which had left the crowded North Sea grounds for better conditions at Iceland, Spitsbergen, and even Norwegian coastal waters. In broad terms, Hjort's objectives were to describe all aspects of the natural history of the cod and the herring, study their environment, and explore conditions for expansion of the fisheries to offshore and distant-water grounds (Hjort, 1909).

The choice of the type of vessel was unconventional and undoubtedly of great significance for the success of the programmes. Hjort recommended that the vessel be built "exactly like one of the modern fishing steamers . . ., and make use of all the fishing appliances of the present day in the service of science" (Hjort, 1909).

This simple principle of using a vessel which, in experiments, could simulate commercial fishing would greatly enhance the value of the observations obtained and is today recognized in the design of most modern fishery research vessels. At the time, it was, however, a new idea. In considering the work done with the RV "Michael Sars" in 1900–1908, Hjort (1909) stated:

> So far as I know she is the first built like one of these fishing steamers which has experimented with all modern methods of ocean research. Now there are several vessels like her, and it would seem to be recognized that they denote a great step forward.

Commissioned in July 1900 after only a year of planning and building, the "Michael Sars", at 226 GRT, was not a large vessel by modern standards, and was only about half the size of the present "Michael Sars", the smallest of the current fleet of the Institute of Marine Research. She was deployed in surveys covering the Skagerrak, northern North Sea, Norwegian Sea, and southwest Barents Sea. The work was intense, and cruises were made in all seasons of the year in spite of unfavourable weather conditions in the winter. The inaugural cruise to the Norwegian Sea, Iceland, Jan Mayen, and Bear Island was directed at the pelagic system over deep-sea areas, in excess of 400 m (Hjort, 1901). The coverage of the North Sea and Skagerrak in later years was part of the cooperative investigations organized by ICES Committee A.

A remarkable finding from the first survey was the wide distribution of drifting juvenile fish in the warm Atlantic water, and Hjort discussed the possibility of obtaining estimates of their abundance. Some 60 years would pass before this approach was employed in the important 0-group surveys started by Dragesund and collaborators off northern Norway (Benko *et al.*, 1970).

The "Michael Sars" surveys were in support of a general research programme with the following elements (Hjort, 1909):

1) *General ocean research* consisting of hydrography and plankton investigations.
2) *Investigations into the natural history of fishes* (the chief scientific task). For these objectives, the surveys were directed towards the various life stages of the fish: eggs and larvae to chart the spawning grounds, pelagic and bottom stages of the post-larval and juveniles, and adults. The systematic collection and analysis of these data would help to describe the distribution, migrations, and movements of the fish and thereby help identify the stocks as well as provide information on size and growth.
3) *Fishery experiments* to test the potential of offshore grounds for an expansion of the Norwegian fisheries.
   The tools and gear used were hydrographic instruments, Hensen nets for vertical plankton hauls, larger plankton nets (up to 7 m in diameter) for towed hauls at various depths for post-larval stages, a 120-ft bottom trawl, longlines, and drift nets.

The novelty in these survey programmes of the Bergen institution was their broad and ambitious approach. They were directed at all life stages of the fishes. The catches of the adults were comparable to commercial catches both in terms of rates and size composition. Relevant commercial data could thus be included in the analyses. The surveys also covered wide ocean areas which encompassed the distributions of nearly all stages of the fish stocks on the Norwegian shelf.

The results were reported with little delay by Hjort and co-authors. The first survey was reported in Hjort (1901), the first four years of work in Hjort (1905), and the period 1900–1908 in Hjort (1909). The final report of ICES Committee A (ICES, 1909a) described the results of the Bergen investigations together with those of the other cooperating countries. Finally, the survey results formed important parts of the database for the now classical "Fluctuations in the great fisheries of northern Europe" (Hjort, 1914).

This period of intensive investigations by the Bergen institution from 1900 until the outbreak of World War I resulted in great advances in knowledge of the seas around Norway and their resources. The main effort was directed towards the Arctic cod and the Norwegian spring-spawning herring. In 1914, the "Michael Sars" was requisitioned for safeguarding Norwegian neutrality. She was never again used for fisheries research, and the Bergen institution lost its most important tool for studying these two highly migratory stocks. Thus, Norway's cod and herring investigations did not continue the remarkable progress of the first "golden age". Not until the 1950s would the Institute of Marine Research in Bergen be able to resume the once successful investigations by means of far-ranging surveys.

Stock age compositions

In addition to describing the life histories of fish, Hjort and his collaborators made a fundamental contribution to fishery science through their utilization of representative age compositions of stocks as a tool to study stock fluctuations, stock identity, and vital stock processes.

Examples of the use of structures in scales, otoliths, and bones for age determination of both freshwater and marine fish were well known by the turn of the century. The first use of this method by the Bergen group was apparently made by Hjort's assistant Hjalmar Broch, who in 1904–1906 conducted a special study of European herring races mainly applying Heincke's method (Broch, 1908). He tested scales of herring from a few different localities and found distinct structures which he assumed to be caused by seasonal variations in growth. Dahl (1907) and Lea (1910) continued the studies of the herring scale, and Lea, over a period of 15–20 years, became deeply involved in its investigation, especially its use for age and growth estimations and as a certificate of origin (Ruud, 1971). Age determination by scales was soon used for other species, especially cod and haddock.

The first and most remarkable results of these investigations, which included a very large number of samples from the North Sea and Skagerrak up to the Barents Sea, were that the age groups for some species, e.g., haddock and herring, showed similar characteristic patterns in samples over very large areas (Hjort, 1907). It was thus possible to describe the fish stocks of certain areas by age "censuses". The dimensions of the year-class fluctuations showed them to be great phenomena of nature and unrelated to the fisheries. The prospects of being able to assign whole fish stocks to age-class systems reminded Hjort of human population studies, and he suggested, in a lecture at the 1907 ICES meeting, that fishery biologists might find it useful to think in such terms (Hjort, 1908).

Some of the data for the stock age composition studies were from the programme of ICES Committee A. This cooperative exercise ceased, however, in 1908, but the work by the Bergen group continued with material and data from Norwegian herring and Arctic cod. These observations gave Hjort and his group sets of age compositions for both of these stocks which, in a most convincing way, demonstrated the validity of the method and its practical application. The 1904 yearclass was unusually abundant in both stocks, an observation which was repeated year by year (Lea, 1929). This series not only confirmed that the age determination must have been correct in a very high proportion of the cases, but also that the system of sampling had given meaningful and repetitive results. Samples of age compositions from the juvenile fat herring and the adult winter herring also demonstrated meaningful passages of strong and weak year classes. An additional type of information on the herring stock was that its area of juvenile life could be identified from the evidence of slow or rapid growth laid down in the patterns of rings on the scales, making them certificates of origin.

In his "Fluctuations in the great fisheries of northern Europe", Hjort delivered a message saying: "By large scale stock age compositions one can identify stocks, classify them by age, measure their growth and make predictions of changes in their fishable biomass." He furthermore indicated that these types of data may be used in some form of vital statistics similar to those used for human population studies. This was a clear and strong communication, but its reception was disappointing.

Sinclair and Solemdal (1987) found that Hjort's introduction of age compositions by stocks was significant in the development of population thinking among European fishery scientists, most of whom had adopted that concept by 1920. This seems, however, to be a limited use of the tools offered by Hjort's findings. As seen below in trying to follow the development of fishery science within the ICES community, a considerable delay seems to have occurred between Hjort's presentations in 1908–1914 of what is termed his breakthrough in fishery biology and its acceptance and actual use by other European fishery scientists, especially the British. In 1929 and 1930, ICES called two special meetings on year-class fluctuations (ICES, 1930a, 1930b) where the subject was approached almost as if the concept were a new one. There was thus a delay of 15–20 years in the reaction of the community of fishery scientists, at least as represented by ICES, to Hjort's spectacular findings.

The introduction of stock age compositions in ICES

For the second ICES preparatory conference in Kristiania in 1901, Hjort contributed a document (ICES, 1901) in which two main problem areas were described: 1) the possible overfishing of local stocks, and 2) the causes of the periodic occurrence of migrating fish. His proposal for international investigations was a description of the survey programme already started by the Bergen institution, emphasizing the importance of scientific surveys stimulated by the results from the "Michael Sars" operations. At the inaugural meeting of ICES in 1902, Hjort was elected Chair of Committee A, which accepted the Bergen group's combined survey programme as a basis for its cooperative work.

As soon as the stock age composition breakthrough was made by the Bergen group in 1907, Hjort proposed to the members of the Committee that annual age censuses be made of the principal food fishes by region, including the North Sea (ICES, 1907). For the last meeting of the Committee in 1908, he had, in advance, circulated a proposal for a further work programme (ICES, 1909b). For gadoids, he recommended continuation of the present programme, including egg surveys, but if funding were scarce, attention should concentrate on age sampling of fish on the largest possible scale. For herring, he also recommended the systematic collection of material for age and growth studies, and pointed to the possibilities of studying the distribution of different populations by these methods.

The 1909 report of Committee A contained a wealth of new information on the Gadoids from the North Sea and other parts of the North Atlantic (ICES, 1909a). In the summary by Hjort, he discussed "some practical fisheries questions in the light of the results obtained". There was evidence of distinct year-class fluctuations in North Sea haddock, and Hjort again made a strong plea for future representative statistics to include length measurements and age determinations in the data collected. It had been proven that commercial size classes (used for analyses by statisticians) contained several age groups and that it was impossible to demonstrate any regularity whatsoever in the changes or fluctuations of these classes, while the study of age groups could lead to factual insights into the question of the relation of fisheries to the stock of fish. This was plain truth, but it must have sounded like very plain language in the ears of D'Arcy Thompson who used commercial size-class data in his contribution to the report.

Progress reports on the herring investigations begun in 1909 were submitted for discussion at the 1910 Council Meeting (Lea, 1910; Hjort, 1910). Lea's paper was a serious treatise on the scale method, but D'Arcy Thompson criticized the age and growth investigations on the grounds that the number of rings were subject to individual variations. When Hjort reported on further progress in the herring investigations at the 1912 Council Meeting (Hjort and Lea, 1911), Thompson again regarded age determination based on the number of scale rings as hypothetical. The full confrontation came at the 1913 Council Meeting (ICES, 1913). In response to lectures to the Council by Hjort and Lea, Thompson stated that he considered the method of age determination by scales to be unproven and that he could not agree with Hjort's views. Hjort then declared that no programme for herring research could be drawn up before this question was settled.

This dispute over herring scales lasted more than 10 years and, according to Went (1972), was probably the first serious rift in the Council since its inception, and Lea claimed that it set back herring research several years. It seems probable, however, that the effects were wider and longer lasting. As noted above, there was a remarkable lack of response to Hjort's repeated "messages" during 1907–1914 regarding the importance of stock age compositions.

The herring scale dispute was settled by a joint practical exercise in Kristiania in 1923, after which the British herring scientists adopted the scale method. Thompson's last year as British Delegate was 1925. A new generation of British fishery scientists took an interest in stock age compositions and population theories as a positive step in the advancement of fishery science.

Towards understanding the effects of fishing

As mentioned above, the 1929 ICES special meeting on "Fluctuations in the Abundance of the Various Year-classes of Food Fishes" (ICES, 1930a) must be seen as the first reaction by European fishery scientists to Hjort's messages of 20 years earlier. In an introductory address to the meeting, Hjort welcomed the great interest shown by the submission of 19 papers and noted the great advances made from the position of 30 years earlier when scientists worked at the species level. He foresaw that systematic international observations of year-class fluctuations would shed new light on many questions regarding fish production. One innovative contribution which demonstrated one of the most important future uses of age determination was Lea's "mortality in the tribe of Norwegian herring". The emphatic statement from one of Hjort's old disciples, Oscar Sund, that age determination in the Arctic cod was "utterly unreliable except for the earlier age groups" created some confusion. It is unclear why Sund stubbornly kept to the scales after 25 years studying this stock and did not try otoliths which had proven so useful in other species. In an analysis of fluctuations in the trawl fishery for North Sea cod, Thompson seemed unsure whether they were caused by year-class fluctuations, while Harold Thompson was certain that the very large variations in the abundance of North Sea haddock were caused by fluctuations in the original brood strengths.

A follow-up meeting on the same subject was called in 1930 to discuss the reports prepared by special council nominees to the 1929 meeting, indicating the main results brought out by papers read at that meeting (ICES, 1930b). In a preface, E. S. Russell pointed out the main problems to be addressed: the validity of the method, organization of regular cooperative studies of the fluctuations, and investigations of the causes of the fluctuations. In his notes for the meeting, Michael Graham, as the reporter for cod, maintained doubts about the age determination of older fish, referring to work by Sund and others. He saw the importance of early observations of brood strength for forecasting stock fluctuations, and recommended the continued assessment of the smallest marketable size groups and observations of pelagic fry – an early recommendation for 0-group surveys. As the reporter for herring, Lea stressed that further racial studies were needed as a basis for reliable stock fluctuation estimates. He called for the standardization of methods and foresaw special problems in obtaining representative sampling from seasonal fisheries. On the causes of fluctuations, he referred to Hjort's hypothesis.

The two meetings served once again to draw attention to the phenomenon of year-class fluctuations and drew out some new data, but did not, apart from Lea's mortality estimates, reveal any advances in methods or new thinking. Apparently little had happened in this field for about 20 years, although Norway continued studies in support of the original work of the Bergen group, with several herring papers by Lea in the 1920s. Especially elegant was the paper "The herring scale as a certificate of origin" (Lea, 1929) which demonstrated his idea of the scale as the identity card of the herring. There is no doubt that Lea emerged as the most distinguished scientist of the Bergen group after Hjort.

A few years after the ICES special meetings on year-class fluctuations, another important contribution to the subject came from Norway, namely Rollefsen's paper "The otoliths of the cod", where he showed that the problem of estimating the age composition of the stock of *skrei* could be solved and that estimates could be made of the spawning class composition of the stock (Rollefsen, 1933). This was a great methodical advance which must have comforted Hjort and perhaps even ended Michael Graham's lingering doubts.

In 1932, ICES called a special meeting on "The Effect upon the Stock of Fish of the Capture of Undersized Fish" (ICES, 1932). The nine papers presented did not contain any clear assessments of the effects, but it was concluded that the existing capture of younger age groups of haddock was extremely undesirable and that considerable savings could be effected by larger trawl meshes. For plaice, it was considered that an unrestricted fishery on the nursery grounds was a danger to the maintenance of a marketable stock and was likely to be followed by a decline in yield.

Hjort made a special contribution to this meeting which seems to have described how most fishery scientists must have felt at the time. The small-fish question was as old as the knowledge that the catches of the North Sea trawlers largely consisted of undersized fish. This problem had been intensively investigated and proposals for "avoiding the enormous waste", size limits, closed areas, and savings trawls had been submitted. However, until then, these had aroused only academic interest, partly owing to practical difficulties and partly through resistance by the fishing industry and governments to accepting any limitations on their unrestricted freedom of action.

There had also been opposition on theoretical grounds that the growth of North Sea fish was inversely related to the number of fish. This "thinning theory" was closely connected with old biological theory and experience dating back to Malthus and Justus von Libig, who showed that populations are dependent on "means of subsistence". Modern marine biological research had also shown a tendency to assume that a population always utilized the existing means of subsistence and was, therefore, always in proportion to that. Hjort showed examples of Norwegian herring with 30-fold changes in year-class abundance but with no change in growth rate. Icelandic haddock and plaice in Danish waters also showed about the same growth rate for year-classes of varying abundance. He concluded that he was unable to abandon the leading idea which had guided ICES from the beginning that the enormous destruction of young fish in the trawl fisheries should be prevented. This was the state of the art in the early 1930s. No convincing assessments of the effects on the stocks of the capture of undersized fish had been made, nor had it been clearly demonstrated that these captures endangered the stocks or caused declines in yield. But clearly there was a risk that this might be so, and the meeting followed what today would be called the principle of cautious management advice. This was sensible, but did not constitute the basis for a strong case which could persuade governments and industry.

The 1934 special ICES meeting on "Size Limits for Fish and, Regulation of the Meshes of Fishing Nets" (ICES, 1934) addressed the practical question of how to limit the capture of undersized fish, the need for which had already been agreed. The by-catch of undersized fish had been perceived as the main "overfishing" problem since the start of Committee B. This was an unfortunate limitation of the concept of overfishing inherited from more than 30 years of discussing the problems of the plaice fisheries. The two special ICES meetings dealing with this problem, which led to the 1937 London Conference, focused attention on fishery regulations on mesh size and landing size for fish, attention which was maintained well into the 1950s, although Britain attempted to start discussions of effort limitations immediately after World War II.

Formulation of a theory of fishing

Parallel to these efforts at fishery regulation, several important contributions were made towards the formulation of a theory of fishing. E. S. Russell (1931) formulated the parameters of an arithmetic function which described yield as a function of recruitment, growth, and natural and fishing mortalities. This identified the important processes, but the practical usefulness of the function was limited by the partial interdependence of the parameters.

In the paper "The optimum catch", Hjort *et al.* (1933) referred to the war effect on the North Sea stock of plaice and postulated that there was every opportunity for an intelligent community to create an industry based on an optimum catch. That Europe had not done so was due to the free forces in the fishing industry. In the theoretical part of the paper, a parallel was drawn between a stock in the sea and a stock of yeast cells in a closed vessel. The rate of increase is initially small, attains a maximum, and then decreases to zero. On this basis, it is possible to estimate theoretical curves representing the dynamics of stock and regeneration and from this to deduce whether the stock will support the catch. These are sigmoid curves, and the point of inflection indicates where the regeneration is highest and, in theory, where the maximum or optimum catch would be obtained.

Graham (1935), after having reviewed recent advances in the theory of fishing from E. S. Russell, Hjort, Jahn, Ottestad, and others, made use of the theoretical basis in assessments of North Sea roundfish and showed with three different approaches that reduced effort would maintain or even give higher yields. Graham's rough total production estimate indicated that the maximum yield from these fisheries would be about 15% higher than the recent level and would be taken with 75% of the effort. This was the first presentation in an ICES document of an estimate of the effect of changes in effort on yield. Graham formulated his "Great Law of Fishing" which described in general terms the relationship between yield and unrestricted fishing effort: "Because of increased fishing effort resulting from improved efficiency and addition of capital, industrial fisheries will, if left to themselves, move in a self defeating process towards a marginal state." The sigmoid curve was the more general form of that law, and in a later paper, Graham (1939) demonstrated how an s-shaped curve describing the dynamic relationship between yield and effort could be derived graphically based on simple biological arguments. There were problems in applying the curve to actual fisheries, but the rough estimates of the state of the stocks of North Sea groundfish presented in 1935 were again quoted. Some of Graham's general conclusions based on the model are important in showing the attitude of a leading British scientist to fishery regulations at the time:

> There will be no permanent profit unless the rate of fishing is controlled.
>
> There can be only temporary prosperity until international agreement is reached to prevent the rate of fishing increasing.

This may well be the background for British attempts to introduce effort regulation immediately after World War II. Under Graham, the Fisheries Laboratory in Lowestoft became a leading institution in fish population dynamics in the decades following World War II.

Summary review of the development during the period

From a general state of ignorance of the life history of the stocks and their response to exploitation at the start of the 20th century, the identity and distribution of the main stocks inhabiting the Northeast Atlantic were described through a step-wise process over 40 years. Towards the end of that period, some members of the scientific community had gained the first insights into the dynamics of exploited fish stocks.

During the first part of the period, investigations of the two main Norwegian stocks, Arctic cod and spring-spawning herring, pointed the way to general progress by the successful use of methods and through important general findings. Hjort and his group in Bergen functioned as the leading fishery research institution in Europe until World War I, and with his stock age composition concept, Hjort was at the point of achieving deeper insights into the complexities of exploited fish stocks.

European fishery research then entered a period of doldrums lasting 15–20 years, caused in part by the unfortunate herring scale dispute which appears to have produced a lack of confidence in Hjort's approach and in age determination in general, at least among the British. A new generation of British scientists played, however, a leading role in the development of fishery science in the 1930s, and based on Hjort's earlier findings and results of investigations of North Sea stocks, the first theories of the effects of fishing on the stocks were developed. The effects of fishing on the stocks were not perceived as urgent problems in the Norwegian fisheries in the 1920s and 1930s, with the exception of whales. These differences in main research problems between Norway and the North Sea countries may also have been a reason for the shift in the leading institution from Bergen to Lowestoft. The attention of many scientists was drawn to the North Sea groundfish stocks which were assumed to be heavily fished, and it was the experience with these stocks that caused the British to take such a strong interest in the theories of fishing. Their findings and the further development of fishery science represented a general advancement in knowledge and understanding which would affect all future fishery research.

Over the entire 40-year period, ICES functioned as an important forum for research cooperation. Its intended function—providing advice on the regulation of international fisheries—did not materialize, however, until the early 1930s when advice based on a precautionary principle for management was submitted, dealing with the protection of undersized fish in trawl fisheries.

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