ICES Journal of
Marine Science

ICES Journal of Marine Science (2020), doi:10.1093/icesjms/fsaa230

Introduction

Introduction to the Symposium: '*Johan Hjort Symposium 2019*'

The legacy of Johan Hjort: challenges and critical periods—past, present, and future

Olav Sigurd Kjesbu [1]*, Jennifer Hubbard[2], Iain Suthers [3], and Vera Schwach[4]

[1]*Institute of Marine Research (IMR), P.O. Box 1870, Nordnes, Bergen 5817, Norway*
[2]*Department of History, Ryerson University, 350 Victoria Street, Toronto, ON M5B 2K3, Canada*
[3]*School of Biological, Earth and Environmental Sciences, University of New South Wales, Sydney, NSW 2052, Australia*
[4]*NIFU, Nordic Institute for Studies in Innovation, Research and Education, P.O. Box 2815, Tøyen, Oslo, Norway*

**Corresponding author: tel: +47 93 04 76 11; e-mail: olav.kjesbu@hi.no.*

Kjesbu, O. S., Hubbard, J., Suthers, I., and Schwach, V. The legacy of Johan Hjort: challenges and critical periods—past, present, and future. – ICES Journal of Marine Science, doi:10.1093/icesjms/fsaa230.

Received 15 October 2020; revised 16 November 2020; accepted 18 November 2020.

The 150th anniversary of Johan Hjort's birth was celebrated by a symposium held in Bergen on 12–14 June 2019 to take a broad perspective on the origins of, and developments in, fisheries science and thereby examine current issues in fisheries science from different perspectives. To establish this type of non-traditional forum, historians of marine science and marine researchers from around the world met to explore potential new directions. The many transdisciplinary panel discussions, especially on subjects such as "the making of fisheries scientists", revealed the pervading influence of family, educators, role models, and social circumstances. The 11 articles included in this symposium issue present a series of advancements in modern fisheries science, highlighting the contributions of Hjort and his contemporaries, Fyodor Baranov and Harald Dannevig. As expected, the effects of changing ocean climate were a dominant theme, which connected this symposium, and complemented, the 2014 symposium in honour of Johan Hjort's influential treatise released in 1914. Although no ground-breaking paradigms were presented, several new research directions were proposed in a creative atmosphere generated by participants. The social context of science had a key influence in Hjort's day and continues to do so today and into the future.

Keywords: climate, fisheries, marine history, ocean studies, population dynamics, recruitment

Introduction

In 2019, we celebrated the 150-year anniversary of the marine researcher Johan Hjort (1869–1948), who introduced the fundamental principles of modern fisheries science (Hjort, 1914). His understanding about the formation of strong and weak year classes and their role in defining population demography and productivity profoundly altered research on commercially important fish stocks, and ultimately, contributed to the management and forecasting of stocks (Rice and Browman, 2015). Hjort's (1914) treatise addressed a fundamental problem in population dynamics: the biology of underlying recruitment processes and stock densities in fish and marine animals. The fusion of the scientific and socio-economic goals was brought into being by concern for decreasing fish catches and economic hardship and had applications that inspired innovations in several fields of marine research.

A century later the Hjort paradigm still prevails. We see layers of nuance in understanding, rather than a shift in perspective regarding, e.g. the role of the larval period in determining year class strength (Houde, 2008). When organizing a symposium to celebrate the 150th anniversary of Hjort's birth, we decided to examine and challenge Hjort's heritage. Do his 1914 lines of thoughts remain valid, or have they reached their limits? Does current fisheries science and fisheries management need a new theoretical framework to deal with a holistic, ecosystem-based approach in light of climate change and the significant alterations we expect in the marine environment? These questions set the context and backdrop for the symposium. In addition, historians of marine science were invited to help explore the connections between the past and the present. Insights from these different perspectives would enable a more profound understanding of the existing scientific framework and generate new ideas.

The ICES Symposium in Bergen, Norway, 12–14 June 2019 was inspired by the 2014 ICES Special Issue (Browman, 2014), the 2014 ICES Symposium, and the resulting 2016 Canadian Journal of Fisheries and Aquatic Sciences Special Issue (Kjesbu *et al.*, 2016), commemorating his influential 1914 treatise (Hjort, 1914, 1926). During the symposium, otolith and scale age readings provided demonstrations of Hjort-related work that still goes on in today's marine laboratories. A photo exhibition of Johan Hjort's life and work, a walking tour across Bergen in Hjort's footsteps, and a visit onboard *R/V Johan Hjort (4)* rounded out the programme.

Challenging the Scientific Legacy of Johan Hjort brought together experts within different fields and scientific disciplines to encourage discussions—all sessions were conducted in plenary. Altogether, 105 scholars from 14 countries, including 14 early-career scientists, attended, contributing 26 oral and 23 poster presentations. Out of 24 submitted manuscripts, 11 were accepted for publication. All of these are summarized in this Introduction to the symposium Issue, along with the keynote contributions and an outline on Hjort's most significant contributions. Altogether, the various presentations during the symposium (Supplementary Appendix S1) strengthened the impression that challenges to fisheries science today are far more complex than during Hjort's lifetime. Climate change not only affects temperature and stratification of the global oceans but is also associated with stresses from altered wind forcing, ocean acidification, acoustic noise, plastics, invasive species, and deoxygenation.

Future ocean conditions may influence phenology and the relevant time scales (match–mismatch) of the production cycles of larval fish and their prey (Oral 25: Neuheimer *et al.*). We learnt about the changing incidence of disease and parasites over 100 years from long-term collections of fish in the NE Pacific, off Washington USA (Oral 03: Welicky *et al.*). Fiksen and Reglero (Oral 11) captured our attention with the iconic northern bluefin tuna (*Thunnus thynnus*) and the possible evolutionary trade-offs during the early life history—why does this species spawn at seemingly inappropriate times? Other evolutionary trade-offs are evident between growth and mortality, in a renewed interest in the ratios of life history parameters—rather than the actual life history parameters themselves, especially for data-poor assessments (Oral 09: Prince). Also presented was a renewed interest on using the slope of the zooplankton biomass size spectrum as an index of the mortality:growth (M/G) ratio of larval fish, and a fine-scale metric of recruitment potential (Oral 10: Suthers and Everett). And no one could have predicted the remarkable use of close-kin mark-recapture in the stock assessment of bluefin tuna (Oral 21: Skaug and Bravington). Considerable attention was given to the ethics of seafood harvests, and how to approach disputes between stakeholders and enhance the ethical governance of marine ecosystems (Oral 14: Lam).

Johan Hjort, heritage, and legacy

Hjort's theory emerged from observations that did not fit the contemporary leading explanation on variations in the size of fish stocks. Important for this paradigm shift was a revolutionary new method to determine the age structure of Norwegian spring-spawning herring (*Clupea harengus*) from the annuli found in the scales. This method, first developed by Hjort's assistants, especially Einar Lea (1887–1969), has since been refined and is still routine (Schwach and Kjesbu, 2016). This perspective change, like other profound shifts in the natural sciences, depended on social circumstances, individuals and research groups. Tracing the research of Johan Hjort shows how he drew on his peers and scientific community (Figure 1), including fisheries managers, fishers, and the fishing industry. The combination of economic, scientific, and social contacts was essential for Hjort's new insights.

Early in 1893, Hjort returned to Norway with a doctoral degree in embryology from the University in Munich, Germany. In addition to a university position, Hjort got an adjunct position as a recipient of a fishery fellowship, which paid twice the salary of his curator position. However, neither economic motives nor a failure in general marine zoology led him to fishery studies (Schwach, 2014). His motive was a strong desire to do field biology and work outdoors, in what the American zoologist Charles A. Kofoid—after his visit to Bergen on his grand Europe tour—called "the hazardous work of carrying on continuous scientific investigations in the storm-swept waters of the North Sea" (Kofoid, 1910, p. 298). The fishery fellowship came with the obligation to research the enormous fluctuations in herring and cod (*Gadus morhua*) catches along the Western and Northern coast of Norway. In 1900, Hjort sailed in "his" new research vessel *Michael Sars* to the fishing industry hub of Bergen – with its easy access to the North Sea and Norwegian Sea – to become head of the scientific fisheries investigations. There, in 1906, Hjort was appointed as the first Director of the Fisheries Directorate

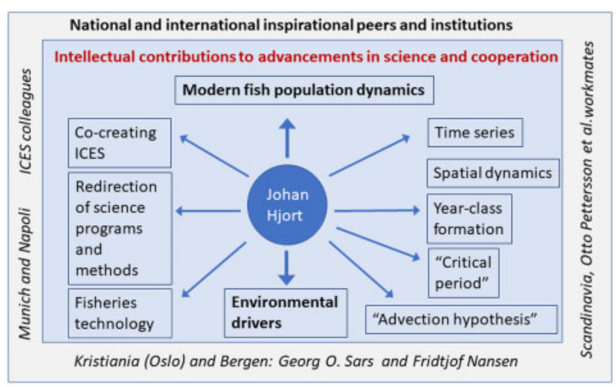

Figure 1. Johan Hjort was a giant who stood on the shoulders of other significant scientists. The figure illustrates his contributions to fisheries and marine science, and how Hjort's concept was influenced by previous researchers, and his social interactions with national and international colleagues and institutions.

(Fiskeridirektoratet), where he continued to combine science and management. He held this position until his resignation in 1917 (Schwach, 2014). So far, four research vessels at the Institute of the Marine Research have been named after Johan Hjort, the first one small and sparsely equipped compared to today's ultramodern vessels (Figures 2–5).

Although Hjort originally thought that catch variations were due to long migrations, he came to understand that natural variations in year-class strength were more important. He opposed the continuance of a hatchery initiated by Gunder M. Dannevig (1841–1911) [father of Harald C. Dannevig (1873–1914)] because his own ambitions for a scientific institution for marine research and for the formation of ICES would be compromised if Dannevig's scheme continued to receive funds at the cost of Hjort's plans (Schwach, 2000). Important here is that Hjort's argument against hatcheries (and thus stock enhancement of the ocean) helped motivate him in developing a conceptual framework to explain the fluctuations in year-class strength. Between 1900 and 1906, Hjort began to doubt whether there was one ocean stock of migrating cod, which was an important step in explaining why fish abundance was so patchy among regions and years. The German zoologist Friedrich Heincke (1852–1929) showed that herring occur in several groups (populations) (Heincke, 1898). The same was found in Norwegian waters.

Around 1904 Hjort gave up his view that all cod belonged to one stock, turned his attention to early survival as the critical stage of reproduction. The Norwegian fisheries biologist Per Solemdal (1946–2016) saw the dispute between G.M. Dannevig and Hjort as a catalyst for Hjort's original hypothesis of the fluctuations in the year classes (Solemdal *et al.*, 1984, pp. 18–19). From Hjort's understanding that survival of the larval stages was critical for year-class strength, arose an awareness of the significance of the different year classes and the causes for large natural fluctuations in fish catches (Schwach, 1998, 2014).

Hjort championed the establishment of ICES as a scientific and fisheries expert community (Schwach, 2002). He chose the

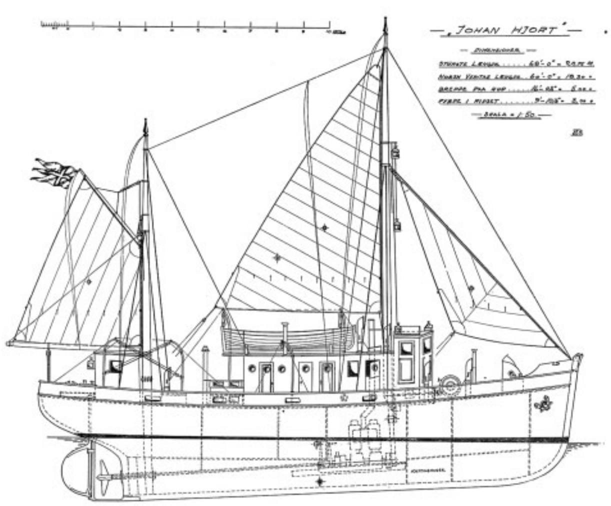

Figure 2. R/V *Johan Hjort* (1). The early definition of the field gave weight to scientific activity on the ocean. For Hjort, the research vessel was an invaluable means to shape knowledge and introduce new technologies, tools, and methods. After the requisition of the ocean-going R/V *Michael Sars* to the Navy during World War One, a small ship, only suited for coastal investigations, *Johan Hjort* (1) was launched in 1922. She was jokingly characterized as a crossover between a rocking chair and a rocking horse. Hjort himself was dissatisfied and declined an invitation to go on board (Broch and Koefoed, 1962; Havforskningsinstituttet, 2008). Technical specifications: Shipyard: Gravdal Skipsbyggeri, Norway; built, 1922 (rebuilt 1928); length, 68 ft; beam, 16 ft; grt., 49 brt; machinery, 70 hp (51 kw); accommodation, 9 bunks. Illustration: Courtesy of Institute of Marine Research.

Figure 3. R/V *Johan Hjort* (2). Johan Hjort (2) was launched in 1931 with the aim to support the fisheries in a period of economic depression. The small ship operated mainly in coastal waters but was the first Norwegian vessel equipped with an echo-sounder (Schwach, 2004; Havforskningsinstituttet, 2008). Technical specifications: Shipyard: Gravdal Skipsbyggeri, Norway; built, 1932; length, 80 ft (25 m.); beam (not known); grt., 67 brt; main machinery, 90–120 hp (66–88 kw). Illustration: Courtesy of Institute of Marine Research.

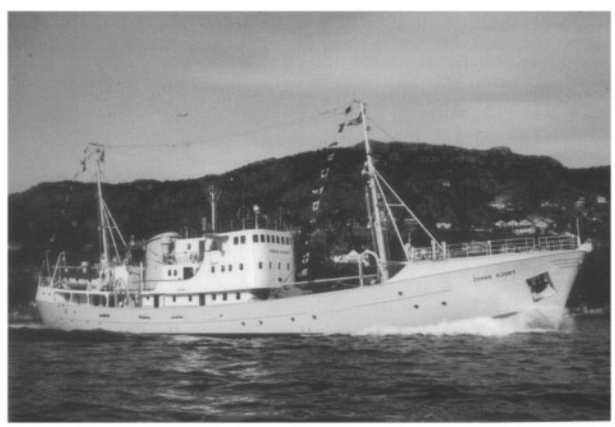

Figure 4. R/V *Johan Hjort* (3). Johan Hjort (3), launched 1958, nicknamed "Hjorten", was an ocean-going ship purchased to expand the fisheries investigations in years of growth in science and the fishing industry. She was especially used for cod and surveys to the northern sea areas. (Schwach, 2000, p. 254, 256; Havforskningsinstituttet, 2008). Technical specifications: Shipyard: Mjellem & Karlsen AS, Norway; built, 1958 (rebuilt 1975); length, 52.3 m; beam, 9.3 m; grt., 697 brt; main machinery, 1300 hp (956 kw); accommodation, 25 cabins (crew, 32 bunks, researchers, 7 bunks). Illustration: Courtesy of Institute of Marine Research.

Figure 5. R/V *Johan Hjort* (4). Johan Hjort (4) launched in 1990 operates mainly in Norway's Exclusive Economic Zone and is built for fisheries and marine environmental research in harsh weather conditions in the Norwegian Sea and the Barents Sea. The ship carries out manifold investigations and its equipment includes advanced acoustics instruments, gear for trawls, plankton samplers, and electronic instruments for hydrographic measurements (CTDs) (Havforskningsinstituttet, 2008; www.imr.no). Technical specifications: Shipyard: Flekkefjord Slipp og Maskinfabrikk AS, Norway; built: 1990; length, 64.4 m; beam, 13.0 m; grt., 1851 brt., machinery, 2400 kw; accommodation, 24 single and 5 double beds. Illustration: Courtesy of Institute of Marine Research.

commercially important herring to unite ICES member countries that had diverse and partly conflicting research interests and goals for fisheries management. Hjort emphasized gaining wide acceptance for his results and was eager to disseminate his methods, research, and findings. His influence spread through reports, international marine courses in Bergen (1902–1913), ICES, and the Canadian Fisheries Expedition (1914–1915), during which Hjort and his crew sailed to Canada and introduced the new methods for analysing fish populations and physical oceanography to his peers across the Atlantic (Schwach, 2000, pp. 179–181; Hubbard, 2006, 2014a).

On the shoulders of our predecessors

Hjort's (1914) pioneering ideas were a result of his scientific and political mission, his close ties to the fisheries industry, and his ambitions to create an international community of scientists and fisheries experts. His treatise was the first coherent approach to explain fluctuations in fisheries and it became an important concept for population studies in adjacent fields of marine science. In his review of Hjort (1914), the renowned British marine biologist and Director of the Marine Biological Association in Plymouth, E. J. Allen, wrote: "There can be little doubt that this report by Dr. Hjort will mark an epoch in the history of scientific fisheries investigations [. . .][i]f the arguments upon which its conclusions are based withstand the test of criticism" (Allen, 1914). A century later, Hjort's (1914) paper and the 1926 summary (Hjort, 1926) are considered seminal classics. Marine scientists in 53 countries have referred to Hjort, and as of 2013, Hjort (1914) was still cited about 40–50 times and Hjort (1926) 5–10 times annually; this is exceptional for a hundred-year-old scientific publication (Aksnes and Browman, 2014).

His concept of "recruitment" (a term that from 1945 replaced year-class fluctuations) (Schwach and Kjesbu, 2016) has been the basis for over a hundred years of research into the physical and biological factors that determine the size of a year class. Hjort examined mainly herring, cod, and other gadoids in the Northeast Atlantic, and in the succeeding decades tested his theory on other fish stocks and species. In retrospect, it is impressive how Hjort arrived at conclusions that would later prove to be correct. A century later, Hjort's (1914) lines of thinking have been elaborated on and refined but still not replaced. The recruitment of fish stocks is still largely not resolved, although it seems to receive less interest as a research question (Rice and Browman, 2015). Rather than scrutinize a series of underlying theories, the 2019 Symposium aimed at strengthening the understanding of the historical development of these research areas and at pointing towards the future.

Keynote addresses: a search for new ideas

Keynote speakers were selected to facilitate deeper insights into the present basis of marine population science but also to search for new ideas and a fresh scientific framework. The symposium included an opening keynote and eight additional keynote presentations. A common thread was the acknowledgement of Johan Hjort's major contributions to marine science and of the progress since then. Although no ground-breaking new paradigms as such were presented, several of the speakers pointed towards new directions in research:

- In the opening keynote address *Ray Hilborn* (Supplementary Appendix S1, p. 15) spoke on "Extending and expanding the legacy of Hjort in management of global fisheries". Hilborn focused on stock productivity, concluding that the most common assumption today is that year-class strength is a random but stationary process. While seemingly a logical contradiction, this relates to the large variability (poor and strong year classes intermixed with medium-strong year classes) that typically persists over time. Other influential contributions, especially the famous Thompson-Burkenroad Debate of the 1930s and 1950s (Skud, 1975), concerned the roles of fishing vs. environmental conditions as regulatory factors. Today, while we know that both factors are important, we still know little about these binary interactions, let alone the broader interactions with other components of the ecosystem. Hilborn then considered stock productivity in the face of regime shifts (changes) and exemplified approaches for forecasting this important recurring phenomenon (e.g. Markov transition models), while conceding that the underlying problem is that "we cannot usually detect a regime change until we are well into it". He concluded by elaborating on progress being made in stock enhancement programs as a means to deal with changing productivity.
- *Svein Sundby* (Supplementary Appendix S1, p. 15) presented "Hjort (1914) vs. Helland-Hansen and Nansen (1909)—cold case reopened 100 years later", describing how Helland-Hansen and Hjort's understanding of fluctuations in fish stocks had gradually diverged. Helland-Hansen and Nansen (1909) applied hydrographical observations to calculate the heat fluxes in the Norwegian fishery waters. They found that growth and maturation in the "food fishes" were affected by the heat fluxes of the warm Atlantic inflow. Hjort attacked their findings in his 1914 treatise and promoted his own ideas that the fluctuations were not dominated by the processes prior to spawning, but rather by subsequent survival during

the early planktonic life history stages. From the perspective of an additional century of marine science, we should not be surprised to encounter a metaphorical "Judgment of Solomon": both the spatiotemporal high-frequency processes linked to larval survival, and the longer-term and interannual processes linked to growth and maturation, are of importance in understanding the variability in fish stocks.

- *Akinori Takasuka et al.* (Supplementary Appendix S1, p. 15) discussed "Revisiting a paradigm of density-dependent effects in the life history of fish". This presentation cast doubt on the commonly held view of a tight relationship between spawning stock biomass (SSB) and stock reproductive potential, represented by total egg production (TEP). Instead, their findings pointed to this coupling being partially distorted by density dependence in TEP, either by intraspecific (Japanese sardine *Sardinops melanostictus*) or by interspecific competition (Japanese anchovy *Engraulis japonicus*). Hence, they proposed reconsidering the fundamental basis of recruitment studies.
- In his talk "Changing herring paradigms", *Robert L. Stephenson* (Supplementary Appendix S1, p. 16) identified three groups, or periods, of paradigms: (i) the "early biological paradigms of Hjort"; (ii) subsequent development of more "ecological paradigms", which include multi-species considerations and broader ecosystem considerations; and (iii) recent development of a "social-ecological systems paradigm", which includes broader interdisciplinary considerations. This framework predicted further evolution of paradigms to respond to the challenges of climate change adaptation, changing trends in participatory governance, and the need for strategic and proactive management of fisheries with other activities in integrated planning and management.
- *Jeffrey A. Hutchings* (Supplementary Appendix S1, p. 16) presented "Stretching the scales of fisheries science: adaptation, regime shifts, and recovery". Hutchings addressed how misidentification of appropriate scales may have implications for the fundamental questions raised, thereby delaying progress in adaptive ecology research. This is because scientists are challenged to test hypotheses, obtain data, and (or) model populations across biologically meaningful, yet empirically tractable, extents of time and space. Spatial mismatches between management units and evolutionary units can hinder efforts to mitigate threats. Furthermore, temporal mismatches between metrics of biological productivity and potential drivers can lead to spurious correlations between cause and effect. He concluded that there is merit in "stretching" the temporal, spatial, and intellectual scales over which much of fisheries science is conducted to advance insights in adaptation, regime shifts, and recovery in marine fishes.
- *Olav Sigurd Kjesbu* spoke (at short notice) on stock productivity aspects in view of climate gradients, fluctuations, and change in the NE Atlantic, with the title "Climate vulnerability assessment—a mechanistic approach". Climate vulnerability assessments (CVAs) have become increasingly important and valuable tools in advice and management routines (Hare *et al.*, 2016) but are expert evaluations rather than the outcome of statistical analyses and (or) model runs, except for the underlying climate model predictions. In some data-rich species (and stocks), CVAs might be validated by up-scaling of response traits and mechanisms, focusing on critical windows (e.g. spawning failure) rather than scoring (weighting) a series of sensitivity attributes. This requires a combination of dedicated experimental and field observations rather than extraction of data not specially defined for the purpose.
- *Dorothy Jane Dankel* (Supplementary Appendix S1, p. 17) discussed "What would Hjort do? An analysis of Hjort's 'Unity of Science' in light of current fisheries controversies". Dankel's provocative keynote asked how Hjort would approach a recent case in which ICES, in September 2018, issued advice for a drastic (42%) reduction in the NE Atlantic mackerel (*Scomber scrombrus*) catch, which was opposed by the industry, and was then reversed the following May with the catch limit more than doubled. She outlined how and why research institutions can, despite their deep familiarity with the limitations of their models and data, place insufficient weight on these caveats and also on external expertise. Dankel argued that Hjort, given his deeply pragmatic approach, would have welcomed the perspectives of external experts and stakeholders: the fishers, social scientists, and economists.
- *Timothy M. Ward et al.* (Supplementary Appendix S1, p. 17) gave a talk on the "Paradigm of pragmatism: managing uncertainty in Australia's small pelagic fisheries". Egg production methods (EPMs) are used worldwide to estimate SSB of small "pelagics". There are three such EPMs, depending principally on the reproductive biology of the fish. In the keynote, Ward and co-authors suggested a new pragmatic way to use the Daily Egg Production Method (DEPM) as this method has been replaced in several fisheries because of imprecise estimates of SSB. Ward reanalysed the DEPM of sardine (*Sardinops sagax*) off southern Australia between 1995 and 2019, to reduce the coefficients of variation of estimates of SSB from 23–59 to 8–12%. This improvement was achieved by considering all historical, rather than just annual, data. They suggest that the spawning area is a useful proxy for the SSB of sardine that can be converted into a precise estimate of SSB using parameter estimates from historical data.

Contributions from the symposium

It is appropriate for Hjort's 150th celebration that four of the articles in this Special Issue concern the dynamics of herring stocks and reproduction. Most of these articles dealt thematically with impacts from a changing climate. For example, reproductive investment by the Norwegian spring-spawning herring over 80 years revealed a relationship with the North Atlantic Oscillation—a decadal weather (atmospheric) phenomenon—and sea surface temperature. However, overfishing led to the collapse of this stock during the mid-1970s, and a reversal of this trend (Claireaux *et al.*, 2020). The effect of the Atlantic Multidecadal Oscillation (AMO)—a long-term (multidecadal) climate forcing (based on sea surface temperature variation)—was also seen in the recruitment patterns of this stock, derived from 28 years of larval abundance surveys; Tiedemann *et al.* (2020) found that weak recruitment relates to an elevated temperature during the larval drift period under a positive AMO phase, as seen today, although they acknowledged the related biological mechanisms remain unknown. Further north, the influence of climate on Arctic ecosystems was evident in the abundance trends of the threespine stickleback (*Gasterosteus aculeatus*) over the past century. This abundant planktivorous and important prey item in the White Sea increases during warm seasonal anomalies and declines during cooler seasonal anomalies (Lajus *et al.*, 2020). In the adjacent Barents Sea, Endo *et al.* (2020) showed significant effects of SSB of Northeast Arctic cod and parental condition (liver index) on the abundance of larvae during their transport into this region. Interestingly, they did not detect that the distribution extent of the larvae *per se* influences recruitment success (at age 3 years). Nonetheless, on the other side of the world, Plagányi *et al.* (2020) found that the drift of larval prawn in the Joseph Bonaparte Gulf (adjacent to the Timor Sea) was related to the Southern Oscillation Index—an integrated index reflecting changing climate drivers including temperature, wind, sea level height, rainfall and the El Niño Southern Oscillation—and speculate how these drivers are altered by anthropogenic climate change.

Reproduction in Atlantic herring stocks is complex, attracting the attention of fisheries and evolutionary biologists, as spawning can occur somewhere in the North Atlantic on almost any day of the year. Samples of spring and autumn-spawning herring revealed the relationship between these populations using three methods of discrimination: a traditional index of gonad morphology and development; the seasonal patterns in larval growth within the otolith; and by genetic discrimination (Berg *et al.*, 2020). While confirming the remarkable fidelity of spawning herring in terms of location and seasonal timing, the relatively low incidence of skipped spawning ($<5\%$) and straying ($\approx 8\%$) was particularly revealing. The trade-off in somatic and gonadal investment normally observed in Atlantic herring was not evident in the scales of Pacific herring (*Clupea pallasii*) (Miller *et al.*, 2020).

In keeping with the symposium's theme of future fisheries, Arkhipkin *et al.* (2020) reflect on the modern management of cephalopod fisheries. The fast growth of squid, and its semelparous life cycle, was nothing that Hjort and his team considered, since they "focused on finfish, whale, and shrimp fisheries[;]…but in the decades since, cephalopods have become an increasingly vital component of marine resources" (Arkhipkin *et al.*, 2020). They suggest a pragmatic approach to assess the declining abundance of each cohort during the fishing season. Future management must consider the "triple bottom line" of social, economic, and environmental considerations, as demonstrated by Dichmont *et al.* (2020) for a line fishery on the Great Barrier Reef, an area that is the focus of tourism, commercial and indigenous fisheries—and a World Heritage Area. This study calls for a paradigm shift in management, involving social ecology as described by Stephenson in his plenary presentation.

Two of the papers focused on introducing the contributions of important historical figures from outside the North Atlantic and North Pacific areas typically associated with early fisheries science. The Russian fisheries scientist Fyodor Ilyich Baranov made significant contributions to understanding the effects of fishing on population size and structure (Sharov, 2020). The Baranov catch equation laid a basis for population dynamics and fisheries assessments. Sharov (2020) discusses why Baranov's groundbreaking results, published in Russian in 1918, received scant attention in the marine science community for another 20 years, and how Soviet ideology and Baranov's opponents hampered the recognition of Baranov's concept in the Soviet Union. Another contemporary of Hjort was Harald Dannevig, who made novel contributions to fisheries science in Australia between 1902 and 1914, including the first demonstration of onshore winds and natural fluctuations of estuarine fisheries (Suthers *et al.*, 2020). His research trawler, built in Australia in 1908, used Hjort's vessel, *Michael Sars*, as a model. Dannevig's efforts to establish new types of coastal and ocean-based fishing operations and his independent investigations of the life history and growth of sea mullet (*Mugil cephalus*) conveyed his Norwegian roots.

Marine science and history

Being an interdisciplinary symposium celebrating the 150th anniversary of Hjort's birth, the past permeated all events and one session "When history meets marine science" focused on the history of oceanography (as defined below). The speakers Helen Rozwadowski, Jennifer Hubbard, and Vera Schwach pointed out that, without historical knowledge of trends and turning points, it is easy to misinterpret research done in the past, which in turn may weaken current science. The study of the history of ocean science has experienced a transition from scientific specialists looking into the antecedents of their own specialties, to trained historians of science dominating the field. The speakers expressed the wish that more scientists would engage in historical studies. The history of oceanography needs both kinds of specialists, where the scientists examine the scientific underpinnings and the origins of their own field, while the professional historians use historical methods and historiography to analyse intellectual and institutional contexts, as well as economic, social, cultural and political circumstances (cf. Stephenson's presentation; Supplementary Appendix S1, p. 16). The importance of history was succinctly summarized by Howard Browman during a later discussion: "History of science gives a better sense of what we do know, to have a better idea of what we don't know".

The speakers showed how oceanographers and fisheries scientists exhibited an interest in their own history of the field well before historians. Scientists' attention to their own past began around 1910, when ocean studies were emerging and coalescing as a discipline (Mills, 1989; Deacon, 1997). John Murray, of *Challenger* fame, joined together with Hjort and his research fellows onboard *Michael Sars*, which was on loan from the Norwegian government for them to explore the depths of the Atlantic Ocean during a four-month voyage in the style of the *Challenger* (1872–1876) expedition (Murray and Hjort, 1912; Schwach, 2000, pp. 177–179). In the introduction to the expedition report, *The Depths of the Ocean*, Murray surveys both earlier and contemporary ocean studies. Knowledge about the past was instrumental in shaping the identity of the emerging field of oceanography, highly multidisciplinary with its biological, chemical, and physical investigations. Murray puzzled over how to characterize his new science and came to a description which gave weight to practical scientific activity on the oceans: "Instead of the complete picture which vision gives, we have to rely upon a patiently put together mosaic representation of the discoveries made from time to time by sinking instruments and appliances into the deep, and bringing to the surface material for examination and study" (Murray and Hjort, 1912, p. 9).

It is noteworthy that Hjort and his book's co-authors had a broad interest in marine science and thus made many contributions to techniques and instruments, studies of phytoplankton, zooplankton, and fishes; as well as physical oceanography. From financial, institutional, and intellectual perspectives, fisheries biology was important for building the multidisciplinary field of oceanography. After the Second World War, when ocean studies often became linked to strategic military interests, and oceanography experienced meteoric growth, the established fisheries investigations remained a solid part of the field. After 1990, with a growing concern about the ocean's climate, fisheries biology forms part of an ecosystem approach, which can be seen as consistent with Hjort's spirit of a multidisciplinary marine research.

Historians investigate scientific activity by binding it to specific local and temporal contexts and examine the influence of individuals, and the economic, political, and cultural contexts, on science. Biographical information is crucial to understand how marine science has developed the way it has and how scientific priorities change. A session, "The making of fisheries scientists" was dedicated to casting light on what drew today's fisheries scientists to the field. What cultural factors and disciplinary backgrounds shaped their decisions, and influenced their choice of career and topics? How did their personal ambitions and creativity impact fisheries science? Did fisheries collapses, environmental crises, or even "role models" play a part? The session included a panel of scientists: Tony J. Pitcher, Kathrine Michalsen, Timothy M. Ward, and Éva Plagányi, who were asked how they came to enter the field, who inspired them, and what kinds of projects excited them the most. The session inspired members of the audience to also tell their own stories, including former Director of the Institute of Marine Research, Odd Nakken. Nakken's involvement in science was spurred by a commercial fishing trip with his father and uncle when he was a teenager. They could find no herring, and both his father and uncle advised him to find another job. Nakken took their advice: he wanted to find out what had happened to the fish! Later, as a newly minted graduate student, Odd Nakken found himself invited to the office of the Director of IMR, where the Director Gunnar Rollefsen (1899–1976) spent a half-day explaining to him the development of Atlantic cod. Nakken was inspired by the humility and dedication of the Director, who would take such care with a student he had never met before. Another participant, Dorothy Dankel, observed, "a lot of forms of science are based on personality", and "scientific networks create a cultural heritage for society".

While there is no record of any correspondence between Hjort and H. C. Dannevig (despite the well-documented debates between Hjort and Gunder Dannevig; Solemdal *et al.*, 1984), it is likely that both men were influenced by the thinking of Professor G.O. Sars while at the University in Kristiania (today Oslo), and clearly there was a strong Norwegian influence that shaped fisheries investigations in the twentieth century (Suthers *et al.*, 2020). On the other hand, for Hjort, there was a decisive German and Scandinavian influence in addition to the national one (Schwach, 2000, pp. 60–82). This came through Hjort's university education, his collaboration with the Swedish chemist and oceanographer Otto Pettersson (1848–1941), the Danish fisheries biologist C.G. Joh. Petersen (1860–1928), and the German fisheries investigations in Kiel and Helgoland (Schwach, 2000, pp. 61–68, 70–80).

The symposium organizers encourage scientists to record any personal narratives about their years in the field, to give future scientists an understanding of the challenges and changes experienced by those who have gone before them (e.g. Campana, 2018; Ovenden, 2019). Such stories can help future scientists and historians to understand how new lines of research are introduced, the assistance and insights provided by technicians, and the agendas, passions, frustrations, and even personal physical dangers that have surrounded the scientific enterprise. Such information helps us to understand how the science has developed the way that it has, and that scientific priorities and even the meanings of words that shape our understanding can change.

Science and management: an uneasy pairing

Applied sciences, such as those concerning fisheries, have built enormous bodies of knowledge. The breadth of research has historically been constrained, especially in periods of budget cuts, but also by the ongoing demands for management-related information and projections. A key question is how marine science has influenced—and been influenced by—fisheries management decisions and fisheries policy?

Intrepid pioneers of ocean and aquatic biology became the earliest scientific experts on fisheries issues and thereby the authorities who took the lead in developing new policies and programs, with very little government interference. For example, the Scottish fisheries scientist J.D.F. Gilchrist began in 1895 to survey the fisheries resources in South Africa, using the 176-t trawler *S.S. Pieter Faure* built in Glasgow in 1897 (Barnard, 1964), leading to new fisheries. Around the same time, Harald C. Dannevig also investigated and promoted the Australian trawling industry based on the knowledge that he gained in Scotland and using the trawler *F.I.S. Endeavour* (Suthers *et al.*, 2020). While at the Directorate, Hjort worked to modernize fisheries in Norway and Canada, as did Hjort's Canadian collaborators (Schwach, 2000; Schwach and Hubbard, 2009).

As pioneers in this field, even though they were operating in a field of applied science, there were few constraints and few bureaucratic demands that would diminish the early scientists' gusto for, or satisfaction with, their field of research (Hubbard, 2006, pp. 38–66, 158–182). Fisheries biologists, animated by an ideal of service to their nation's fishing communities and fishing industry, were in frequent contact with stakeholders. For instance, since their field had emerged only recently, they were receptive to the ideas and knowledge fishers shared with them (Hind, 2015).

By the middle of the twentieth century, as fisheries science funding increased in the context of the Cold War, the tentacles of government bureaucracy began to entangle fisheries science with demands for specific social and economic outcomes, and economists began to edge out biologists as the main experts guiding policy. As the science matured, the dominant paradigm highlighted fisheries scientists using data from commercially fished populations to create mathematical models incorporating studies of variable year-class strengths, stock–recruitment relationships, and changing productivity, as parts of fishing theory. This pathway isolated many scientists from other fisheries stakeholders (Hubbard, 2014b; Stephenson: Supplementary Appendix S1, p. 16). However, since the 1990s, as Stephenson outlined in his keynote address, fisheries scientists and governments have recognized the necessity for more "ecological paradigms"—which he termed "Hjort+"—to include multi-species considerations, biodiversity, the creation or maintenance of habitats, precautionary approaches, and the like. He also described the recent development of a "social-ecological systems paradigm", which involves the direct input of a range of stakeholders in the management of the fisheries and the marine environment, bringing together ecological, economic, and socio-cultural as well as institutional aspects of fisheries and fisheries-dependent communities.

While Hjort himself would have welcomed a move to and beyond the socially conscious fisheries science of his own time, it must be recognized that these changes pose enormous challenges for scientists (Dichmont *et al.*, 2020). Fisheries scientists are now called upon to increase their envelope of expertise to include social and economic outcomes and to work with social scientists as well as economists, to devise methods for an optimum social yield rather than merely for some bio-economic goal of sustainability. Scientists must now negotiate problems and goals with sociologists and other experts, which is problematic as each field has its own specific vocabulary and way of understanding issues. Fisheries scientists also face constrained funding while being expected to add these new dimensions to their research portfolio (Dichmont *et al.*, 2020).

Conclusion

Hjort's research rested on a specific combination of intellectual, temporal, institutional, and political contexts. Researchers, theories, methods, and time spent at sea laid the foundation for modern fisheries science. Johan Hjort and Bergen had an important role in shaping scientific knowledge and practices. His intellectual and political mission, the proximity to fisheries managers and the fishing industry, and his fervour to export and circulate knowledge laid the foundation for a paradigm in a formative era of marine and fisheries science. It is beyond doubt that Hjort's groundbreaking concepts and practical approaches have withstood the test of time and criticism and have not been replaces, at least not yet.

During the next 50 years, the global population will approach 11 billion people (https://www.pewresearch.org/fact-tank/2019/06/17/worlds-population), with more than half concentrated along the coastline. Global sea levels may rise by half a metre or more (Oppenheimer *et al.*, 2019). Food security and access to marine resources will be a source of international tension, and far greater attention will be given to seafood production on the continental shelves. Today's semi-permanent installations for oil and gas will likely transform into facilities for mariculture and renewable energy facilities on a massive scale. Climate change, pollution, the growing issue of invasive species, and other forces mean that we can expect significant changes in the marine environment. "Sea safaries or adventures" and the development of more industries sited on continental shelves, mean a greater diversity of users will be dependent on ocean resources.

By the 200th anniversary of Hjort's birth, the ocean realm will be used to a much greater extent. Fisheries research and fisheries management will need a holistic, ecosystem-based approach to address challenges that Hjort and his contemporaries could not have anticipated. The global ocean-observing community has already transformed itself to provide easily accessible and quality data for scientists and the public (e.g. the Global Ocean Observing System and Australia's Integrated Marine Observing System; Eriksen *et al.*, 2019). Today, the national and especially international collaborations initiated by Hjort have become essential for climate science, such as in the development of the Argo program (Roemmich *et al.*, 2019), which quantitatively dominates the global data sets for vertical profiles of temperature and salinity from the surface to 2000 m.

The need for such systems of observation and monitoring will only increase. With new technologies and improved observational capabilities will come new paradigms, moving beyond those identified by Stephenson (above). Perhaps fisheries scientists will return to the 100-year-old debates between Hjort and G.M. Dannevig concerning hatchery production, sea-ranching, and stock enhancement, as suggested by one speaker. Ocean observing and mariculture could possibly combine to orchestrate strong year-class strengths, by seeding key areas of the ocean (fronts or eddies) at specific times with eggs and larvae. The elements of a new paradigm could include more process knowledge of factors that affect fisheries productivity and distributions, which would again require scientists to investigate the kinds of biological puzzles identified by Hjort. Such future paradigms would also require precautionary approaches that address multiple management objectives (ecological, economic, social) while also prioritizing models with higher certainty and complexity.

Such new paradigms would inevitably build on the foundation that Hjort created. The scientists who work to develop and use these new scientific approaches would be wise to also consider the past. The 2019 Hjort Symposium, with its unusual combination of marine researchers and historians, proved to be successful and stimulating for both groups. Fisheries scientists and historians should join forces in revisiting the past, for a deeper understanding of both successes and failures, and at the same time stimulate and inform each other in a search for approaches to current and future challenges.

Supplementary data

Supplementary material is available at the *ICESJMS* online version of the manuscript.

Acknowledgements

The Scientific Steering Committee is warmly thanked for taking part in the production of the scientific program as well as chairing sessions: Gregory Ferguson-Cradler (University of Bergen), Bronwyn M. Gillanders (University of Adelaide) (until mid-April 2019), Jane Aanestad Godiksen (IMR) (from mid-April 2019), Brian R. MacKenzie (DTU Aqua, representing also ICES, giving a Welcome and Summing-Up Speech), Tom J. Miller (Chesapeake Biological Laboratory, University of Maryland), and Helen Rozwadowski (University of Connecticut). We would also like to acknowledge the members of the Local Organizing Committee for invaluable help: Andreas Angerman (IMR), Kathrin Gjerdevik (IMR), Anne Karin Hufthammer (University Museum of Bergen), Thassya dos Santos Schmidt (IMR), Gunnar Sætra (IMR), Peter Tjørnevik, Kari Østervold Toft (IMR), and Monica Tolleshaug (IMR).

Funding

The symposium was sponsored by IMR (www.imr.no), ICES (http://www.ices.dk/events/symposia/Pages/Johan-Hjort-symposium.aspx), International Commission of the History of Oceanography (ICHO) (https://oceansciencehistory.wordpress.com), and a grant from The Research Council of Norway (NFR project number 298274) (www.forskningsradet.no).

Data availability statement

No research data as such were extracted or consulted as part of the production of this article.

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