"Linking Herring": do we really understand plasticity?

Mark Dickey-Collas, Maurice Clarke, and Aril Slotte

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M. Dickey-Collas: Wageningen IMARES, PO Box 68, 1970 AB IJmuiden, The Netherlands. M. Clarke: Marine Institute, Rinville, Oranmore, Co. Galway, Ireland. A. Slotte: Institute of Marine Research, PO Box 1870, Nordnes, 5817 Bergen, Norway. Correspondence to M. Dickey-Collas: tel: +31 317 487166; fax: +31 317 487326; e-mail: mark.dickeycollas@wur.nl

When you study herring, there are no wrong answers.
A. J. Geffen ("Linking Herring" Symposium, 2009)

The symposium was organized to link our understanding of herring biology, population dynamics, and exploitation in the context of ecosystem complexity. It is beyond argument that herring play a pivotal role in shaping the structure and dynamics of many boreal continental-shelf ecosystems. Therefore, in moving to an ecosystem approach to fishery management, the time seemed right for ICES to hold another herring symposium. Since the last ICES symposia on herring in the 1960s ("Herring Symposium", 1961; "Biology of Early Stages and Recruitment Mechanisms of Herring", 1968), many of the old paradigms have been rejected, and substantial progress has been made by striking out along new avenues. In addressing this particular topic, we were also able to follow on from the decadal herring symposia series held in North America, and thus cover new research from both the ICES and PICES communities.

The symposium took place from 26 to 29 August 2008, at the National University of Ireland, Galway, Ireland. The conference was co-sponsored by the Marine Institute (Ireland), Institute of Marine Research (Norway), ICES, the Irish Tourist Board, PICES, and Wageningen IMARES (the Netherlands), and was supported by GLOBEC. In total, there were 80 presentations: 64 oral and 16 posters. These studied the Atlantic (NE and NW), Pacific (NE and NW), Baltic, and Arctic herrings. Delegates, 100 in total, attended from Ireland, the UK, Norway, Denmark, Italy, France, the Netherlands, Germany, Canada, the United States, Russia, Latvia, Iceland, and Poland. The local organization was lead by MC (Marine Institute) and Patricia Walsh (National University of Ireland, Galway).

At this gathering in Galway in summer of 2008, it became clear that the subject of herring still stirs strong and often divergent opinions. We surmise that this engagement reflects both the plasticity of the species and the diversity of people's experiences of working with local stocks. Many of the notions that have evolved over the last 400 years have been abandoned. As clearly illustrated by our keynote speaker, Mike Sinclair, as we learn more about herring, our general understanding of fisheries and the marine environment also changes. Shifts in productivity of populations—typical of small pelagic fish species—challenge our ideas of how fishery science and management should cope with biomass reference points. The flexibility in spawning time within and between regions—in every month of the year, there are herring spawning somewhere in the northern hemisphere—and the highly complex population structure, with barely- or non-detectable genetic differences, mean that we must question the standard concept of the unit stock. The concept of herring "changing their minds" and "learning" new migration routes leads to problems when developing standard survey techniques and assessing stocks.

Herring occupy key positions in relatively simple trophic systems (e.g. Norwegian Sea, and Baltic Sea), but are also found in more complicated systems (North Sea, Celtic Sea, Bay of Fundy, and the eastern Pacific), and to species such as cod, they are both predator and prey. The determination of their key role in ecosystem functioning remains a challenge to scientists. One rule, which holds true universally, is that herring spawn benthic eggs; however, the substratum varies with the stock, ranging from intertidal macrophytes to offshore gravel beds.

In many ways, the herring is a model fish for study. Many stocks have been of great economic importance for centuries, a factor that has contributed to long time-series of statistics and other datasets. Overexploitation of some stocks has resulted in their collapse, so providing more empirical insight into the population dynamics at low biomass than is available for almost any other fish species. Because of the herring's commercial importance to many fishing nations, research has been extensive and is also core to the work of ICES. Consequently, we have a large library of work from the last 150 years to draw on when formulating and testing hypotheses. The intensive surveying of many stocks provides valuable information about migrations, life-history strategies, and population dynamics. As herring are spread across the boreal waters of the Atlantic and Pacific, there are many populations on which to test our ideas and assumptions.

Scientists who study herring are often asked "Why do you think herring are special?" The answer, of course, is that they are not, except in the way that all species are different from each other. Each species is characterized by specific life-history strategies, physiological constraints, habitat requirements, etc. Nevertheless,

there are certain things about herring that break the general paradigms for commercially exploited finfish and make them special. The herring represents a successor of a very early teleost, and some of its characteristics still show its freshwater origin. The species can spawn at any time of year, and its distribution ranges from almost fresh (Baltic) to oceanic (Norwegian Sea) waters. As a consequence, the herring fails to fit into a distinct box (which is what we, as scientists, so often require). This issue may be illustrated by a recent debate between an author and an editor about how best to describe the spawning habitat of North Sea autumn-spawning herring and Norwegian spring-spawning herring: coastal, offshore, along the coast, or off the coast? In terms of recruitment dynamics, the unusually high hatching densities of larvae emerging from the extensive egg beds suggest that herring are probably different from fish which produce pelagic eggs that are instantly spread out spatially. As referred to at "Linking Herring", the effective population size (in terms of genetics) of some herring stocks is often so large that it cannot be measured. This also contrasts with genetic studies on most other exploited fish stocks. From discussions on fishery-induced evolutionary change, it appears that the investigators of herring stocks have failed to show evidence for declining trends in maturity- and size-at-age, as seen in cod or plaice (which are inferred to result from exploitation), despite—or perhaps because of—collapse and recoveries of populations. Is this an example of phenotypic plasticity reducing an evolutionary response?

So what did we learn at "Linking Herring"? The science of estimating biomass of exploited populations appears to be strong and adaptive to stock-specific problems and to the varying data available. John Simmonds demonstrated, for North Sea herring, that the effort being given to improve the methods for "counting fish" and developing novel techniques is paying off in terms of assessment quality. More generally, the border between research surveys and information from commercial vessels is becoming increasingly blurred. Nevertheless, when trying to estimate a biomass or a number, we should always be aware that a population can suddenly change its behaviour, in response to exploitation or to the environment. Nothing can be assumed to be fixed for all time. There is little information on the less-exploited stocks, which limits our understanding of the mechanisms operating at the edges of the distribution.

Audrey Geffen gave a stimulating presentation on recent advances in herring biology. Although fishery scientists tend to think in terms of tonnes of fish, every single herring appears to be different. The fertilization success rate on eggs of the sperm produced by individual males differs and also varies with each female. A choice is made at some point in time by each individual to invest in growth and/or in maturation, and it determines the rate of atresia in the ovaries and the likelihood of skipping spawning during a particular year. The empirical evidence suggests that "skipped spawning" is a rare event. Such choices may also determine spawning time. We were taught that the focus on herring as a pelagic species ignores its close association with specific substrata and topographic features. If we are too blinkered by the assumption of constant natural mortality in our assessment models, we may forget that varying numbers of herring die by different causes every year. The general theme was that the biology of the individual should be taken into account when trying to model the population dynamics within an ecosystem.

People have been heard to ask how such a "primitive" teleost can be so resilient to exploitation? Although it is true that herring have sustained huge fisheries and also appear able to recover quickly after collapse, managing these fisheries for sustainable exploitation remains problematic. It is, by definition, difficult to sustain industries on a boom-and-bust basis without a strong resolve to maintain agreements about targets and associated actions. When the North Sea herring stock collapsed in the 1970s, the assessments relied on catch per unit effort as an indicator of abundance. This index of abundance was found to be misleading for a schooling species, because high-intensity surveys have been used to provide fishery-independent indices of abundance. Some stocks support fisheries which are large enough to warrant the costly surveys that provide valuable data for ecologists in addition to data for assessment scientists. However, this approach cannot be used for small stocks, and recent financial constraints may necessitate cuts and changes, even for the larger stocks. The over-reliance on surveys has induced inertia and may have blinded fishery scientists to the development of cheaper options; now new ways are being sought, involving closer cooperation and partnerships with fishers, to tackle stocks for which fewer data are available. We must accept that information-poor situations demand risk-averse management and, consequently, lower target yields.

As our understanding increases, the concept of the unit stock is being more and more questioned. Does it really matter for sustainable exploitation whether populations mix or are connected? New thinking is required to address the complex meta-population structure. Evidence for interstock connectivity is being identified in the signals from both commercial and research-vessel catch compositions at a regional level, which are not identified at a stock-area level. Fortunately, these scientific questions are attracting scientists from outside the assessment world because the species provides an interesting model for studies of population integrity and connectivity. Dave Secor described potential approaches for testing hypotheses about herring at a meta-population level, and many contributions addressed techniques for tracking individuals originating from different components. Nearly all involved apportioning dead fish to a particular origin, but tagging has also proven useful. Even so, more research is needed to understand better the interactions of population size, recruitment, growth, drift, migration, and mixing. Simulation frameworks to test various ideas were presented, and these may help us address this issue for a variety of unit stocks.

The ultimate objective of "Linking Herring" was to consider the herring as the focus in the dynamic ecosystems in which it is present. Andrew Bakun showed that this is a challenging concept. He described herring, in relation to cod, as "zebras that eat lion cubs" and illustrated a range of conceptual scenarios that might be considered appropriate. All the possible outcomes were difficult to investigate based on empirical data, particularly because it is unlikely that any system would remain stable and, therefore, relationships would be changing continuously. The examples given of herring impacting on whales, salmon, zooplankton, cod, seals, and pelagic fish eggs strongly supported this message. The lack of presentations on herring as indicators of ecosystem well-being suggests that research in this field has not yet matured, although there is a tendency to manage herring as a core component in the Baltic. Examples were also given of the impact of disease on herring populations, and a broad discussion noted that it was our naivety that prevented us from taking serious account of the underlying dynamics of mortality. Why do we think that fish, especially a highly schooling and abundant fish such as the herring, do not suffer disease that may restrict growth,

reduce recruitment, or increase mortality? Disease may not matter when managing herring as a single stock using within-year surveys, but it may well influence the projections of stock dynamics and the management of herring within an ecosystem.

The session on managing change again centred on single-stock management. Most contributors acknowledged that population characteristics are not stationary but, even so, we must try to achieve resilience to exploitation. There was also consensus with Martin Pastoors that management plans must be developed in liaison with stakeholders. The move towards harvest control rules, and the testing of these rules through simulation, was seen as a positive advance but, again, almost all simulations treated herring as if they were operating in isolation of the system and solely controlled by their own dynamics.

According to expectations, "Linking Herring" was an exciting symposium that successfully described state-of-the-art herring science and management. However, there are still huge challenges ahead, particularly in understanding the role of the herring within the ecosystem approach and how to translate this into practicable management measures. Fixed rules appear to be few, and any current paradigm is likely to shift in future. Exploiting herring in a sustainable manner may never be possible because its populations naturally come and go, even without exploitation. The example of Norwegian spring-spawning herring shows us that the choices of individuals belonging to a highly plastic species results in populations that adapt and vary over time. Our most important task is to ensure that any assumptions underlying management advice reflect this plasticity, even if we do not understand its genetic and phenotypic origin completely.

We regret that these proceedings cannot include all oral and poster presentations, or even cover the total range of issues addressed. However, we feel that they do provide a historical perspective, an overview of the current landscape, and a panoramic prospect of the future, which in combination may serve as another milestone in herring research in the broader context of sustainable exploitation of our seas. We thank Niels Daan for his energetic and constructive editing of these proceedings in the ICES Journal of Marine Science.

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