Deep-Sea Research Part II 159 (2019) 1–3

Contents lists available at ScienceDirect

Deep-Sea Research Part II

journal homepage: www.elsevier.com/locate/dsr2

Drivers of dynamics of small pelagic fish resources: environmental control of long-term changes

1. Background

Populations of small pelagic fish (SPF), also called forage fish, such as sardine, anchovy, herring, capelin, mackerel and other species provide about 25% of the total annual yield of capture fisheries globally. The well-being of many coastal communities around the world, particularly in developing countries, depends critically on these resources. Population sizes of SPF exhibit extreme fluctuations in abundance and geographic distribution due to the impact of environmental factors, which are often amplified by anthropogenic influences. Despite many internationally coordinated research efforts, we still do not have sufficient knowledge about the drivers of SPF recruitment and particularly the interactive effects of environmental and anthropogenic factors.

The Fisheries and Agriculture Organization (FAO) and Intergovernmental Oceanographic Commission (IOC) organized in 1983 an international symposium titled "*The Expert Consultation to Examine Changes in Abundance and Species Composition of Neritic Fish Resources*" in San José, Costa Rica (FAO Fisheries Report 291, 1983, 3 Volumes). The symposium was a major success and inspired many research efforts on SPF for the next three decades.

As there had been no global symposium on SPF since 1983, and the exchange of information about SPF globally had declined since the end of the GLOBEC project in 2008, a PICES/ICES international symposium on *"Drivers of Dynamics of Small Pelagic Fish Resources"* was organized from 6-11 March 2017 in Victoria, BC, Canada, (https://www.pices.int/smallpelagics2017) as a follow-up event to the FAO/IOC Conference. The goal of the symposium was to revitalize global international cooperation on investigations of SPF.

The symposium was organized around six themes:

1. Environmental control of spatio-temporal changes in population size, distribution and migration of small pelagic fish in the ecosystem context
2. External drivers of change in early life history, growth and recruitment processes
3. The role of small pelagic fish in food web dynamics between plankton and top predators
4. Comparison of methods for assessment of small pelagic fish populations
5. Future challenges for ecosystem-based management of highly variable fish populations
6. Small pelagic fish and humans - social, economic and institutional dimensions.

Whereas contributions to the latter five topics are published as a Theme Section in the journal Marine Ecology Progress Series (Alheit and Peck, in press), this Special Issue focuses on the first topic. Planktivorous SPF species display specific patterns of behavior and growth dynamics different from higher trophic level species. Firstly, they are more volatile in their spatial distributions and may, to a larger extent than demersal and piscivore fish species, expand beyond the characteristic boundaries of Large Marine Ecosystems (LMEs) with respect to both feeding areas and spawning areas. Secondly, they display particularly large temporal and spatial variability in their abundances on interannual to decadal and multidecadal timescales with oscillations between close to extinct populations to extremely high abundances. These features seem independent of the structure and function of the particular ecosystem which they inhabit and have also been occurring historically and prior to the increasing fishing pressure developed during the second half of the 20th century. We see such features in the large eastern boundary upwelling ecosystems as well as in high-latitude spring-bloom ecosystems from temperate regions to the Arctic. These responses indicate that they could be more sensitive to environmental variability than other fishes, although the kind of environmental variability differs considerably between the various ecosystems. Climate variability on decadal to multidecadal scales linked to large scale climate modes such as the El Niño Southern Oscillation, North Atlantic Oscillation, Atlantic Multidecadal Oscillation and Pacific Decadal Oscillation has been shown to be an important factor for large-scale population fluctuations and migrations as demonstrated by observations sometimes stretching over centuries. Also, there are periods of alternating sardine- or anchovy-dominated ecosystems separated by regime shifts, when the species composition of the pelagic zone changes substantially, a puzzle we are still attempting to understand. These are the themes of the 15 contributions of this Special Issue,

2. Highlights of papers appearing in this volume

Two articles explore the long-standing suggestion of synchronous alternations between sardines and anchovies. Izquierdo et al., (2019) re-examine the hypothesis that sardine (*Sardinops* spp.) and anchovy (*Engraulis* spp.) populations fluctuate synchronously on a global basis whereby the two species alternate. Their analyses include additional populations outside of the eastern and western boundary currents and extend the data up to 2015. The results show that the hypothesis of synchrony does not hold, as only sardines and anchovies in the Humboldt and Kuroshio currents exhibit synchronous population fluctuations with alternations between both species. Oozeki et al., (2019) focus their study on these two current systems and include jack mackerel (*Trachurus* spp.) and chub mackerel (*Scomber* spp.). They confirm the results with respect to anchovies and sardines, but show that there is no synchronous alternation between the other species.

The Salish Sea (all inland marine waters of Washington State and British Columbia) is the most northern area of distribution of the

https://doi.org/10.1016/j.dsr2.2018.12.005

northern anchovy (*E. mordax*) along the west coast of North America. A noticeable very recent increase in its abundance led Duguid et al., (2019) to compile recent and historical qualitative and quantitative fishery-dependent and -independent data to understand spatio-temporal patterns of distribution and fluctuations in abundance over the last century. The anchovy is found to be a resident of the Salish Sea and continued warming might lead to greater abundance of this species with potentially important consequences for the entire ecosystem.

Hay et al., (2019) demonstrate that age-specific declines in length and weight of Pacific herring (*Clupea pallasi*) in British Columbia occurred from 1985-2010 concurrently with decreasing egg density as estimated by the numbers of egg layers on spawning grounds. They conclude that climate-induced changes in herring growth, beginning in the first year of life, can subsequently impact parameters of reproduction and spawning behavior.

In a thorough, complex study to find the reason for the recent decrease in size and condition of sardine (*Sardina pilchardus*) and anchovy (*E. encrasicolus*) in the Gulf of Lions in the Mediterranean Sea, which has been reflected in lower landings, Saraux et al., (2019) conclude that neither fisheries impact nor top down control or diseases are the cause. Instead, a dietary shift to smaller zooplankton prey species seems to be responsible for the changes.

Silva et al., (2019) use a novel methodology to evaluate connectivity and spatial structure of a metapopulation of the European sardine (*S. pilchardus*) inhabiting the Bay of Biscay and the waters off the Iberian peninsula. The results highlight the need to explore multi-area/metapopulation assessment approaches and to account for the higher risks of depleting source areas and/or less productive sub-populations.

Using a novel approach to identify aggregation structures at two different spatial scales (large and meso-scale structures), Moron et al., (2019) find that the temporal and spatial variations of the aggregation behavior, and biomass values, of the Peruvian anchovy (*E. ringens*) are highly influenced by seasonal changes and El Niño events.

Jurado-Ruzafa et al., (2019) evaluate the impact of seasonal changes in SST and chlorophyll-a on the landings of the most important SPF around the Canary Islands. They find that cooler seasons (lower SST and higher Chl-*a*) are characterized by catches of Atlantic chub mackerel (*Scomber colias*) and horse mackerels (*Trachurus* spp.), and warmer seasons (higher SST and lower Chl-*a*) by sardines (*S. pilchardus*) and sardinellas (*Sardinella* spp.).

SPF constitute the bulk of the landings of Northwest African countries bordering the Canary Current. Lakhnigue et al., (2019) highlight the challenges encountered and the contributions delivered to science-based fisheries management by the regional FAO Working Group on the Assessment of Small Pelagic Fish within the framework of the collaboration by the Northwest African countries.

Martínez-Rincón et al., (2019) evaluate the effects of environmental forcing at multiple spatial scales (local, regional, basin-wide) on the variability of Pacific sardine (*Sardinops sagax*) catches at three widely separated fishing ports in Canada, the US and Mexico using generalized additive models. They show that changes in Pacific circulation, sea surface temperature, upwelling strength and primary productivity are the most influential factors explaining Pacific sardine variability.

Three articles analyze the impact of climate variability on the dynamics of SPF. Ma et al., (2019) examine the relationship between the Arctic Oscillation Index and the East Asian Winter Monsoon Index on six pelagic species in the marginal China seas. Catches of anchovy (*E. japonicus*), sardine (*Sardinops melanostictus*) and herring (*C. pallasi*) reflected clearly decadal climatic shifts in the late 1980s and the mid-1990s. Alheit et al., (2019) show that Northeast Atlantic marine ecosystems such as the Bay of Biscay, Celtic Sea, English Channel, Subpolar Gyre region, Icelandic waters and North Sea as well as the Mediterranean Sea exhibited concomitant 'regime shift'-like changes around the mid-1990s, which involved all biota of the pelagial: phytoplankton, zooplankton, pelagic fish assemblages, demersal fish assemblages and top predators. These shifts were caused by complex ocean-atmosphere interactions initiating large-scale changes in the strength and direction of the current systems, that move water masses around the North Atlantic, and involved the North Atlantic Oscillation (NAO), the Atlantic Meridional Overturning Circulation (AMOC), and the subpolar gyre (SPG). The contractions and expansions of the SPG and fluctuations of the Atlantic Multidecadal Oscillation (AMO) play a key role in these complex processes. SPF population trends were the sentinels of these changes in the mid-1990s in the ecosystems under investigation. Tsikliras et al., (2019) examine the effect of the AMO and the NAO on eight Mediterranean SPF using various catch ratios and the mean temperature of the pelagic catch (MTpC) method for the period 1970-2014. The SPF in the central and eastern Mediterranean responded most strongly to AMO variability, whereas those of the central and western Mediterranean also reacted to NAO variability, so reflecting the known differential regional impact of both oscillations.

A fourth article (Olafsdottir et al., 2019) suggests that the recent geographical extension of Northeast Atlantic mackerel (*Scomber scombrus*) in the Nordic Seas was determined by spawning biomass stock size and temperature. These distributional changes of mackerel were probably also associated with the AMO, but this was not further evaluated in the article.

Erauskin-Extramiana et al., (2019) analyze the historical evolution of anchovy (*E. encrasicolus*) spawning in the Bay of Biscay and assess the impact of future warming on spatial-temporal spawning distribution. Their findings suggest that the suitable spawning habitat, egg production and, hence, anchovy population size will increase by mid- and end-of-the-21st century under the RCP8.5 climate change scenario.

This symposium presented the state of the art of research on SPF and, by emphasizing new methods and approaches, provided a deeper understanding on the drivers of dynamics of SPF resources, as exemplified by the articles of the two special issues. The symposium participants were a mixed interdisciplinary group of physical oceanographers, plankton experts, fish biologists, fisheries experts, economists and social scientists who all contributed to provide a cross-cutting integrative view of recent research on SPF. The aim of the symposium was to revitalize global international cooperation on investigations of SPF. Towards this goal, the attendees were encouraged to develop an international cooperative framework, including regular future symposia, to identify and investigate unresolved questions in relation to SPF.

Acknowledgments

We thank the primary international sponsors of the symposium, PICES and ICES, and the local sponsor, Fisheries and Oceans Canada, for organizing the event. Additional support was received from FRA (Fisheries Research and Education Agency, Japan), FAO (Food and Agriculture Organization of the United Nations), GFCM (General Fisheries Commission for the Mediterranean), IFFO (The Marine Ingredient Organization), IMBER (Integrated Marine Biogeochemistry and Ecosystem Research), IRD (Institut de Recherche pour le Développement, France), JSFO (Japanese Society of Fisheries Oceanography, Japan), JSFS (Japanese Society of Fisheries Science, Japan), NOAA-Fisheries (National Marine Fisheries Service, USA), NPFC (North Pacific Fisheries Commission), NPRB (North Pacific Research Board, USA), SCOR (Scientific Committee on Oceanic Research), and WWF-Canada (World Wildlife Fund Canada). Without their generous support the symposium and this special issue would not have been possible.

References

Alheit, J., Peck, M.A., 2019. Drivers of dynamics of small pelagic fish resources: biology, management and human factors. Mar. Ecol. Prog. Ser (In press).

Alheit, J., Gröger, J., Licandro, P., McQuinn, I.H., Pohlmann, T., Tsikliras, A.C., 2019. What happened in the mid-1990s? The coupled ocean-atmosphere processes behind

climate-induced ecosystem changes in the Northeast Atlantic and the Mediterranean. Deep-Sea Res. Part II. 159, 130–142.
Duguid, W., Boldt, J., Chalifour, L., Greene, C., Galbraith, M., Hay, D., Lowry, D., McKinnell, S., Qualley, J., Neville, C., Sandell, T., Thompson, M., Trudel, M., Young, K., Juanes, F., 2019. Historical fluctuations and recent observations of Northern Anchovy in the Salish Sea. Deep-Sea Res. Part II. 159, 22–41.
Erauskin-Extramiana, M., Alvarez, P., Arrizabalaga, H., Ibaibarriaga, L., Uriarte, A., Cotano, U., Santos, M., Ferrer, L., Cabré, A., Irigoien, X., Chust, G., 2019. Historical trends and future distribution of anchovy spawning in the Bay of Biscay. Deep-Sea Res. Part II. 159, 169–182.
Hay, D., Schweigert, J., Boldt, J., Thomson, M., 2019. Temporal changes in size-at-age: impacts and implications for reproductive biology, egg density and management of Pacific herring in British Columbia. Deep-Sea Res. Part II. 159, 42–51.
Izquierdo-Peña, V., Lluch-Cota, S.E., Hernandez-Rivas, M.E., Martínez-Rincón, R.O., 2019. Revisiting The Regime Problem hypothesis: 25 years later. Deep-Sea Res. Part II. 159, 4–10.
Jurado-Ruzafa, A., González-Lorenzo, G., Jiménez, S., Sotillo, B., Acosta, C., Santamaría, M.T.G., 2019. Seasonal evolution of small pelagic fish landings index in relation to oceanographic variables in the Canary Islands (Spain). Deep-Sea Res. Part II. 159, 84–91.
Lakhnigue, A., Tandstad, M., Fuller, J., Sambe, B., Caramelo, A.M., 2019. More than fifteen years of collaboration on the assessment of small pelagic fish off Northwest Africa: lessons learned and future perspectives. Deep-Sea Res. Part II. 159, 92–102.
Ma, S., Cheng, J., Li, J., Liu, Y., Wan, R., Tian, Y., 2019. Interannual-decadal variability in the catches of small pelagic fishes from China seas and its responses to climatic regime shifts. Deep-Sea Res. Part II. 159, 112–129.
Martínez-Rincón, R.O., Saldívar-Lucio, R., Morales, M., Lluch-Cota, S.E., Lluch-Cota, D.B., Salvadeo, C., Ponce-Díaz, G., 2019. Contribution of ocean variability to climate-catch models of Pacific sardine. Deep-Sea Res. Part II. 159, 103–111.
Moron, G., Galloso, P., Gutiérrez, D., Torrejon-Magallanes, J., 2019. Temporal changes in meso-scale aggregations and spatial distribution scenarios of the Peruvian anchovy (*Engraulis ringens*). Deep-Sea Res. Part II. 159, 75–83.
Olafsdottir, A.H., Utne, K.J., Jacobsen, J.A., Jansen, T., Óskarsson, G.J., Nøttestad, L., Elvarsson, B.Þ., Broms, C., Slotte, A., 2019. Geographical expansion of Northeast Atlantic mackerel (Scomber scombrus) in Nordic seas from 2007 to 2016 was primarily driven by stock size and constrained by low temperatures. Deep-Sea Res. Part II. 159, 152–168.
Oozeki, Y., Ñiquen, M., Takasuka, A., Ayón, P., Kuroda, H., Tam, J., Okunishi, T., Vásquez, L., Gutiérrez, D., Okamura, H., Guevara-Carrasco, R., 2019. Synchronous multi-species alternations between the Northern Humboldt and Kuroshio Current systems. Deep-Sea Res. Part II. 159, 11–21.
Saraux, C., van Beveren, E., Brosset, P., Queiros, Q., Bourdeix, J.-H., Dutto, G., Gasset, E., Jac, C., Bonhommeau, S., Fromentin, J.-M., 2019. Small pelagic fish dynamics: A review of mechanisms in the Gulf of Lions. Deep-Sea Res. Part II. 159, 52–61.
Silva, A., Garrido, S., Ibaibarriaga, L., Pawlowski, L., Riveiro, I., Marques, V., Ramos, F., Duhamel, E., Iglesias, M., Bryère, P., Mangin, A., Citores, L., Carrera, P., Uriarte, A., 2019. Adult-mediated connectivity and spatial population structure of sardine in the Bay of Biscay and Iberian coast. Deep-Sea Res. Part II. 159, 62–74.
Tsikliras, A.C., Licandro, P., Pardalou, A., McQuinn, I.H., Gröger, J.P., Alheit, J., 2019. Synchronization of Mediterranean pelagic fish populations with the North Atlantic climate variability. Deep-Sea Res. Part II. 159, 143–151.

Jürgen Alheit[1,*]
Leibniz Institute for Baltic Sea Research
Seestr. 15, 18119 Warnemünde, Germany
E-mail address: juergen.alheit@io-warnemuende.de.

Emanuele Di Lorenzo
School of Earth and Atmospheric Sciences
Georgia Institute of Technology
311 Ferst Drive, Atlanta, GA 30332, USA

Ryan R. Rykaczewski
School of the Earth, Ocean & Environment
Department of Biological Sciences, University of South Carolina
Columbia, SC 29208, USA

Svein Sundby
Institute of Marine Research, P.O. Box 1870 Nordnes
Bergen, N-5817 Norway

* Corresponding author.
[1] Present address: Hohe Lieth 12, 27607 Geestland, Germany