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Fisheries Oceanography: The First 30 Years and New Challenges in the 21st Century

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Abstract. The journal *Fisheries Oceanography* provides a global forum for fisheries scientists and oceanographers to understand how marine ecosystems, and the services they provide to society, are structured and shaped by environmental variability and climate change. With this Special Issue, as well as the 30th Anniversary Virtual Issue of the most influential papers from the journal's history, we commemorate 30 years of publishing leading research in the field of fisheries oceanography. These Issues showcase the extent, depth and impact of the research published in *Fisheries Oceanography*. We also reflect on the evolution of research themes through the journal's history, and highlight key emergent themes in our field. We look forward to continuing to publish impactful research in the pages of *Fisheries Oceanography* in the years ahead.

The 30th Anniversary of *Fisheries Oceanography* (1992-2022)

The field of fisheries oceanography can be said to have originated with the 1914 publication of 'Fluctuations in the Great Fisheries of Northern Europe Viewed in the Light of Biological Research' by Johan Hjort in *Conseil Permanent International Pour l'Exploration de la Mer: Rapports et Procès-Verbaux des Réunions*. Motivated by an interest in understanding the effects of migratory behavior and fishing on the abundance of key European fisheries, Hjort found that changes in migration had a minimal effect on the number of spawning adults, but that year-class strength was largely (environmentally) driven by the success of first-feeding larvae and eventual recruitment into the spawning stock (Hjort, 1914, 1926). This "critical period hypothesis", that survival of fishes at the early larval stage is the primary driver of year-class variability (Houde, 2008), remains a core research theme in fisheries oceanography more than a century after Hjort, reflecting the persistent challenges of understanding how changes in the ocean environment impact marine populations and the critical ecosystem services they provide to society (Barange et al., 2014; Bograd et al., 2014; Hare, 2014).

In March 1992, 78 years after the seminal Hjort paper, the first issue of *Fisheries Oceanography* was published. From its inception, the journal has had leading fisheries oceanographers at its helm, with Dr. Timothy Parsons[1] serving as founding Editor-in-Chief (1992-1997), followed by Dr. Michael Mullin (1997-2000), Dr. David Checkley (2000-2014) and Dr. Steven Bograd (2015-present). Many leading scientists have served as Associate Editors of the journal, as well as on the Editorial Board (https://onlinelibrary.wiley.com/page/journal/13652419/homepage/editorialboard.html). One of Dr. Parsons' key motivations for founding the journal was to unify the previously 'separate' fields of fisheries and ocean sciences. As we celebrate our first three decades of publishing leading research in fisheries oceanography, we also recognize that the world has changed dramatically since that first issue was published. The natural environmental fluctuations studied by Hjort are now compounded by a rapidly changing climate, in addition to numerous other

[1] "It might be of historical interest to know that the founding of this journal was a combined effort of several persons who supported the idea of fisheries oceanography as a scientific discipline. These persons include Professor Takashiga Sugimoto (Ocean Research Institute, The University of Tokyo), Professor Michitaka Uda (Japanese Society of Fisheries Oceanography) and Dr. John Strickland (who was my early mentor in marine science). It was largely due to their support that I became the founding Editor of a new journal called *Fisheries Oceanography*." – Dr. Timothy Parsons, *Fisheries Oceanography* founding editor, pers.comm., 2021.

human-induced stressors on the ocean environment, including over-fishing, pollution, and loss or degradation of habitat (Halpern et al., 2015). In 1990, the IPCC reported that emissions from human activities were “substantially increasing” greenhouse gas concentrations in the atmosphere, which would lead to warming. By 2013, the panel had concluded that “it is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century.” In the latest IPCC report, published in 2022, the panel said "It is a statement of fact, we cannot be any more certain; it is unequivocal and indisputable that humans are warming the planet." This warming is "already affecting many weather and climate extremes in every region across the globe". In the context of a changing climate, it has become even more critical to understand how environmental drivers impact the structure and function of marine ecosystems, including the world’s fish stocks upon which society is so dependent.

Seafood harvests from the global oceans, together with inland waters, provide ‘more than 20% of dietary animal protein for more than 3.3 billion people worldwide and livelihoods for about 60 million people’ (FAO 2020; Cooley et al. 2022). The increasing necessity of sustaining healthy and productive marine ecosystems, and contributing to an expanding global ‘blue economy’ (Pauly, 2018), underlines the importance of advancing our understanding of the interaction between marine fish and their environments across multiple life-history stages. By seeking to elucidate mechanistic relationships between fish species and their surrounding oceanic habitats, the field of fisheries oceanography aims to provide a solid understanding of fish behavior, population dynamics, and life history with an ecosystem perspective (Bograd et al., 2014). As it has for 30 years, *Fisheries Oceanography* aims to provide a global forum for fisheries scientists and oceanographers to understand how marine ecosystems, and the services they provide to society, are structured and shaped by environmental variability and climate change. The journal’s scope differentiates it from other journals in marine science and fisheries, emphasizing:

- original research relating the production and dynamics of fish populations to the marine environment;
- examining entire food chains and their community interactions - not just single species;
- identifying mechanisms controlling abundance, including anthropogenic factors and climate/oceanographic variability;
- exploring factors affecting the recruitment and abundance of fish species and all higher marine trophic levels.

Here we commemorate 30 years of publishing leading research in fisheries oceanography (**Figure 1**), and look forward to continuing to publish impactful research in the years ahead.

Virtual Issue of Most Influential Papers

Fisheries Oceanography has been publishing important research on these and other themes for 30 years now, reflecting, and leading, advances in the field of fisheries oceanography. To celebrate the journal's influence and the contributions of the many authors who have published their research in our journal, we have published a 30th Anniversary Virtual Issue. This collection contains 30 of the most influential papers from the journal's history, selected by the Editors, and showcases the extent and depth of research topics published within the journal. While our selection of the top papers was subjective, it was informed by the Editors' varied proficiency in different research topics, as well as our regional expertise in the eastern Pacific and eastern boundary current systems (SJB), the western Pacific (SI), the Atlantic and U.S. waters (JN), and the Atlantic and European waters (ME). We also considered manuscript bibliometrics, particularly the number of citations (for the older papers). Collectively, this virtual issue provides an illustration of the transformative research published in *Fisheries Oceanography* over the past three decades.

Nine papers were selected to represent the theme of '*Oceanographic Impacts on Fishery Distribution and Production*', following in the tradition of classical fisheries oceanography as established by Hjort (1914). These include Springer et al (1996), the most highly cited paper in the journal's history (615 citations as of August 2022), which describes a classic case of 'bottom-up' drivers of marine ecosystem productivity. Physical processes on the broad Bering Sea continental shelf sustain enhanced primary and secondary production, which, in combination with a thermal refuge at the shelf break, leads to aggregations of fish, squid, marine birds and mammals, high trophic transfer efficiency, and enhanced multi-trophic biomass yield. Spencer and Collie (2003) analyzed patterns of variability in 30 stocks representing different life history traits, and demonstrated that these patterns could be reproduced with simple multiple-equilibrium population models with varying intrinsic population growth rate and the time scale and amplitude of environmental variability. Other highlighted papers investigate hypotheses of environmentally-driven impacts on the distribution, feeding ecology, productivity or population dynamics of fish species off the northeast U.S. coast (Marsh et al., 2001; Hare and Able, 2006); within the Gulf of St. Lawrence (Swain, 2001); the northern North Atlantic (Dutil and Brander, 2003); within the Canary Current upwelling system off the northwest African coast (Thiaw et al.,

2017); in the central Gulf of Alaska (Kaeriyama et al., 2004); and via El Niño impacts throughout the eastern North and South Pacific (Bakun and Broad, 2003).

The critical importance of environmental drivers on mortality at early life stages, and hence recruitment into the fishery, has been a guiding principle of fisheries oceanography since Hjort (1914). Seven papers in our virtual issue were selected to represent the theme of '*Larval Ecology and Recruitment*', investigating environmental drivers of recruitment of: yellowtail flounder in the Middle Atlantic Bight (Sullivan et al., 2005); Japanese sardine and chub mackerel in the western North Pacific (Yatsu et al., 2005); cod in the North Atlantic (Ottersen et al., 2006); jack mackerel in the East China Sea (Sassa et al., 2006); European eel in the Sargasso Sea (Bonhommeau et al., 2007); and stone flounder in Sendai Bay, Japan (Yamashita et al., 2008). Stachura et al. (2014) investigated the hypothesis that synchronous recruitment across 52 marine fish stocks within three northeast Pacific large marine ecosystems is driven by shared susceptibility to environmental processes.

As already emphasized, there has been an accelerated effort in the field, and within the pages of *Fisheries Oceanography*, to understand the drivers and impacts of climate change on marine ecosystems, fisheries and marine ecosystem services. We selected six papers to represent the theme of '*Climate Impacts on Fisheries*', describing century-scale climate drivers of herring abundance in northern European waters (Alheit and Hagen, 2003); decadal variations in environmental conditions and lower trophic biomass in the subarctic Pacific and Bering Sea (Sugimoto and Tadokoro, 2003); and ecosystem responses to regime shifts in the northeast Pacific (Francis et al., 2003). Petitgas et al. (2012) investigate climate impacts on habitat availability and connectivity across life stages for several fish species in European waters, highlighting the need to integrate physiological and behavioral processes across life cycles to understand population responses to climate variability and change. Two papers focus on the impacts of specific, ecologically critical climate-driven changes: the declining mid-ocean oxygen content and changes in the timing of important seasonal processes (phenology). Prince and Goodyear (2006) describe the vertical compression of viable habitat of tropical pelagic fishes driven by the expansion of hypoxic waters in the eastern tropical Pacific. Staudinger et al. (2019) review the ecosystem impacts of shifts in timing of key seasonal processes, including earlier spring and later fall onset, on key life history events in the Gulf of Maine ecosystem, highlighting the wide-ranging, pan-trophic impacts of changing seasonal processes.

In addition to the 'classic' fisheries oceanography studies outlined above, the editors also selected two papers for each of the themes of '*Observations and Instrumentation*', '*Higher Trophic Levels*', '*Ecosystem Models*', and '*Forecasting, Projections and Management*'. Reid et al. (2003) quantify changes in North Sea zooplankton abundance using data from the Continuous Plankton Recorder survey, one of the world's longest (begun in 1931) and most geographically extensive ocean monitoring programs. Checkley et al. (2003), on the other hand, describe the new development and implementation of a continuous, underway fish egg sampler (CUFES) system, which is now regularly used on ship-based surveys to quantify species-specific fish egg distributions and estimate spawner biomass. Continuing the theme of technological advancements in ocean observing, two papers use biologging (electronic tags) to describe the movements of loggerhead turtles in the central North Pacific (Polovina et al., 2003) and bluefin tuna in the California Current System (Kitagawa et al., 2007) in relation to oceanographic features and variability. Without the foresight of these instruments and long-term modeling, key advances in fisheries oceanography could not have been made.

Advances in instrumentation and monitoring have enabled advances in ecological modeling. Lehody et al. (2003) use a spatial environmental population model to explore the hypothesis that spatial variability in oceanic conditions, food availability and predation risk constrain tuna recruitment in the tropical Pacific. Planque et al. (2010) describe population dynamic models that provide a statistical framework to investigate spatial distributions of fish constrained by environmental conditions, density-dependent habitat selection, population demographic structure, and species interactions, among other processes. More recently, progress has been made in biophysical models that inform dynamic spatial management of southern bluefin tuna in eastern Australian waters (Hobday et al., 2007) and that provide seasonal forecasts of ocean conditions off the U.S. West Coast and corresponding spatial distributions of sardine (Kaplan et al., 2015). These studies demonstrate that improved understanding of environmental and climate impacts on marine ecosystems, which is the basis of fisheries oceanography research, has important applications for the sustainable management of our living marine resources.

Advances in science, such as those represented in the papers highlighted above, require infusions of passion and new ideas. To encourage these advances, *Fisheries Oceanography* is highlighting the pioneering work being conducted by students and early career researchers across all fields of fisheries oceanography through its annual Early Career Researcher Award (https://onlinelibrary.wiley.com/page/journal/13652419/homepage/early_career_researcher_award.html?). Our first (2020) ECR awardee, Alesandro Cresci, used a biophysical advection model

to demonstrate that European eel recruitment to North Sea coastal waters is substantially enhanced through lunar-driven orientation during their migrations (Cresci et al., 2021). Our 2021 awardee, Mariana Santana-Cisneros, modeled the larval dispersal of four species of octopus in the Gulf of Mexico, showing that species-specific fertility, combined with surface temperature and circulation, drove settlement rates and eventual abundances (Santana-Cisneros et al., 2021). We look forward to publishing exciting research by a new, diverse generation of fisheries oceanographers.

The Anniversary Special Issue

To complement the Anniversary Virtual Issue of most influential papers published in *Fisheries Oceanography*, we now turn to the *future* of fisheries oceanography and publish several new peer-reviewed manuscripts that provide reviews and updates of previous research, highlight how the field has progressed, and present exciting new research on emerging themes. Leading off this issue, **Perry** (this issue) provides a memorial to the founding Editor-in-Chief of *Fisheries Oceanography*, Dr. Tim Parsons. Following this memorial, **Langan et al** (this issue) explore the capacity to rebuild fish stocks in a changing climate. Using the depleted stock of southern New England/Middle Atlantic Bight winter flounder as a case study, they employ a life-cycle model to demonstrate that environmental factors influencing juvenile mortality inhibited recovery of the stock. Furthermore, projections of recovery appear unlikely to be achieved even under favorable climate conditions and aggressive management interventions, highlighting the limitations of assessing climate-driven population trends against biological reference points set under past environmental regimes. **Schwing** (this issue) provides a review of the evolution of observing technologies and strategies used in fisheries oceanography over the 30-year period of *Fisheries Oceanography*, as well as recommendations for future observations. Across observing systems, he recognizes several common themes, including the need for long-term support through public-private partnerships, maintaining a backbone of core observations, and pursuing innovations in technology and the synthesis and dissemination of data. Noting that mortality at early life stages often constrains recruitment**, Di Stefano et al** (this issue) examine the abiotic drivers of spawning and larval dispersal, using white seabream in the Mediterranean Sea as a case study. They combined Lagrangian back-tracking simulations with early-life observations to identify and locate a number of spawning events, allowing them to model spatio-temporal variability in spawning success. **Ottersen and Holt** (this issue) approach this issue from the perspective of the adult spawning stock, and test the specific hypothesis that recruitment from spawning stocks dominated by young fish and few age classes is most vulnerable to environmental change. The authors expand upon their earlier paper (Ottersen et al., 2006), which is one of the highlighted

papers in the Anniversary Virtual Issue, to investigate Barents Sea cod dynamics over the period 1922-2019 and strengthen support for this hypothesis. **Sivel et al** (this issue) use a food-web model to explore the combined impacts of climate change and fishery pressure on the stability of the Barents Sea ecosystem, finding that fisheries amplify the effects of temperature. In particular, warming leads to a shift from synergistic to antagonistic effects between the two drivers. **Kaeriyama** (this issue) investigates the effects of a warming climate on the migration, growth and survival of southern populations of chum salmon. He reports a greater decline in population size for cold-current populations (affected by the Oyashio Current) relative to warm-current populations (affected by the Tsushima Current), suggesting that the latter population is better adapted to global warming. Finally, **Igeta et al** (this issue) conduct particle-tracking experiments from a data-assimilative numerical model of the coastal seas of the western Pacific, and show that declining recruitment of Japanese jack mackerel may be partly explained by a reduction in the transport of juveniles to Pacific coastal waters since 2000. We thank the authors for contributing these insightful papers to mark our 30th anniversary, and look forward to many years of continued advances in the field within the pages of *Fisheries Oceanography*.

Evolving and Emergent Themes in Fisheries Oceanography, 1992-2022

The research published over the first 30 years of *Fisheries Oceanography* spans a broad and evolving range of topics. An evaluation of keywords that have appeared in paper titles and abstracts reflects the changing emphasis of research themes over the years (**Figure 2**). The dominant keywords during the first decade of publishing include ‘recruitment’, ‘growth’, ‘survival’, ‘circulation’ and ‘climate’. Some keywords have persisted over the 30 years, most notably ‘recruitment’ and ‘variability’, reflecting the field’s foundational theme of relating environmental variability to fish early life history raised by Hjort more than 100 years ago. Following the first decade, new keywords emerged that represented a renewed emphasis on broader life-history studies (‘behavior’, ‘migration’), important physical processes (‘regime shifts’, ‘upwelling’), and broader applications (‘simulation’, ‘prediction’, ‘management’). In the most recent period (2010-2019), ‘climate change’ emerges as a dominant theme, along with a stronger emphasis on ‘ecosystem’.

The field of fisheries oceanography has advanced significantly since *Fisheries Oceanography* published its first issue, concomitant with advances in ecological theory, enhanced observational capacity, improvements in climate and ecological modeling, including short-term predictions and long-term projections, and implementation of new ecosystem-based management strategies. Perhaps the key emergent topic in fisheries oeanography is the exploration of climate extremes

and climate change impacts on ecosystem structure, function and dynamics. Global climate change will alter the frequency of extreme events (e.g., marine heat waves, hypoxic events) and significantly alter the marine environment. This will in turn impact the size, distribution, and abundance of marine biota, the phenology of trophic interactions, the community structure of regional ecosystems, and the availability of fisheries to coastal communities. It is particularly important to investigate the interactions between climate-driven change in fishery populations and fishing activity (Pörtner and Peck, 2010; Bundy et al., 2021). It is urgent that we better understand, and accelerate the potential to predict, climate impacts on marine ecosystems and to develop climate-resilient pathways to support marine ecosystem services.

Conclusions

Climate change is drastically changing the world's oceans, including all marine life and the productivity and resilience of marine ecosystems. Now, more than ever, the research published in *Fisheries Oceanography* is vitally important for ocean sustainability and human wellbeing. The papers we have highlighted in the Anniversary Virtual Issue and Special Issue have laid the foundation for studies that will allow us to understand the effects of climate change on the world's ocean and help us anticipate, mitigate and adapt now and into the future. We encourage our readers to contribute to advances in our field and publish their research in the pages of *Fisheries Oceanography*.

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Figure 1: History of citation numbers for papers published in *Fisheries Oceanography*.

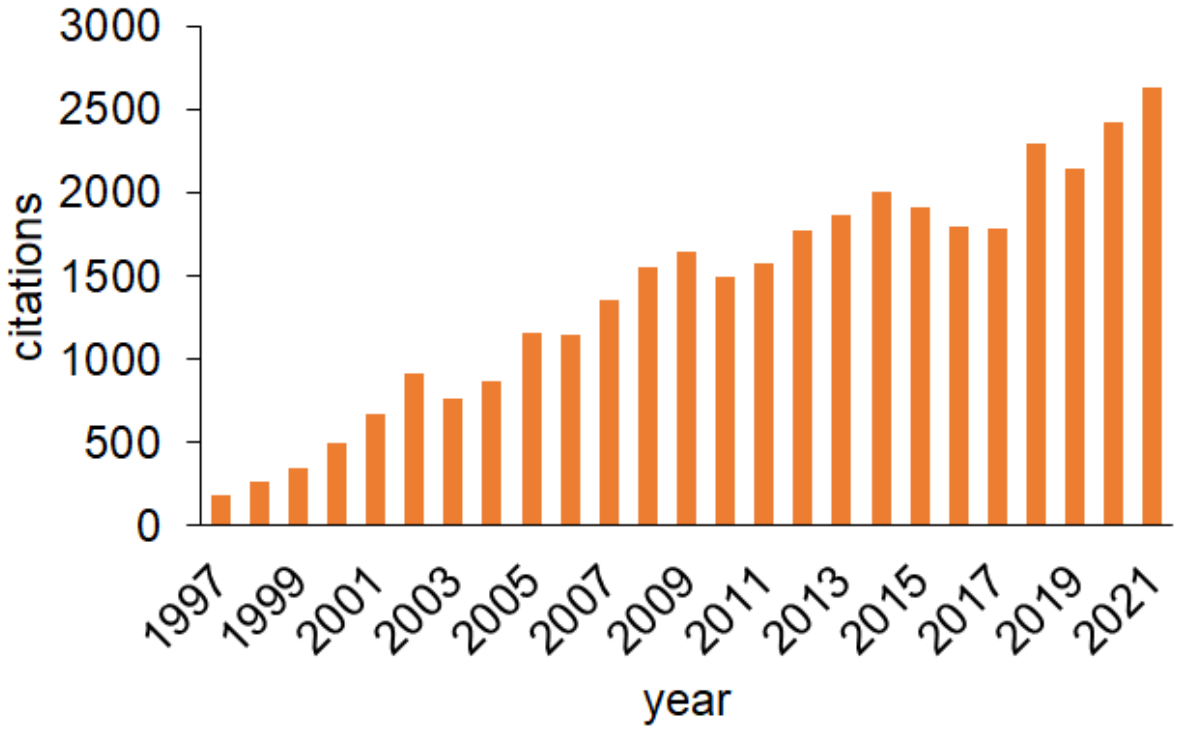

Figure 2: Keyword map for papers published in Fisheries Oceanography during (a) 1990-1999, (b) 2000-2009, and (c) 2010-2019. The size of the circles shows the overall weight of the keyword (total times it has been mentioned in journal article titles or abstracts). The lines show the links between keywords (NB only strongest links shown). Keywords are positioned in space based on other keywords that are closely related, and are clustered in colors based on similarity.