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EDITORIAL

Editorial

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Climate is a critical driver of aquatic ecosystems and fish populations, strongly influencing latitudinal, seasonal, and depth distribution and abundance of marine and inland fishes through survival, growth, reproduction, and interactions with habitat and other species (Perry et al. 2005; Pörtner et al. 2014; Lynch et al. 2016). Climate variability has been linked with fish production variability with high levels of confidence in both marine and freshwater systems (e.g., Mantua et al. 1997; Chavez et al. 2003; Lynch et al. 2015).

Unlike climate variability, climate change is shifting the baseline. Global land and ocean surface temperatures show an average increase of 0.85 °C from 1880 to 2012; since the beginning of the industrial era, oceans have increased in acidity by 26%; and between 1901 and 2010, global mean sea level has risen by 0.19 m (IPCC 2014). For both marine and inland systems, climate change related shifts in thermal, chemical, and physical habitat will continue to alter fish populations and productivity of capture fisheries (Ficke et al. 2007; Pörtner and Peck 2010; Gattuso et al. 2015; Whitney et al. 2016). In some cases, the fisheries will have the potential to expand; some will likely diminish; and yet others will remain stable but shift location (Parmesan 2006; Rahel et al. 2008; Cheung et al. 2016).

For marine systems, increasing sea temperatures, thermal expansion, glacial melting, increasing density

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stratification, acidification and dissolved oxygen are changing the habitat for marine fishes (Perry et al. 2005; Pörtner et al. 2014; Jones and Cheung 2015). But warming rates and other physical and biogeochemical impacts of climate change are not uniform; global 'hotspots,' where the ocean is warming the fastest, are often at most risk for rapid biological change (Hobday and Pecl 2014). Additionally, climate change can have an indirect effect on fish populations by influencing primary production and species composition in the habitats to which the fish have adapted (Stock et al. 2017). For inland systems, increasing temperatures, lower precipitation, and higher evapotranspiration are directly changing water levels and water quality which impact inland fish habitat (Brander 2007). While climate change-induced redistribution of species is often unencumbered in marine habitats, many inland species, such as those in headwater streams, are limited in their ability to expand to more suitable conditions (Buisson and Grenouillet 2009).

The nine articles within this special issue discuss the current state of understanding for climate change impacts on marine and inland fishes, ranging from projected range shifts of arid-land fishes to diminished body condition in coral reef predators. A common theme in both marine and inland systems is that the effects of climate change on fishes are complex and often cannot be distilled into one cause and one direct effect. Temperature is often a dominant factor (see Carlson et al. 2017; Henderson et al. 2017; Klein et al. 2017; Pratchett et al. 2017), but it is not the only driving variable (see Al-Chokhachy et al. 2017; Myers et al. 2017; Whitney et al. 2017). Also, temperature can influence fishes directly through physiological processes and indirectly through interspecific interactions (see Myers et al. 2017). Additionally, climate change often interacts with other anthropogenic stressors with unanticipated consequences (see Collingsworth et al. 2017; Klein et al. 2017). The resilience or adaptive ability of many species to adjust to new climate scenarios and new externalities can only be projected at this point (see Myers et al. 2017). In some cases, the changes may have a positive effect on fish production (e.g., increased survival) and, in others, a negative one (e.g., reduced habitat). In all cases, an increased understanding of species sensitivity will assist with societal adaptation (Paukert et al. 2017).

Changing water temperature is already having a discernable impact on fish populations. Coral grouper (*Plectropomus* spp.) are already experiencing temperatures (≥30 °C) that compromise individual performance and body condition (Pratchett et al. 2017). Klein et al. (2017) reviewed research on effects of changes in temperature, salinity, dissolved oxygen, pH, and ocean currents on pelagic life stages, post-settlement life stages, and reproduction of four species in the New England groundfish fishery and found that most studies only examined temperature and projected adverse outcomes for the fishery. Likewise, changes in seasonal temperature transition also impact fish populations. Longer summers and later fall cooling were shown to have a strong effect on both abundance and biomass of the majority of 43 fish stocks examined along the continental shelf in the northeastern U.S. (Henderson et al. 2017).

While temperature is often considered the "master variable," climate change manifests through many other environmental variables, such as stream flow or ice cover. Myers et al. (2017) conducted a review of documented and projected climate impacts on inland fishes globally and found that research to date tended to address how temperature increases alone would affect fishes; however, studies that looked at other climate variables found that that temperature is not the only climate factor that will affect fishes in a changing climate. Al-Chokhachy et al. (2017), for example, conducted a review of stream hydrologic patterns across the Greater Yellowstone Area in the United States and found that with shifts to earlier peak discharge, reduction in summer minimum stream flows, declines in duration of river ice, and decreases in total water volume, particularly during the most recent time period, are critical habitat metrics for resident salmonids.

Climate change, however, does not act in isolation; interactions with other stressors can lead to complex, unexpected and nonlinear consequences (e.g., Klein et al. 2017). Collingsworth et al. (2017), for instance, pointed out that human activities will moderate climate impacts to fisheries of the Laurentian Great Lakes. While in isolation, lake habitats are expected to experience increased temperatures and reduced ice cover which could increase the habitat suitability for many fish species; however, human activities have increased the occurrence of bottom hypoxia, susceptibility to invasive species, nutrient eutrophication, and altered precipitation which impact fish phenology and the outlook for the future of Great Lakes ecosystems and the fisheries that they support (Collingsworth et al. 2017).

Data often drive research discussions. In a region with substantial fish population and environmental data (e.g., stream water temperature) available, Carlson et al. (2017) were able to compare two modeling approaches, generalized models and more resource-intensive stream-specific models, to forecast thermal habitat suitability for salmonids in groundwater-dominated and runoff-dominated streams. While generalized models predict groundwater-dominated thermal habitat suitability with 82% accuracy, stream-specific models are likely necessary for runoff-dominated systems where the generalized models only have 54% accuracy (Carlson et al. 2017).

When considering climate impacts, data limitations often make traditional approaches to assessment difficult. However, there are still methods that can be used to inform and project how fishes are likely to respond. For example, Whitney et al. (2017) used a trait-based approach to examine arid river fishes in the southwestern United States, forecast shifts in the limits, center, and size of fish elevational ranges and relate those shifts to fish traits for arid river fishes in the southwestern United States with climate change. They found trophic (e.g., trophic guild, diet breadth) and dispersal traits (e.g., maximum body length, shape factor) were associated with range shift metrics, although range shifts were largely idiosyncratic across species (Whitney et al. 2017). This study highlighted the influence of climate change on species distribution and abundance, and suggested that traits related to dispersal ability may be an important factor in shaping the magnitude of some of the projected range shifts with climate change.

Current and projected climate change, the rate of change, and the addition of external stressors (e.g., fishing, pollution, invasive species) is unprecedented. This special issue also highlights many key knowledge gaps on how these factors will impact marine and inland fishes and fisheries. Much is still unknown with regards to the tolerances of many fish species to changes in temperature, flow, salinity, and other environmental factors linked to climate change and their adaptive capacity to adjust to these changes. In reviewing documentation of climate change impacts on inland fishes, most of which focused on responses of salmonids in North America and Europe, Myers et al. (2017) highlighted the major gaps in the literature in terms of taxonomic groups and geographic focus. Klein et al. (2017), as another example, noted that for the impacts of salinity, dissolved oxygen, pH, and ocean currents on the New England groundfish fishery, there are still many more unknowns than knowns.

More broadly, Myers et al. (2017) revealed the deficiency of detailed analysis and experimentation on changes in fish assemblages and assemblage dynamics; dearth of taxonomic and geographic diversity in climate change and inland fish studies; and, lack of overlap between quantitative comparisons of projected and documented research to compare observations and predictions. As a next step, Paukert et al. (2017) called for a comprehensive assessment of how climate change affects inland fishes, fisheries, and aquaculture at a global scale because of the importance of inland fishes to global food security, livelihoods, and recreational fisheries.

Several of the contributions to the special issue detailed the need to consider short-term and long-term strategies to effectively incorporate climate change considerations in the management of fish and fisheries. Collingsworth et al. (2017) suggested the management need to balance the immediate concerns of overfishing, eutrophication, and invasive species with the long-term stressors associated with climate change. Likewise, Henderson et al. (2017) highlighted the need to better understand phenological responses of fishes to warming and the incorporation of such knowledge into stock assessments.

Collectively, the articles of this special issue highlight the importance of understanding climate impacts on marine and inland fishes. While this is a rapidly expanding field of study, it is important to note that the principal motivation for research is highly applied—to inform strategies and approaches to address ongoing and anticipated consequences of this global phenomenon. This special issue seeks to help researchers and decision makers identify research priorities and provide a framework to help sustain fish populations and fisheries for the diversity of uses and users around the globe in a changing climate.

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