
6. Climate Change-Mediated Range Shifts in Tropical Reef Fishes: Implications for Management and Coral Ecosystem Services along the Kuroshio Region

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Global thermal gradients play a significant role in structuring many organisms' geographic ranges, such as the global distribution of reef fishes (Briggs 1999, 2006). Thus, evolution concentrates higher diversities of reef fishes in tropical regions, as exhibited in the Indo-Pacific Region (Briggs 1999; Mora et al. 2003), while biodiversity decreases with increasing latitude due to thermal barriers (i.e., latitudinal diversity gradients; Willig et al. 2003; Hillebrand 2004; Briggs 2006). However, recent climatic changes warmed oceans and significantly changed ocean circulations, such as the acceleration of the western boundary currents (Wu et al. 2012), which shifted the ocean thermal zones (Sen Gupta et al. 2015). Hence, it created global biodiversity "hotspots" for tropical organisms in temperate waters, resulting in the tropicalization of temperate marine communities (Vergés et al. 2014). The significant global increase in sea surface temperature (SST) threatened and challenged many tropical marine organisms' physiological responses, which led to a notable change in their range distribution (Brierly and Kingsford 2009). Species sensitive to sea temperature increases at tropical regions (i.e., trailing ranges) are documented to have exhibited poleward range distribution shifts (range shifts) at the leading ranges or latitudinal edges (Bates et al. 2014). These range shifts are a known response of many tropical organisms facing potential range contraction because of significant thermal changes beyond their habitat's maximum thermal range to adapt and avoid extinction (Thomas et al. 2004; Brierly and Kingsford 2009; Maggini et al. 2011).

Such climate change-mediated range shifts in marine taxa are more pronounced in western boundary regions (Vergès et al. 2014), facilitated by poleward-flowing western boundary currents (e.g., Kuroshio Current) carrying tropical organisms in larval stages from lower latitudes (e.g., reef fishes; Soeparno et al. 2012). This includes the poleward expansion of habitat-forming tropical corals (Precht and Aronson 2004; Yamano et al. 2011) and the observed range shifts in tropical reef fishes in temperate waters (Nakamura et al. 2013; Booth and Sear 2018). Tosa Bay, Kochi Prefecture, southwestern Japan, is among the global hotspots for biological change in western boundary regions as "thermally bound habitat-forming organisms" respond to the warming of coastal waters involving the decline of kelps and increase of corals (Vergés et al. 2014; Pecl et al. 2017; Figure 1). Range shifts in marine taxa have an estimated average rate of 19.0 km year⁻¹, which is substantially faster than the range shifts in terrestrial taxa at only 0.61 km year⁻¹ (Sorte et al. 2010). However, marginal novel environments (e.g., temperate waters offer various conditions different from range-shifting organisms' native range. Hence, a species' basic resource requirements need to be met to successfully

establish a permanent population at higher latitudes (referred to as successful poleward colonization). Despite evidence of range shifts in tropical reef fishes, factors affecting their successful poleward colonization remain uncertain (Feary et al. 2014). This chapter addresses the possible determinants of successful poleward colonization of tropical reef fishes in high latitude reefs at Tosa Bay and suggests the research direction for fish resource management under climate change.



Figure 1 Tropical reef fishes began colonizing reef-building corals that have been rapidly developing in Tosa Bay's temperate coast (Kochi Prefecture, southwestern Japan) since 1990s.

1. Key Determinants for Successful Poleward Colonization of Tropical Reef Fishes at Higher Latitudes

Various studies have demonstrated the importance of larval supply and thermal suitability of temperate waters in predicting successful range shifts on tropical reef fishes (Booth et al. 2007; Figueira and Booth 2010; Nakamura et al. 2013). Thus, pelagic larval dispersals (PLD) and distance to larval sources have been considered (Booth and Parkinson 2011). However, not all species of tropical reef fishes occur in Japanese temperate waters despite the presence of available habitat (i.e., corals) and a relatively similar dispersal ability (PLD) with the occurring and reproducing species, as exhibited in Tosa Bay (Tose et al. 2007; Soeparno et al. 2012). Hence, this may indicate that larval dispersal may not be a solid plausible factor in the variations in tropical reef fishes' latitudinal range distribution.

The successfully established hermatypic tropical corals may have facilitated the colonization of tropical reef fishes in temperate waters (Nakamura et al. 2013; Booth and Sear 2018). These fishes are also predicted to withstand mid-water winter conditions with persistent SST increases (Eme and Bennett 2008; Figueira et al. 2009; Figueira and Booth 2010; Feary et al. 2014). However, Nakamura et al. (2013) have demonstrated significant declines in tropical reef fishes in Tosa Bay during winter. Additionally, Leriorato et al. (2021) found significantly high mortality of rarely and/or non-occurring (non-adapted) species compared with their temperate-adapted congeners at 15 °C (i.e., the average minimum winter water temperature in Kochi) during the simulation experiment. Therefore, this indicates that winter is still a population bottleneck amidst contemporary climate change. Hence, species' trait-based responses (e.g., physiology and acclimation

capacity) to mid-water winter thermal conditions also play a significant role in shaping the population structure of tropical reef fishes in temperate waters (Leriorato et al. 2021). The unprecedented extreme cold event in Tosa Bay, southwestern Japan, exacerbated the winter condition (i.e., extreme low SSTs) that resulted in massive coral bleaching and the demise of > 90% corals in the area (Figure 2; Leriorato and Nakamura 2019). Both of which devastatingly affected the population structure of tropical reef fishes (Leriorato and Nakamura 2019). Thus, this demonstrates that both the mid-water local winter temperatures and the availability of “tropicalized” coral habitats strongly affect the establishment of a permanent population and the structure of tropical reef fishes at the leading range (Leriorato and Nakamura 2019).

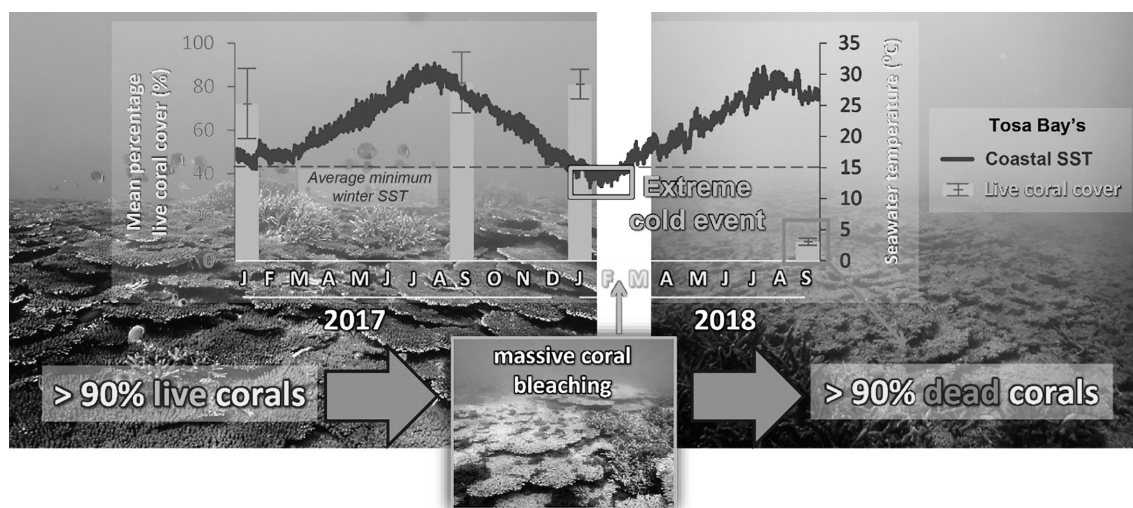


Figure 2 Tosa Bay's coastal sea surface temperature (SST) and percent coral cover (before, during, and after an extreme cold event). Adapted and modified from “Unpredictable extreme cold events: a threat to range-shifting tropical reef fishes in temperate waters,” by JC Leriorato and Y Nakamura, 2019, *Marine Biology*, 166:110.

2. Range-Shift Implications for Management at Trailing and Leading Ranges

Climate change-mediated shifts in the range distribution of tropical marine organisms (e.g., corals and reef fishes) may have offered potential ecosystem service opportunities (e.g., fishery and tourism) at the leading ranges (Booth et al. 2018; Woodhead et al. 2019). Although tropical reef fishes are not a target for fisheries in mainland Japan (e.g., in Tosa Bay), recreational and educational services such as snorkeling have started emerging in several areas where corals have developed (Woodhead et al. 2019). However, poleward range shifts in tropical reef fishes due to climate change may lead to a large-scale redistribution of global fisheries catch potential, yielding a 40% drop of the yield in the tropics while yielding an average of 30–70% increase in high-latitude ranges (Cheung et al. 2010). Hence, this may have potential socio-economic and management implications on the access to livelihood opportunities of many tropical countries, such as in the Philippines, whose communities mainly obtain dietary protein resources from coastal fisheries products. Tropical reef ecosystems mainly comprise small-bodied non-commercially targeted reef fishes (e.g., Pomacentridae or damselfishes; Pratchet et al. 2008). However, most of these species constitute the

commercially larger reef fishes' fundamental food source and diet niche. Hence, changes in these organisms' community structure may disrupt the biodiversity of coral ecosystems (Munday et al. 2008; Cheung et al. 2009) that may indirectly affect commercial reef fisheries resources. Thus, understanding how these organisms respond to present and future climatic changes and their current and future ranges may increase our capacity to effectively develop and establish conservation and management responses to the already-established marine protected areas (MPAs).

Establishments of MPAs may have contributed to reef resilience at a local spatial scale by reducing human-related fishery exploitations and potentially mitigating other disturbances and pollution. Hence, it effectively provides conservation actions on fishery management and habitat protection (Boersma and Parrish 1999). However, these MPAs offer limited protection from extrinsic disturbances such as climate change (Munday et al. 2008), as they typically have significant impacts at a larger spatial scale. The stability of coral ecosystems as the source of food and refuge to many marine organisms is mainly affected by its impacts, often resulting in habitat degradation (e.g., coral bleaching and mortality). Most reef fishes are vulnerable to these climate-induced ecosystem and habitat changes (Pratchett et al. 2008). Hence, climate change impacts not only alter the system functioning of tropical marine ecosystems but may also likely increase the risk of fisheries collapse (Munday et al. 2008), thereby affecting the ecosystem services it provides (e.g., fishery and tourism industry; Booth et al. 2018; Woodhead et al. 2019). As ocean temperatures and frequencies of extreme events are predicted to increase amidst climate change persistently and rapidly (Timmermann et al. 1999; Easterling et al. 2000; Meehl and Tebaldi 2004; Wang et al. 2010; Yara et al. 2011), understanding the extent of these impacts on marine ecosystems is crucial as most of it is inevitable and irrevocably devastating.

During the recent climate change, tropical ranges (e.g., the Indo-West Pacific Region, known as the center of origin) serve as an essential larval source of tropical marine organisms, which actively contribute and maintain biodiversity at high-latitude edges (Briggs 2003). Conversely, high-latitude edges serve as complementary ranges for range-shifting tropical organisms sensitive to thermal increases at the trailing edge, thereby mitigating the possibility of their range contraction or extinction. Hence, establishing a conservation priority system in these areas is essential since climate change-driven persistent warming at the trailing ranges (Munday et al. 2008; Pratchett et al. 2008; Cheung et al. 2009), and the unpredictable extreme events at the leading ranges significantly change their ecosystem structure. For example, the 1998 ENSO-driven global coral bleaching event in tropical oceans (Goreau et al. 2000) and the significant habitat (kelp and corals) structural changes in temperate caused by extreme heat events (i.e., marine heatwaves; Wernberg et al. 2013, 2016) and cold events (cold snaps/spells; Coles and Fadlallah 1991; Hoegh-Guldberg et al. 2005; Lirman et al. 2011; Leriorato and Nakamura 2019). All of which can plausibly impair the ongoing and future benefits from the fishery and tourism services of the coral ecosystem at both the trailing ranges (i.e., tropical regions) and leading ranges (i.e., temperate waters as the global tropicalization "hotspots"). Thus, incorporating climate change-related impacts in sustainable planning and management strategies at both ranges is essential (Munday et al. 2008) not only to foster the ongoing economic benefits derived from the coral ecosystem (i.e., livelihood opportunities and jobs from tourism and fisheries) but also in providing food security to current and future generations.

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