Coral reef conservation must embrace the role of nutrient enrichment and altered N:P stoichiometry: editorial comment on the article by B.E. Lapointe et al. (2019)

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The primary role of nitrogen (N) rather than phosphorus (P) as a driver of eutrophication in coastal marine waters has been known since the early 1950 s (Ryther 1954). The consequences of ignoring N-fueled marine eutrophication include shifts from benthic (i.e., corals, seagrasses) to pelagic (i.e., phytoplankton) dominated primary producers, and ultimately harmful algal blooms and “dead zones”, with adverse effects on ecosystem services and human health (NRC 2000). Coastal zone management programs in temperate and subtropical estuaries have long recognized this with a number of case studies showing great success in managing anthropogenic N loads (Conley et al. 2009; Greening et al. 2014).

Coral reefs support much of the world’s marine biodiversity, and provide significant livelihoods (i.e., fisheries, reef-related tourism) and coastal protection, but have been in decline since the 1970s (Gardner et al. 2003; Bellwood et al. 2004). Coincidental with increasing levels of coral diseases and bleaching, stony coral cover has decreased and been replaced by benthic algae (macroalgae, turf algae) in Jamaica and other areas of the Caribbean (Lapointe et al. 2018). Some coral reef biologists concluded this “phase-shift” was caused exclusively by “top-down” factors associated with decreased reef grazing, such as overfishing of herbivorous fishes (parrotfish, surgeonfish) and mortality of the long-spined sea urchin *Diadema antillarum* (Hughes 1994). This viewpoint led to management actions directed at the protection of “herbivores” through expansion of marine-protected areas (MPA) and no-take areas where fishing is banned, in an effort to sustain grazing on the expanding

benthic algal community. Unfortunately, the well-known role of N enrichment and “bottom-up” controls on coral reefs were largely ignored, even as human population and migration to the coast have dramatically increased.

The 3-decade empirical study published in *Marine Biology* (Lapointe et al. 2019) provides a clear example of how not implementing simultaneous “top-down” and “bottom-up” management scenarios can lead to catastrophic failure in coral reef ecosystems, even under high levels of algal grazing. The core area at Looe Key reef, located 10 km offshore of the lower Florida Keys, USA, has been an MPA (no-take zone) since 1981 and supports large populations of mobile grazing parrotfish and surgeonfish; however, the upland watersheds impacting this reef include not only the rapidly urbanizing Florida Keys, but also the Everglades basin that extends north to Orlando, FL, which includes intensive agricultural, urban and tourism-based land uses. The long-term monitoring data between 1984 and 2014 show a trend of increasing concentrations of reactive nitrogen (ammonium, nitrate), chlorophyll *a*, and N:P ratios in the water column, as well as the N:P ratio in reef macroalgae. The temporal patterns in the data reveal the connectivity of increased N-rich runoff events associated with heavy rainfall and the Comprehensive Everglades Restoration Plan (CERP) to increasing algal blooms, hypoxia, altered N:P stoichiometry, coral disease, mass bleaching events, and coral die-off.

Lessons learned from Looe Key have important implications for coral reef stewardship in the Caribbean region and globally. This case study illustrates how offshore coral reefs can exceed a “safe operating space” for reactive N (Rockström et al. 2009) and altered N:P ratios (Rosset et al. 2017) and how these conditions interact with other stressors, such as climate change, i.e., warming and excessive rainfall. The data make clear that this is not an either (temperature) or (nutrients) situation, but rather a multiple stressor reality. Aggressive management is especially important as new threats to coral health continue to emerge, such as the

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“Stony Coral Tissue Loss Disease” in the Florida Keys and Caribbean region. Implementation of regional N management strategies (Conley et al. 2009) is critical for CERP if, as identified, the goals include recovery of downstream coral reefs. Globally, improved management of water quality at the local and regional levels could moderate N inputs and maintain more balanced N:P stoichiometry, thereby reducing the risk of coral bleaching, disease and mortality under the current level of temperature stress.

Compliance with ethical standards

Conflicts of interest There are no conflicts of interest.

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