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Editorial: Mangroves in the Anthropocene: From local change to global challenge

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Editorial on the Research Topic
Editorial: Mangroves in the Anthropocene: From local change to global challenge

Recently, Norman Duke et al. published a doom alert on a world without mangroves, where extinction of entire forests or over-fragmentation of large stretches of mangroves was a real and present nightmare (Duke et al., 2007). Historically, mangroves have been considered either a nuisance or a source of rapid and easy profit, both views resulting in degradation and loss. The few exceptions were the traditional "Mangrove People" (Vannucci, 1989), traditional human groups throughout the tropics living in balance with these ecosystems while directly benefitting from their services and goods. These traditional populations have suffered pressure from growing production and resource exploitation in most of today's societies and continue to be systematically displaced along with mangrove destruction and degradation.

Globally, over 90% of mangroves are located in developing tropical and subtropical countries, where rates of loss and degradation are high. Mangrove deforestation started in early colonial times, when mangrove forests were estimated to cover 200,000 km^2. Like other tropical forests, about 70% of these mangroves were deforested and converted to other uses (Duke et al., 2007). In addition, rates of loss have accelerated in the past 50 years and eradicated about 20% of this remaining total coverage (36,000 km^2) between 1980 and 2005 (FAO, 2007). A more detailed analysis of recent mangrove area loss (1996 to 2016) shows that deforestation and conversion resulted in a further loss of 9,736 km^2 (6.6%) and degraded an additional 1,389 km^2 (0.95%) of mangroves worldwide.

Mangrove loss rates, however, are highly variable through space and time. Between 1996 and 2016 global annual mangrove loss was about 0.21% of the total area, whereas in North & Central America and the Caribbean the average rate was 0.36% and in SE Asia of 0.29%. Other regions showed lower rates, such as the Middle East (0.23%);

Australia/New Zealand and South America, with 0.14% and even lower rates in West & Central Africa and the Pacific Islands (0.06%) and even a small gain in mangrove area of 0.03%. year^{-1} in East Asia (Worthington and Spalding, 2018). In general, however, these figures represent a relative reduction in deforestation rates compared to late 20th century figures. Also, notwithstanding the present threats to mangrove survival, an intensive restoration effort is being witnessed in many regions of the world. Globally, a range of coordinated empirical studies linking drivers of loss and mangrove deforestation to global policy development for mangrove conservation have been put forward. These provide some optimism to the future of mangrove conservation (Friess et al., 2019), but beyond climate change, the developmentalism paradigm and economic crises will put more pressure on mangroves and other wetlands and may negatively impact restoration programs (Ferreira et al., 2022).

Most major drivers of mangrove degradation also vary regionally in intensity and include tourism, salt extraction, timber and charcoal productions and industrialization. Some, such as urbanization and intensive shrimp aquaculture, however, affect mangroves at a global scale (Lacerda et al., 2019, 2021). Wherever well-conserved mangroves are threatened by anthropogenic activities, traditional populations are also at risk.

Inter-related and spatially variable climate change pressures, including sea-level rise, increased storminess, altered precipitation regime and increasing temperature, are impacting mangroves at both global and regional scales (Ward et al., 2016). Hernández et al. determined the spatial-temporal regeneration dynamics of plant cover and composition during the first 2 years after hurricane María in a coastal urban wetland in San Juan Bay, Puerto Rico. They analyzed the distribution of plant functional types using small unmanned aerial vehicles (s-UAVs) and simultaneously monitored regional climate and local environmental data. The observed a high recovery rate of about 87% over the study period, mostly due to plants with high specific leaf area. However, they also showed that the regeneration rate was influenced by groundwater conductivity and waterlogging and was favored by high nutrient availability, increasing the system's regeneration rate. After 2 years, the wetland's plant cover and composition of functional plant types proved resilient to the initial hurricane effect and subsequent changes in conductivity and freshwater conditions.

Changes in conductivity expressed by extreme salinity stress can also lead to mangrove mortality, although mangroves are adapted to saline habitats. This was highlighted following a largescale mangrove dieback event following hypersalinity in temperate mangroves in South Australia evaluated using airborne remote sensing (LIDAR, RGB and hyperspectral imagery) and ground truth measurements (Dittman et al.). Hypersalinity persisted in soils a year after the event, making it one of the most extreme hypersalinity cases recorded in mangroves. However, CO_2 efflux from sediment as well as carbon stocks in mangrove biomass and soil did not differ between the zones a year after the event. Mangrove photosynthetic traits and physiological characteristics indicated that mangrove health was impacted beyond the immediate dieback zone. The response to extreme hypersalinity in these temperate semi-arid mangroves was similar to that observed in tropical latitudes also under semi-arid climates and suggests they are already close to their physiological tolerance limit, and therefore more sensitive to environmental change, which places them more at risk from extreme hypersalinity regardless of latitude. These findings have relevance for understanding the generality of disturbance effects on mangroves, with added significance as semi-arid climate regions are likely to experience global change derived impacts, such as decreasing rainfall and extended duration of extreme droughts.

To fully comprehend the key role of nutrient availability to mangroves it is fundamental to understand resistance and eventually resilience of mangrove ecosystems and their response to drivers of mangrove degradation. Wigand et al. reported on nutrient storage and accumulation in mangroves and described them as "coastal kidneys," efficiently trapping sediments, and "filtering" contaminants and excess nutrients. These authors observed much higher present-day Nitrogen (N) storage and accumulation rates than those estimated prior to 1970 and have associated this increase with urbanization. Estuary-wide (San Juan Bay in Puerto Rico) mangrove soil N accumulation rates were over twice as high in recent decades and were twice the rate of human-consumed food N that is exported as wastewater. This strongly suggests a high capacity of mangroves to sequester human-derived N, thus playing a significant role in maintaining water quality in coastal tropical regions.

Biotic factors associated to mangrove structure and community shaping have been largely understudied. Hence, the effect of climate change over key faunal groups and the consequences in forest community structure are yet unknown. Hendy et al., give an insight on the influence of rising sea level over forest inundation and their influence on the amount of wood degraded by wood boring organisms, biodegraders that have an important role in nutrient and carbon dynamics through wood decomposition process, also of living trees. The authors studied the guilds of terrestrial and marine wood biodegrading organisms across a tidal gradient in an Indonesian mangrove. These authors showed that within the high intertidal regions, terrestrial biodegradation processes dominated, whereas in the low intertidal region, marine wood-boring animals belonging to the family Teredinidae were the dominant biodegraders, and their activity reduces large woody debris volume and speeds up this loss, influenced by inundation time. In the context of rising sea levels, such an impact over large mangrove extents can affect the amount of carbon stored in, and released by, the forest ecosystem. The results of their study have significant implications also for biodegrading guilds, due to

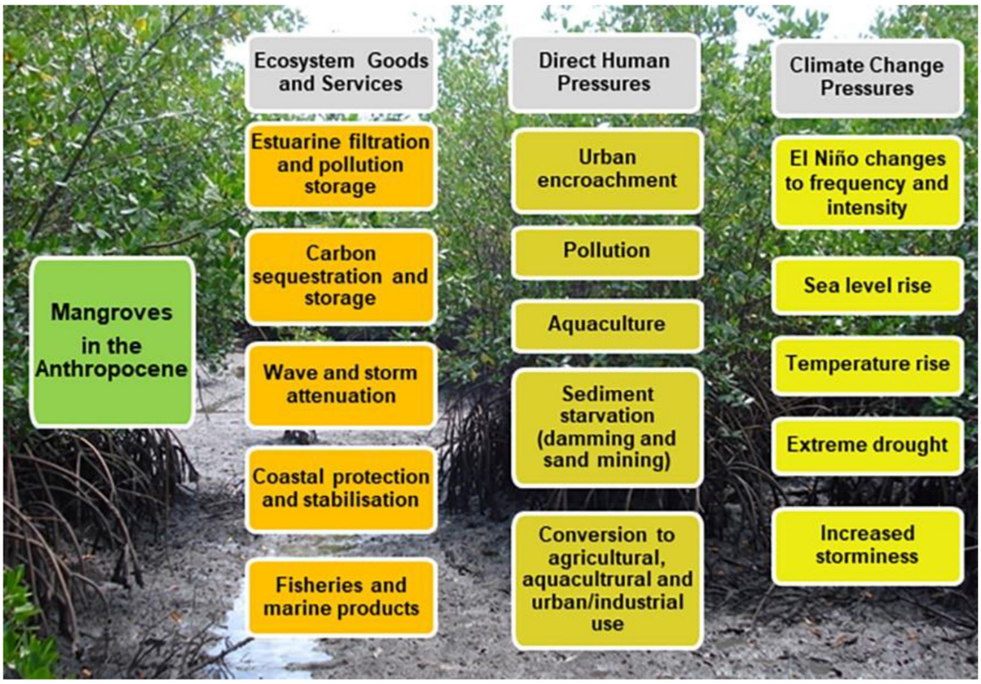

FIGURE 1
Major challenges for mangrove ecosystems in the Anthropocene: as providers of goods and services and as receptor of impacts from direct and indirect environmental drivers of anthropogenic origin.

their importance in assessing mangrove carbon stores and their fate.

From a global perspective, climate change derived drivers together with other local anthropogenic drivers strongly affect the balance of pollutants in mangrove-dominated estuaries, particularly those that are non-degradable, like metals. Mangroves may act as mitigators or trigger metal mobilization in response to climate change, as discussed in the review by Lacerda et al.. In general, most chalcophile metals accumulate in mangrove soils associated with sulfides while high sedimentation rates avoid their oxidation. Exudation of oxygen by roots fixes Fe, which co-precipitates metals as oxyhydroxides in the rhizosphere. These biogeochemical processes reduce metal bioavailability and mobility. Climate change-driven pressures are likely to alter this geochemical equilibrium. Sea level rise increases erosion, which dissociates deposited sulfides, releasing metals to the water column that adsorb onto suspended particles and can re-deposit in the estuary or be exported to continental shelf sediments. Saline intrusion may oxidize deeper sediment layers releasing metals to porewaters. Part of the mobilized metals may remain in solution complexed with dissolved organic matter making it highly bioavailable. Disruption of traditional humans dwelling in mangrove dominated coastlines may result from these processes by increasing contamination of the coastal fisheries that these groups depend upon.

Sea level rise also promotes mangrove migration inland and at their latitudinal limits may lead to a change in the ecosystem's soil carbon storage. In mangrove stands thriving in the Atlantic northern limit, in Florida, USA, Steinmuller et al., based on soil profile $\delta^{13}C$ compositions, observed a range of values reflective of C3 and C4 plant inputs. They suggested that shifts in plant taxa occur, but indicated that mangrove soil organic carbon burdens are less than or equal to that of co-located tidal marsh habitats. Several proposed explanatory variables (climate, environmental setting, plant physiology and productivity, and duration of encroachment) were identified to influence how soil organic carbon density in mangroves might increase over time, which is critical to forecasting how continued mangrove expansion might affect blue carbon storage as these habitats evolve.

The different approaches and results from the comprehensive studies reported in this issue help draw a scenario of the challenges posed to mangroves facing climate change. Figure 1 summarizes most of the concerns noted in this issue, while also highlighting the goods and services provided by mangroves in the Anthropocene, and direct anthropogenic threats as well as those from climate change. However, there are also opportunities offered by the current increased interest and recognition of the importance of these vital systems. Increased data on mangrove ecosystems and the mechanisms that influence their condition and function are vital, at both a local and global scale. Yet, some significant knowledge gaps exist, mostly dealing with global drivers and impacts on local processes. For example, the effects of climate change on key faunal/microorganism groups for mangrove functionality need to be assessed. Without this background information it is not possible to make informed decisions concerning management and conservation, as well as supporting proper ecosystem function and service provision. Furthermore, as has been highlighted in this issue, many mangroves are in a degraded condition and many more have been lost, and without information on local or national conditions, restoration programs are likely to fail. Particular notice should be given to regions that are underrepresented in the research sphere, particularly those from Africa, Latin America and parts of Asia.

Another visible gap that stands out from the articles presented here and in other mangrove literature is that there is little that directly relates to social pressures, and more detailed, specific accounts of human-experienced impacts are urgently needed. Few, if any, of the published studies, and that may be expanded to the global mangrove literature, deals with Vannucci's "Mangrove People" and the critical threshold they are facing as a result of our changing planet.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

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