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Editorial: Human impacts on river catchments and coastal ecosystems: A meta-ecosystem perspective

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Editorial on the Research Topic
Human impacts on river catchments and coastal ecosystems: A meta-ecosystem perspective

Meta-ecosystems can be defined as a set of ecosystems connected by spatial flows of energy, matter and organisms (Loreau et al., 2003; Cid et al., 2022). A paradigmatic meta-ecosystem is the one formed by the interaction of river catchments and coastal ecosystems. For example, rivers transport enormous amounts of nutrients to coastal waters (Schlünz and Schneider, 2000; Li et al., 2020), determining primary and secondary productivity (Gibson et al., 2002; Garnier et al., 2010). Thus, estuaries are highly productive areas (Levin et al., 2001), with a higher value of ecosystem services per hectare than any other ecosystem (Costanza et al., 1997; Newton et al., 2018). At the same time, river basins are subjected to multiple human disturbances (e.g. hydrological disturbances, pollution, habitat degradation) that accumulate downstream until they reach the sea (Newton et al., 2012; Flo et al., 2019). This makes estuaries one of the most degraded ecosystems on Earth (Kaiser et al., 2011).

This meta-ecosystem perspective is extremely important to guide effective management efforts, since the environmental challenges that human societies face are not restricted to ecosystem boundaries. In the case of the river-coastal meta-ecosystem, this can be clearly illustrated with eutrophication (Smith, 2003; Smith et al., 2006). River catchments receive large phosphorus and nitrogen inputs from urban and industrial wastewater discharges and agricultural runoff (Meybeck and Helmer, 1989; Strokal et al., 2016). These nutrients accumulate in the estuaries and coastal zones, which receive more nutrients per unit area than any other ecosystem on Earth (Smith, 2003). Nutrient accumulation leads to changes in planktonic communities (Romero et al., 2013) that might trigger cascading effects, changing the ecosystem state (Scheffer et al., 2001). For example, eutrophication often stimulates toxic algal blooms such as some cyanobacteria and dinoflagellates (Wurtsbaugh et al., 2019) that could have cascading effects on local fisheries (Anderson et al., 2008). These blooms are influenced not only by the total concentration of nutrients but also by their ratio (C:Si:N:P), which determines the metabolism of phytoplankton (Redfield, 1958; Justić et al., 1995). Thus, the alteration of the nutrient ratio can favor different phytoplankton species depending on their metabolism (Glibert et al., 2018). In addition to toxic blooms, phytoplankton proliferation can cause the degradation of submerged vegetation through competition for light and nutrients (Munkes, 2005). Also, the excess of primary and secondary production is deposited in the sediments leading to hypoxic situations due to the great demand for oxygen by decomposing microorganisms (Díaz and Rosenberg, 2008). So, overall, when nutrients are added along the river catchment the coastal ecosystem might shift from a clear water state dominated by submerged vegetation into a turbid water state dominated by phytoplankton (including toxic species), leading to a general decline in aquatic biodiversity (Duarte, 2009; Rabalais et al., 2009; Rodríguez-Gallego et al., 2017).

As the human pressure on ecosystems increases (Díaz et al., 2019), an integrated management of river catchments and the coastal areas associated with them is becoming increasingly needed (Álvarez-Romero et al., 2011; Cantasano et al., 2020; Lewis et al., 2021). However, such approach can only be effective if it is based on a deep understanding on the links between freshwater and marine ecosystems. Within this context, this special issue provides insights into the interaction of river and coastal ecosystems, laying out the foundations of future research.

Lessons learned from this Research Topic

Pargaonkar and Vinayachandran show the presence of Irrawaddy River jets for the first time in the Andaman Sea during summer monsoon. The Irrawaddy is the largest river discharging into the Andaman Sea. River plumes are considered important in the shelf seas all across the world's oceans (Kang et al., 2013; Milliman and Farnsworth, 2013; Horner-Devine et al., 2015). When the river meets the ocean at the coast the discharge from the river forms a region of freshwater with a distinct dynamical process. River discharge to the coastal ocean modifies the local circulation and associated biogeochemistry. This study presents the first comprehensive evidence through satellite and model simulation to show that during the summer monsoon the discharge from the Irrawaddy spreads as a freshwater jet oriented towards southeast and accumulates over the shelf at the eastern coast of the Andaman Sea.

The meta-ecosystem perspective of river and coastal ecosystems is very relevant from the point of view of ecosystems services, which often rely on the interaction between river and coastal dynamics. One good example is maritime transportation, which strongly contributes to local and regional economic development *via* global supply chains. In this Research Topic, Muñoz et al. show how sea-level rise and river flows interact to determine wetland inundation and vessel navigability. Their study demonstrates that an integrated management of river catchments and coastal areas is needed to find environmental-friendly solutions for increasing cargo transportation.

Deltas are areas of wide interest as they are usually widely populated and they harbour unique ecosystems characterized by an active mixing of seawater and freshwater, connecting the land and the ocean (Nicholls et al., 2020). As a result, delta systems such as the massive Ganga and Brahmaputra delta in India and Bangladesh (Allison, 1998), the Nile delta in Egypt (Negm, 2017), the Pearl delta in China (Chan et al., 2021), the Frazer delta in Canada (Hill and Lintern, 2021), and many others across the globe (Syvitski, 2008), are widely studied. In this Research Topic, Gallo-Vélez et al., provide a socioeconomic assessment of growing pollution in the Magdalena delta in Colombia. The authors looked into nitrogen, phosphorous, and biological oxygen demand, as well as fecal coliform and their impact on socio-economic development. The study found fecal coliforms were more than 4 orders of magnitude higher in untreated wastewater, while agriculture and livestock are theoretically the largest contributors of nitrogen (i.e., 14.84 t d-1 and 48.99 t d-1) and phosphorus (i.e., 5.90 t d-1 and 19.46 t d-1) in the basin. The study shows that waste generated within the study area has an adverse impact on the mangrove ecosystems, severely affecting the coastal population. The study highlights the state of contamination and pollution in the Magdalena delta, and its impact on increased cleaning maintenance on beaches, loss of tourism revenue, increased living cost, and loss of cultural values. Overall, the paper provides a comprehensive study of the socio-ecological system by identifying the drivers of contamination, pressure, and state of pollution, and its impact on livelihood. In the same vein, Magel and Francis evaluate the multi-benefit outcomes of potential management interventions to address population growth and development, which still remains a major management challenge for most coastal systems. Integrative decision support tools that consider socio-economic, cultural and ecological objectives remain overlooked. In this study, which focuses on the Puget Sound fjord-type estuary (USA), a conceptual model to represent the connections between human stressors and ecosystem components was developed. This allowed exploring alternative scenarios for accommodating human population growth. The study reported that moderate levels of coordinated interventions on both urban and rural lands had favorable outcomes for more ecosystem objectives, showcasing the value of qualitative tools for cross-habitat evaluations. Together, these studies showcase the vulnerability of deltas and estuaries in the Anthropocene and the need for developing integrated management actions that incorporate the complexity of socio ecological systems.

Future research needs

The study of river and coastal ecosystems as a continuum is still quite rare. Marine ecology and limnology have been developed as two separate fields of research that don't communicate as often as they should, with estuarine environments (i.e. transitional waters *sensu* Water Framework Directive) being comparatively less studied than coasts and rivers. Thus, there are still many research needs to be covered, such as:

The study of river plumes and freshwater inputs on coastal processes

A good example of this is the northern Indian ocean, which has a complex circulation system that undergoes seasonal reversal and determines shelf biogeochemistry (Naqvi et al., 2006; Zhang et al., 2010). India has 7000 km coastline and several glacial rivers flowing through major cities that have the potential to change the coastal nutrient budget and ecosystem dynamics (Samanta et al., 2015). Further, freshwater inputs also have the potential to enhance ocean stratification thereby influencing the salinity budget (Seo et al., 2009). From a regional point of view, the response of the phytoplankton population to freshwater input and its influence in carbon dynamics can be important areas for future research. For example, how the nutrient stoichiometry changes in the freshwater system over time and its physical controls can be one interesting area of research.

Salinity dynamics driven by the interaction between sea-level rise, groundwater dynamics and freshwater abstraction

Salinity is a key parameter determining the distribution of the species along the riverine-estuarine-coastal continuum (Remane, 1934; Whitfield et al., 2012). For example, magrove forests, which provide important ecosystem services such as carbon sequestration (Adame et al., 2021), are highly dependent on salinity dynamics (Bunt et al., 1982; Krauss et al., 2008). The water salinity along the river-coastal metaecosystem is heavily modified by humans through three different mechanisms: 1) sea-level rise associated with climate change (Pörtner et al., 2022); 2) groundwater overexploitation (Alfarrah and Walraevens, 2018); and 3) reductions in river discharge due to the proliferation of dams (Grill et al., 2019; Bellafiore et al., 2021). Understanding the complex hydrological dynamics resulting from the interaction of these three factors is urgently needed to preserve biodiversity and food and water security in the face of global change.

The spread of invasive species

Many rivers around the world are getting saltier due to different human drivers such as agriculture, resource extraction and transportation (Cañedo-Argüelles et al., 2013; Thorslund et al., 2021). This might promote the invasion of brackishwater species from coastal and estuarine environments (Kefford et al., 2016). For example, the crustacean *Gammarus tigrinus* was able to colonize large sections of the River Werra in Germany due to the salinization caused by the potash mining industry (Koop and Grieshaber, 2000; Bäthe and Coring, 2011; Szöcs et al., 2014). Although the spread of invasive species in aquatic ecosystems has been well documented around the world (Williams and Grosholz, 2008; Gallardo et al., 2016), there is still little information on how the modification of meta-ecosystem dynamics by humans might affect the distribution of aquatic invasive species along the coast-river continuum (Lago et al., 2019).

Conclusion

Overall, it is clear that rivers and coasts should not be managed as separate ecosystems given the strong socioecological connections that they have (Lago et al., 2019; Gladstone-Gallagher et al., 2022). Therefore, we call freshwater and marine scientists to collaborate to produce an integrated perspective of aquatic ecosystems, which is urgently needed to halt global biodiversity loss and ecosystem degradation.

Author contributions

All authors contributed to conceptualizing the paper. MC-A led the writing process and AB, IS and RR also contributed to writing and providing critical comments. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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