Subject strapline: "Water Resources"

River-to-sea ecosystem management

Human changes to freshwater flows affect marine ecosystems, but such impacts are rarely considered in development plans involving dam building and water abstraction from rivers. New research shows how approaches that integrate flow management and marine fisheries can improve coastal ecosystem sustainability.

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Globally, rivers release over 39 thousand cubic kilometers of freshwater into the oceans every year[1]. These freshwater flows and associated sediment loads play a vital role in the formation and dynamics of coastal seascapes[2]. The downstream impacts of water resource development such as dam building and irrigation modify river hydrology and can cause important changes in saltwater ecosystems. Yet, current management practices for dam siting and flow allocation typically fail to incorporate potential impacts to ecosystem function and services of downstream marine environments[3]. In their recent article in *Nature Sustainability*, Éva Plagányi *et al*.[4] provide insights on flow management strategies that minimize the negative effects of water resource development on key marine ecosystems and fisheries in the Gulf of Carpentaria, northern Australia. Their approach connects flows across a portfolio of rivers with simplified ecosystem models to support management of marine fisheries, mangrove forests and endangered species like the large tooth sawfish, providing renewed hope that integrated river-to-sea management is achievable in coastal systems.

More than 40% of river flows worldwide are intercepted by dams, and consequently, the annual amount of fluvial sediment that reaches the oceans has been diminished by 49%[1]. Deposits of fluvial sediment maintain deltas and estuaries, and their disruption can lead to subsidence or erosion of important coastal habitats. Nutrients and organic matter transported to coast through river discharges contribute to biological productivity and sustain diverse ecosystems like mangrove forests and estuaries[2]. Nearly 200 commercially fished marine

species are linked to freshwater flows in at least part of their life cycle, a group that accounts for almost 60% of annual harvests of global wild fisheries tracked by the Food and Agriculture Organization[2]. As growing human demands for water and hydropower are poised to further disrupt riverine inputs to coastal ecosystems[5], management approaches that take into account the linkages between fluvial and marine ecosystems will be critical for coastal sustainability.

Integrative management approaches that incorporate ecosystem linkages have made substantial advancements in freshwater and marine systems. In riverscapes, the concept of 'environmental flows' recognizes the quantity and timing of water flows that sustain aquatic ecosystems and the resulting services that support multiple human needs[6]. Environmental flows management has spearheaded a transition from past myopic, utilitarian water use practices towards a holistic framework that better balances environmental and socioeconomic objectives. Similarly, marine fisheries management has seen a paradigm shift from a focus on single species to an 'ecosystem' approach that emphasizes ecosystem integrity in supporting harvest sustainability[7]. Although environmental flows and ecosystem-based fisheries management represent advancements within these respective domains, connections between freshwater flows and coastal ecosystems remain largely invisible in water resource development and fisheries planning. Plagányi *and colleagues*[4] reinforce the potential benefits of integrating across river and coastal ecosystems to unite decision making and achieve improved management outcomes.

Environmental flows and ecosystem-based fisheries management applications have been increasing, thanks also to integrative decision support tools that facilitate holistic management in the context of increased complexity[8,9]. Plagányi *and co-authors*[4] extend these concepts to a river-to-sea application and demonstrate modeling approaches that link flow management and marine fisheries. Full scale river-to-sea systems modeling would be highly complex and difficult to develop, however the authors overcome this challenge by focusing on key linkages between river flows and coastal fisheries. The authors consulted with industry, government and local community stakeholders to first identify priority ecosystem components. Subsequently, they employed ensemble modeling approaches that encompass portfolios of river flows to better describe harvest dynamics of commercially important fisheries like banana prawn (*Penaeus merguiensis*), a species that migrates between estuarine mangrove nurseries and offshore spawning grounds[10] (Fig. 1). This tropical case study provides an example of how practical river-to-sea management could be advanced by constraining system complexity to focal eco-hydrological connections between water resource development and coastal ecosystem components.

It is important to highlight that broader applications of river-to-sea management will rely heavily on robust monitoring programs that measure river flows, aquatic food web dynamics, and fisheries, among other sources. Therefore, expanding ecosystem approaches as those demonstrated by Plagányi *et al*.[4] to other areas of the globe could be difficult due to limitations imposed by data availability. High-quality long-term datasets for either freshwater or marine

ecosystems are rare, and so developing coupled river and coastal ecosystem monitoring programs will prove challenging. In addition, the implementation of new long-term ecosystem monitoring programs can be slow and costly to maintain over time[7,11,12]. In some regions of the world, we have seen the opposite trend with examples of hydrologic, ecological and catch monitoring systems being progressively defunded and dismantled[11,12]. Any river-to-sea management approach will inevitably face data limitation challenges, emphasizing a need for innovation and investment to support data collection in both river and coastal ecosystems.

Given the rising global demand for water, food, and energy, identifying management strategies with mutual benefits for freshwater and marine ecosystems will be important for achieving sustainable use of aquatic resources. Recognition of the need for river-to-sea management dates back to at least the early 1990s[13], yet progress in the field has been slow[3]. River-to-sea concepts have advanced in a few management systems such as the case of migratory Pacific salmon in the western U.S.A. and Canada[14], but by and large freshwater and marine resources are still managed separately across many coastal ecosystems. The study from Plagányi *and colleagues*[4] in tropical Australia suggests that practical modeling approaches to support river-to-sea management are possible. Future advancements of river-to-sea management will rest on investments into coupled freshwater and marine data collection and efforts to coordinate across management silos through inclusive decision-making processes that incorporate a greater diversity of aquatic resource stakeholders.

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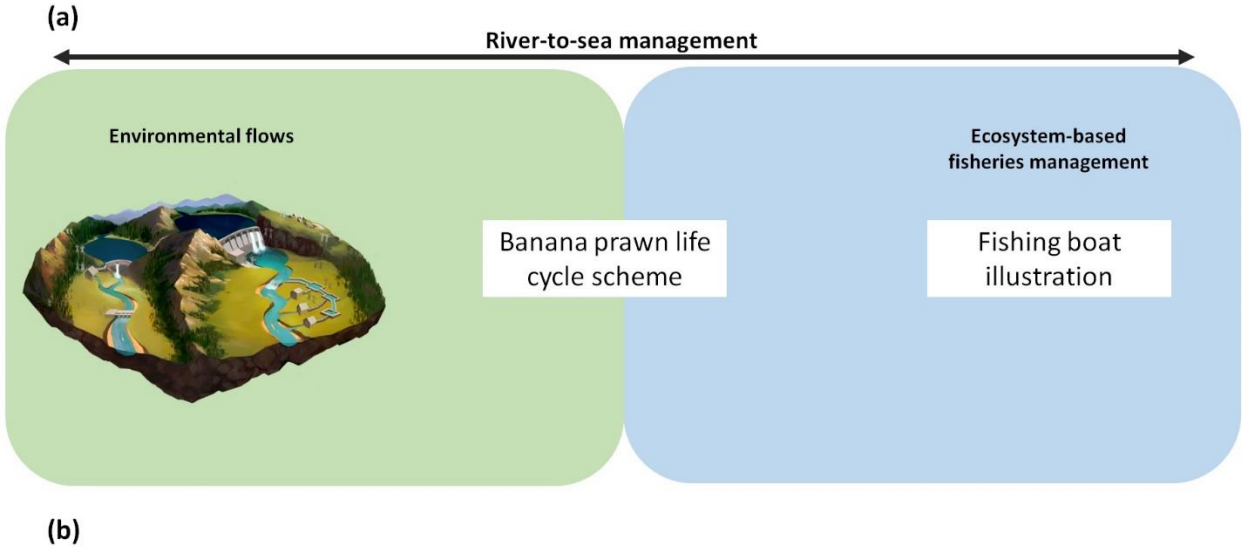

Fig. 1 | River-to-sea ecosystem management. a. Conceptual framework for an integrated river-to-sea management approach for tropical coastal fisheries. The life cycle of banana prawns (*Penaeus merguiensis*) is reliant on both estuarine and marine habitats. Upland water resource

management impacts estuarine life stages of banana prawns, which then in turn affects marine fisheries for prawns. Holistic management approaches that recognize ecosystem linkages have made advances within freshwater (environmental flows) and marine (ecosystem-based fisheries management) domains, however connections between the two systems have typically not been directly addressed. Integrated river-to-sea management can balance trade-offs between water resource development (dams, irrigation) and coastal ecosystem services (fisheries). b. Examples of observed and projected catch history of banana prawns (*P. merguiensis*), barramundi fish (*Lates calcarifer*), and giant mud crabs (*Scylla serrata*) in fishing zones under influence of the Flinders River in the Gulf of Carpentaria, Australia4. Projections that incorporate river flows (red) consistently perform better than those based exclusively on fishing effort (blue). Figs. 1a and 1b are adapted from Vance & Rothlisberg (2020)[10] and Plagányi et al.[4], respectively.