Global Sustainability

cambridge.org/sus

Review Article

Cite this article: Hansen HH, Bergman E, Cowx IG, Lind L, Pauna VH, Willis KA (2023). Resilient rivers and connected marine systems: a review of mutual sustainability opportunities. *Global Sustainability* **6**, e2, 1–19. https://doi.org/10.1017/sus.2022.19

Received: 31 March 2022
Revised: 26 September 2022
Accepted: 10 November 2022

Key words:
river to sea; rivers; SDG 14; SDG acceleration actions; sustainability; transboundary waters

Author for correspondence:
Henry H. Hansen,
E-mail: henry.hansen@kau.se

Resilient rivers and connected marine systems: a review of mutual sustainability opportunities

Henry H. Hansen[1], Eva Bergman[1], Ian G. Cowx[2], Lovisa Lind[1], Valentina H. Pauna[3] and Kathryn A. Willis[4]

[1]Department of Environmental and Life Sciences, Karlstad University, Karlstad, Sweden; [2]Hull International Fisheries Institute, University of Hull, Hull, UK; [3]Norwegian Institute for Sustainability Research, Fredrikstad, Norway and [4]Centre for Marine Socioecology, University of Tasmania, Hobart, Australia

Non-technical summary. Rivers are crucial to the water cycle, linking the landscape to the sea. Human activities, including effluent discharge, water use and fisheries, have transformed the resilience of many rivers around the globe. Sustainable development goal (SDG) 14 prioritizes addressing many of the same issues in marine ecosystems. This review illustrates how rivers contribute directly and indirectly to SDG 14 outcomes, and also provides ways to potentially address them through a river to sea view on policy, management and research.
Technical summary. The United Nations initiated the SDGs to produce 'a shared blueprint for peace and prosperity for people and the planet, now and into the future'. Established in 2015, progress of SDGs directed at the aquatic environment is slow despite an encroaching 2030 deadline. The modification of flow regimes combined with other anthropogenic pressures underpin ecological impacts across aquatic ecosystems. Current SDG 14 targets (life below water) do not incorporate the interrelationships of rivers and marine systems systematically, nor do they provide recommendations on how to improve existing management and policy in a comprehensive manner. Therefore, this review aims to illustrate the linkages between rivers and marine ecosystems concerning the SDG 14 targets and to illustrate land to sea-based strategies to reach sustainability goals. We provide an applied case study to show how opportunities can be explored. We review three major areas where mutual opportunities are present: (1) rivers contribute to marine and estuary ecosystem resilience (targets 14.1, 14.2, 14.3, 14.5); (2) resilient rivers are part of the global fisheries sustainability concerns (targets 14.4, 14.6, 14.7, 14.B) and (3) enhancing marine policy and research from a river and environmental flows perspective (targets 14.A, 14.C).
Social media summary. Restoring resilience to rivers and their environmental flows helps fulfil SDG 14.

1. Introduction

1.1 Background of sustainable development goals

The United Nations sustainable development goals (SDGs) simultaneously address some of society's greatest challenges while also accommodating for sustainable use and extraction of the world's natural resources. Many of these SDGs lack specific quantitative indicators and data, while other SDGs that do have these essentials are only slowly progressing towards their ideal deadline (often 2030), one of which is SDG 14, Conserve and sustainably use the oceans, seas and marine resources for sustainable development. For example, target 14.2: Protect and restore ecosystems, has the indicator, 'proportion of national exclusive economic zones managed using ecosystem-based approaches', but no data exist despite having a target completion date of 2020 (Goal 14, 2021) (Supplementary Table S1.1). Pursuit of economic productivity (e.g. agricultural output), infrastructure, energy and waste management improvements are still compromising ecosystems, despite progress towards achieving SDGs and their intent on reducing tradeoffs and incentivizing co-benefits among the SDGs (Gordon et al., 2010; van Zanten & van Tulder, 2020). Nexus approaches and biodiversity recovery plans have highlighted two key opportunities for improved SDG implementation: (1) linking among and within human–nature systems and (2) expanding research towards aquatic systems for sustainability initiatives (Arthington, 2021; Liu et al., 2018). One could argue that any progress for human well-being, including biodiversity and its services, will require functioning and healthy freshwater ecosystems – particularly rivers – with natural or near natural flows, or environmental flows as a surrogate of the natural condition (Arthington, 2021). The premise that a modified water cycle can enhance water security at the cost of biodiversity has led to the precept of environmental flows in managing highly modified and regulated rivers across the world (Arthington et al., 2018; Grill et al., 2019; Vörösmarty et al., 2010).

Environmental flows are 'the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems' (Arthington et al., 2018). In 2007, prior to the enactment of the SDGs, 750 scientists, economists, engineers, resource managers and policy-makers from over 50 countries proclaimed that environmental flows are the foundation for many water-related SDGs, and summarized this intent in what is now known as the Brisbane Declaration (Arthington et al., 2010) (Supplementary Figure S2.1). The SDGs were developed with reference to existing international commitments that express the most relevant global priorities (Kim, 2016), but the inclusion of environmental flows and rivers was not explicit. A decade later the revised declaration re-emphasized 'an urgent call for action to protect and restore environmental flows and aquatic ecosystems for their biodiversity, intrinsic values, and ecosystem services, as a central element of integrated water resources management, and as a foundation for achievement of water-related SDGs' (Arthington et al., 2018).

Despite evidence indicating that rivers are directly and indirectly linked to many of the SDGs and their targets, SDG targets have not typically included provisions and indicators for rivers and their appropriate management, which would enable resilient outcomes. The importance of river health for food value that is provided by river-based fisheries is a direct example of one way that rivers affect SDG 14 through target 14.4, which measures the sustainable management of fisheries (Opperman et al., 2018). An indirect example would be the extraction of groundwater to support agricultural production (Falke et al., 2011), which would support SDG target 2.4, 'sustainable food production and resilient agricultural practices'. This gap emphasizes a key consideration for the future progress of the SDGs; if river systems sit at the crossroads among and between SDGs, how will resilient rivers be achieved if SDG progress inherently comes with tradeoffs? Furthermore, what pathways in policy, research and management are necessary to achieve this future, particularly for the ecosystems in which rivers are connected? The precedence of this gap becomes readily apparent as the global conditions of rivers degrade.

SDG 6 ('Ensure access to water and sanitation for all') has four targets that are directly related to river systems: wastewater and water quality (6.3), freshwater stress and water-use efficiency (6.4), integrated water resources management and transboundary cooperation (6.5) and protection of freshwater systems (6.6). Trends for these targets are progressing positively, but there is a substantial data gap with most data for these indicators coming from high-GDP countries (United Nations Environment Programme, 2021b). Additionally, some of the indicators used within this target are subject to criticism as they may not reflect actual ecosystem condition but just metrics of water body change (Ladel et al., 2020; Vanham et al., 2018). For indicators focused on effective management, increased management may not translate to appropriate management actions. As illustrated in the monitoring methodology of indicator 6.6.1, metrics are prefaced with the condition: 'The direction [of an indicator] is recorded as either positive or negative but the use of this terminology does not necessarily imply a positive or negative state of the water-related ecosystem being monitored' (United Nations Environment Programme, 2021a, 2021b; UN-Water, 2017). To accelerate progress for SDG 6 targets globally, five areas of action have been suggested by the latest SDG 6 report, which are: (1) capacity development, (2) data and information, (3) innovation, (4) financing and (5) governance. One pathway that incentivizes development of these areas simultaneously is the participation of institutions in the SDG 6 IWRM Support programme, where numerous tools and packages are available to facilitate adoption. Parts of the scientific community consider SDG 6 progress as 'off-track' and at the will of other SDGs that require substantial water resources. The dilemma of tradeoff and synergies sits at the forefront of SDG 6 progress and the progress of other SDGs, including SDG 14 (Essex et al., 2020). Progress in SDG 6 should support progress in SDG 14, but the strength of this relationship is understudied.

1.2 Current status of rivers and freshwater biodiversity

Rivers and freshwater biodiversity have systematically been altered and degraded for many centuries, with the vast majority of rivers over 1000 km in length being no longer free-flowing (Grill et al., 2019). In Europe, for example, more than 1 million barriers fragment river systems (Belletti et al., 2020) and indications of the status of freshwater fish biodiversity, such as in the living planet index, have reported declines of over 70% for both anadromous and potamodromous fishes (Deinet et al., 2020). Conflicts concerning water rights have consequences ranging from lawsuits to armed violent conflicts, which occur both within and between nations (Levy & Sidel, 2011). Furthermore, pressures from climate change, such as seasonal and decadal droughts, pose potentially harmful outcomes to both perennial river systems (Kovach et al., 2019) and intermittent rivers (Datry et al., 2014).

Tickner et al. (2020) urged that an emergency recovery plan for freshwater biodiversity loss is needed and emphasized that the current SDGs (as well as Aichi Biodiversity Targets – Convention on Biological Diversity) need substantial refinement to better serve rivers more comprehensively. One of the major similarities between this recovery plan and the Brisbane Declaration was the recognition of the absence of environmental flow targets and management. Arguably, the most critical SDG that fails to mention the importance of rivers and environmental flows to its own success is SDG 14 – 'Life below water'. Even prior to the development of the SDGs, the obvious connection between rivers and marine systems was not consistently included in the fisheries policy arena, nor has this connection been articulated in SDG 14 and its targets (Elliott et al., 2022). To fulfil the targets proposed by SDG 14, clear recognition of riverine resilience in both policy and practice is needed.

1.3 Connecting SDG 14 to rivers

River systems contribute to marine ecosystem form and functioning, resilience and ecosystem services, but they do not feature in SDG 14. Instead, freshwater systems are integrated in several other SDGs, for example in SDG 15 – 'Life on land' and SDG 6 – 'Clean water and sanitation'. This disconnect fails to show the mutual opportunities that can benefit the sustainability and resilience of both freshwater and marine systems. The SDG 14 targets 14.1 – reduce marine pollution, 14.2 – protect and restore ecosystems, 14.3 – reduce ocean acidification, and 14.5 – conserve coastal and marine areas, are broad marine ecosystem goals, but they are being influenced by society's current interactions with rivers and watersheds. For example, experts have demonstrated that 70–80% of marine plastic pollution originates from land-based activities and makes its way to the sea via rivers (Duncan et al., 2020). Furthermore, the fisheries-focused targets of SDG 14 do not currently account for the inland fisheries sector (Elliott et al., 2022) and dependency on resilient river ecosystems, despite the importance of this sector in supporting some of the world's most vulnerable populations (Funge-Smith & Bennett, 2019). Additionally, SDG 14 neglects to incorporate how rivers may influence marine fish production, habitat loss, fisheries economics and fisheries policy.

This review aims to demonstrate links between rivers and marine ecosystems with regards to SDG 14's targets, such that policy and management strategies relevant to achieving sustainability goals can be proposed. In this review we present recent literature and specific examples illustrating how rivers and their environmental flows directly or indirectly link to SDG 14's progress or lack of progress. We also show how key actions recommended by the river science community can help build win-win sustainability outcomes for rivers and marine ecosystems. This review is separated into three main themes building off the SDG 14 targets and their means of implementation: (1) rivers contribute to marine and estuary ecosystem resilience (targets 14.1, 14.2, 14.3, 14.5); (2) resilient rivers are part of global fisheries sustainability concerns (targets 14.4, 14.6, 14.7, 14.B) and (3) enhancing marine policy and research from a river and environmental flows perspective (targets 14.A, 14.C). An overview of targets and indicators is provided in the Supplementary information. The first two themes present how rivers are relevant to the above listed SDG targets, assess existing indicators with or without the consideration of rivers, and provide potential mutual sustainability opportunities to improve marine ecosystems. The last theme focuses on joint policy opportunities between freshwater and marine ecosystems. We also include in a specific case study for the Mekong river highlighting the key findings from the review in an applied context.

2. Rivers contribute to marine and estuary ecosystem resilience

2.1 Relevance of river processes to SDG 14

Marine debris and nutrient pollution from land-based activities are predominantly transported to coastal and marine ecosystems by rivers (Duncan et al., 2020; Harris et al., 2021; Schmidt et al., 2017; Strokal et al., 2019, 2020). For example, an estimated 1.15–2.41 million tonnes of plastic debris flow from rivers into oceans every year with temporal variations attributed to river hydrodynamics (Lebreton et al., 2017). The Mekong river, for example, accounts for an estimated 40,000 tonnes of plastic into the world's oceans each year. The wide spectrum of plastic debris sizes, chemical additives and chemical compositions transported by rivers poses multiple environmental hazards for the receiving freshwater and marine ecosystems (van Emmerik & Schwarz, 2020). Similarly, river basins that encompass agriculture production can transport large quantities of nutrient pollution, such as nitrogen and phosphorus, from point and non-point sources to marine ecosystems (Strokal et al., 2016). One example of this is the Mississippi river, where decades of nutrient runoff has resulted in a hypoxic dead zone in the Gulf of Mexico (Tian et al., 2020; Turner & Rabalais, 2003). The flow rate of a river is a major process that affects the delivery of nutrient loading (Pinckney et al., 2001). Predicted increases in eutrophication and hypoxia events, as well as plastic pollution from rivers, have affected and will continue to affect fisheries and food webs in the marine environment (Borrelle et al., 2020; Rabalais et al., 2009). Flooding, magnified by climate change and deforestation, could potentially increase these impacts further (Polvi et al., 2020), for example, via washing microplastic particles present in soil and other terrestrial environments into waterways (Mouyen et al., 2018; Vogelsang et al., 2019).

Aside from the transportation of pollutants, the provisioning and regulating services from rivers play a vital role in coastal and marine ecosystem resilience. For instance, access to freshwater is essential for mangrove productivity (Santini et al., 2015), and transport and deposition of riverine sediments can have strong linkages to coastal zones and fisheries (Broadley et al., 2022; Darnaude et al., 2004; Kondolf et al., 2014a, 2014b). In addition, water extraction and diversion is expected to increase in many areas around the world and the current availability of groundwater will not meet the needs of 1.7 billion people in the near future, particularly in North America and Asia (Gleeson et al., 2012). One extreme example is the Colorado river, where these water-development needs have resulted in the river no longer reaching the ocean (Pitt et al., 2017). Building upon this predicament, natural phenomena, such as droughts and floods, can also influence river-connected coastal ecosystems by interrupting salinity dynamics (Lee et al., 2012), increasing mangrove mortality (Saintilan et al., 2019), and changing fisheries production (Ferguson et al., 2013; Gillson et al., 2012).

2.2 Evaluating SDG 14 indicators and identifying mutual opportunities

Target 14.1 (reduce marine pollution) seeks to prevent and significantly reduce all forms of pollution using an index focused on coastal areas that shares complementary goals with SDG 12.4: 'responsible management and production of chemicals and waste'. Despite having an earlier proposed completion date of 2025 instead of 2030, indexes for these targets have only been recently approved (Recuero Virto, 2018; United Nations Environment Programme, 2021a, 2021b). The new eutrophication index focuses primarily on water quality levels in the marine environment (e.g. chlorophyll-a, dissolved inorganic nitrogen, dissolved inorganic phosphorus), while the new marine plastic debris index focuses on floating debris in the ocean as well as beach litter (United Nations Environment Programme, 2021a, 2021b). Both of these indexes include monitoring parameters concerning rivers (e.g. river discharge, river water quality, river litter), but are relegated to 'level 3', which are supplementary indicators and not described in detail. The eutrophication index suggests that hydrology data are needed to quantify nutrient export, but instead focuses on discharge and retention. Shifting river measurements to a supplemental priority limits the potential to tackle SDG 14 issues before they enter the marine environment. In order to include riverine measurements into SDG 14 progress we highlight a more holistic array of datasets that could enable evidence-based decision-making and address issues at the source (Supplement 2).

While many marine systems are threatened by both sea and river sources, ecosystem-based management seems to be a top management priority for SDG 14, as one indicator for target 14.2 seeks to quantify the number of countries using ecosystem-based approaches to manage marine areas (United Nations Environment Programme, 2021a, 2021b). The scope of this management approach is often designed primarily to address marine issues at regional scales (Link, 2017), such as fisheries management regimes that are already seeking ecosystem management programmes through policy initiatives (Link, 2017). Extending this management approach to include rivers, estuaries and seas may require a meta-ecosystem perspective that emphasizes cross-ecosystem flows (Gounand et al., 2018). This has been recognized in recent river basin-to-ocean scale plastic waste management programmes and frameworks (Mathews et al., 2019; Moura et al., 2020). Combining efforts between marine, estuarine and freshwater ecosystem-based management to manage nature's contributions to people (Pascual et al., 2017), and achieve SDG 14 targets could be a synergistic outcome, but would also require extensive planning (Langhans et al., 2019; Needles et al., 2015).

Including river impact radius is a valuable approach to evaluate how rivers may impact marine regions given ocean processes (Fredston-Hermann et al., 2016). One example, the dispersal capabilities of plastic pollution via large oceanic currents, means that plastic emissions from rivers can threaten sensitive marine habitats and protected areas far beyond their immediate near-shore and coastal environments (Harris et al., 2021; Huserbråten et al., 2022; Lebreton et al., 2017) (Figure 1). In addition, Lindo (2020) showed that terrestrial species can conduct transoceanic dispersal by riding on top of macroplastic debris, which has the potential to introduce new species in non-native habitats. Since most marine plastic pollution originates from land-based activities, often via rivers (Duncan et al., 2020; Sundt et al., 2014), filling the knowledge gap of relations between river networks health and the presence of plastic pollution in the marine environment could support a connected ecosystem management approach (Azevedo-Santos et al., 2021). This could be particularly important in relation to the push to conserve large parts of the ocean

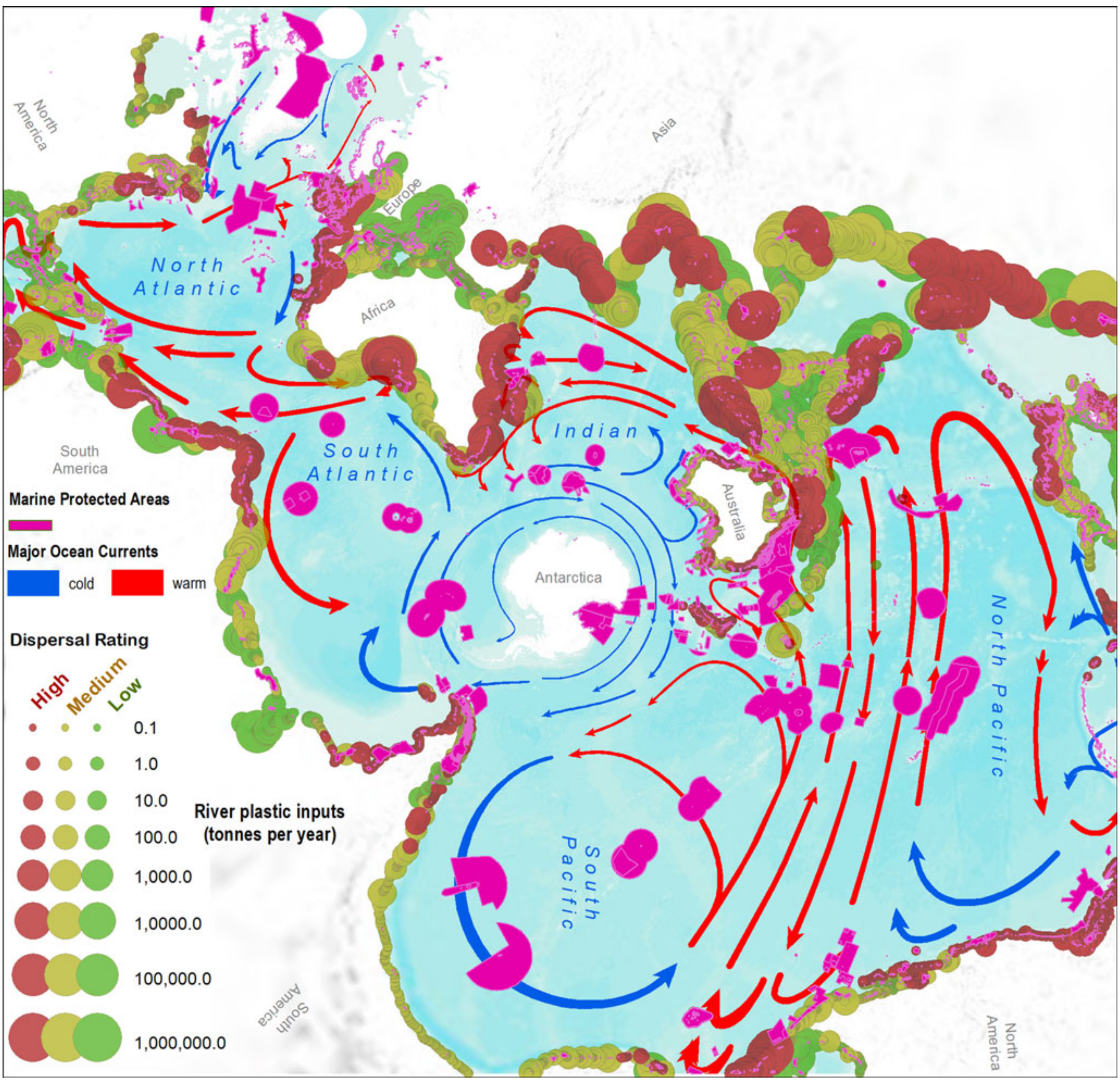

Figure 1. Map showing how major ocean currents and gyres can widely disperse pollutants, such as plastics, from rivers to MPAs. Projected using a Spilhaus projection, which distorts the map to fit all oceans into a single plane. This 'fish' view of oceans demonstrates how interlinked the plastic pollution problem is given the range of dispersal capabilities of plastics. Data for plastic output and dispersal were provided by Harris et al. (2021) and Esri basemaps were used for currents and elevation. MPAs came from protectedplantet.net (UNEP-WCMC, 2019).

through marine protected areas (MPAs), which is one of SDG 14's most often achieved targets. The success of MPAs and conservation areas may diminish if they do not have measures in place to manage widely dispersing threats emanating from rivers. Achieving many SDG 14 targets depends on the range at which these issues impact marine systems and goes beyond the river delta.

Actionable recommendations from the Brisbane Declaration, across governance, management and research bodies suggest the development of adaptive management frameworks that focus on balancing environmental flows for both human and ecological water requirements (Arthington et al., 2018). An environmental flows programme focused on river–estuary connections could forge new paths to identify key moments to implement mitigation measures (Stein et al., 2021). The timing and magnitude of river discharge predictions could, for example, provide insights on plastic dispersal ranges in relation to coast types (Harris et al., 2021), or could also be used by managers to know when to clean litter traps to avoid bypass or overflow during a flood event. An environmental flows style framework may also enable development of high-resolution, down-scaled estuarine indexes that provide predictions of ecosystem-wide scenarios given hydrological changes (Van Niekerk et al., 2019). If ecosystem-based management regimes are achieved in the marine/estuary environment, large-scale flow experiments may help evaluate water management actions for both the river and estuary (Olden et al., 2014).

A failure to accommodate a connected ecosystem perspective may result in lasting changes of the biophysical processes that connect rivers and coastal ecosystems (Thom et al., 2020). Furthermore, overlooking connections between SDG 6 and SDG 14 could result in achieving one SDG, but negatively affect the other (Wang et al., 2022). Developing policies that support both river ecosystem needs as well as estuary and marine needs may improve adoption of environmental flow principles and management. Environmental flow-based management shows promising restoration outcomes for historically over-utilized rivers, and can produce benefits for both rivers and estuaries when appropriately funded (Kendy et al., 2017). Further research to investigate flow–ecology relationships and ecosystem services that directly benefit rivers, estuaries and seas across a range of taxa and industries would also be beneficial (Arthington et al., 2018).

3. Resilient rivers are part of the global fisheries sustainability opportunity

3.1 Relevance of river processes to SDG 14

The SDGs do not recognize inland fisheries explicitly, and certainly do not recognize overfishing in lakes and rivers (Allan et al., 2005; Elliot et al., 2022; Lynch et al., 2017), despite fisheries from freshwater ecosystems (connected or unconnected to the marine environment) provide food security, primary protein and nutrition supply to some of the world's least developed nations and roughly 158 million people (Ainsworth et al., 2021; Funge-Smith & Bennett, 2019; McIntyre et al., 2016). It is important to point out that this issue also affects developed countries for a variety of fishery types (Driscol, 2015; Embke et al., 2019). Often inland fisheries are highly dispersed, lack infrastructure and management capacity, consist of artisanal or small-scale fishing, are lower in economic value and result in a subsistence-oriented harvest. The combination of these factors makes understanding impacts difficult (Bartley et al., 2015). Progress towards improving inland fisheries, as suggested by the United Nation's Rome Declaration (Cooke et al., 2021), has become constrained by these limitations and in many cases freshwater fisheries are heavily fished (Lynch et al., 2020). Most recently, a 10-year fishing moratorium for the Yangtze river was put into effect on 1 January 2021, which affects roughly 250,000 fishers according to mainstream media (Xiaoyi & Yameng, 2021). Drastic management actions, such as fishery closures, can help restore biodiversity and combat overfishing, but can work against the livelihoods and rights (e.g. ancestral, cultural, access arrangements, food security) of small-scale and subsistence fishers.

The construction and removal of water infrastructure (i.e. dams, water diversions, power plants and levees) is an example of a drastic ecosystem intervention that poses both opportunities and challenges for inland fisheries (Grill et al., 2019). On the one hand, fishery production of a reservoir can provide ways to increase capture and develop aquaculture, although it rarely replaces the lost river fisheries. On the other hand, barriers may generally result in reductions in fish catches, loss of biodiversity and interruption of ecosystem processes (Hughes, 2021; Petts, 1984). They may also prevent migration of diadromous and potadromous fishes if appropriate fish passage facilities are not installed (Winemiller et al., 2016). In extreme cases, large-scale water diversions could both fundamentally change flows within river systems and contribute to water scarcity (Shumilova et al., 2018).

Dams are designed for many purposes, which results in a complex array of impacts for both freshwater and diadromous fishes (Barbarossa et al., 2020). Often, such infrastructure development involves neither fishing communities in the planning nor discussions around needs for fish passage or other mitigation measures. For example, floodplain fisheries in the Mekong river basin that depend on annual flood regimes have encountered conflict with rice farmers as their levees and water management structures are used to convert floodplains into rice production (Lynch et al., 2019). Similar conflicts among inland fisheries and irrigation needs have been shown in the Murray–Darling basin (Lynch et al., 2019). Tributaries that are unobstructed by dams can still be affected by main stem rivers that are dammed because of the backwater effects of inundation and disconnection of migratory fish pathways (swimways) (Worthington et al., 2022). Riverine capture fisheries, such as the Murray–Darling basin, Brazilian Amazon and the Columbia river, are minimizing further deterioration by supporting science-based management and adapting governance for a shared water body (Cooke et al., 2021).

Systems that cannot overcome the challenges associated with existing capture fisheries have also considered further development of aquaculture (Valenti et al., 2021). Aquaculture is an independent production system that has the potential to increase the economic benefits of these fisheries, but has many economic limitations and risks for inland fishing communities as well (Lynch et al., 2017). Eutrophication from aquaculture may work against ecosystem management goals intended to reduce excess nutrients and algal blooms in rivers (Wang et al., 2020). Lack of regulations, inspections and monitoring can result in the escapement of non-native aquaculture farmed species, which threaten native biodiversity (Nobile et al., 2020). Opportunities to address some of these issues can be seen in Chinese freshwater aquaculture where dramatic changes to reach long-term sustainability initiatives are occurring: eliminating fertilizer application for fish culture, combining aquaculture with rice culture systems, increasing emphasis on aquaponics use, prioritizing culture of indigenous fish species, and increasing regulation (Wang et al., 2018). Subsidies geared to enhance more sustainable practices of freshwater aquaculture can also increase economic benefits and profitability without jeopardizing ecosystem integrity (Aheto et al., 2019; Guillen et al., 2019).

For marine systems, ending harmful subsidies that enable illegal, unreported and unregulated fishing practices is critical to prevent overfishing and promote sustainability of fish stocks. Conversely, in freshwater systems, fisheries can be harmed by subsidies or incentives that enable barrier construction, unsustainable aquaculture production, sand mining and other undesired by-products, which can alter natural flow regimes, reduce biodiversity and decrease the productivity of fish communities (Ainsworth et al., 2021; Arantes et al., 2019; Hackney et al., 2020; Kano et al., 2016; Pelicice et al., 2017). Subsidies for detrimental developments on rivers directly contribute to the degradation of ecosystem resilience and productivity, jeopardizing any existing fishing enterprises. For example, Badcock and Lenzen (2010) found that global financial subsidies for hydropower totalled 116 billion USD between 1960 and 2007. The total subsidies for all dams, not just hydropower, during this time period is unclear, but recent estimates of large hydroelectric projects (over 50 MW) was 16 billion USD in 2018 (United Nations Environment Programme & Frankfurt School-UNEP Centre, 2019) and for small hydropower development it was approximately 170 million euros in 2018 (Gallop et al., 2019).

Disagreement among stakeholders has made it unclear whether hydropower should be expanded to assist with efforts to decarbonize energy production and whether subsidies, such as the Kyoto Protocol's clean development mechanism, should be used to support this initiative (Ascher, 2021; Fearnside, 2015; Zarfl et al., 2015). As the cost of installing wind, solar and battery storage decreases, developing countries must decide on which renewable energy sources to invest (Thieme et al., 2021). Construction of hydropower dams is not only considered a viable means to meet SDG 7 (ensure access to affordable, reliable, sustainable and modern energy for all), but is a key investment goal for both hydropower developers and some global funding agencies (World Commission on Dams, 2000). Figure 2 highlights hydropower financing flows from 2000 to 2019, and according to the International Renewable Energy Agency (2022), total transactions reached 92.51 billion USD. The top five recipients were Brazil, Nigeria, Pakistan, Lao PDR and Ethiopia, and the largest donor was China. The implications for global financing of hydropower projects are directly linked to the future resilience of river systems, environmental flows and fishing-related targets of SDG 14, and many other food security-related SDGs as well as energy-related SDGs. The accessibility and increase of water security may provide opportunities for SDG 2 (end hunger, achieve food security and improved nutrition and promote sustainable agriculture) if agricultural development is pursued at the cost of SDG 14. Synergies between SDG 14, SDG 2 and SDG 3 (ensure healthy lives and promote well-being for all at all ages) become more realistic if a healthy river ecosystem is maintained. Tradeoffs and synergies among SDGs is not a new issue but solutions are often case-by-case specific where there is potential for conflict among stakeholders (Thieme et al., 2021).

3.2 Evaluating SDG 14 indicators and identifying mutual opportunities

Fishing at sustainable levels, implementing policies to restrict harmful fishing subsidies, increasing economic output of fisheries, and providing support for small-scale fishers (targets 14.4, 14.6 and 14.B) could be readily adapted to inland fisheries. One of the greatest challenges lies in the international characteristics of many of the world's large rivers. These transboundary rivers may have complex socio-ecological relationships concerning

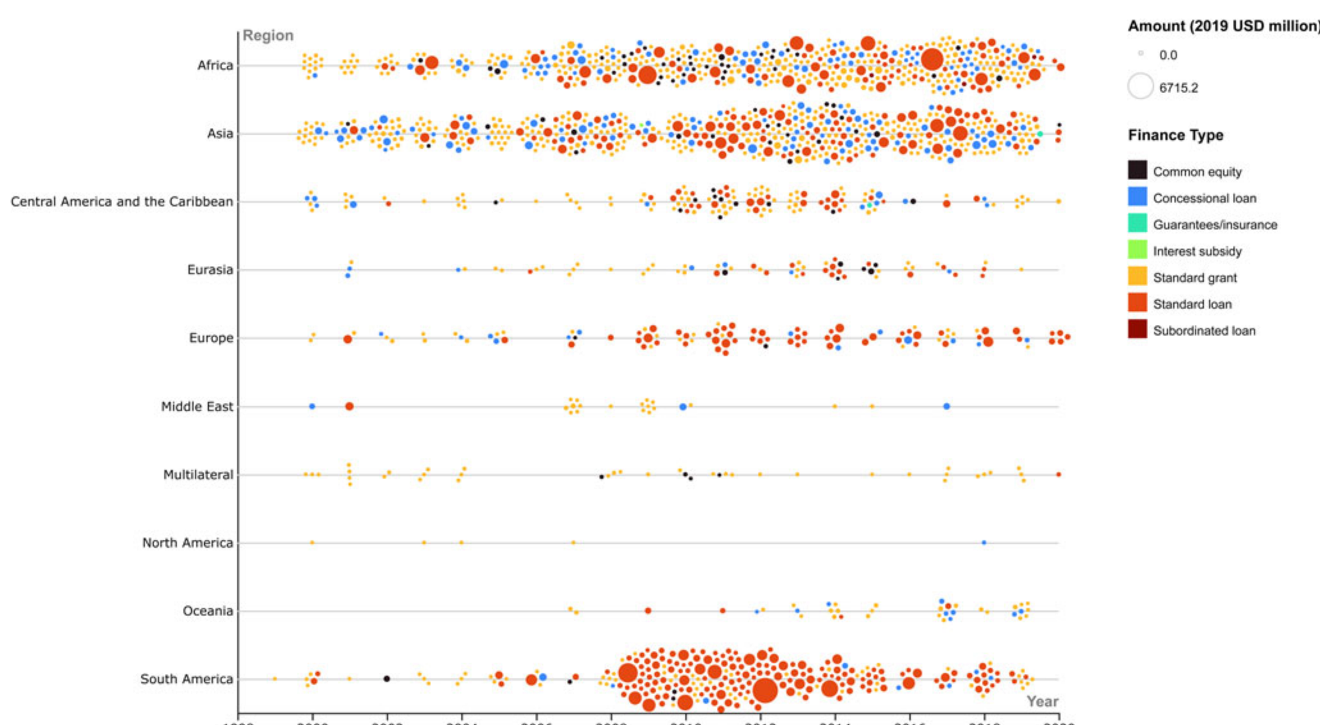

Figure 2. Bee-swarm plot showing the hydropower finance transactions by financing type from 2000 to 2019. Regions on the *y*-axis are the location of the recipient country. Data were retrieved from International Renewable Energy Agency (2022) and plotted using RAWGraphs (Mauri et al., 2017).

fishing, which may lead to conflict among different stakeholders (Ainsworth et al., 2021). For example, water abstraction from adjacent aquifers may also have multinational dimensions, issuing another series of challenges. Polycentric-governance is a potential opportunity that can supplement or even replace existing state-based governance systems to better accommodate transboundary issues in a flexible manner (Baltutis & Moore, 2019). Improving science-based management for these systems may be challenging for migratory species that cross political boundaries and ecosystems. The likely suspects framework is one potential approach that attempts to unify management of Atlantic salmon (*Salmo salar*) across its life history, which includes both marine and freshwater systems (Bull et al., 2022). The 'swimway' management approach is a recommendation for freshwater migratory fish species that span multiple basins and political jurisdictions (Pracheil et al., 2012; Worthington et al., 2022). Similarly, creating agreements for sustainable societal developments may require cooperation at multiple scales throughout a river basin to avoid power hierarchies (e.g. upstream and downstream socio-political dynamics).

Prohibiting certain fishing activities and river development subsidies that contribute to unsustainable practices and less resilient marine and freshwater systems will require different strategies. Many large rivers intersect with multiple countries that may have competing interests in regards to both energy and food production (e.g. the Mekong river intersects China, Myanmar, Thailand, Lao PDR, Cambodia and Vietnam). Implementation of international instruments focused on dam development incentives – particularly for developing and least developed countries – may need to operate at a transnational scale to avoid conflict over downstream water requirements. Unless mechanisms are in place to override activities in the watershed, there is always the risk that countries will act independently. For example, proposed dam development projects in free-flowing rivers over 500 km are focused in Asia, South America and Africa, which have the potential to: (1) affect some of the world's largest river basins and deltas; (2) involve multiple countries and (3) have implications for estuaries and marine environments (Thieme et al., 2021). Where aquaculture is being developed, careful consideration should be warranted to ensure artisanal fisheries are not substituted by aquaculture production. In the case of sand mining, regulating and monitoring, which is often not conducted, is just beginning to understand longitudinal impacts on the river system and the connected marine system (Hackney et al., 2020).

Application of legal, regulatory, policy or institutional frameworks for riverine small-scale fisheries can be improved by developing inclusive adaptive management programmes that incorporate fisher values and knowledge. Emphasis is particularly focused on full and equal participation of small-scale fishing communities and associated cultures for all parts of the governance process: planning, assessment, implementation, monitoring and management. This approach may present opportunities to subsidize sustainable development projects that can directly increase economic benefits from river fisheries. This co-development approach also provides a straightforward opportunity in making the planning process gender-inclusive, which has met resistance historically, despite high proportions of the workforce being women (Bartley et al., 2015; Biswas et al., 2018; Harper et al., 2020).

For riverine or reservoir capture fisheries, opportunities exist to optimize dam operations to integrate with fish life history requirements. However, such options are often hard to design and even harder to predict (Holtgrieve et al., 2018; Olden et al., 2014; Richter & Thomas, 2007; Sabo et al., 2017; Williams, 2018). The Brisbane Declaration suggests environmental flows should be assessed well before the development of new dams, and actively incorporated within the planning process once development commences (Arthington et al., 2018). Adopting an adaptive management approach for existing large infrastructure may also help promote environmental flows in a cost-effective manner (Olden et al., 2014). For systems where reservoir development is appropriate, consideration of multi-purpose operation and optimization could increase co-benefits as opposed to single-purpose implementation (Bhaduri et al., 2016). Dams have broad socio-ecological impacts upstream and downstream of their reservoir (Richter et al., 2010), and this issue persists well after the lifespan of the dam has surpassed and restoration is needed (Bellmore et al., 2019; Hansen et al., 2019; Perera et al., 2021; Tullos et al., 2016). Broader discussion and debate now concern how funds and subsidies are allocated for dams and their anticipated impacts (Hirsch, 2010; Thieme et al., 2021).

4. Case study snapshot: SDG 14 and environmental flow implications for the Mekong river and its delta

The Mekong river is one of the world's most important rivers. It is among the largest in terms of discharge, it is a 'hotspot' for freshwater aquatic biodiversity and the river basin supports a population of approximately 60 million people, where 70% of communities are rural and rice farming and fishing are primary occupations. Living aquatic resources, including fish and other aquatic animals, make a vital contribution to regional food security and nutrition, cash income and employment and have strong cultural and religious significance. More than 2.3 million tonnes of fish and a further 0.6–0.9 million tonnes of other aquatic organisms, valued at an estimated 17 billion USD, are harvested annually from the Lower Mekong basin (LMB) downstream of China (Nam et al., 2015)

The resilience of the Mekong basin hinges on the extent of multiple anthropogenic stressors: (1) climate change, (2) dams, (3) sediment mining, (4) groundwater extraction, (5) sea level rise, (6) land-use change, (7) fragmentation, (8) pollution, (9) non-native species and (10) water abstraction (Best & Darby, 2020). These stressors directly or indirectly affect the flows in the system, ecosystem functioning of the river's delta and the integrity of the adjacent marine ecosystem. For example, some may directly impact the artisanal fisheries and exploitation of aquatic products along the river, and will have indirect impacts on the fishery, subsistence agriculture and the delta by altering flow dynamics and the movement of sediments (Dugan et al., 2010). The large dams in the Mekong – particularly those in China and the major tributaries of the LMB – alter the flow regime, but also block or alter the passage of aquatic biota and sedimentary materials. The large run-of-river hydropower plants in the mainstream of the LMB also impact movement of aquatic biota and sediments but are less prone to alter the hydrology, except in the few hundred kilometres downstream of the dam where hydropeaking occurs. The size of the migratory fish resource at risk from dams on the Mekong mainstream alone has been estimated at 0.7–1.6 million tonnes per year (equivalent to approximately 30–60% of the annual catch in the Mekong) (DHI, 2015; Mekong River Commission, 2021). This is a conservative estimate because it does not account for the economic benefits that flow from the trade and processing of fish products.

One of the insidious impacts will be the capture of sediments in the impoundments that will fundamentally alter the river form and functioning (Hackney et al., 2021). It is estimated that 96% of the 160 million tonnes historically deposited in the South China Sea (Kondolf et al., 2014a, 2014b) (now estimated at 87 million tonnes per year; Darby et al., 2016) will be captured and deplete the sediment deposition in the floodplain and coastal regions. This problem with sediment depletion by the dams is exacerbated by sand and gravel mining in the lower basin, with around 55 million tonnes removed annually, considerably more than what is naturally transported in the system under the current damming regime (Hackney et al., 2021). The further consequences of this loss in sediment is the reduction in nutrient transport and thus productivity of aquatic plants and animals, especially in the flood plain areas of the LMB (Kondolf et al., 2018), and also in the South China Seas fisheries, which currently yields about 500,000–726,000 tonnes per year. In addition, the sediment depletion is leading to considerable coastal erosion, which is currently up to 12 m per year (DHI, 2015), affecting mangrove forests and nursery areas of many fish and shellfish species.

These changes brought about by the flow regulation and sediment depletion have a considerable impact on achieving SDG 14 and targets 14.4 and 14.B in terms of stock recovery and sustaining small-scale fisheries. The disruption to ecosystem functioning, reduction in extent and duration of flooding in the LMB, erosion of coastal habitat and loss of productivity of coastal fisheries in the South China Sea all compromise the extensive small-scale and subsistence fisheries, and ultimately access to critical aquatic resources that sustain millions of people in the region. To bridge the gap between SDG 14 targets and the guiding environmental flow principles of the Brisbane Declaration, we highlight how this dual approach can address the Mekong river's most pressing challenges. Table 1 provides an overview of SDG 14 targets in relation to the organizational units as proposed in the Brisbane Declaration to highlight how environmental flow guidance can mutually benefit both riverine goals and marine-focused targets. The mentioned references support and describe the critical issue in more detail and also highlight how alternative definitions of environmental flows that emphasize the inclusion of sediments and transported material (de Jalón et al., 2016) may be critical to connected riverine–marine systems.

The Mekong river system has a variety of issues that span waste management, natural resources and political challenges that are both directly and indirectly related to the environmental flows of the system. Supplementary Figure S2.1 showcases the Brisbane Declaration as primary components of a 'planetary' gear system, how each component relates to the six primary themes of the declaration and are scaled to the three different stakeholder organizations: leadership and governance, management and research. This illustrates the profound importance of a cooperatively driven system maintained by scientifically rigorous data as key requirements for future advancement and application of environmental flows. Using the 'planetary gear' view and the Brisbane Declaration as inspiration, we applied its framework of leadership and governance, management and research to show possible mutual opportunities that can benefit the river and the marine system (Table 1). Of course, not all of SDG 14's targets are applicable, which is to be expected for any river system. The main takeaway from Table 1 is to showcase how river–marine issues can be readily shown as win-win opportunities and it is anticipated that other river systems can develop site-specific strategies and achieve similar mutual outcomes. Bringing together stakeholders from both systems will ideally bring about a more cohesive and functioning operation towards conservation goals and sustainable development.

5. Enhancing marine outcomes through river and catchment policy

The current relationship between society and the global water cycle is unsustainable (Abbott et al., 2019). Environmental flows comprise primarily the surface water aspects of freshwater use; however, while important, contextualizing such efforts into broader water planetary boundaries may yield even greater outcomes (Gleeson et al., 2020). The previous sections highlighted the reliance between river health and marine ecosystem health as well as their direct benefits to society. To maintain the resiliency of well-managed systems and recover the resilience of impacted systems, pathways via policy and management need to be identified and implemented. Special attention to the challenges that prevent linking these systems is ideal areas to develop scale-appropriate legislation, management approaches and policy. In the following sections, we showcase how scalable policies are critical to incorporating environmental flow opportunities.

There are many layers of policy and stakeholders that need to be taken into consideration for policies to function as intended. For example, at the highest level (the transnational level), the European Union Water Framework Directive (WFD-2000/60/EC) is designed to improve surface and groundwater conditions while also linking with the EU Marine Strategy Framework Directive (MSFD). Both policies promote using scalable management plans: for freshwater systems a river basin management system, and for marine systems an integrated coastal management system and an ecosystem-based approach. This push comes from the EU's green deal strategy to become the world's first climate-neutral continent (European Commission. Directorate General for Maritime Affairs and Fisheries, 2019). Although it is unclear how hydropower and dams will be involved during this transition to pursue carbon-neutral energy sources, the marine directive MSFD identified the need for additional measures to address riverine-sourced issues concerning plastic pollution and nutrient runoff. Enhancing policy-driven environmental flow management and data collection in areas such as regulation of rivers, freshwater aquaculture and nutrient runoff, as well as understanding any relationships between flow and hypoxic dead zone areas, and relationships between flow and sensitive habitats, could mutually benefit rivers and marine systems. Other systems could follow suit with their own transnational cooperation, or look to others such as the International Joint Commission (North America: USA and Canada boundary waters), Orange-Senqu River Basin Commission (Africa: Botswana, Namibia, Lesotho and South Africa) or the Mekong River Commission (mentioned in the case study) (Raadgever et al., 2008).

After transnational agreements, lower on the scale are national laws and regional policies, which more directly influence and regulate how rivers will interact with marine systems. One example that includes the whole range of regulations is the Baltic Sea eutrophication governance. Nine coastal countries (Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden) surround the Baltic Sea, and despite mitigations such as wastewater treatments and better agricultural practices in the 1980s and 1990s, the amount of nutrients and sediment that is transported from land-to-river-to-sea is still high. The intergovernmental organization The Helsinki Convention (HELCOM) consists of the nine surrounding coastal countries and the EU as contracting parties. In their work of approaching the objective of a good environmental status and sustainability, they use the instrument Baltic Sea Action Plan (BSAP) (Baltic Sea Action Plan – HELCOM, 2021)

https://doi.org/10.1017/sus.2022.19 Published online by Cambridge University Press

Table 1. Overview of possible actions that organizational bodies could undertake for addressing critical river and marine issues in the Mekong river basin and delta

SDG 14 target	TARGET 14·1 REDUCE MARINE POLLUTION	TARGET 14·2 PROTECT AND RESTORE ECOSYSTEMS	TARGET 14·4 SUSTAINABLE FISHING	TARGET 14·5 CONSERVE COASTAL AND MARINE AREAS	TARGET 14·A INCREASE SCIENTIFIC KNOWLEDGE, RESEARCH AND TECHNOLOGY FOR OCEAN HEALTH	TARGET 14·B SUPPORT SMALL SCALE FISHERS	TARGET 14·C IMPLEMENT AND ENFORCE INTERNATIONAL SEA LAW
Critical river–marine issue	*Plastic and human debris* *High nutrient loading* *Freshwater aquaculture*	*Sediment flux and mining* *Hydropower Development* *Protection of critical nursery habitats in transitional waters*	*Overfishing* *Migratory fishes and movement barriers*	*Wetlands, mega-deltas and mangroves*	*Data collection and sharing*	*Prioritize co-management and enhancement of sustainable fishing activities*	*International cooperation throughout river-to-sea continuum*
Ongoing and anticipated impact on estuary and marine environment	Pollution with low-dispersal capacity disturbs estuary ecosystem functions Buoyant pollution contributes to gyre-based pollution accumulation areas Waste products from aquaculture directly impact sensitive habitats (i.e. mangroves)	Flow and sediment regimes do not resemble historical conditions and drive coastal erosion of Mekong delta Unprotected fish nursery areas limit recovery potential of fish stocks	Overfished fisheries decrease food security and negatively affect livelihoods Migration barriers decrease recruitment of migratory fish species	Loss of sensitive habitats is directly linked to biodiversity loss throughout the river–sea continuum	Limited data collection and accessibility barriers prevent transparency and evidence-based decision making that often require international collaboration	Lack of co-management adoption hinders conservation goals of target and non-target species (i.e. river dolphins and fish species of high-conservation value) throughout the river–sea continuum	Inadequate intergovernmental cooperation regarding fisheries, markets and investments encourages an upstream vs. downstream policy space
Leadership and governance	Form an enforceable body of harmonized legislation in the LMB to incentivize reduction in indiscriminate waste disposal and excess use of fertilizers Introduce environmentally friendly aquaculture management practices	Develop capacity for a basin and coastal wide sediment management plan Abide by 1995 Mekong Agreement[1] to 'do no harm' through development activities	Ensure legislative framework is in place to allow for adaptive co-management with transboundary support Ensure suitable fish passage solutions are designed into water resource development schemes, especially dams and agricultural development	Update the MRC wetlands database and implement the core river monitoring network programme	Finance and continue to develop MRC mutual data sharing standards, practices and licenses that are available to all stakeholders	Promote equitable planning and decision-making processes and planning to enable sustainable harvests, identify new fish conservation zones, and reduce bycatch	Develop and ratify transboundary agreements for all countries in watershed regarding water use and infrastructure development
Management	Reach out to marine-protected and coastal zone areas that are affected by river outputs Increase monitoring	Prepare a sustainable management plan for sediment mining that accounts for	Develop fishery regulations that prevent overfishing of highly mobile species Improve	Promote-protected areas for critical and suitable habitat types under MRC critical habitats framework	Design a robust data environmental flows monitoring network and open data portal in line with	Incorporate community values and knowledge into main-stem river management actions and provide management	Promote transnational legislative frameworks under the 1995 Mekong Agreement[1]. And build off existing fisheries legislation to

(*Continued*)

Table 1. (*Continued.*)

SDG 14 target	TARGET 14·1 REDUCE MARINE POLLUTION	TARGET 14·2 PROTECT AND RESTORE ECOSYSTEMS	TARGET 14·4 SUSTAINABLE FISHING	TARGET 14·5 CONSERVE COASTAL AND MARINE AREAS	TARGET 14·A INCREASE SCIENTIFIC KNOWLEDGE, RESEARCH AND TECHNOLOGY FOR OCEAN HEALTH	TARGET 14·B SUPPORT SMALL SCALE FISHERS	TARGET 14·C IMPLEMENT AND ENFORCE INTERNATIONAL SEA LAW
	and risk analysis associated with expanding aquaculture	development and maintains ecosystem functioning Adopt dam operation schemes that minimize impact on aquatic systems	accessibility of migratory fishes throughout the basin via appropriate mitigation measures at barriers, transboundary management and appropriate legislation		the MRC Core River Monitoring Network	opportunities for community driven initiatives	ensure freshwater and marine investments support one another
Research	Analyse e-flow dynamics in relation to societal impacts Explore potential of aquaculture as an offset for riverine capture fisheries, including for conservation of endangered species	Model e-flow sediment dynamics to physical and ecological outcomes of river, delta and coastal systems Research fisheries enhancement and habitat improvement measures to mitigate loss of impacted small-scale fisheries	Evaluate performance of fish conservation zones in the context of livelihoods Evaluate e-flow life history requirements for migratory fish, including needs of fish passage mitigation structures, and potential challenges	Classify critical habitat susceptible to changing e-flow conditions	Uncover relations between resilience and extreme events that affect river, estuarine and marine areas	Further improve knowledge about e-flow connections (e.g. flooding patterns) to biodiversity and system resilience Aid in the development of bycatch reduction methods for species such as river dolphins	Enhance existing collaborative research from different countries through the MRC umbrella and include other nations within river impact radius
References	Haberstroh et al. (2021); Mekong River Commission (2021); United Nations Environment Assembly of the United Nations Environment Programme (2022)	Bussi et al. (2021); Hackney et al. (2021); Marchesiello et al. (2019); Mekong River Commission (2021); Tamura et al. (2020), Gratiot et al. (2017)	Mekong River Commission (2021); Vu et al. (2021)	Halladay et al. (2003); Mekong River Commission (2021)	Mekong River Commission (2021)	Arias et al. (2014); Lu et al. (2014); Mekong River Commission (2021, 2022); Ngor et al. (2018); Vu et al. (2020)	Kuenzer et al. (2013); Mekong River Commission (2021, 2022)

Structure and guidance of this table builds off the ideas proposed in the Brisbane Declaration (Supplement S2). Targets 14.3, 14.6 and 14.7 were removed as no direct linkage to the river or catchment is present for this system. This table is not a comprehensive list but is to highlight the largest issues for this international system and encourage others to consider a similar evaluation for their own river-to-sea continuum.

[1]https://www.mrcmekong.org/assets/Publications/policies/agreement-Apr95.pdf.

and co-operate with management authorities for each river basin. In the BSAP, it is concluded that the nutrient load is still high, and establishment of buffer zones is mentioned as one example of action. Protection of riparian zones along streams and lakes will influence the nutrient loading to the aquatic system since riparian zones filter water, nutrients and sediment (Hasselquist et al., 2020). The current removal of protection of riparian buffers in Sweden can function as an example where the Swedish environmental objectives conflict with Agenda 2030 global goals at a national level. Here, the goal of 'Zero eutrophication' collides with the goal of a 'Varied agricultural landscape', where one goal promotes protection of the riparian buffers and the other one sets to limit buffers to open up the landscape.

Lowest on the scale are local laws, policies and ordinances that can shape how society interacts with rivers before they reach the marine environment. Broadly speaking, storm-water management (Harding et al., 2020), ice and salt management in colder climates (Szklarek et al., 2022) and road development (Kemp & O'Hanley, 2010) are commonplace in urban settings and directly affect a variety of environmental flow criteria and indirectly affect SDG 14 targets. Terrestrial-focused policies, such as bans or reductions of single-use plastics, can be either national in their implementation or fragmented at a variety of different scales (Adam et al., 2020). In the rural setting, land developments may not be concentrated making it harder to enforce and regulate industrial waste products directly entering rivers. For example, in China poor regulation and environmental measures in combination with rural development growth allowed industries to operate without proper waste treatment facilities, resulting in a public health crisis (Wang et al., 2008).

At every level of the policy-making environment the problem of the ranking and prioritization of SDG goals exists, both in legislative arenas and implementation. An emerging example that intersects multiple scales concerns SDG 9 (Build resilient infrastructure, promote sustainable industrialization and foster innovation) where infrastructure development, particularly in developing countries, is directed towards increased development in rural areas where ecosystem integrity is often highest (Baffoe et al., 2021). But without successful progress in SDG 9, many SDGs related to human well-being and economic advancement become limited. Progress of SDG 14 has shown that without appropriate infrastructure, developing countries have greater difficulty to (1) increase economic benefits from domestic fishery products, (2) transition to greener technology throughout the fishery supply chain (i.e. aquaculture facilities) and (3) increase scientific capacity to ensure sustainable fisheries production. Recognizing the scale most appropriate for SDG implementation will be critical for future progress.

5.1 Evaluating SDG 14 indicators and identifying mutual opportunities

We argue that a key theme for embracing environmental flows thinking in the current political landscape is to enact long-term monitoring programmes as soon as possible to reduce uncertainty in our understanding of flow dynamics and their potential changes as climate change progresses and as society continues to develop. Additionally, this data-driven basis has the capacity to inform design and implementation of policies regardless of which scale is considered (e.g. transnational, national/regional, local/urban/rural). Prioritizing environmental flow data can provide more holistic understandings of the proposed SDG indexes and a better ability to predict management scenarios influenced by flow. This is in contrast to today's approach, where the current SDGs focus on budgets towards marine technology and maritime laws put the responsibility on coastal countries, despite the contributions of upstream countries to the variety of issues reported in this article.

A number of conceptual frameworks exist to aid investigations of river ecosystem dynamics, implementation of restoration approaches, assessment of tradeoffs and decision-making guidance that could also inform issues in marine systems. A non-exhaustive list includes the ecological limits of hydrologic alteration framework, the restoring rivers for effective catchment management framework and the motivation and ability (MOTA) framework (Friberg et al., 2016; Nguyen et al., 2019; Poff et al., 2010). The source-to-sea conceptual framework emphasizes scale-based interconnectivity of various flows: water, sediment, pollutants, materials, biota and ecosystem services (Granit et al., 2017). Inclusion of social components into frameworks or policy has the opportunity to include local values and cultures into the decision-making and prioritization processes. However, greater framework development is needed to demonstrate clear biophysical and socio-economic connections between rivers, estuaries and marine ecosystems so resilience can be systematically linked and quantified.

In addition to conceptual frameworks, there exists partnership-driven approaches that encompass the interconnections of land, water and coastal systems as a central guiding theme (Silvestri et al., 2010), often to protect biodiversity with an ecosystem services focus (Reuter et al., 2016). The ridge-to-reef approach encourages joint public–private partnerships among terrestrial and marine stakeholders, which has been primarily adopted for island countries and states near the equator (Carlson et al., 2019). Locally collected spatial data of multiple stressors are critical to develop a synergistic modelling framework (i.e. terrestrial drivers, anthropogenic drivers, marine drivers, groundwater/nutrient models, coastal discharge models, coral reef predictive model) (Comeros-Raynal et al., 2019; Delevaux et al., 2018; Rude et al., 2016) or landscape indicators (Rodgers et al., 2012) necessary to inform ridge-to-reef decision making. The white water to blue water initiative was a Caribbean-focused ancillary that attempted to develop public, private and non-profit partnerships that could jointly improve management of watershed and marine ecosystems in support of sustainable development (Laughlin et al., 2006). More recently, a wholescape approach to marine management has been proposed that intends to expand upon the pre-existing catchment-based approach in England and Wales (Catchment Based Approach: Improving the Quality of Our Water Environment, 2013; Maltby et al., 2019; Stojanovic & Barker, 2008). Expanding the scope of these strategies to other river systems and marine environments offers an opportunity to identify efficient pathways to mutual sustainability success.

6. Conclusions

Global fisheries sustainability concerns and a global water crisis put the sustainability of rivers and other freshwater ecosystems in jeopardy. Many costly lessons have been learned from American and European efforts to utilize river systems to the fullest extent, and this has left a legacy of persistent environmental issues that have no short-term solutions and contentious long-term prospects. Stewardship of rivers seems to come after development needs instead of in tandem when rivers are contributing

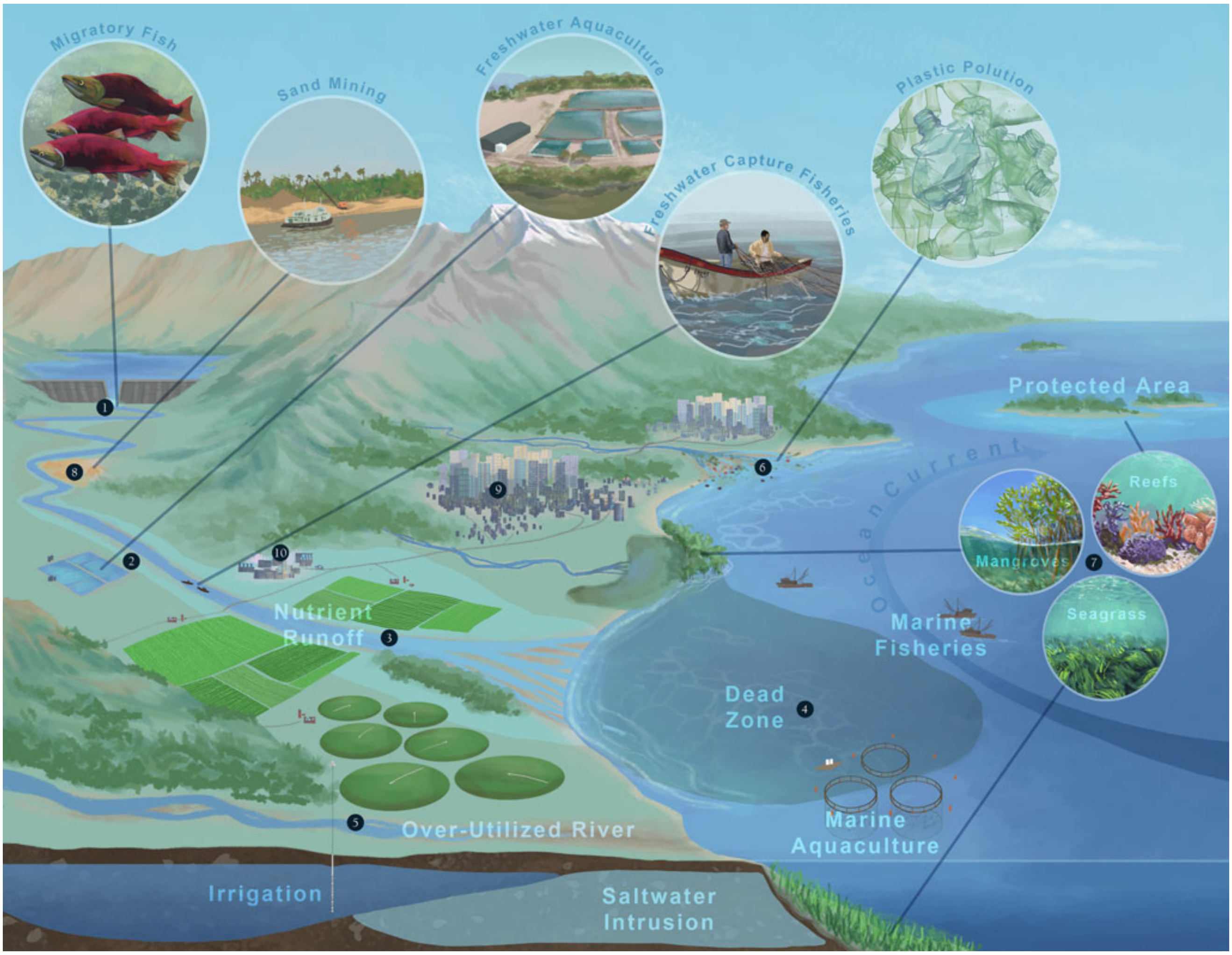

Figure 3. Graphical depiction of how marine ecosystem health is tightly linked with riverine ecosystem health and environmental flows. Within this river–marine landscape, we highlight 10 areas where environmental flow opportunities can mutually benefit both systems and achieve SDG targets. Specific details of each point can be found in the main text but an overview for each point is provided as follows: (1) regulation of rivers, (2) freshwater aquaculture, (3) nutrient runoff, (4) flow relationships to hypoxic dead zone areas, (5) freshwater-dependent ecosystems and groundwater-dependent ecosystems, (6) environmental flow relationships with plastic types and sizes, (7) flow relationships from rivers to sensitive habitats, (8) tradeoffs of river development, (9) engage stakeholders and (10) equal participation and knowledge production.

to human enterprise and delivery of multiple ecosystem services. Society in general can learn from these many ecological mistakes and adopt, prevent, maintain and restore strategies based on those experiences.

As a way to provide researchers, managers and policy makers with recommendations to improve both marine and freshwater environments and make cross-system conservation more accessible (Álvarez-Romero et al., 2012; Reuter et al., 2016), we present 10 areas that relate this review to the land–marine interface and SDG 14 (Figure 3). In select places below, we have mentioned ongoing SDG acceleration actions (in italics) that provide management agencies and practitioners approaches that can be considered for implementation.

(1) *Regulation of river flows* supports multiple SDGs, but often negatively affects migratory fishes (critical for both freshwater and marine ecosystems) and fishes that depend on natural flow regimes. Developing incentives or mitigation measures to allow fish passage and restore natural flow regimes can support the SDGs jointly, especially if subsidies are used to support such development. Similarly, identifying 'focused flows' can support estuarine nursery habitats for fish during dry periods (Montagna et al., 2021). A data-driven approach directed at decision makers may be an effective means to build technical capacity and enable restoration particularly for freshwater systems and their estuaries.
(2) *Freshwater aquaculture* has the potential to boost food production from inland waters that cannot enhance capture-based production (Cooke et al., 2016; Gephart et al., 2021). Identifying hydrologic connectivity and flood dynamics to reduce escapement of non-native species and poor water quality spillover, particularly for pond-based aquaculture (Boyd et al., 2020), may help maintain river and estuary ecosystem health while also supporting food security.
(3) Developing long-term gauging systems and water-monitoring programmes in rivers provides a crucial data prerequisite to understanding key estuarine and coastal ecosystem processes (Chilton et al., 2021). These can include

hydrodynamics, salinity, regulation, sediment dynamics, nutrient cycling and trophic transfer and connectivity. For example, identifying critical time periods and discharges of *nutrient runoff* from non-point source polluters and other future rural development requires modelling of environmental flows when implementing preventative and reactive management actions (e.g. riparian buffers) (Lind et al., 2019; Van Niekerk et al., 2019).

(4) Understanding *flow relationships to hypoxic dead zone areas* may better inform impact radii and synergistic effects with ocean currents. Predicted relationships may help inform fishing production for both capture fisheries and aquaculture. This is particularly relevant for aquaculture located in protected bays and deltas that rely on flow conditions and/or coastal currents. One idea to capitalize on this problem is to install seaweed or mollusc aquaculture to assimilate nutrients causing dead zones (Racine et al., 2021).

(5) Identifying the *relationship between freshwater-dependent ecosystems and groundwater-dependent ecosystems* may help delineate saltwater intrusion for coastal cities and water resource management for land-based agriculture. Monitoring and mapping water-chemistry parameters (e.g. chloride) in wells can detect saltwater intrusion and inform water-use practices (Cherry & Peck, 2017).

(6) Uncovering *flow relationships with plastic types and sizes* may improve capture efficiency and pollution reduction before it reaches marine environments. A transboundary diagnostic analysis/strategic action programme methodology could be deployed in tandem with river basin management to link flow regimes to land-based sources of pollution.

(7) Quantifying *flow relationships from rivers to sensitive habitats* can improve conservation outcomes, but can also reveal how pollution from rivers can disperse among regions using ocean currents (Carlson et al., 2021). Developing ecosystem-based adaptation measures such as managed-access and reserves can provide pathways for economic and ecological resilience.

(8) Assess *tradeoffs between river development (e.g. sand mining), historic water quality and sediment dynamics* as functions of environmental flows. Many other forms of rural development (e.g. logging, ranching) occur adjacent or near to rivers with direct influence on environmental flows and downstream water quality. Analysing either modern high-resolution imagery or historical imagery can provide a cost-effective means to quantifying changes in the landscape and its impact on adjacent freshwater–marine systems (Hackney et al., 2021; Nita et al., 2018).

(9) *Engage stakeholders* throughout the development chain to uncover cultural heritage values and generate awareness of sustainable marine commodity platforms that allow for policy dialogue from a bottom-up approach. For systems with small-scale fishing communities that may be data poor we recommend the small-scale fisheries resource and collaboration hub and their guide on community-based resource management.

(10) Build *equal participation* capacity and empower *local knowledge production* to inform management practices, governance approaches and co-development best practices. One way to implement this in practice is the *source-to-sea* approach which is a collaborative and participatory-oriented framework to embed projects and programmes into the source-to-sea continuum (Mathews et al., 2019).

We recognize that watersheds and estuaries have unique circumstances but the challenges that they face are globally prevalent. It is our goal to encourage policy makers, researchers and managers to build metaphorical bridges to their marine counterparts where appropriate. Through these partnerships, we expect innovative methodologies, practices and policies will yield greater progress towards maintaining resilient ecosystems, recovering resilience in altered ones and achieving SDG 14 targets.

In summary, freshwater and marine systems alike are physically and ecologically connected so it is ideal that the policies that govern these systems follow suit. While this review only focused on SDG 14, further work examining other SDG topics such as energy development, food production and drinking water would be particularly valuable. Addressing these issues from a global scale, such as the hydrological cycle, would be the ideal means to connect ecosystems to bring about collaboration at larger spatial scales. This paper, instead, serves to link the two most critical ecosystems needed to support SDG 14 – marine ecosystems and the rivers that feed them.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/sus.2022.19.

Acknowledgements. A diverse array of stakeholders interested in fisheries, rivers and oceans have collectively shaped our thoughts on this topic but particular thanks is given to the course leader of the Bergen Summer School's Life Below Water Course, Katja Enberg, who encouraged this manuscript and provided feedback on early development of the manuscript. Thanks also go to the students of the course who presented many lovely personal insights on fish, fisheries and oceans. Special thanks go to Jennifer Clausen at jacdraws.com for help in designing and drawing Figure 3.

Author contributions. H. H. H. conceptualized the manuscript, coordinated the improvements, designed the figures and assisted in writing. K. A. W. and V. H. P. wrote Section 1 of the paper and edited the manuscript. H. H. H. wrote Section 2 of the paper and edited the manuscript. L. L. and E. B. wrote Section 3 of the paper and edited the manuscript. I. G. C. and H. H. H. wrote the case study section of the paper and edited the manuscript.

Financial support. This project has received funding from the European Union Horizon 2020 Research and Innovation Programme under the Marie Sklodowska-Curie Actions, Grant Agreement No. 860800: RIBES 'River flow regulation, fish Behaviour and Status'. K. A. W. is supported by the Australian-American Fulbright Commission. V. H. P.'s contribution to this work is funded by NORSUS basic funding from the Research Council of Norway.

Conflict of interest. None.

Data. The associated data can be found at: https://doi.org/10.5281/zenodo.7251395.

References

Abbott, B. W., Bishop, K., Zarnetske, J. P., Minaudo, C., Chapin, F. S., Krause, S., Hannah, D. M., Conner, L., Ellison, D., Godsey, S. E., Plont, S., Marçais, J., Kolbe, T., Huebner, A., Frei, R. J., Hampton, T., Gu, S., Buhman, M., Sara Sayedi, S., … Pinay, G. (2019). Human domination of the global water cycle absent from depictions and perceptions. *Nature Geoscience*, *12*(7), 533–540. https://doi.org/10.1038/s41561-019-0374-y.

Adam, I., Walker, T. R., Bezerra, J. C., & Clayton, A. (2020). Policies to reduce single-use plastic marine pollution in West Africa. *Marine Policy*, *116*, 103928. https://doi.org/10.1016/j.marpol.2020.103928.

Aheto, D. W., Acheampong, E., & Odoi, J. O. (2019). Are small-scale freshwater aquaculture farms in coastal areas of Ghana economically profitable? *Aquaculture International*, *27*(3), 785–805. https://doi.org/10.1007/s10499-019-00363-9.

Ainsworth, R., Cowx, I., & Funge-Smith, S. (2021). *A review of major river basins and large lakes relevant to inland fisheries*. FAO. https://doi.org/10.4060/cb2827en.

Allan, J. D., Abell, R., Hogan, Z., Revenga, C., Taylor, B. W., Welcomme, R. L., & Winemiller, K. (2005). Overfishing of inland waters. *BioScience*, *55*(12), 1041–1051. https://doi.org/10.1641/0006-3568(2005)055[1041:OOIW]2.0.CO;2.

Álvarez-Romero, J., Pressey, R., Ban, N., Vance-Borland, K., Willer, C., Klein, C., & Gaines, S. (2012). Integrated land-sea conservation planning: The missing links. *Annual Review of Ecology, Evolution, and Systematics*, *42*, 381–409. https://doi.org/10.1146/annurev-ecolsys-102209-144702.

Arantes, C. C., Fitzgerald, D. B., Hoeinghaus, D. J., & Winemiller, K. O. (2019). Impacts of hydroelectric dams on fishes and fisheries in tropical rivers through the lens of functional traits. *Current Opinion in Environmental Sustainability*, *37*, 28–40. https://doi.org/10.1016/j.cosust.2019.04.009.

Arias, M., Piman, T., Lauri, H., Cochrane, T., & Kummu, M. (2014). Dams on Mekong tributaries as significant contributors of hydrological alterations to the Tonle Sap Floodplain in Cambodia. *Hydrology and Earth System Sciences*, *18*, 5303–5315. https://doi.org/10.5194/hess-18-5303-2014.

Arthington, A. (2021). Grand challenges to support the freshwater biodiversity emergency recovery plan. *Frontiers in Environmental Science*, *9*, 664313. https://doi.org/10.3389/fenvs.2021.664313.

Arthington, A., Bhaduri, A., Bunn, S. E., Jackson, S. E., Tharme, R. E., Tickner, D., Young, B., Acreman, M., Baker, N., Capon, S., Horne, A. C., Kendy, E., McClain, M. E., Poff, N. L., Richter, B. D., & Ward, S. (2018). The Brisbane Declaration and global action agenda on environmental flows (2018). *Frontiers in Environmental Science*, *6*, 1–15. https://doi.org/10.3389/fenvs.2018.00045.

Arthington, A. H., Naiman, R. J., Mcclain, M. E., & Nilsson, C. (2010). Preserving the biodiversity and ecological services of rivers: New challenges and research opportunities. *Freshwater Biology*, *55*(1), 1–16.

Ascher, W. (2021). Rescuing responsible hydropower projects. *Energy Policy*, *150*, 112092. https://doi.org/10.1016/j.enpol.2020.112092.

Azevedo-Santos, V. M., Brito, M. F. G., Manoel, P. S., Perroca, J. F., Rodrigues-Filho, J. L., Paschoal, L. R. P., Gonçalves, G. R. L., Wolf, M. R., Blettler, M. C. M., Andrade, M. C., Nobile, A. B., Lima, F. P., Ruocco, A. M. C., Silva, C. V., Perbiche-Neves, G., Portinho, J. L., Giarrizzo, T., Arcifa, M. S., & Pelicice, F. M. (2021). Plastic pollution: A focus on freshwater biodiversity. *Ambio*, *50*(7), 1313–1324. https://doi.org/10.1007/s13280-020-01496-5.

Badcock, J., & Lenzen, M. (2010). Subsidies for electricity-generating technologies: A review. *Energy Policy*, *38*(9), 5038–5047. https://doi.org/10.1016/j.enpol.2010.04.031.

Baffoe, G., Zhou, X., Moinuddin, M., Somanje, A. N., Kuriyama, A., Mohan, G., Saito, O., & Takeuchi, K. (2021). Urban–rural linkages: Effective solutions for achieving sustainable development in Ghana from an SDG interlinkage perspective. *Sustainability Science*, *16*(4), 1341–1362. https://doi.org/10.1007/s11625-021-00929-8.

Baltic Sea Action Plan – HELCOM (2021). https://helcom.fi/baltic-sea-action-plan/.

Baltutis, W. J., & Moore, M.-L. (2019). Degrees of change toward polycentric transboundary water governance: Exploring the Columbia river and the Lesotho Highlands Water Project. *Ecology and Society*, *24*(2), art6. https://doi.org/10.5751/ES-10852-240206.

Barbarossa, V., Schmitt, R. J. P., Huijbregts, M. A. J., Zarfl, C., King, H., & Schipper, A. M. (2020). Impacts of current and future large dams on the geographic range connectivity of freshwater fish worldwide. *Proceedings of the National Academy of Sciences*, *117*(7), 3648–3655. https://doi.org/10.1073/pnas.1912776117.

Bartley, D. M., Graaf, G. J. D., Valbo-Jørgensen, J., & Marmulla, G. (2015). Inland capture fisheries: Status and data issues. *Fisheries Management and Ecology*, *22*(1), 71–77. https://doi.org/10.1111/fme.12104.

Belletti, B., Garcia de Leaniz, C., Jones, J., Bizzi, S., Börger, L., Segura, G., Castelletti, A., van de Bund, W., Aarestrup, K., Barry, J., Belka, K., Berkhuysen, A., Birnie-Gauvin, K., Bussettini, M., Carolli, M., Consuegra, S., Dopico, E., Feierfeil, T., Fernández, S., … Zalewski, M. (2020). More than one million barriers fragment Europe's rivers. *Nature*, *588*(7838), 436–441. https://doi.org/10.1038/s41586-020-3005-2.

Bellmore, J. R., Pess, G. R., Duda, J. J., O'Connor, J. E., East, A. E., Foley, M. M., Wilcox, A. C., Major, J. J., Shafroth, P. B., Morley, S. A., Magirl, C. S., Anderson, C. W., Evans, J. E., Torgersen, C. E., & Craig, L. S. (2019). Conceptualizing ecological responses to dam removal: If you remove it, what's to come? *BioScience*, *69*(1), 26–39. https://doi.org/10.1093/biosci/biy152.

Best, J., & Darby, S. E. (2020). The pace of human-induced change in large rivers: Stresses, resilience, and vulnerability to extreme events. *One Earth*, *2*(6), 510–514. https://doi.org/10.1016/j.oneear.2020.05.021.

Bhaduri, A., Bogardi, J., Siddiqi, A., Voigt, H., Vörösmarty, C., Pahl-Wostl, C., Bunn, S. E., Shrivastava, P., Lawford, R., Foster, S., Kremer, H., Renaud, F. G., Bruns, A., & Osuna, V. R. (2016). Achieving sustainable development goals from a water perspective. *Frontiers in Environmental Science*, *4*, 1–13. https://doi.org/10.3389/fenvs.2016.00064.

Biswas, N., Food and Agriculture Organization of the United Nations, & International Collective in Support of Fishworkers. (2018). *Towards gender-equitable small-scale fisheries governance and development: A handbook in support of the implementation of the voluntary guidelines for securing sustainable small-scale fisheries in the context of food security and poverty eradication*. https://www.un-ilibrary.org/content/books/9789210472593/read.

Borrelle, S. B., Ringma, J., Law, K. L., Monnahan, C. C., Lebreton, L., McGivern, A., Murphy, E., Jambeck, J., Leonard, G. H., Hilleary, M. A., Eriksen, M., Possingham, H. P., Frond, H. D., Gerber, L. R., Polidoro, B., Tahir, A., Bernard, M., Mallos, N., Barnes, M., & Rochman, C. M. (2020). Predicted growth in plastic waste exceeds efforts to mitigate plastic pollution. *Science (New York, N.Y.)*, *369*(6510), 1515–1518. https://doi.org/10.1126/science.aba3656.

Boyd, C. E., D'Abramo, L. R., Glencross, B. D., Huyben, D. C., Juarez, L. M., Lockwood, G. S., McNevin, A. A., Tacon, A. G. J., Teletchea, F., Tomasso Jr., J. R., Tucker, C. S., & Valenti, W. C. (2020). Achieving sustainable aquaculture: Historical and current perspectives and future needs and challenges. *Journal of the World Aquaculture Society*, *51*(3), 578–633. https://doi.org/10.1111/jwas.12714.

Broadley, A., Stewart-Koster, B., Burford, M. A., & Brown, C. J. (2022). A global review of the critical link between river flows and productivity in marine fisheries. *Reviews in Fish Biology and Fisheries*, *32*, 805–825. https://doi.org/10.1007/s11160-022-09711-0.

Bull, C. D., Gregory, S. D., Rivot, E., Sheehan, T. F., Ensing, D., Woodward, G., & Crozier, W. (2022). The likely suspects framework: The need for a life cycle approach for managing Atlantic salmon (*Salmo salar*) stocks across multiple scales. *ICES Journal of Marine Science*, *79*(5), 1445–1456. https://doi.org/10.1093/icesjms/fsac099.

Bussi, G., Darby, S. E., Whitehead, P. G., Jin, L., Dadson, S. J., Voepel, H. E., Vasilopoulos, G., Hackney, C. R., Hutton, C., Berchoux, T., Parsons, D. R., & Nicholas, A. (2021). Impact of dams and climate change on suspended sediment flux to the Mekong delta. *Science of the Total Environment*, *755*, 142468. https://doi.org/10.1016/j.scitotenv.2020.142468.

Carlson, R., Evans, L., Foo, S., Grady, B., Li, J., Seeley, M., Xu, Y., & Asner, G. (2021). Synergistic benefits of conserving land-sea ecosystems. *Global Ecology and Conservation*, *28*, e01684. https://doi.org/10.1016/j.gecco.2021.e01684.

Carlson, R. R., Foo, S. A., & Asner, G. P. (2019). Land use impacts on coral reef health: A ridge-to-reef perspective. *Frontiers in Marine Science*, *6*, 1–19. https://www.frontiersin.org/articles/10.3389/fmars.2019.00562.

Catchment Based Approach: Improving the Quality of Our Water Environment. (2013). Department for Environment Food and Rural Affairs. www.gov.uk/defra.

Cherry, G. S., & Peck, M. (2017). Saltwater intrusion in the Floridan aquifer system near downtown Brunswick, Georgia, 1957–2015. In *Open-File Report* (No. 2017-1010). U.S. Geological Survey. https://doi.org/10.3133/ofr20171010.

Chilton, D., Hamilton, D. P., Nagelkerken, I., Cook, P., Hipsey, M. R., Reid, R., Sheaves, M., Waltham, N. J., & Brookes, J. (2021). Environmental flow requirements of estuaries: Providing resilience to current and future climate and direct anthropogenic changes. *Frontiers in Environmental Science*, *9*, 534. https://doi.org/10.3389/fenvs.2021.764218.

Comeros-Raynal, M. T., Lawrence, A., Sudek, M., Vaeoso, M., McGuire, K., Regis, J., & Houk, P. (2019). Applying a ridge-to-reef framework to support watershed, water quality, and community-based fisheries management in American Samoa. *Coral Reefs*, *38*(3), 505–520. https://doi.org/10.1007/s00338-019-01806-8.

Cooke, S. J., Bartley, D. M., Beard, T. D., Cowx, I. G., Goddard, C. I., Fuentevilla, C., Leonard, N. J., Lynch, A. J., Lorenzen, K., & Taylor, W. W. (2016). *From ideas to action: Ten steps to responsible inland fisheries that support livelihoods, food security, and healthy aquatic ecosystems*. p. 11.

Cooke, S. J., Nyboer, E., Bennett, A., Lynch, A. J., Infante, D. M., Cowx, I. G., Beard, T. D., Bartley, D., Paukert, C. P., Reid, A. J., Funge-Smith, S., Gondwe, E., Kaunda, E., Koehn, J. D., Souter, N. J., Stokes, G. L., Castello, L., Leonard, N. J., Skov, C., … Taylor, W. W. (2021). The ten steps to responsible inland fisheries in practice: Reflections from diverse regional case studies around the globe. *Reviews in Fish Biology and Fisheries*, *31*, 843–877. https://doi.org/10.1007/s11160-021-09664-w.

Darby, S. E., Hackney, C. R., Leyland, J., Kummu, M., Lauri, H., Parsons, D. R., Best, J. L., Nicholas, A. P., & Aalto, R. (2016). Fluvial sediment supply to a mega-delta reduced by shifting tropical-cyclone activity. *Nature*, *539*(7628), 276–279. https://doi.org/10.1038/nature19809.

Darnaude, A. M., Salen-Picard, C., Polunin, N. V. C., & Harmelin-Vivien, M. L. (2004). Trophodynamic linkage between river runoff and coastal fishery yield elucidated by stable isotope data in the Gulf of Lions (NW Mediterranean). *Oecologia*, *138*(3), 325–332. https://doi.org/10.1007/s00442-003-1457-3.

Datry, T., Larned, S. T., & Tockner, K. (2014). Intermittent rivers: A challenge for freshwater ecology. *BioScience*, *64*(3), 229–235. https://doi.org/10.1093/biosci/bit027.

Deinet, S., Scott-Gatty, K., Rotton, H., Twardek, W. M., Marconi, V., McRae, L., Baumgartner, L. J., Brink, K., Claussen, J. E., Cooke, S. J., Darwall, W., Eriksson, B. K., Garcia de Leaniz, C., Hogan, Z., Royte, J., Silva, L. G. M., Thieme, M. L., Tickner, D., Waldman, J., ... Berkhuysen, A. (2020). *The living planet index (LPI) for migratory freshwater fish: Technical report*. The Netherlands: World Fish Migration Foundation.

de Jalón, D. G., Bussettini, M., Rinaldi, M., Grant, G., Friberg, N., Cowx, I. G., Magdaleno, F., & Buijse, T. (2016). Linking environmental flows to sediment dynamics. *Water Policy*, *19*(2), 358–375. https://doi.org/10.2166/wp.2016.106.

Delevaux, J. M. S., Whittier, R., Stamoulis, K. A., Bremer, L. L., Jupiter, S., Friedlander, A. M., Poti, M., Guannel, G., Kurashima, N., Winter, K. B., Toonen, R., Conklin, E., Wiggins, C., Knudby, A., Goodell, W., Burnett, K., Yee, S., Htun, H., Oleson, K. L. L., … Ticktin, T. (2018). A linked land-sea modeling framework to inform ridge-to-reef management in high oceanic islands. *PLoS One*, *13*(3), e0193230. https://doi.org/10.1371/journal.pone.0193230.

DHI (2015). *Study on the impacts of mainstream hydropower on the Mekong river – Final report*. Ministry of Natural Resources and Environment. http://www.vncold.vn/modules/cms/upload/10/English/151113/MDSIAR_VolumeI.pdf.

Driscol, J. (2015). *Walleye, lake whitefish, northern pike, and yellow perch Lake Manitoba, Lake Winnipeg, and Lake Winnipegosis midwater gill net*. Monterey Bay Aquarium's Seafood Watch.

Dugan, P. J., Barlow, C., Agostinho, A. A., Baran, E., Cada, G. F., Chen, D., Cowx, I. G., Ferguson, J. W., Jutagate, T., Mallen-Cooper, M., Marmulla, G., Nestler, J., Petrere, M., Welcomme, R. L., & Winemiller, K. O. (2010). Fish migration, dams, and loss of ecosystem services in the Mekong basin. *Ambio*, *39*(4), 344–348. https://doi.org/10.1007/s13280-010-0036-1.

Duncan, E. M., Davies, A., Brooks, A., Chowdhury, G. W., Godley, B. J., Jambeck, J., Maddalene, T., Napper, I., Nelms, S. E., Rackstraw, C., & Koldewey, H. (2020). Message in a bottle: Open source technology to track the movement of plastic pollution. *PLoS One*, *15*(12), e0242459. https://doi.org/10.1371/journal.pone.0242459.

Elliot, V. L., Lynch, A. J., Phang, S. C., Cooke, S. J., Cowx, I. G., Claussen, J. E., Dalton, J., Darwall, W., Harrison, I., Murchie, K. J., Steel, A. E., & Stokes, G. L. (2022). A future for the inland fish and fisheries hidden within the SDGs. *Frontiers in Environmental Science*, *10*, 1–11.

Embke, H. S., Rypel, A. L., Carpenter, S. R., Sass, G. G., Ogle, D., Cichosz, T., Hennessy, J., Essington, T. E., & Zanden, M. J. V. (2019). Production dynamics reveal hidden overharvest of inland recreational fisheries. *Proceedings of the National Academy of Sciences*, *116*(49), 24676–24681. https://doi.org/10.1073/pnas.1913196116.

Essex, B., Koop, S. H. A., & Van Leeuwen, C. J. (2020). Proposal for a national blueprint framework to monitor progress on water-related sustainable development goals in Europe. *Environmental Management*, *65*(1), 1–18. https://doi.org/10.1007/s00267-019-01231-1.

European Commission. Directorate General for Maritime Affairs and Fisheries (2019). *The EU blue economy report 2019*. Publications Office. https://data.europa.eu/doi/10.2771/21854.

Falke, J. A., Fausch, K. D., Magelky, R., Aldred, A., Durnford, D. S., Riley, L. K., & Oad, R. (2011). The role of groundwater pumping and drought in shaping ecological futures for stream fishes in a dryland river basin of the western Great Plains, USA. *Ecohydrology: Ecosystems, Land and Water Process Interactions, Ecohydrogeomorphology*, *4*(5), 682–697. https://doi.org/10.1002/eco.158.

Fearnside, P. M. (2015). Tropical hydropower in the clean development mechanism: Brazil's Santo Antônio Dam as an example of the need for change. *Climatic Change*, *131*(4), 575–589. https://doi.org/10.1007/s10584-015-1393-3.

Ferguson, G. J., Ward, T. M., Ye, Q., Geddes, M. C., & Gillanders, B. M. (2013). Impacts of drought, flow regime, and fishing on the fish assemblage in southern Australia's largest temperate estuary. *Estuaries and Coasts*, *36*(4), 737–753. https://doi.org/10.1007/s12237-012-9582-z.

Fredston-Hermann, A., Brown, C. J., Albert, S., Klein, C. J., Mangubhai, S., Nelson, J. L., Teneva, L., Wenger, A., Gaines, S. D., & Halpern, B. S. (2016). Where does river runoff matter for coastal marine conservation? *Frontiers in Marine Science*, *3*, 1–10. https://doi.org/10.3389/fmars.2016.00273.

Friberg, N., Angelopoulos, N. V., Buijse, A. D., Cowx, I. G., Kail, J., Moe, T. F., Moir, H., O'Hare, M. T., Verdonschot, P. F. M., & Wolter, C. (2016). Chapter eleven – Effective river restoration in the 21st century: From trial and error to novel evidence-based approaches. In A. J. Dumbrell, R. L. Kordas, and G. Woodward (eds), *Advances in ecological research* (Vol. *55*, pp. 535–611). Academic Press. https://doi.org/10.1016/bs.aecr.2016.08.010.

Funge-Smith, S., & Bennett, A. (2019). A fresh look at inland fisheries and their role in food security and livelihoods. *Fish and Fisheries*, *20*(6), 1176–1195. https://doi.org/10.1111/faf.12403.

Gallop, P., Vejnović, I., & Pehchevski, D. (2019). *Western Balkans hydropower who pays, who profits?* CEE Bankwatch Network. https://bankwatch.org/wp-content/uploads/2019/09/who-pays-who-profits.pdf.

Gephart, J. A., Golden, C. D., Asche, F., Belton, B., Brugere, C., Froehlich, H. E., Fry, J. P., Halpern, B. S., Hicks, C. C., Jones, R. C., Klinger, D. H., Little, D. C., McCauley, D. J., Thilsted, S. H., Troell, M., & Allison, E. H. (2021). Scenarios for global aquaculture and its role in human nutrition. *Reviews in Fisheries Science & Aquaculture*, *29*(1), 122–138. https://doi.org/10.1080/23308249.2020.1782342.

Gillson, J., Suthers, I., & Scandol, J. (2012). Effects of flood and drought events on multi-species, multi-method estuarine and coastal fisheries in eastern Australia. *Fisheries Management and Ecology*, *19*(1), 54–68. https://doi.org/10.1111/j.1365-2400.2011.00816.x.

Gleeson, T., Wada, Y., Bierkens, M. F. P., & van Beek, L. P. H. (2012). Water balance of global aquifers revealed by groundwater footprint. *Nature*, *488*(7410), 197–200. https://doi.org/10.1038/nature11295.

Gleeson, T., Wang-Erlandsson, L., Zipper, S. C., Porkka, M., Jaramillo, F., Gerten, D., Fetzer, I., Cornell, S. E., Piemontese, L., Gordon, L. J., Rockström, J., Oki, T., Sivapalan, M., Wada, Y., Brauman, K. A., Flörke, M., Bierkens, M. F. P., Lehner, B., Keys, P., … Famiglietti, J. S. (2020). The water planetary boundary: Interrogation and revision. *One Earth*, *2*(3), 223–234. https://doi.org/10.1016/j.oneear.2020.02.009.

Goal 14: Life below Water – SDG Tracker. (2021). Our World in Data. https://sdg-tracker.org/oceans.

Gordon, L. J., Finlayson, C. M., & Falkenmark, M. (2010). Managing water in agriculture for food production and other ecosystem services. *Agricultural Water Management*, *97*(4), 512–519. https://doi.org/10.1016/j.agwat.2009.03.017.

Gounand, I., Harvey, E., Little, C. J., & Altermatt, F. (2018). Meta-ecosystems 2.0: Rooting the theory into the field. *Trends in Ecology & Evolution*, *33*(1), 36–46. https://doi.org/10.1016/j.tree.2017.10.006.

Granit, J., Liss Lymer, B., Olsen, S., Tengberg, A., Nõmmann, S., & Clausen, T. J. (2017). A conceptual framework for governing and managing key flows in a source-to-sea continuum. *Water Policy*, *19*(4), 673–691. https://doi.org/10.2166/wp.2017.126.

Gratiot, N., Bildstein, A., Anh, T. T., Thoss, H., Denis, H., Michallet, H., & Apel, H. (2017). Sediment flocculation in the Mekong river estuary, Vietnam, an important driver of geomorphological changes. *Comptes Rendus Geoscience*, *349*(6), 260–268. https://doi.org/10.1016/j.crte.2017.09.012.

Grill, G., Lehner, B., Thieme, M., Geenen, B., Tickner, D., Antonelli, F., Babu, S., Borrelli, P., Cheng, L., Crochetiere, H., Macedo, H. E., Filgueiras, R., Goichot, M., Higgins, J., Hogan, Z., Lip, B., McClain, M. E., Meng, J., Mulligan, M., … Zarfl, C. (2019). Mapping the world's free-flowing rivers. *Nature*, *569*(7755), 215. https://doi.org/10.1038/s41586-019-1111-9.

Guillen, J., Asche, F., Carvalho, N., Fernández Polanco, J. M., Llorente, I., Nielsen, R., Nielsen, M., & Villasante, S. (2019). Aquaculture subsidies in the European Union: Evolution, impact and future potential for growth. *Marine Policy*, *104*, 19–28. https://doi.org/10.1016/j.marpol.2019.02.045.

Haberstroh, C. J., Arias, M. E., Yin, Z., Sok, T., & Wang, M. C. (2021). Plastic transport in a complex confluence of the Mekong river in Cambodia. *Environmental Research Letters*, *16*(9), 095009. https://doi.org/10.1088/1748-9326/ac2198.

Hackney, C. R., Darby, S. E., Parsons, D. R., Leyland, J., Best, J. L., Aalto, R., Nicholas, A. P., & Houseago, R. C. (2020). River bank instability from unsustainable sand mining in the Lower Mekong river. *Nature Sustainability*, *3*(3), 217–225. https://doi.org/10.1038/s41893-019-0455-3.

Hackney, C. R., Vasilopoulos, G., Heng, S., Darbari, V., Walker, S., & Parsons, D. R. (2021). Sand mining far outpaces natural supply in a large alluvial river. *Earth Surface Dynamics*, *9*(5), 1323–1334. https://doi.org/10.5194/esurf-9-1323-2021.

Halladay, P., Design, K., & Martin, M. S. (2003). *Review of protected areas and development in the Lower Mekong river region, Indooroopilly, Queensland, Australia*. Regional Report on Protected Areas and Development. International Centre for Environmental Management.

Hansen, H. H., Forzono, E., Grams, A., Ohlman, L., Ruskamp, C., Pegg, M. A., & Pope, K. L. (2019). Exit here: Strategies for dealing with aging dams and reservoirs. *Aquatic Sciences*, *82*(1), 2. https://doi.org/10.1007/s00027-019-0679-3.

Harding, L. B., Tagal, M., Ylitalo, G. M., Incardona, J. P., Davis, J. W., Scholz, N. L., & McIntyre, J. K. (2020). Urban stormwater and crude oil injury pathways converge on the developing heart of a shore-spawning marine forage fish. *Aquatic Toxicology*, *229*, 105654. https://doi.org/10.1016/j.aquatox.2020.105654.

Harper, S., Adshade, M., Lam, V. W. Y., Pauly, D., & Sumaila, U. R. (2020). Valuing invisible catches: Estimating the global contribution by women to small-scale marine capture fisheries production. *PLoS One*, *15*(3), e0228912. https://doi.org/10.1371/journal.pone.0228912.

Harris, P. T., Westerveld, L., Nyberg, B., Maes, T., Macmillan-Lawler, M., & Appelquist, L. R. (2021). Exposure of coastal environments to river-sourced plastic pollution. *Science of the Total Environment*, *769*, 145222. https://doi.org/10.1016/j.scitotenv.2021.145222.

Hasselquist, E. M., Mancheva, I., Eckerberg, K., & Laudon, H. (2020). Policy change implications for forest water protection in Sweden over the last 50 years. *Ambio*, *49*(7), 1341–1351. https://doi.org/10.1007/s13280-019-01274-y.

Hirsch, P. (2010). The changing political dynamics of dam building on the Mekong. *Water Alternatives*, *3*(2), 312–323.

Holtgrieve, G. W., Arias, M. E., Ruhi, A., Elliott, V., Nam, S., Ngor, P. B., Rasanen, T. A., & Sabo, J. L. (2018). Response to comments on "'Designing river flows to improve food security futures in the Lower Mekong basin'. *Science (New York, N.Y.)*, *361*(6398), eaat1477. https://doi.org/10.1126/science.aat1477.

Hughes, K. (2021). *The world's forgotten fishes*. World Wide Fund for Nature (WWF).

Huserbråten, M. B. O., Hattermann, T., Broms, C., & Albretsen, J. (2022). Trans-polar drift-pathways of riverine European microplastic. *Scientific Reports*, *12*(1), 3016. https://doi.org/10.1038/s41598-022-07080-z.

International Renewable Energy Agency. (2022). *Renewable energy finance flows*. https://www.irena.org/Statistics/View-Data-by-Topic/Finance-and-Investment/Renewable-Energy-Finance-Flows.

Kano, Y., Dudgeon, D., Nam, S., Samejima, H., Watanabe, K., Grudpan, C., Grudpan, J., Magtoon, W., Musikasinthorn, P., Nguyen, P. T., Praxaysonbath, B., Sato, T., Shibukawa, K., Shimatani, Y., Suvarnaraksha, A., Tanaka, W., Thach, P., Tran, D. D., Yamashita, T., & Utsugi, K. (2016). Impacts of dams and global warming on fish biodiversity in the Indo-Burma hotspot. *PLoS One*, *11*(8), e0160151. https://doi.org/10.1371/journal.pone.0160151.

Kemp, P. S., & O'Hanley, J. R. (2010). Procedures for evaluating and prioritising the removal of fish passage barriers: A synthesis. *Fisheries Management and Ecology*, *17*(4), 297–322. https://doi.org/10.1111/j.1365-2400.2010.00751.x.

Kendy, E., Flessa, K. W., Schlatter, K. J., de la Parra, C. A., Hinojosa Huerta, O. M., Carrillo-Guerrero, Y. K., & Guillen, E. (2017). Leveraging environmental flows to reform water management policy: Lessons learned from the 2014 Colorado river delta pulse flow. *Ecological Engineering*, *106*, 683–694. https://doi.org/10.1016/j.ecoleng.2017.02.012.

Kim, R. E. (2016). The Nexus between International Law and the Sustainable Development Goals. *RECIEL*, *25*, 15–26. https://doi.org/10.1111/reel.12148.

Kondolf, G. M., Gao, Y., Annandale, G. W., Morris, G. L., Jiang, E., Zhang, J., Cao, Y., Carling, P., Fu, K., Guo, Q., Hotchkiss, R., Peteuil, C., Sumi, T., Wang, H.-W., Wang, Z., Wei, Z., Wu, B., Wu, C., & Yang, C. T. (2014a). Sustainable sediment management in reservoirs and regulated rivers: Experiences from five continents. *Earth's Future*, *2*(5), 256–280. https://doi.org/10.1002/2013EF000184.

Kondolf, G. M., Rubin, Z. K., & Minear, J. T. (2014b). Dams on the Mekong: Cumulative sediment starvation. *Water Resources Research*, *50*(6), 5158–5169. https://doi.org/10.1002/2013WR014651.

Kondolf, G. M., Schmitt, R. J. P., Carling, P., Darby, S., Arias, M., Bizzi, S., Castelletti, A., Cochrane, T. A., Gibson, S., Kummu, M., Oeurng, C., Rubin, Z., & Wild, T. (2018). Changing sediment budget of the Mekong: Cumulative threats and management strategies for a large river basin. *Science of the Total Environment*, *625*, 114–134. https://doi.org/10.1016/j.scitotenv.2017.11.361.

Kovach, R. P., Dunham, J. B., Al-Chokhachy, R., Snyder, C. D., Letcher, B. H., Young, J. A., Beever, E. A., Pederson, G. T., Lynch, A. J., Hitt, N. P., Konrad, C. P., Jaeger, K. L., Rea, A. H., Sepulveda, A. J., Lambert, P. M., Stoker, J., Giersch, J. J., & Muhlfeld, C. C. (2019). An integrated framework for ecological drought across riverscapes of North America. *BioScience*, *69*(6), 418–431. https://doi.org/10.1093/biosci/biz040.

Kuenzer, C., Campbell, I., Roch, M., Leinenkugel, P., Tuan, V. Q., & Dech, S. (2013). Understanding the impact of hydropower developments in the context of upstream–downstream relations in the Mekong river basin. *Sustainability Science*, *8*(4), 565–584.

Ladel, J., Mehta, M., Gulemvuga, G., & Namayanga, L. (2020). Water policy on SDG6.5 implementation: Progress in integrated & transboundary water resources management implementation. *World Water Policy*, *6*(1), 115–133. https://doi.org/10.1002/wwp2.12025.

Langhans, S. D., Domisch, S., Balbi, S., Delacámara, G., Hermoso, V., Kuemmerlen, M., Martin, R., Martínez-López, J., Vermeiren, P., Villa, F., & Jähnig, S. C. (2019). Combining eight research areas to foster the uptake of ecosystem-based management in fresh waters. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *29*(7), 1161–1173. https://doi.org/10.1002/aqc.3012.

Laughlin, T., Dionne, S. G., Colmenares, N. A., McDonald, F., & Smith, S. E. (2006). A new wave in Caribbean sustainable development: The white water to blue water partnerships. *Journal of International Wildlife Law & Policy*, *9*(3), 277–288. https://doi.org/10.1080/13880290600764968.

Lebreton, L. C., Van Der Zwet, J., Damsteeg, J.-W., Slat, B., Andrady, A., & Reisser, J. (2017). River plastic emissions to the world's oceans. *Nature Communications*, *8*(1), 1–10.

Lee, R. S., Black, K. P., Bosserel, C., & Greer, D. (2012). Present and future prolonged drought impacts on a large temperate embayment: Port Phillip Bay, Australia. *Ocean Dynamics*, *62*(6), 907–922. https://doi.org/10.1007/s10236-012-0538-4.

Levy, B. S., & Sidel, V. W. (2011). Water rights and water fights: Preventing and resolving conflicts before they boil over. *American Journal of Public Health*, *101*(5), 778–780. https://doi.org/10.2105/AJPH.2010.194670.

Lind, L., Hasselquist, E. M., & Laudon, H. (2019). Towards ecologically functional riparian zones: A meta-analysis to develop guidelines for protecting ecosystem functions and biodiversity in agricultural landscapes. *Journal of Environmental Management*, *249*, 109391. https://doi.org/10.1016/j.jenvman.2019.109391.

Lindo, Z. (2020). Transoceanic dispersal of terrestrial species by debris rafting. *Ecography*, *43*(9), 1364–1372. https://doi.org/10.1111/ecog.05155.

Link, J. (2017). A conversation about NMFS' ecosystem-based fisheries management policy and road map. *Fisheries*, *42*(10), 498–503. https://doi.org/10.1080/03632415.2017.1391596.

Liu, J., Hull, V., Godfray, H. C. J., Tilman, D., Gleick, P., Hoff, H., Pahl-Wostl, C., Xu, Z., Chung, M. G., Sun, J., & Li, S. (2018). Nexus approaches to global sustainable development. *Nature Sustainability*, *1*(9), 466–476. https://doi.org/10.1038/s41893-018-0135-8.

Lu, X. X., Kummu, M., & Oeurng, C. (2014). Reappraisal of sediment dynamics in the Lower Mekong river, Cambodia. *Earth Surface Processes and Landforms*, *39*, 1855–1865. https://doi.org/10.1002/esp.3573.

Lynch, A. J., Bartley, D. M., Beard, T. D., Cowx, I. G., Funge-Smith, S., Taylor, W. W., & Cooke, S. J. (2020). Examining progress towards achieving the ten steps of the Rome Declaration on responsible inland fisheries. *Fish and Fisheries*, *21*(1), 190–203. https://doi.org/10.1111/faf.12410.

Lynch, A. J., Baumgartner, L. J., Boys, C. A., Conallin, J., Cowx, I. G., Finlayson, C. M., Franklin, P. A., Hogan, Z., Koehn, J. D., McCartney, M. P., O'Brien, G., Phouthavong, K., Silva, L. G. M., Tob, C. A., Valbo-Jørgensen, J., Vu, A. V., Whiting, L., Wibowo, A., & Duncan, P. (2019). Speaking the same language: Can the sustainable development goals translate the needs of inland fisheries into irrigation decisions? *Marine and Freshwater Research*, *70*(9), 1211–1222. https://doi.org/10.1071/MF19176.

Lynch, A. J., Cowx, I. G., Fluet-Chouinard, E., Glaser, S. M., Phang, S. C., Beard, T. D., Bower, S. D., Brooks, J. L., Bunnell, D. B., Claussen, J. E., Cooke, S. J., Kao, Y.-C., Lorenzen, K., Myers, B. J. E., Reid, A. J., Taylor, J. J., & Youn, S. (2017). Inland fisheries – Invisible but integral to the UN sustainable development agenda for ending poverty by 2030. *Global Environmental Change*, *47*, 167–173. https://doi.org/10.1016/j.gloenvcha.2017.10.005.

Maltby, E., Acreman, M., Maltby, A., Bryson, P., & Bradshaw, J. (2019). *Wholescape thinking: Towards integrating the management of catchments, coast and the sea through partnerships – A guidance note. [Online] Natural capital initiative*. Natural Capital Initiative.

Marchesiello, P., Nguyen, N. M., Gratiot, N., Loisel, H., Anthony, E. J., Dinh, C. S., Nguyen, T., Almar, R., & Kestenare, E. (2019). Erosion of the coastal Mekong delta: Assessing natural against man induced processes. *Continental Shelf Research*, *181*, 72–89. https://doi.org/10.1016/j.csr.2019.05.004.

Mathews, R., Stretz, J., SIWI, & Wasteaware. (2019). *Source-to-sea framework for marine litter prevention: Preventing plastic leakage in river basins*. Stockholm International Water Institute. https://iwlearn.net/resolveuid/92e2a284-6be7-444a-92e4-e7606d51e56c.

Mathews, R. E., Tengberg, A., Sjödin, J., & Liss Lymer, B. (2019). *Implementing the source-to-sea approach: A guide for practitioners*. Stockholm International Water Institute.

Mauri, M., Elli, T., Caviglia, G., Uboldi, G., & Azzi, M. (2017). RAWGraphs: A visualisation platform to create open outputs. In *Proceedings of the 12th Biannual Conference on Italian SIGCHI Chapter* (pp. 28:1–28:5). New York, NY, USA: ACM.

McIntyre, P. B., Liermann, C. A. R., & Revenga, C. (2016). Linking freshwater fishery management to global food security and biodiversity conservation. *Proceedings of the National Academy of Sciences*, *113*(45), 12880–12885. https://doi.org/10.1073/pnas.1521540113.

Mekong River Commission. (2021). *The integrated water resources management-based basin development strategy for the Lower Mekong basin 2021–2030 and the MRC strategic plan 2021–2025*. Mekong River Commission.

Mekong River Commission. (2022). *Mekong low flow and drought conditions in 2019–2021, hydrological conditions in the Lower Mekong river basin*. MRC Secretariat. https://www.mrcmekong.org/assets/Publications/LowFlowReport20192021.pdf.

Montagna, P. A., McKinney, L., & Yoskowitz, D. (2021). Focused flows to maintain natural nursery habitats. *Texas Water Journal*, *12*(1), 129–139. https://doi.org/10.21423/twj.v12i1.7123.

Moura, M. R. F., Falcão, S. M. P., da Silva, A. C., Neto, A. R., Montenegro, S. M. G. L., & da Silva, S. R. (2020). Developing a plastic waste management program: From river basins to urban beaches (case study). *Journal of Engineering and Technological Sciences*, *52*(1), 108–120. https://doi.org/10.5614/j.eng.technol.sci.2020.52.1.8.

Mouyen, M., Longuevergne, L., Steer, P., Crave, A., Lemoine, J.-M., Save, H., & Robin, C. (2018). Assessing modern river sediment discharge to the ocean using satellite gravimetry. *Nature Communications*, *9*(1), 3384. https://doi.org/10.1038/s41467-018-05921-y.

Nam, S., Phommakon, S., Vuthy, L., Samphawamana, T., Hai Son, N., Khumsri, M., Peng Bun, N., Sovanara, K., Degen, P., & Starr, P. (2015). Lower Mekong fisheries estimated to be worth around $17 billion a year. *Catch and Culture*, *21*(3), 4–7.

Needles, L. A., Lester, S. E., Ambrose, R., Andren, A., Beyeler, M., Connor, M. S., Eckman, J. E., Costa-Pierce, B. A., Gaines, S. D., Lafferty, K. D., Lenihan, H. S., Parrish, J., Peterson, M. S., Scaroni, A. E., Weis, J. S., & Wendt, D. E. (2015). Managing Bay and estuarine ecosystems for multiple services. *Estuaries and Coasts*, *38*(1), 35–48. https://doi.org/10.1007/s12237-013-9602-7.

Ngor, P. B., McCann, K. S., Grenouillet, G., So, N., McMeans, B. C., Fraser, E., & Lek, S. (2018). Evidence of indiscriminate fishing effects in one of the world's largest inland fisheries. *Scientific Reports*, *8*(1), 8947. https://doi.org/10.1038/s41598-018-27340-1.

Nguyen, H.-Q., Korbee, D., Luan, P., Tran, D., Loc, H., & Hermans, L. (2019). *Manual for application of the MOTA framework theory and practice (version 1)*. Center of Water Management and Climate Change.

Nita, M. D., Munteanu, C., Gutman, G., Abrudan, I. V., & Radeloff, V. C. (2018). Widespread forest cutting in the aftermath of World War II captured by broad-scale historical Corona spy satellite photography. *Remote Sensing of Environment*, *204*, 322–332. https://doi.org/10.1016/j.rse.2017.10.021.

Nobile, A. B., Cunico, A. M., Vitule, J. R. S., Queiroz, J., Vidotto-Magnoni, A. P., Garcia, D. A. Z., Orsi, M. L., Lima, F. P., Acosta, A. A., da Silva, R. J., do Prado, F. D., Porto-Foresti, F., Brandão, H., Foresti, F., Oliveira, C., & Ramos, I. P. (2020). Status and recommendations for sustainable freshwater aquaculture in Brazil. *Reviews in Aquaculture*, *12*(3), 1495–1517. https://doi.org/10.1111/raq.12393.

Olden, J. D., Konrad, C. P., Melis, T. S., Kennard, M. J., Freeman, M. C., Mims, M. C., Bray, E. N., Gido, K. B., Hemphill, N. P., Lytle, D. A., McMullen, L. E., Pyron, M., Robinson, C. T., Schmidt, J. C., & Williams, J. G. (2014). Are large-scale flow experiments informing the science and management of freshwater ecosystems? *Frontiers in Ecology and the Environment*, *12*(3), 176–185. https://doi.org/10.1890/130076.

Opperman, J., Orr, S., Baleta, H., Garrick, D., Goichot, M., McCoy, A., Morgan, A., Turley, L., & Vermeulen, A. (2018). *Valuing rivers: How the diverse benefits of healthy rivers underpin economies*. WWF.

Pascual, U., Balvanera, P., Díaz, S., Pataki, G., Roth, E., Stenseke, M., Watson, R. T., Başak Dessane, E., Islar, M., Kelemen, E., Maris, V., Quaas, M., Subramanian, S. M., Wittmer, H., Adlan, A., Ahn, S., Al-Hafedh, Y. S., Amankwah, E., Asah, S. T., … Yagi, N. (2017). Valuing nature's contributions to people: The IPBES approach. *Current Opinion in Environmental Sustainability*, *26–27*, 7–16. https://doi.org/10.1016/j.cosust.2016.12.006.

Pelicice, F. M., Azevedo-Santos, V. M., Vitule, J. R. S., Orsi, M. L., Lima Junior, D. P., Magalhães, A. L. B., Pompeu, P. S., Petrere Jr., M., & Agostinho, A. A. (2017). Neotropical freshwater fishes imperilled by unsustainable policies. *Fish and Fisheries*, *18*(6), 1119–1133. https://doi.org/10.1111/faf.12228.

Perera, D., Smakhtin, V., Williams, S., North, T., & Curry, A. (2021). *Ageing water storage infrastructure: An emerging global risk*. United Nations University Institute for Water, Environment and Health. https://doi.org/10.53328/QSYL1281.

Petts, G. E. (1984). *Impounded rivers: Perspectives for ecological management*. Wiley. https://westminsterresearch.westminster.ac.uk/item/94×30/impounded-rivers-perspectives-for-ecological-management.

Pinckney, J. L., Paerl, H. W., Tester, P., & Richardson, T. L. (2001). The role of nutrient loading and eutrophication in estuarine ecology. *Environmental Health Perspectives*, *109*, 8.

Pitt, J., Kendy, E., Schlatter, K., Hinojosa-Huerta, O., Flessa, K., Shafroth, P. B., Ramírez-Hernández, J., Nagler, P., & Glenn, E. P. (2017). It takes more than water: Restoring the Colorado river delta. *Ecological Engineering*, *106*, 629–632. https://doi.org/10.1016/j.ecoleng.2017.05.028.

Poff, N. L., Richter, B. D., Arthington, A. H., Bunn, S. E., Naiman, R. J., Kendy, E., Acreman, M., Apse, C., Bledsoe, B. P., & Freeman, M. C. (2010). The ecological limits of hydrologic alteration (ELOHA): A new framework for developing regional environmental flow standards. *Freshwater Biology*, *55* (1), 147–170.

Polvi, L. E., Lind, L., Persson, H., Miranda-Melo, A., Pilotto, F., Su, X., & Nilsson, C. (2020). Facets and scales in river restoration: Nestedness and interdependence of hydrological, geomorphic, ecological, and biogeochemical processes. *Journal of Environmental Management*, *265*, 110288. https://doi.org/10.1016/j.jenvman.2020.110288.

Pracheil, B. M., Pegg, M. A., Powell, L. A., & Mestl, G. E. (2012). Swimways: Protecting paddlefish through movement-centered management. *Fisheries*, *37*(10), 449–457. https://doi.org/10.1080/03632415.2012.722877.

Raadgever, G. T., Mostert, E., Kranz, N., Interwies, E., & Timmerman, J. G. (2008). Assessing management regimes in transboundary river basins: Do they support adaptive management? *Ecology and Society*, *13*(1). https://doi.org/10.5751/ES-02385-130114.

Rabalais, N. N., Turner, R. E., Díaz, R. J., & Justić, D. (2009). Global change and eutrophication of coastal waters. *ICES Journal of Marine Science*, *66* (7), 1528–1537. https://doi.org/10.1093/icesjms/fsp047.

Racine, P., Marley, A., Froehlich, H. E., Gaines, S. D., Ladner, I., MacAdam-Somer, I., & Bradley, D. (2021). A case for seaweed aquaculture inclusion in U.S. nutrient pollution management. *Marine Policy*, *129*, 104506. https://doi.org/10.1016/j.marpol.2021.104506.

Recuero Virto, L. (2018). A preliminary assessment of the indicators for sustainable development goal (SDG) 14 'Conserve and sustainably use the oceans, seas and marine resources for sustainable development'. *Marine Policy*, *98*, 47–57. https://doi.org/10.1016/j.marpol.2018.08.036.

Reuter, K. E., Juhn, D., & Grantham, H. S. (2016). Integrated land-sea management: Recommendations for planning, implementation and management. *Environmental Conservation*, *43*(2), 181–198.

Richter, B., Sandra, P., Carmen, R., Thayer, S., Bernhard, L., Allegra, C., & Morgan, C. (2010). Lost in development's shadow: The downstream human consequences of dams. *Water Alternatives*, *3*, 14–42.

Richter, B., & Thomas, G. (2007). Restoring environmental flows by modifying dam operations. *Ecology and Society*, *12*(1). https://doi.org/10.5751/ES-02014-120112.

Rodgers, K. S., Kido, M. H., Jokiel, P. L., Edmonds, T., & Brown, E. K. (2012). Use of integrated landscape indicators to evaluate the health of linked watersheds and coral reef environments in the Hawaiian Islands. *Environmental Management*, *50*(1), 21–30. https://doi.org/10.1007/s00267-012-9867-9.

Rude, J., Minks, A., Doheny, B., Tyner, M., Maher, K., Huffard, C., Hidayat, N. I., & Grantham, H. (2016). Ridge to reef modelling for use within land–sea planning under data-limited conditions. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *26*(2), 251–264. https://doi.org/10.1002/aqc.2548.

Sabo, J. L., Ruhi, A., Holtgrieve, G. W., Elliott, V., Arias, M. E., Ngor, P. B., Rasanen, T. A., & Nam, S. (2017). Designing river flows to improve food security futures in the Lower Mekong basin. *Science (New York, N.Y.)*, *358*(6368), eaao1053. https://doi.org/10.1126/science.aao1053.

Saintilan, N., Rogers, K., Kelleway, J. J., Ens, E., & Sloane, D. R. (2019). Climate change impacts on the coastal wetlands of Australia. *Wetlands*, *39*(6), 1145–1154. https://doi.org/10.1007/s13157-018-1016-7.

Santini, N. S., Reef, R., Lockington, D. A., & Lovelock, C. E. (2015). The use of fresh and saline water sources by the mangrove *Avicennia marina*. *Hydrobiologia*, *745*(1), 59–68. https://doi.org/10.1007/s10750-014-2091-2.

Schmidt, C., Krauth, T., & Wagner, S. (2017). Export of plastic debris by rivers into the sea. *Environmental Science & Technology*, *51*(21), 12246–12253.

Shumilova, O., Tockner, K., Thieme, M., Koska, A., & Zarfl, C. (2018). Global water transfer megaprojects: A potential solution for the water–food–energy nexus? *Frontiers in Environmental Science*, *6*, 1–11. https://doi.org/10.3389/fenvs.2018.00150.

Silvestri, S., Kershaw, F., United Nations Environment Programme, & World Conservation Monitoring Centre. (2010). *Framing the flow: Innovative approaches to understand, protect and value ecosystem services across linked habitats*. UNEP.

Stein, E. D., Gee, E. M., Adams, J. B., Irving, K., & Van Niekerk, L. (2021). Advancing the science of environmental flow management for protection of temporarily closed estuaries and coastal lagoons. *Water*, *13*(5), 595. https://doi.org/10.3390/w13050595.

Stojanovic, T., & Barker, N. (2008). Improving governance through local coastal partnerships in the UK. *The Geographical Journal*, *174*(4), 344–360. https://doi.org/10.1111/j.1475-4959.2008.00303.x.

Strokal, M., Kahil, T., Wada, Y., Albiac, J., Bai, Z., Ermolieva, T., Langan, S., Ma, L., Oenema, O., Wagner, F., Zhu, X., & Kroeze, C. (2020). Cost-effective management of coastal eutrophication: A case study for the Yangtze river basin. *Resources, Conservation and Recycling*, *154*, 104635. https://doi.org/10.1016/j.resconrec.2019.104635.

Strokal, M., Ma, L., Bai, Z., Luan, S., Kroeze, C., Oenema, O., Velthof, G., & Zhang, F. (2016). Alarming nutrient pollution of Chinese rivers as a result of agricultural transitions. *Environmental Research Letters*, *11*(2), 024014. https://doi.org/10.1088/1748-9326/11/2/024014.

Strokal, M., Spanier, J. E., Kroeze, C., Koelmans, A. A., Flörke, M., Franssen, W., Hofstra, N., Langan, S., Tang, T., van Vliet, M. T., Wada, Y., Wang, M., van Wijnen, J., & Williams, R. (2019). Global multi-pollutant modelling of water quality: Scientific challenges and future directions. *Current Opinion in Environmental Sustainability*, *36*, 116–125. https://doi.org/10.1016/j.cosust.2018.11.004.

Sundt, P., Schulze, P.-E., & Syversen, F. (2014). Sources of microplastic-pollution to the marine environment. *Mepex for the Norwegian Environment Agency*, *86*, 20.

Szklarek, S., Górecka, A., & Wojtal-Frankiewicz, A. (2022). The effects of road salt on freshwater ecosystems and solutions for mitigating chloride pollution – A review. *Science of the Total Environment*, *805*, 150289. https://doi.org/10.1016/j.scitotenv.2021.150289.

Tamura, T., Nguyen, V. L., Ta, T. K. O., Bateman, M. D., Gugliotta, M., Anthony, E. J., Nakashima, R., & Saito, Y. (2020). Long-term sediment decline causes ongoing shrinkage of the Mekong megadelta, Vietnam. *Scientific Reports*, *10*(1), 8085. https://doi.org/10.1038/s41598-020-64630-z.

Thieme, M. L., Tickner, D., Grill, G., Carvallo, J. P., Goichot, M., Hartmann, J., Higgins, J., Lehner, B., Mulligan, M., Nilsson, C., Tockner, K., Zarfl, C., & Opperman, J. (2021). Navigating trade-offs between dams and river conservation. *Global Sustainability*, *4*. https://doi.org/10.1017/sus.2021.15.

Thom, B., Rocheta, E., Steinfeld, C., Harvey, N., Pittock, J., & Cowell, P. (2020). The role of coastal processes in the management of the mouth of the River Murray, Australia: Present and future challenges. *River Research and Applications*, *36*(4), 656–667. https://doi.org/10.1002/rra.3551.

Tian, H., Xu, R., Pan, S., Yao, Y., Bian, Z., Cai, W.-J., Hopkinson, C. S., Justic, D., Lohrenz, S., Lu, C., Ren, W., & Yang, J. (2020). Long-term trajectory of nitrogen loading and delivery from Mississippi river basin to the Gulf of Mexico. *Global Biogeochemical Cycles*, *34*(5), e2019GB006475. https://doi.org/10.1029/2019GB006475.

Tickner, D., Opperman, J. J., Abell, R., Acreman, M., Arthington, A. H., Bunn, S. E., Cooke, S. J., Dalton, J., Darwall, W., Edwards, G., Harrison, I., Hughes, K., Jones, T., Leclère, D., Lynch, A. J., Leonard, P., McClain, M. E., Muruven, D., Olden, J. D., … Young, L. (2020). Bending the curve of global freshwater biodiversity loss: An emergency recovery plan. *BioScience*, *70*(4), 330–342. http://dx.doi.org/10.1093/biosci/biaa002.

Tullos, D. D., Collins, M. J., Bellmore, J. R., Bountry, J. A., Connolly, P. J., Shafroth, P. B., & Wilcox, A. C. (2016). Synthesis of common management concerns associated with dam removal. *JAWRA: Journal of the American Water Resources Association*, *52*(5), 1179–1206. https://doi.org/10.1111/1752-1688.12450.

Turner, R. E., & Rabalais, N. N. (2003). Linking landscape and water quality in the Mississippi river basin for 200 years. *BioScience*, *53*(6), 563–572. https://doi.org/10.1641/0006-3568(2003)053[0563:LLAWQI]2.0.CO;2.

UNEP-WCMC. (2019). *User Manual for the World Database on Protected Areas and world database on other effective area-based conservation measures: 1.6*. Cambridge, UK: UNEP-WCMC.

United Nations Environment Assembly of the United Nations Environment Programme (2022). *End plastic pollution: Towards an international legally binding instrument*. United Nations Environment Assembly of the United Nations Environment Programme.

United Nations Environment Programme (2021a). *Understanding the state of the ocean: A global manual on measuring SDG 14.1.1, SDG 14.2.1 and SDG 14.5.1*. https://wedocs.unep.org/xmlui/handle/20.500.11822/35086.

United Nations Environment Programme (2021b). *Progress on ambient water quality global indicator 6.3.2 updates and acceleration needs*. United Nations Environment Programme. https://www.unwater.org/sites/default/files/app/uploads/2021/09/SDG6_Indicator_Report_632_Progress-on-Ambient-Water-Quality_2021_EN.pdf.

United Nations Environment Programme, & Frankfurt School-UNEP Centre. (2019). *Global trends in renewable energy investment 2019*. https://wedocs.unep.org/xmlui/handle/20.500.11822/29752.

UN-Water (2017). *Integrated monitoring guide for SDG 6 step-by-step monitoring methodology for SDG indicator 6.6.1*. United Nations. https://www.unwater.org/sites/default/files/app/uploads/2017/05/Step-by-step-methodology-6-6-1_Revision-2017-01-20_Final-1.pdf.

Valenti, W. C., Barros, H. P., Moraes-Valenti, P., Bueno, G. W., & Cavalli, R. O. (2021). Aquaculture in Brazil: Past, present and future. *Aquaculture Reports*, *19*, 100611. https://doi.org/10.1016/j.aqrep.2021.100611.

van Emmerik, T., & Schwarz, A. (2020). Plastic debris in rivers. *WIREs Water*, *7*(1), e1398. https://doi.org/10.1002/wat2.1398.

Vanham, D., Hoekstra, A. Y., Wada, Y., Bouraoui, F., de Roo, A., Mekonnen, M. M., van de Bund, W. J., Batelaan, O., Pavelic, P., Bastiaanssen, W. G. M., Kummu, M., Rockström, J., Liu, J., Bisselink, B., Ronco, P., Pistocchi, A., & Bidoglio, G. (2018). Physical water scarcity metrics for monitoring progress towards SDG target 6.4: An evaluation of indicator 6.4.2 '"Level of water stress'. *Science of the Total Environment*, *613–614*, 218–232. https://doi.org/10.1016/j.scitotenv.2017.09.056.

Van Niekerk, L., Taljaard, S., Adams, J. B., Lamberth, S. J., Huizinga, P., Turpie, J. K., & Wooldridge, T. H. (2019). An environmental flow determination method for integrating multiple-scale ecohydrological and complex ecosystem processes in estuaries. *Science of the Total Environment*, *656*, 482–494. https://doi.org/10.1016/j.scitotenv.2018.11.276.

van Zanten, J. A., & van Tulder, R. (2020). *Towards nexus-based governance: Defining interactions between economic activities and sustainable development goals (SDGs)*. https://doi.org/10.1080/13504509.2020.1768452.

Vogelsang, C., Lusher, A., Dadkhah, M. E., Sundvor, I., Umar, M., Ranneklev, S. B., Eidsvoll, D., & Meland, S. (2019). Microplastics in road dust – Characteristics, pathways and measures. In *7361*. Norsk institutt for vannforskning. https://toi.brage.unit.no/toi-xmlui/handle/11250/2670146.

Vörösmarty, C. J., McIntyre, P. B., Gessner, M. O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S. E., Sullivan, C. A., Liermann, C. R., & Davies, P. M. (2010). Global threats to human water security and river biodiversity. *Nature*, *467*(7315), 555–561. https://doi.org/10.1038/nature09440.

Vu, A. V., Baumgartner, L. J., Doran, G. S., Mallen-Cooper, M., Thiem, J. D., Howitt, J. A., Limburg, K. E., Gillanders, B. M., & Cowx, I. G. (2021). Variability in water chemistry in the Lower Mekong basin: Considerations for fish life history reconstruction. *Estuarine, Coastal and Shelf Science*, *255*, 107355. https://doi.org/10.1016/j.ecss.2021.107355.

Vu, A. V., Baumgartner, L. J., Mallen-Cooper, M., Howitt, J. A., Robinson, W. A., So, N., & Cowx, I. G. (2020). Diadromy in a large tropical river, the Mekong: More common than assumed, with greater implications for management. *Journal of Ecohydraulics*, 1–13. https://doi.org/10.1080/24705357.2020.1818642.

Wang, J., Beusen, A. H. W., Liu, X., & Bouwman, A. F. (2020). Aquaculture production is a large, spatially concentrated source of nutrients in Chinese freshwater and coastal seas. *Environmental Science & Technology*, *54*(3), 1464–1474. https://doi.org/10.1021/acs.est.9b03340.

Wang, M., Janssen, A. B. G., Bazin, J., Strokal, M., Ma, L., & Kroeze, C. (2022). Accounting for interactions between sustainable development goals is essential for water pollution control in China. *Nature Communications*, *13*(1), Article 1. https://doi.org/10.1038/s41467-022-28351-3.

Wang, M., Webber, M., Finlayson, B., & Barnett, J. (2008). Rural industries and water pollution in China. *Journal of Environmental Management*, *86*(4), 648–659. https://doi.org/10.1016/j.jenvman.2006.12.019.

Wang, Q., Li, Z., Gui, J.-F., Liu, J., Ye, S., Yuan, J., & De Silva, S. S. (2018). Paradigm changes in freshwater aquaculture practices in China: Moving towards achieving environmental integrity and sustainability. *Ambio*, *47*(4), 410–426. https://doi.org/10.1007/s13280-017-0985-8.

Williams, J. G. (2018). Comment on 'Designing river flows to improve food security futures in the Lower Mekong basin'. *Science (New York, N.Y.)*, *361*(6398), eaat1225. https://doi.org/10.1126/science.aat1225.

Winemiller, K. O., Mcintyre, P. B., Castello, L., Fluet-Chouinard, E., Giarrizzo, T., Nam, S., Baird, I. G., Darwall, W., Lujan, N. K., & Harrison, I. (2016). Balancing hydropower and biodiversity in the Amazon, Congo, and Mekong. *Science (New York, N.Y.)*, *351*(6269), 128–129.

World Commission on Dams. (ed.) (2000). *Dams and development: A new framework for decision-making*. Earthscan.

Worthington, T. A., van Soesbergen, A., Berkhuysen, A., Brink, K., Royte, J., Thieme, M., Wanningen, H., & Darwall, W. (2022). Global swimways for the conservation of migratory freshwater fishes. *Frontiers in Ecology and the Environment*, *20*, 573–580. https://doi.org/10.1002/fee.2550.

Xiaoyi, L., & Yameng, L. (2021). *10-year Yangtze fishing ban in full swing, shows China's determination in ecological restoration*. Global Times. https://www.globaltimes.cn/page/202104/1221074.shtml.

Zarfl, C., Lumsdon, A. E., Berlekamp, J., Tydecks, L., & Tockner, K. (2015). A global boom in hydropower dam construction. *Aquatic Sciences*, *77*(1), 161–170. https://doi.org/10.1007/s00027-014-0377-0.