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Dammed deltas: sinking Asian deltas in a warming world

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Summary

People who live on tropical deltas are making local adaptations to tackle myriad challenges, but should we be looking upstream? Rapid expansion of dams for hydropower is damaging the rivers that supply deltas, increasing the uncertainty about how delta communities should adapt in the future.

Deltas depend on rivers to provide the water, sediment and nutrients on which delta inhabitants rely. Upstream dams for hydroelectric power (HEP) generation are disrupting rivers, placing additional stresses on populous delta regions, amplifying downstream pressures of high resource demand, pollution and saline intrusion. This presents a deep-rooted paradox - that of balancing the needs of communities for livelihood improvement - which requires energy - versus the environmental degradation, and associated threat to livelihoods, caused by expanding use of HEP to supply that energy. In contextualising how upstream activities affect entire river basins including their highly vulnerable delta social-ecological systems, we highlight where progress needs to be made and the important role for transdisciplinary approaches to livelihood transformation.

The interconnectivity of river-delta systems

Deltas are the low-lying termini of much larger river basins, which are linked to vast upstream areas of land relative to their size (Figure 1A). The mega-deltas of South and Southeast Asia

(Ganges-Brahmaputra-Meghna (GBM), Mekong and Red River Deltas) include the world's largest delta (GBM) and together they support some 215 million people. Deltas are built on river sediment and the dependence of people on river-derived resources and services (e.g. fertile soils, productive aquatic ecosystems, diverse landscapes and navigation) leads to complex socio-ecological systems, with distinctive natural cultural heritage: The two "rice bowls" of Vietnam are located in the Mekong and Red River Deltas. The GBM, Mekong and Red River Deltas are important for biodiversity, together hosting eleven Ramsar wetlands of international conservation importance and the Sundarbans Biosphere Reserve and World Heritage Site in the GBM, the world's largest contiguous mangrove forest and a key refuge for the Bengal tiger.

Within deltas, the pressures associated with climate warming and rapid development create complex and interconnected challenges for inhabitants. The low-lying situation of deltas makes them especially vulnerable to sea level rise and coastal storm surges, but upstream impoundment and extensive pumping of groundwater to supply delta mega-cities is causing some deltas to sink, greatly exacerbating the risks of coastal flooding and saline incursion[1]. Inland encroachment of seawater has prompted the installation of large sluice gates in the Mekong Delta to stem the incursion but nevertheless, agriculture in a number of delta provinces (e.g. Ben Tre) is being forced to transition from rice towards crops which are more salinity-tolerant. Asian mega-deltas are highly exposed to storms such as Cyclone Amphan, the strongest storm to strike the GBM, which caused $31 billion worth of damage in 2020. Agricultural intensification and growth of urban and industrial areas, has led to river channelisation and water pollution, increasing the dependency on groundwater. Many of these pressures are set to intensify under future scenarios of climate warming and economic growth.

Looking up-river

Socio-economic development is increasing the demand for power across Asia, and hydroelectric power (HEP) generation from damming of rivers has been viewed as one solution to that need, with 50% of all large dams located in Asia[2]. HEP schemes have produced some of the world's largest dams, necessarily located in upstream mountainous regions where the power of rivers is greatest. Most large dams installed within the Red and Mekong River basins are for currently for HEP, and HEP is an major focus for future regional economic development (Figure 1). The semi-complete Lancang Cascade of dams in the upper Mekong is developing power generation capacity for China, while Lao PDR's stated ambition to become 'the battery of Asia' is underpinned by a need for more HEP schemes. In contrast, in the GBM basin, reservoir-based HEP projects are limited due to the high risk of earthquake damage; most dams in this region were installed over the past century for irrigation (Figure 1A)[2]. Yet, current plans for the Medong “Super-dam” on the Great Bend of the Brahmaputra cast a shadow over downstream nations. Some HEP dams can lead to the creation of massive reservoirs which have a major impact on the environmental integrity of downstream rivers, with adverse consequences for deltas and their inhabitants who are struggling to adapt to downstream pressures (Figure 2A). Finding solutions to this interlinked problem is intensified because these rivers cross multiple nations (Figure 1A).

Land versus sea

Low-lying deltas are vulnerable to sea level rise, but it is becoming increasingly clear that supply versus loss, and redistribution of sediment will be more important in shaping where and how people live on deltas in the coming century[1]. Deltas need sufficient sediment to maintain their land mass above sea level (encompassing future storm surges), but dams threaten this supply[3]. Dams trap river sediments directly in reservoirs, but also harvest the power of the water which reduces peak flows and restricts the ability of rivers to carry sediments. Upstream impoundments in both Vietnam (Figure 1B) and China have led to a decline in suspended sediments in the Red River from around 79 million tonnes per year in the 1960s to about 6 million tonnes per year in the 2010s[4]. The supply problem triggers downstream issues because sediment-hungry rivers will cut into their banks, eroding riparian areas and stagnating the growth of coastal landscapes. Concurrently, sediment loss through sand mining to support the overseas construction industry is removing around 50 Mt of sand from the Mekong Delta each year, which is almost 10 times more than is presently supplied from upstream[5]. Consequently, shoreline erosion and river channel deepening in the Mekong Delta has led to land loss of up to 2.3 km^2 of (primarily valuable agricultural) land each year[6]. The effects of this significant sediment deficit in the Mekong Delta is strongly exacerbated by excessive groundwater extraction which is causing the land surface to sink[3].

In addition to sediment trapping, dams change how and where sediment is deposited within deltas by altering seasonal flooding patterns. The mean elevation of the Mekong is only 0.8m above sea level[7], so changes in river-borne sediment during seasonal floods can affect landscape topography at scales that, while small, are vitally important to delta inhabitants at risk of inundation[8]. In the GBM, creation of temporary sediment islands (chars) by fluvial geomorphological processes are critical for char-based communities with their unique cultural heritage. This delta has a net surplus sediment supply due to active erosion of the Hindu Kush Himalaya (HKH)[3], but hard engineering schemes in Bangladesh have isolated river channels from the land, choked them with sediment and exacerbated river flooding. In contrast, in the sediment-starved Mekong system, erosion initiated by dams and sand mining appears to have ‘locked in’ tidal ingress for the coming century[1], with the combined effects of groundwater extraction exacerbating the sinking of the delta. Despite variation in downstream impacts in these South and SE Asian deltas, the common outcome of upstream flow interference are invariably adverse for delta social-ecological systems.

Water: quantity versus quality

Dams alter the timing and quantity of water delivered to deltas, which is vital for sustaining delta regions, e.g. to support a projected requirement for doubling of water supply to urban areas of Vietnam between 2009 and 2031. Dams dampen variability in water flows which in turn degrades the functioning of river-connected wetlands and floodplains where the flood cycle is key to system productivity and biodiversity. For example, in Bangladesh, seasonal flooding of farmland appears to be important in chemically mobilizing soil nutrients and so enhancing soil fertility[9]. Dam-induced changes in downstream river flows are known to influence the culturally-important lake-wetland Tonle Sap in Cambodia which relies on the seasonal flood pulse to sustain vital freshwater fisheries in Cambodia. The location of eleven Ramsar sites across the three delta regions indicates their important role in connecting international bird flyways but dam-induced damage to these aquatic ecosystems through loss of temporal and spatial connectivity threatens regional biodiversity.

By trapping nutrients within their sediments, dam impoundments trap elements (carbon, nitrogen, phosphorus, silicon) carried by river waters which support downstream productivity[10]. Upstream reservoirs in the Red River are slowly capturing phosphorus, reducing the riverine supply of this element to downstream agricultural regions, enhancing the reliance on artificial fertilizers[11]. Both “rice bowl” deltas of Vietnam in the Red River and Mekong Deltas are locally polluted by nitrogen from fertilizer overapplication and there are pollution hotspots for nutrients and heavy metals within the Red River Delta close to the city of Hanoi[12]. Due to intensive nutrient cycling and additions within deltas it is hard to predict the downstream implications of damming for coastal environments where nutrients are important for supporting marine food webs. Despite the restorative capacity of deltas to sequester excess loads of nutrients, heavy metals and other pollutants, it may be that system thresholds are being rapidly approached which may not become evident until tipping points are reached - making adaptive management a harder task, especially given the risks of river downcutting and remobilization of legacy sediments.

The changing river basin picture

While changing climate is intensifying threats to Asian deltas (i.e. sea level rise, more intense and variable rainfall and increased intensity of storms) it also has significant consequences upstream for the rivers which feed deltas (Figure 2A). Hydrological changes to rivers which supply HEP plants will alter their efficiency and could require shifts in their operation, with knock-on consequences for downstream regions, while the reservoirs formed by dams can also add to regional greenhouse gas emissions, especially methane[13]. The Himalayan Hindu Kush (HHK) region is often termed the "Watertower of Asia"; here, global heating is causing permafrost to melt, and glaciers to retreat, reducing water delivery to the Ganges and Brahmaputra Rivers during the dry season[14] (Figure 2A). This uncertainty in water supply for HEP schemes is likely to threaten the operation of less environmentally-damaging "run-of-the-river" HEP schemes and instead increase the pressure to develop large reservoirs where water storage and power generation can be more tightly controlled.

Raising delta social-ecological resilience is essential

Given their diverse geographies and natural-cultural heritages, as well as their fragile geopolitics and economies, transboundary river basin and delta management in South and Southeast Asia faces significant challenges. For deltas, the need for cooperative transboundary water resource management is becoming urgent, each of the deltas discussed here are detrimentally impacted by upstream dam development located in other nation states. Outcomes to date have, however, not been encouraging: a long-standing dispute exists between India and Bangladesh regarding appropriate allocation and development of the water resources of the Ganges River, and the Brahmaputra-Meghna Basin lacks a common legal framework and transboundary institutional mechanism to support communication, planning, and development. More than 70 dams spread across the six riparian countries (China, Myanmar, Thailand, Laos, Cambodia, and Vietnam) make the management of the transboundary Lancang-Mekong River Basin a daunting task, especially in the absence of China's participation . None of Bangladesh, Cambodia, China, India, Lao PDR or Thailand are signatories to either of the United Nations transboundary water conventions. Intergovernmental organizations such as the Mekong River Commission (including Lao PDR, Cambodia, Vietnam, and Thailand - but not China) have improved regional coordination, but regulatory power is weak. Two bilateral agreements between India and Bangladesh since 2011 on conservation of the Sundarban and protection of the Bengal tiger have not led to the more integrated approaches essential for raising delta resilience to the rising pressures they face.

Basin-scale monitoring is key to underpin delta adaptation

Full regional-scale cost-benefit analyses of the consequences of HEP dams are required, but this needs better understanding of the environmental and social costs of dams at a variety of scales and encompassing the whole river basin[15] (Figure 2B). Since deltas are located at the end of the river, the upstream benefits from HEP are generally heavily outweighed by disbenefits to landscapes, biodiversity, and livelihoods in delta regions. The planning process for HEP projects is often focused on economic aspects and typically conducted at the national scale. Assessments focused on basin-scale biophysical understanding remain an urgent requirement but these face challenges in terms of data-sharing, uneven baselines and depths of monitoring. Longer term monitoring data on basin-scale river flows/discharges and suspended sediment are a minimum requirement to allow accurate sediment budget projections, but these are often lacking. Nutrient monitoring can highlight local water quality issues, while basin-scale nutrient balances can support decision-making on agriculture, fisheries, and inform carbon policy under different scenarios of dam operation[12]. Unfortunately, despite numerous methodological advances to determine environmental flows and optimise dam releases, implementation has not followed suit[16]. Integrating environmental flow requirements in the design of new impoundment schemes is relatively easier than changing operations of existing dams but the international cooperation necessary to allow either is not in place in these deltas. To aid policy decisions and transnational communication, simple indices and communication tools can be effective[17] but there are persistent issues in effectively incorporating human agency and governance.

For both human well-being and river system sustainability, understanding the complexity of human–nature interactions is essential. Returning to our initial paradox: reconciling the social justice of livelihood improvement - which requires energy - versus the environmental degradation and threat to livelihoods from HEP, urgently requires models that fully integrate human and biophysical systems and consider the particular challenges faced by transboundary river systems. Better-constrained sediment budgets at the basin and sub-basin scale alongside geomorphological risk assessments can link sediment regimes with the local-scale consequences for delta communities[8]. In the Mekong Delta, such approaches can provide the necessary evidence base to address unsustainable and often illegal sand mining and groundwater abstraction[6]. Traditional hydrological river modelling struggles to parametrize complex and heavily-modified mega-delta systems however, simplified modelling approaches which incorporate socioeconomic and biophysical data could help to identify more sustainable source-to-sea management interventions[18]. The challenge is developing these modelling advances rapidly enough to keep abreast of the accelerating pace of impoundment which provides an existential threat to the integrity of many of our iconic and important South and Southeast Asian river systems.

References

1. Vasilopoulos, G., Quan, Q.L., Parsons, D.R., Darby, S.E., Tri, V.P.D., Hung, N.N., Haigh, I.D., Voepel, H.E., Nicholas, A.P., and Aalto, R. (2021). Establishing

sustainable sediment budgets is critical for climate-resilient mega-deltas. Env. Res. Lett. *16*, 064089. 10.1088/1748-9326/ac06fc

2. Mulligan, M., van Soesbergen, A., and Sáenz, L. (2020). GOODD, a global dataset of more than 38,000 georeferenced dams. Sci. Data *7*, 31. 10.6084/m9.figshare.10538486
3. Edmonds, D. A., Caldwell, R. L., Brondizio, E. S., and Siani, S.M.O. (2020). Coastal flooding will disproportionately impact people on river deltas. Nat. Comms. 11, 4741. 10.1038/s41467-020-18531-4
4. Le, N.D., Le, T.P., Phung, T.X., Duong, T.T., Didier, O. (2020). Impact of hydropower dam on total suspended sediment and total organic nitrogen fluxes of the Red River (Vietnam). Proc. Int. Assoc. Hydrol. Sci. 383, 367-74. 10.5194/piahs-383-367-2020
5. 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. Nat. Sustain. 3, 217–225. 10.1038/s41893-019-0455-3
6. 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., and Wild, T. (2018). Changing sediment budget of the Mekong: Cumulative threats and management strategies for a large river basin. Sci. Tot, Env. 625, 114-134. 10.1016/j.scitotenv.2017.11.361
7. Minderhoud, P.S.J., Coumou, L., Erkens, G., Middelkoop, H. and Stouthamer, E. (2019). Mekong delta much lower than previously assumed in sea-level rise impact assessments. Nat. Comms. 10, 3847. 10.1038/s41467-019-11602-1
8. Paszkowski, A., Goodbred Jr., S., Borgomeo, E., Khan, M.S.A., and Hall, J.W. (2021). Geomorphic change in the Ganges–Brahmaputra–Meghna delta. *Nat. Rev. Earth Env.* 2, 763-780. 10.1038/s43017-021-00213-4
9. Brammer, H. (2016). Bangladesh: Landscapes, soil fertility and climate change (University Press Limited).
10. Maavara, T., Chen, Q., Van Meter, K., Brown, L.E., Zhang, J., Ni, J., Zarfl, C. (2020). River dam impacts on biogeochemical cycling. Nat. Rev. Earth Env. 1, 103-16. 10.1038/s43017-019-0019-0
11. Quynh, L.T.P., Billen, G., Garnier, J., Théry, S., Fézard, C., and Minh, C.V. (2005). Nutrient (N, P) budgets for the Red River basin (Vietnam and China). (2005). Glob. Biogeochem. Cyc. 19. 10.1029/2004GB002405
12. Salgado, J., Duc, T.A., Panizzo, V.N., Bass, A.M., Zheng, Y., Taylor, S., Roberts, L.R., Lacey, J.H., Leng, M.J. and McGowan, S. (2022). Urbanization and seasonality strengthens the CO2 capacity of the Red River Delta, Vietnam. *Env. Res. Lett. 17*, 104052. 10.1088/1748-9326/ac9705

13. Harrison, J.A., Prairie, Y.T., Mercier-Blais, S., and Soued, C. (2021). Year-2020 global distribution and pathways of reservoir methane and carbon dioxide emissions according to the greenhouse gas from reservoirs (G-res) model. Glob. Biogeochem. Cyc. 35, e2020GB006888. 10.1029/2020GB006888
14. Biemans, H., Siderius, C., Lutz, A.F., Nepal, S., Ahmad, B., Hassan, T., von Bloh, W., Wijngaard, R.R., Wester, P., Shrestha, A.B., and Immerzeel, W.W. (2019). Importance of snow and glacier meltwater for agriculture on the Indo-Gangetic Plain. Nat. Sust. *2*, 594-601.10.1038/s41893-019-0305-3
15. Intralawan, A., Smajgl, A., McConnell, W., Ahlquist, D.B., Ward, J. and Kramer, D.B. (2019). Reviewing benefits and costs of hydropower development evidence from the Lower Mekong River Basin. WIRes: Water, 6, e1347. 10.1002/wat2.1347
16. Hairan, M.H., Jamil, N.R., Looi, L.J., and Azmai, M.N.A. (2021). The assessment of environmental flow status in Southeast Asian Rivers: A review. J. Clean. Product. *295*, 126411. 10.1016/j.jclepro.2021.126411
17. Vollmer, D., Shaad, K., Souter, N.J., Farrell, T., Dudgeon, D., Sullivan, C.A., Fauconnier I., MacDonald, G.M., McCartney, M.P., Power, A.G., and McNally, A. (2018). Integrating the social, hydrological and ecological dimensions of freshwater health: The Freshwater Health Index. Sci. Tot. Env. 627, 304-313.10.1016/j.scitotenv.2018.01.040
18. Do, T.N., Tran, V.B., Trinh, A.D., and Nishida, K. (2019). Quantification of nitrogen load in a regulated river system in Vietnam by material flow analysis. J. Mat. Cyc. Waste Mgmt. 21, 974-983.

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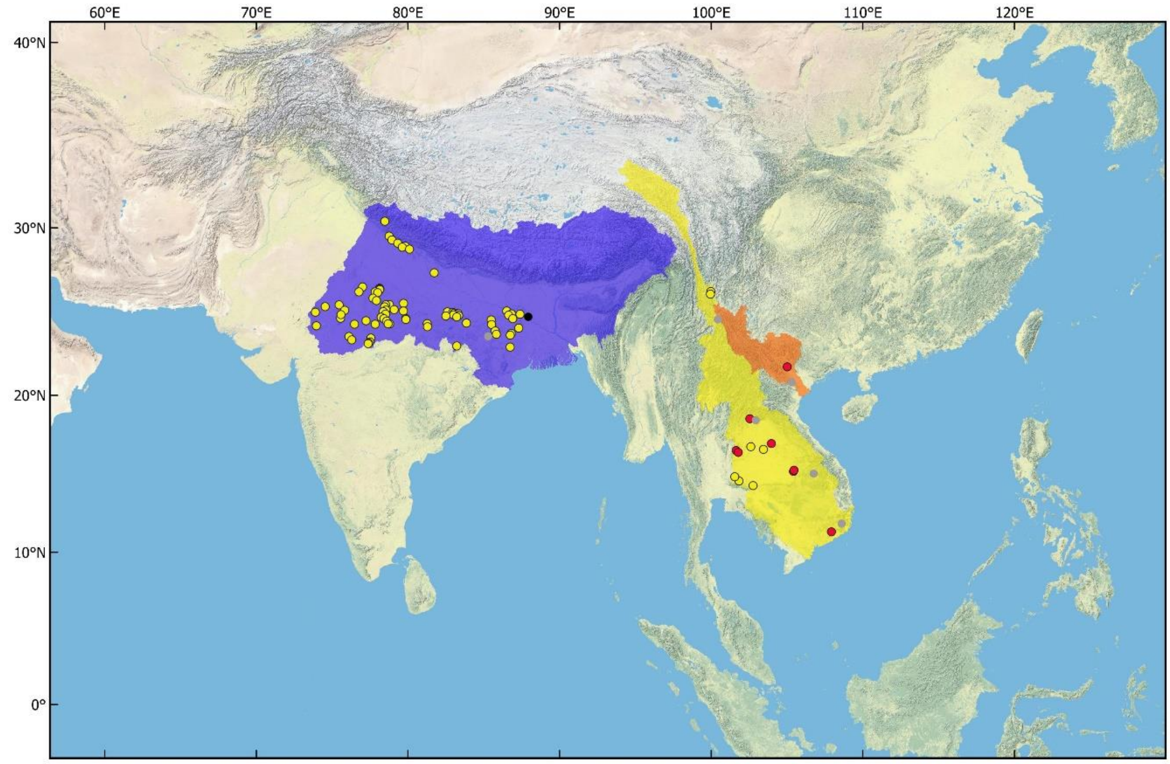

Figure 1. **Rivers and dams in South and Southeast Asian deltas**. (A) The location and characteristics of the South and Southeast Asian river basins (as determined using Hydrosheds.org). The number of dams and their usage (Red = HEP, yellow = irrigation, black = navigation, grey = unknown) is from the GRanD v1.3 database which was updated in 2019 and includes large (≥0.1km^3) impoundments[2]. *Note*: the number of dams on the Red River (2) is an underestimate, as the GRaND database only captures around 12% of dams globally, but it does have attribute data; numerous other dams exist on tributaries, both in Yunnan (China) and Vietnam. (B) The Hoa Binh HEP dam upstream of Hanoi on the Red River Delta.

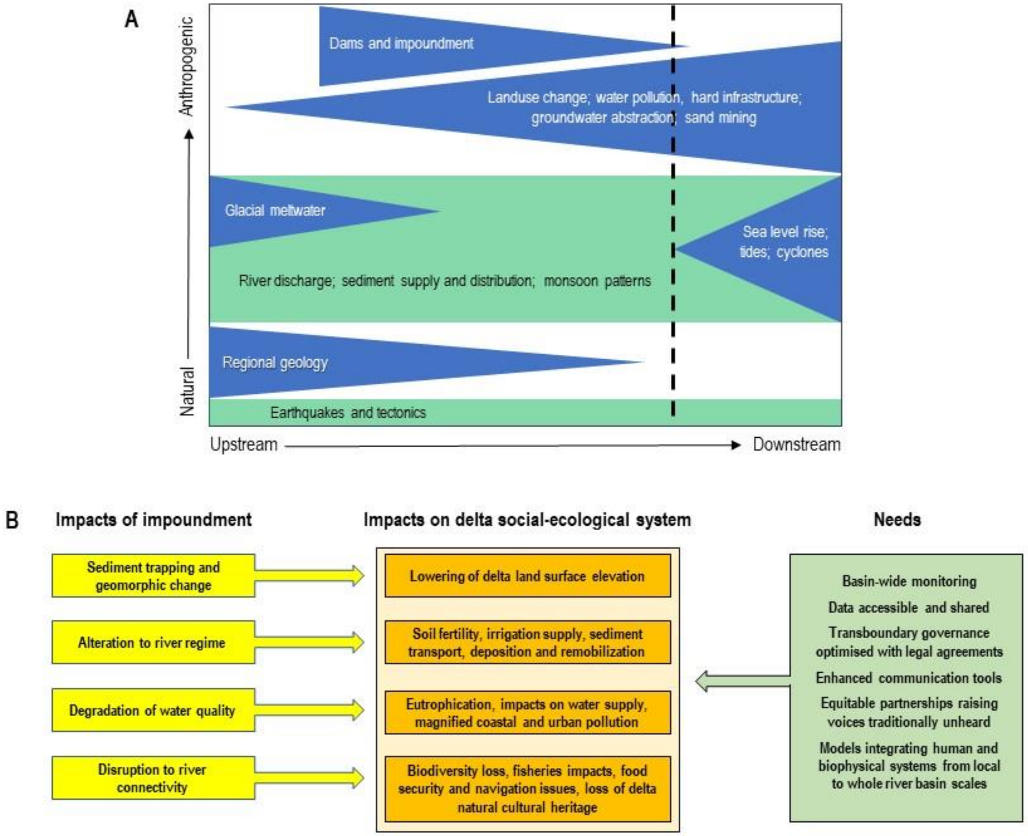

Figure 2. **Upstream-downstream stressors and ways forward for deltas.** (A) Summary of biophysical drivers operating along a river basin from upstream to downstream which vary in the degree to which they derive from natural and anthropogenic processes. The dotted line indicates where the delta area begins in the downstream side of the diagram. (B) Major impacts of dams on delta systems and existing gaps and needs for raising resilience of delta social-ecological systems.