# COMMENT

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HELMUT IGNAT/NATL GEOGRAPHIC ROMANIA

**White pelicans feed on the Danube delta in Romania, a global biodiversity hotspot.**

# Protect the world's deltas

## Sea-level rise and river engineering spell disaster, say **Liviu Giosan** and colleagues.

More than a century after Mark Twain argued that the Mississippi River could never be tamed by engineers, dams and dikes constrain the great waterway. Its once muddy waters run clearer[1]. Starved of sediment and fragmented by economic development, the Mississippi delta downstream is shrinking by thousands of hectares per year. The rich delta ecosystem and the services it provides — storm protection, nutrient and pollution removal and carbon storage — are being destroyed. Fisheries and the bayou cultural heritage are threatened.

Deltas worldwide share this fate[2]. In Pakistan, one-fifth of the Indus delta plain has been eroded since the river was first dammed in 1932. In China, the northern shore of the Yellow River delta has retreated 300 metres each year for the past 35 years.

Rising seas compound the sediment crisis. Coastal lowlands less than a metre above sea level will be inundated by the turn of the century. Areas at risk of flooding in deltas will grow by 50%[2]. This global scale of delta drowning has been unprecedented in the past 7,000 years.

Better-preserved deltas such as the Danube, the most extensive wetland in the European Union and a global biodiversity hotspot, show what will be lost. Its labyrinth of channels, lakes, marshes and dunes are home to about 2,000 plant and 5,000 animal species, many of them threatened.

More than 500 million people worldwide live on deltas, many in sprawling megacities such as Shanghai, Dhaka and Bangkok. Conservative estimates value major deltas worldwide at trillions of US dollars in terms of economic revenue and ecosystem services.

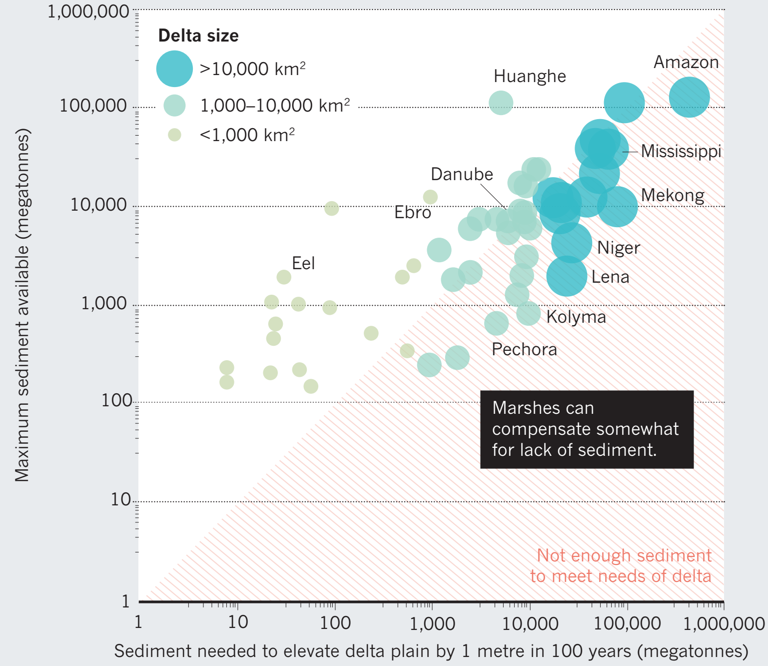
In Pakistan, people are leaving the lower Indus delta because saltwater-soaked soils make agriculture difficult. Nearly ten years after hurricanes Katrina and Rita overwhelmed protective levees in New Orleans, Louisiana, the city's population is still 17% lower than in 2005. In other deltas in the tropical-cyclone belt, such as the Ganges–Brahmaputra in India and Bangladesh, and the Irrawaddy in Myanmar, marsh and mangrove destruction has reduced flood protection and damaged communities and economies. The consequences of delta loss are global: huge losses of ecological services, economic and social crises, and large-scale migrations.

### STARVED LANDS

We call on the United Nations to establish an international body of experts to coordinate delta-maintenance initiatives worldwide. We urge governments to accelerate scientific ▶

**IN THE RED**

Most large- and medium-sized deltas cannot grow fast enough to keep up with sea-level rise in the next century. Damming reduces sediment load further and pushes more deltas into the red.

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research and expand monitoring and forecasting programmes, impact studies and public consultations.

Deltas can exist only where rivers discharge enough sand and mud to overcome the currents that wash them away. But fluvial loads have plummeted[3]. The Nile and the Indus carry 98% and 94% less mud, respectively, than they did a century ago. Deficits afflict waterways on all scales, from continental systems such as the Mississippi (carrying 69% less sediment than when it was first dammed) and the Danube (60% less) to the smaller rivers such as the Rhône (85% less) in Europe. China's Three Gorges Dam will reduce the Yangtze's load to well below its current 66% reduction from when it was first damned. The Mekong in southeast Asia will follow this downward trend as dams are built in its basin.

Deltas' naturally high subsidence rates are exacerbated by human activities[2]. For example, the Chao Phraya delta in Thailand is sinking by 5–15 centimetres each year because of intense groundwater use. The Po delta in Italy subsided by 3–5 metres in the twentieth century, mainly as a result of methane extraction. As marshes falter, vegetation dies and halts soil formation, speeding land loss.

Initiatives are trying to save deltas. They include Future Earth and Sustainable Deltas 2015, supported by the International Council of Science, and networks such as the Delta Alliance. But their findings are yet to be implemented. Methods such as rebuilding marshes with dredged sediments, installing coastal protection and diverting river channels to build land are being used on or planned for the Mississippi delta, for example, by the Louisiana Coastal Protection and Restoration Authority. It is too soon to know how effective these efforts will be.

Restoration of drowned delta areas is expensive. The plan for the Mississippi — the most ambitious yet — will run for 50 years, and cost between US$500 million and $1.5 billion a year. And it will only stave off future land loss, not recover the vast amount of wetlands already gone.

Knowledge gaps impede the adoption of generic solutions. Delta plains comprise an ever-shifting web of high ground surrounded by low wetlands, shallow lakes and lagoons. Rising sea levels, subsidence and marsh destruction expand lakes. Riverbanks and raised sand ridges become more isolated and vulnerable. Yet there is scarcely any real-time monitoring of water and sediment redistribution, subsidence or ecosystem dynamics. For most deltas, sediment budgets and ratios of mud, sand and organic soils in the upper few metres of a delta plain — crucial for preventing drowning — have yet to be assessed.

The proportion of sediment that ends up on and off shore is poorly quantified[4–6]. The majority is washed away because delta plains are inefficient sediment traps; even more so when they host engineered infrastructure.

Sediment retention depends on particle size, delta structure and vegetation. Sand makes up less than 10% of the load in most rivers. It is important for building land, especially during the early life of a delta. Sandy deltas such as the Krishna and Godavari in India or the Doce and São Francisco in Brazil have more land above sea level (30% by volume on average) than do muddy ones such as the Danube, Ebro and Rhône (10%).

Mud is just as important in building and maintaining large deltas, even though it is more mobile. It improves soil consistency and longevity, keeping marshes and mangroves healthy[7,8]. Yet little is known about the optimal amount of mud needed to support freshwater and saltwater ecosystems.

The majority of deltas are on course to drown. Even without coastal erosion, marine inundation will exceed the potential for growth in all deltas larger than 10,000 square kilometres and most of those from 1,000 to 10,000 square kilometres (see 'In the red').

The reasons that some deltas grew so large hold lessons for the future. Deltaic 'lobes' may persist when rivers change course. Several channels remain active in the Danube, Niger and Mekong deltas, for instance. Coastal barrier islands protect inland areas from erosion by the sea in the Mississippi and Danube deltas. And sediment loads were boosted by historical deforestation and agricultural practices in Asia, Europe and the United States.

By contrast, deltas less than 1,000 square kilometres are nearly all smaller today than would have been predicted from their sediment loads pre-damming. They have lost a lot of sediment at the coast and have few lakes and lagoons to trap mud. Although small sandy deltas might survive for a while, muddy ones such as the Ebro or Rhône may quickly lose to the sea. Much of the Po delta is already embanked — below sea level and surrounded by artificial banks, levees and pumps.

The health of wetlands is crucial to delta resilience[2]. Decaying vegetation can compensate for fluvial sediment loss. But we do not know enough about the volume and extent of organic soils, nor about the optimal sediment supply, salinity and nutrients for wetland health.

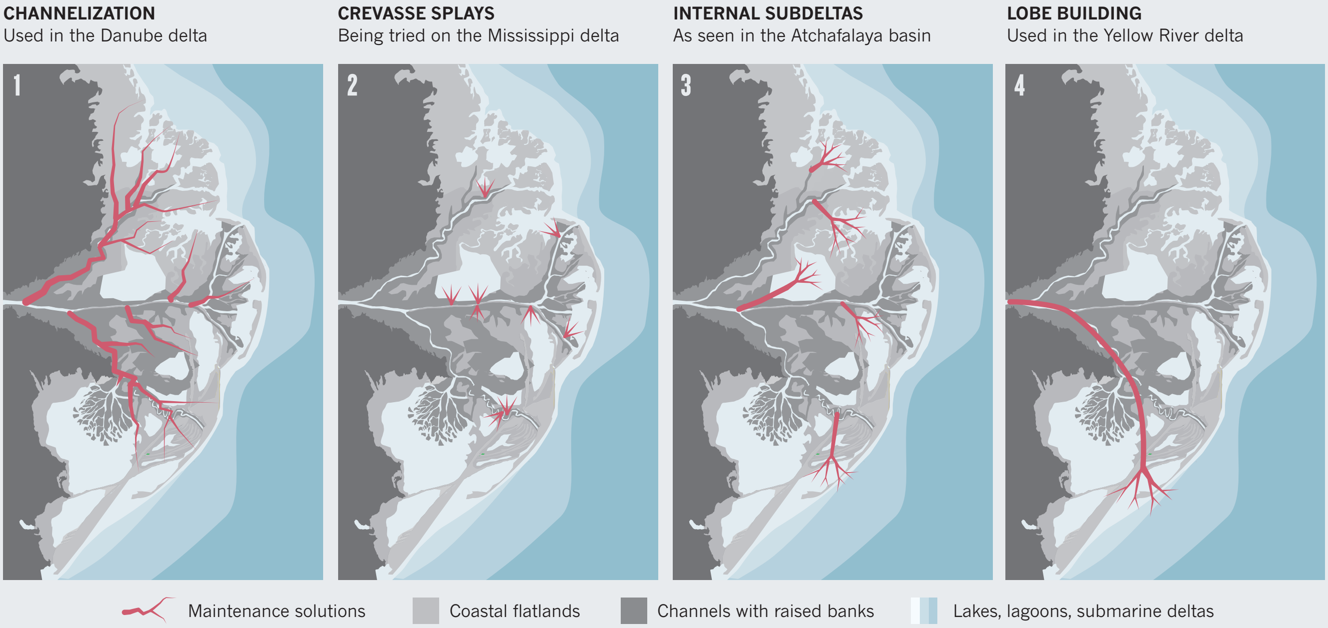
## WORK WITH NATURE

Maintenance strategies can limit delta drowning[4,5]. These include boosting sediments in river waters, diverting them before they reach the coast, optimizing the trapping abilities of the delta plain and keeping wetlands healthy[2,4,5–9]. Starting upstream, sluices or flushing mechanisms allow sediment to flow past dams[10]. On small rivers, dredging or removing dams may increase sediment flow.

Within the delta, soft engineering strategies should take advantage of natural processes and feedbacks (see 'Fixing the flow'). Multiple channels can be dug to spread sediments across the delta plain[5] and build marshes, fill ponds and extend lobes[4]. Deliberately breaching levees during floods or redirecting a river to fill basins can enhance natural backwater effects and promote wetland formation.

## FIXING THE FLOW

Delta maintenance should mimic natural processes by (**1**) cutting new channels, (**2**) breaking banks to build crevasses, (**3**) constructing small internal deltas in lakes and lagoons or (**4**) creating new larger lobes in areas protected from waves and tides.




The success of some historical practices is encouraging. In the Danube delta, dredging of new fishing channels off the main river has boosted sediment trapping and local livelihoods[5]. On the Ebro delta, the control of river-sediment supply for rice agriculture has increased mud retention on the plain, so that in places the land is rising faster now than the sea level and the rate of subsidence[9].

At the coast, hard barriers, levees, dikes and locks may be inevitable. Massive projects are expensive — the enclosure of the Rhine–Meuse delta in the Netherlands cost €5 billion (US$6.3 billion). Where retreat is an option, reshaping the coast as sandy beaches, barriers and mudflats may allow the landscape to adapt to higher sea levels. Urbanized deltas will feel the most acute pressures. In cities such as Shanghai, Bangkok and Dhaka, infrastructure and architecture will have to adapt to recurrent floods and evacuation plans.

The level of protection possible will depend on a region's wealth[2]. Difficult decisions on which lands to preserve and which to abandon are unavoidable. Pakistan cannot afford to revive the Indus delta without jeopardizing its irrigation system, one of the largest in the world. For rivers such as the Mekong, Danube or Indus, which cross multiple countries, negotiations on sediment rights, like those on water allocation, will be complex.

The window to stabilize the world's deltas is closing fast. By 2100, land losses from rising sea levels alone could reach 5% for higher deltas such as the Krishna–Godavari or the Ganges–Brahmaputra, 30% for the Mekong, Nile and Yellow, and more than 80% for the lower Danube delta. And the sea will keep rising for centuries even if global warming is stemmed and sediment flow to deltas is restored. Restoration schemes must be bigger, faster and better. They must include all deltas, respond to the rapid pace of environmental and economic change, and support data collection, modelling and real-time monitoring.

### NEXT STEPS

Plugging the knowledge gaps is the most urgent task. Observations should take advantage of new techniques and sensors. Satellite-based estimates of fluvial discharge or land subsidence are advancing. But more hydrological stations, tidal gauges and subsidence measurements are badly needed.

Biophysical and biogeochemical research on wetland processes must be expanded to address the wide range of deltaic conditions. Agricultural and industrial practices need to be assessed to select sustainable practices.

Governments of delta nations and of countries in their watersheds, helped by international funding agencies, should undertake this enormous effort using standardized methodologies developed under the advice of UN experts. Knowledge and data sharing on a common platform is crucial.

A science-based global strategy for protecting deltas needs to be developed to reduce costs and risks. A UN body of experts should be set up to coordinate existing international and national initiatives. Sustained investment could come from the UN environment and development programmes (UNEP and UNDP) and the World Bank. Developing economies will need assistance.

River deltas need maintenance now rather than costly restoration later to prevent the collapse of vast expanses of coastline. ■

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