DELTAS: Catalyzing Action Towards Sustainability of Deltaic Systems with an Integrated Modeling Framework for Risk Assessment

Deltas are bread baskets for large global areas, and are also complex, fragile social-ecological systems. The fragility of these systems and uncertainties around climate change impacts mean that unique ecosystems and millions of people are under threat. The DELTAS project tackled this complexity by working together across disciplines and with key local stakeholders in three major deltas: Amazon, Mekong, and Ganges-Brahmaputra to develop comprehensive risk assessment frameworks which incorporate environmental, physical and social indicators and are applicable to deltas globally. The DELTAS approach can be adopted for other vulnerable areas, including drylands, glaciers, and urban areas to analyze contemporary and future risks and explore scenarios for risk-reducing investments.

We present below three research domains built upon different arrangements of interdisciplinary collaborations.

Understanding deltas as biophysical systems: advancing quantitative delta classification

A rigorous mathematical framework for studying deltas using graph theory was developed wherein delta channel networks are represented as directed graphs, with junctions as nodes and channels as links, and it was shown that via simple algebraic operations on the 'adjacency matrix' (a sparse matrix that contains all information about network connectivity), several topologic and dynamic properties of deltas can be computed, as well as vulnerability maps constructed depicting the areas of the network where disturbances would most significantly affect the shoreline fluxes. This framework allowed the research team to develop a suite of metrics that capture the topologic and dynamic complexity of deltas. This TopoDynamic perspective of delta networks sets the foundation for quantitative and comparative classifications of deltas.

Understanding deltas as social-ecological systems: conceptualization and application

One of the focal areas of the project has involved the design of a problem-oriented conceptual framework to analyze deltas as coupled social-ecological systems. The two main components of the framework are: (a) defining boundaries and interdependencies and (b) defining and outlining the components of the collective action situation. This framework has been used to give a new definition of the Amazon delta that combines biophysical, hydrological, and social-political dimensions. An application of the framework is on the modeling and analysis of socio-economic vulnerability to flooding in urban areas of the Amazon delta. The framework is also currently being used to help diagnose a growing collective-action problem related to the impacts of urban growth and pollution on small-scale fishing resources in the Amazon delta.

Understanding delta vulnerability through modeling and participatory approaches

Comparative assessment of relative risk to flooding for 48 deltas globally

The research team developed estimates of flood risk in terms of the expected loss caused by flood events. Risk is high in deltas where extreme flood events are more likely to occur (high hazards), where more people live in low-lying areas exposed to flooding (high exposure), and where social vulnerability to flooding is high and greater flood exposure is more likely to cause harm (high vulnerability). Empirically defined indicators were used to locate 48 global deltas within the risk space defined by these three components, supporting a comparative assessment of relative levels of risk. The indicator-based risk framework can be used effectively in large-scale inter-delta comparative studies, especially as a complement to higher-resolution studies at the local scale.

Global Delta Vulnerability Index (GDVI)

The GDVI aims to provide a social-ecological system (SES) centered assessment approach for delta vulnerability globally and includes: (1) a multi-hazard vulnerability assessment method encompassing social and ecosystem susceptibility, social adaptive and coping capacities as well as ecosystem robustness; (2) a set of multidimensional indicators developed from a combination of a detailed literature review and regional expert consultations and knowledge co-production workshops in focal deltas; and, (3) an 'indicator library' allowing for a flexible indicator selection depending on the environment and data availability. Regional expert consultations with stakeholder groups helped characterize sub-delta areas prone to different types of hazards and developed a list of vulnerability indicators relevant to both the social and ecological part of the SES.

Besides advancing scientific knowledge, the BF Deltas project team also played a leading role in raising international awareness of the importance and vulnerability of deltas worldwide that includes writing a collaborative article calling for an International Year of Deltas and creation of the ICSU 'Sustainable Deltas Initiative' 2015. Products of the project include: peer reviewed publications including synthesis and action papers (~75 with papers published in Science, Nature Climate Change, Nature Sustainability, PNAS, among others), 2 Special issues in scientific journals (*Sustainability Science* and *Elementa: Deltas in the Anthropocene*), and Science Brief on the Sustainable Development Goals (SDGs). Data sets and web-based modelling tools are open access and accessible via the project website: https://delta.umn.edu. Public outreach activities include the video *Minute Earth: Why Do Rivers Have Deltas?* with 1.14 million views as of July 12, 2018, *Science on a Sphere,* and *River Delta animation*.

Figures

Fig. 1. Deltas at risk. Rapidly eroding coastline of the Ganges-Brahmaputra-Mehgna delta after cyclone Sidr, May 2012.

Photo credit: Irina Overeem (Project PI)

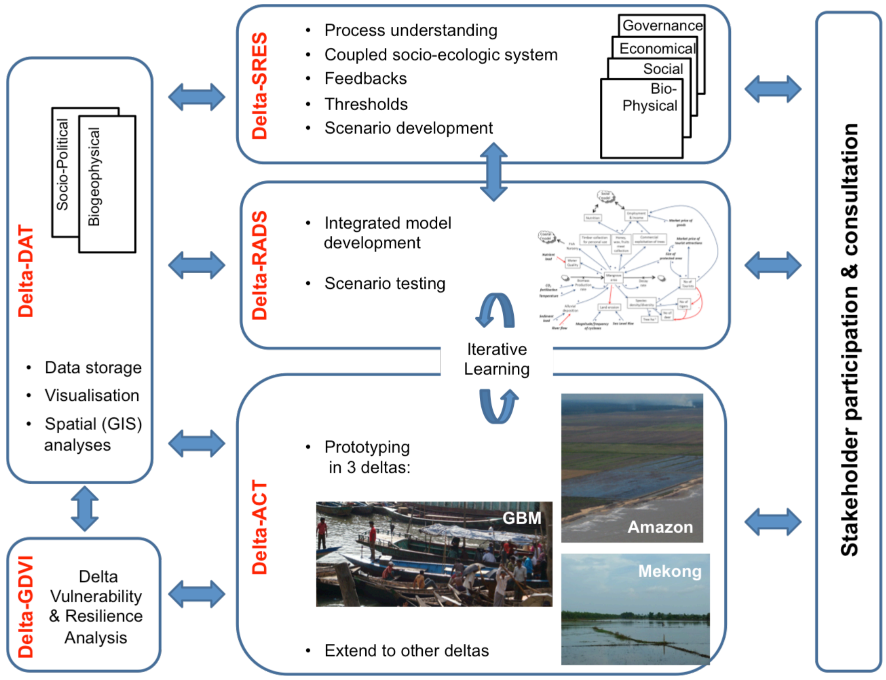

Fig. 2. The BF-Deltas Project Research Framework. Key components of the DELTAS project, whereby deltas are treated as fully coupled socio-ecological systems and scientist-stakeholder feedback is emphasized at all levels.

Photo credit: Obtained Permission to Reuse from COSUST

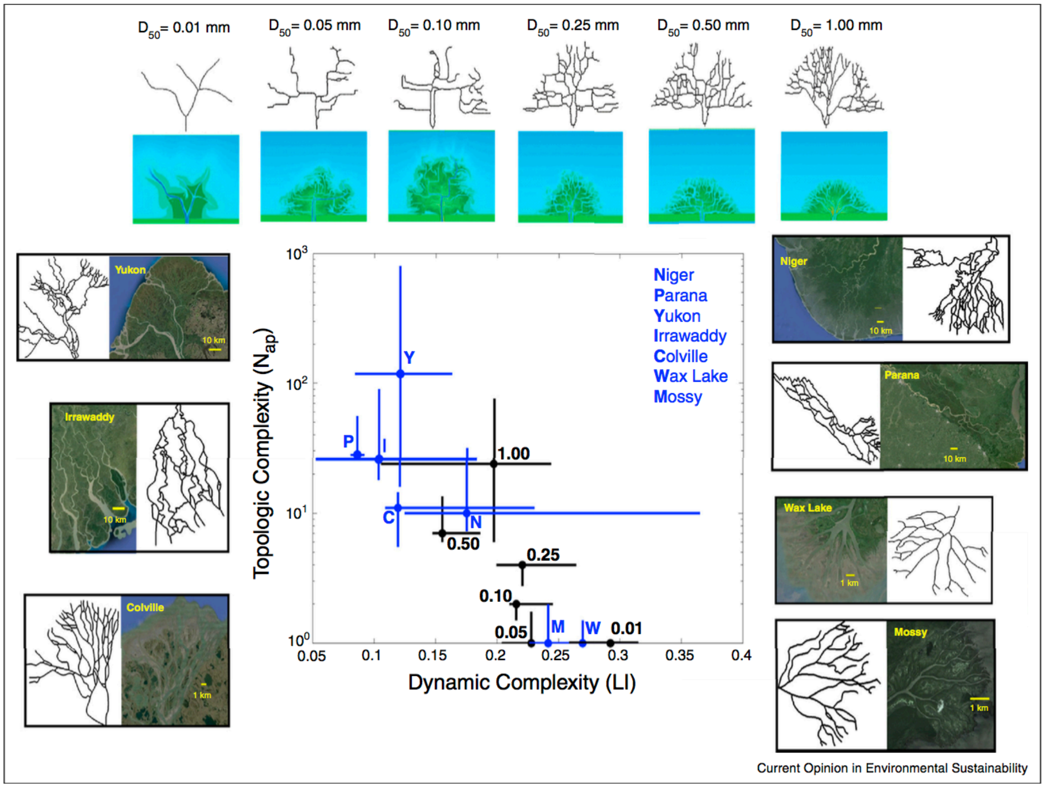

Fig. 3. 2D TopoDynamic Space. Combining both the Topologic (Number of alternative paths, N_{ap}) and Dynamic (Leakage Index, LI) complexity, each delta is positioned uniquely in the TopoDynamic space. For both field and numerical deltas, cohesive deltas (fine grained) have low topologic and high dynamic complexity, and a transition to high topologic and low dynamic complexity with increasing grain size is observed.

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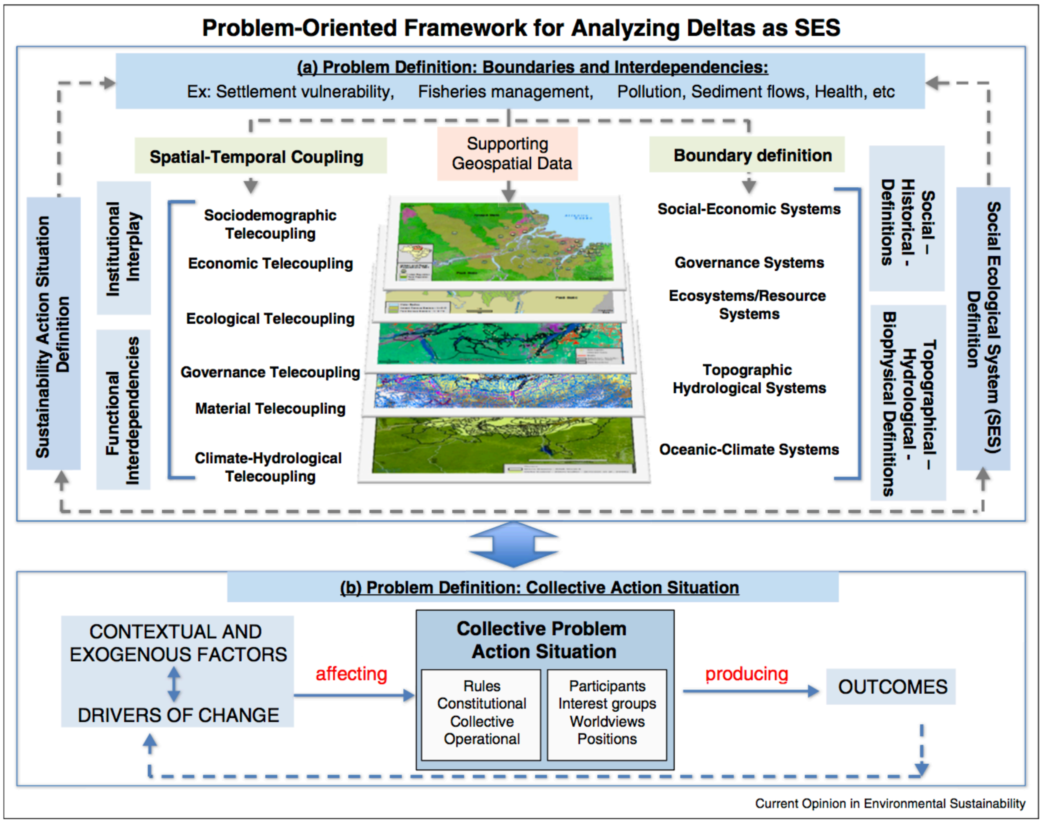

Fig. 4. The Deltas-SES framework. A problem-oriented framework for analyzing deltas as coupled social-ecological systems.

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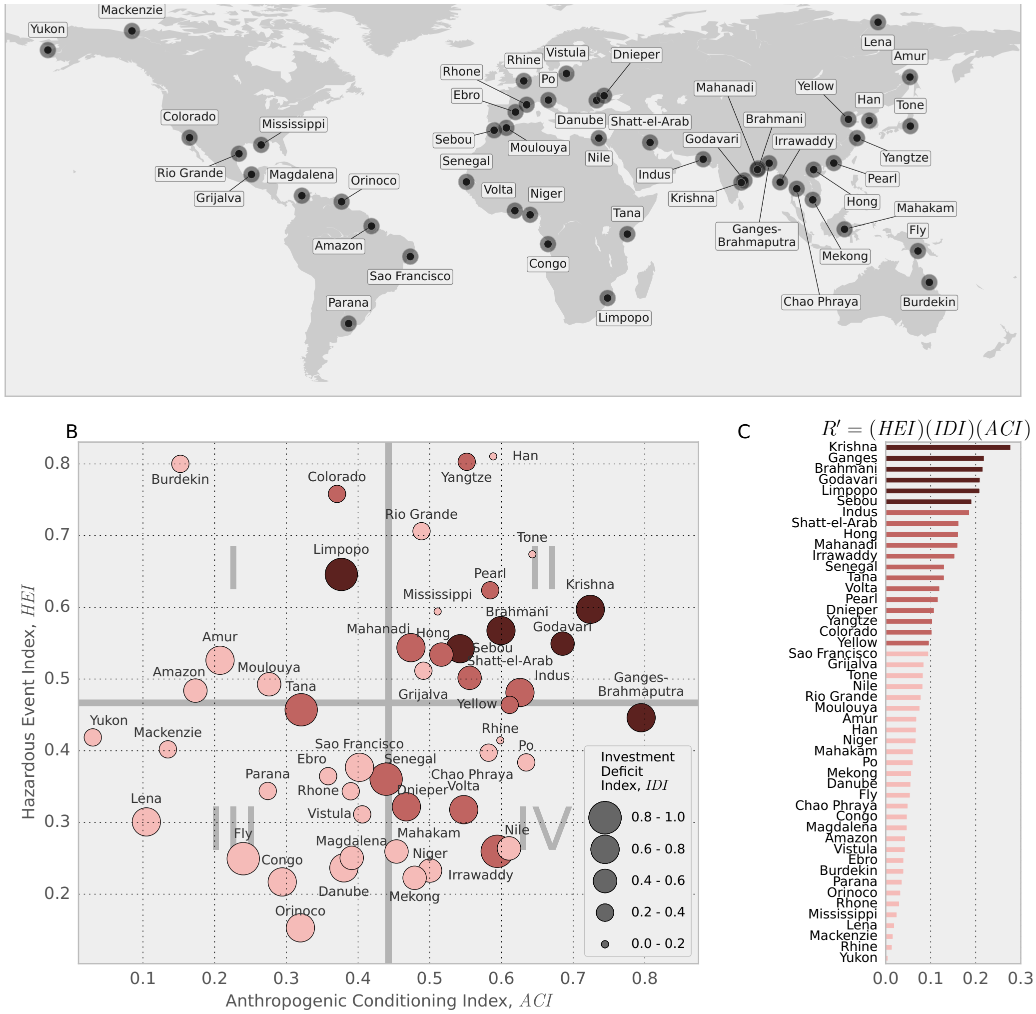

Science (2015)

Fig. 5. Risk trends for deltas worldwide. (A) Map showing the 48 deltas included in the study. (B) Phase diagram of contemporary risk assessment results, showing the three component proxy indices used to estimate per-capita risk trend R'. QIII deltas have predominantly low R', whereas QII deltas have high R'. (C) Estimates of the relative rate of change in risk, or risk trend, for each delta due to increasing exposure associated with Relative Sea Level Rise.

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Fig. 6. Belmont Forum DELTAS team. First annual project meeting held during the American Geophysical Union Fall Meeting (San Francisco, 2014).