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Deltas in Crisis: From Systems to Sophisticated Conjunctions

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Abstract: In recent years, threatened deltas have emerged as a significant matter of concern in numerous fields. While Earth System science and social-ecological systems focus on topics like global water circulation and sediment transport, social scientists tend to consider the problems facing particular deltas in the context of modernization or (post)-colonial development. There is nevertheless broad agreement that the delta crisis raises fundamental questions about modern approaches to infrastructure planning. Thus, environmental and sustainability scientists have come to recognize "the social" as integral to the delta crisis. This understanding of "the social," however, takes two quite different forms. As an object of social-ecological systems research, the social is modeled alongside ecological systems. However, as a context for scientific interventions in environmental policy it appears as an obstacle to achieving sustainable delta policies. Based on a careful examination of Earth System science and associated discourses, we show that this instability of "the social", combined with the ambition to integrate 'it' in an encompassing system poses serious problems for interdisciplinary delta research and for more imaginative and inclusive collaborative efforts to tackle the delta crisis—including, but going considerably beyond, policy and governance. Rather than integrative systems, we argue that the situation requires the creation of sophisticated conjunctions of epistemologies, methods, and practices. Such conjunctions, we suggest, pave the way for a cosmo-ecological approach, where social, environmental and sustainability sciences work together with designers, urban planners, policy-makers, and affected or concerned citizens on solving multi-scalar delta problems by working across their differences.

Keywords: deltas; Earth Systems; co-construction; social-ecological systems; STS

1. Introduction

The extreme 2011 floods in Thailand made the vulnerability of modern infrastructures to large-scale flooding plainly visible. Alongside widely circulating images of the destructions wrought by hurricanes like Katrina (in New Orleans, 2005) and Harvey (in Houston, 2017), rising flood risks in deltas across the world have stirred up deep concern over climate change and sea-level rise [1,2]. Thus, deltas have recently emerged as a significant matter of concern in numerous fields from Earth system science, sustainability science, and disaster management, to anthropology, political ecology, and science and technology studies (STS).

Approaches to the delta crisis are characterized by numerous differences in orientation and emphasis. While social scientists tend to identify land reclamation as a crucial risk factor [3–5], Earth system scientists depict delta submergence as a symptom of planetary environmental change. This difference manifests in the spatial and temporal scales these studies tend to employ. Social scientists usually consider the problems facing particular deltas in the context of modernization or (post)-colonial development. Environmental scientists are generally more concerned about global water circulation and sediment transport, and tend to locate delta transformations within a geological time scale.

Despite the differences, social and natural sciences converge in emphasizing the role of modern infrastructure planning—massive projects such as river engineering and land reclamation—as major causes of the rising flood risk in deltas [1,6]. This critique of infrastructure goes hand in hand with an emergent view of the environment as inherently dynamic and unpredictable. In fact, Earth system science has characterized the planetary environment as far more dynamic than previously imagined. It is this dynamism that undermines modern infrastructural planning, which has always assumed the stability of the ground. There is a general agreement, then, that the delta crisis raises fundamental questions about modern approaches infrastructure planning [2,5,7,8]. Environmental scientists have come to recognize "the social" as an integral part of the delta crisis.

Earth System science and social-ecological systems, however, face difficulties in dealing with these social dimensions. Through a close examination of the discourses and collaborative practices of these sciences, we show that the understanding of "the social" takes two quite different forms. As an object of social-ecological systems research, the social is modeled and quantified alongside ecological systems. However, as a context for scientific interventions in environmental policy it appears in the quite different shape of an obstacle to achieving sustainable delta policies. Crucially, this happens for reasons that escape social-ecological systems analyses.

The instability of the social creates tensions both in how Earth System science imagines and tackles its policy challenges. On the one hand, the ecological notion of resilience has been translated into a social orientation towards emergence and collective learning, which manifests in proposals for adaptive environmental governance [9,10]. On the other hand, confronted with the repeated failures of governance to learn and adapt, Earth System science falls back on a technocratic ideal, according to which the role of science is to guide or manage the behavior of human populations via policy [11] (p. 217) (For example, [12] evokes a future in which the research and engineering community faces the daunting task of "guiding mankind" towards global, sustainable, environmental management while [13] imagines the role of sustainability science to be "reconnecting" a knowledge-deficient humanity with the biosphere). This reproduces a view of society as amenable to rational manipulation, which social science disciplines including political ecology and STS have shown to be fictitious, e.g., [14]. At the same time, by centering on informing policy, these discussions paradoxically disregard their own fundamental insight that governance is highly unlikely to provide a solution to the delta crisis, since such a solution would require large-scale dismantling of modern river infrastructures in many parts of the world.

Based on a careful examination of Earth System science and associated discourses, we show that the instability of "the social," combined with the ambition to integrate 'it' in an encompassing system, poses serious problems for interdisciplinary delta research and for more imaginative and inclusive collaborative efforts to tackle the delta crisis—efforts that must include but also go considerably beyond policy and governance. Addressing the crisis requires opening Earth Systems and sustainability science more generally to substantially different understandings of the relations between science, politics, and "the social" (see also [15] (p.6)). Rather than integrative systems [15], the situation requires experimenting with sophisticated conjunctions [16] of epistemologies, methods, and practices, and the sensitization of researchers to their own blind spots and perspectival limitations. Such conjunctions, we argue, pave the way for a cosmo-political approach, where social, environmental and sustainability sciences work together, for example, with designers, urban planners, policy-makers, and affected or concerned citizens on solving multi-scalar delta problems by working across their differences.

2. Deltas in Crisis

In 2012, the journal Global Change featured a cover story titled "Anthropocene: An Epoch of Our Making." Focusing on how "humans have changed the Earth in a number of fundamental ways [. . .], which are far less known than global warming" [1] (p. 13), the geologist James Syvitski and co-authors paid particular attention to the flux of soil:

"[I] Infrastructure—dams, cities, transportation networks and coastal-management measures—has led to lasting and profound impacts. [. . .] The large dams [. . .] trap more than 2.3 Gt of sediment every year in reservoirs. This starves deltas of sediment and, in combination with the mining of water, oil and gas, has led to a situation where large deltas are sinking at four times the rate of sea-level rise. [. . .] By any unbiased and quantitative measure, humans have affected the surface of the Earth at a magnitude that ice ages have had on our planet, but over a much shorter period of time" [1] (p. 14).

Despite different terminologies and research foci, this description aligns with those of social scientists, urban planners and architects working on environmental vulnerabilities of deltas in one crucial respect [3,5,17]. The latter also repeatedly emphasize the adverse effects of essentially terrestrial modern infrastructure development, which have severely limited the capacity of cities to adapt to flooding [6]. Quite differently from social scientists, who tend to locate the problem of submerging deltas within the context of modernization, however, Syvitski et al. [1] depict delta transformations as effects of massive, slowly accumulating environmental changes caused by dams, dikes and urban infrastructures. Drawing on remote sensing facilities from major national research organizations gathered under the International Geosphere Biosphere Program (IGBP), submerging deltas are articulated as a global issue, integral to the human-induced transformation known as the Anthropocene.

The diagnosis evokes a series of elements that is significantly different from the one that links climate change and the Anthropocene. The latter causally connects entities and processes such as carbon dioxide emissions, oil infrastructure, the capitalist economy, deforestation, ocean acidification, biodiversity loss and sea-level rise in a chain that (often) begins with the extraction of fossil fuels and the making of modern energy infrastructure, which accelerates carbon dioxide emissions and leads to global temperature rise and ocean acidification. (These analyses have led to starkly diverging conclusions about the appropriateness of the term Anthropocene itself (see [12] for the original definition and [8,18–20] for discussions within social science). In contrast, the former foregrounds the complex and unruly nature of delta ecologies and the unintended outcomes of a variety of human interventions: "As the intersection of landmass, river basin, and large bodies of water, deltas are naturally very dynamic. They grow, sink and change courses, shaping land and aquatic ecosystems, posing challenges for human settlements and navigation. Humans attempt to stabilize delta dynamics by various means, [. . .] many of them involving coastal engineering, channeling and land reclamation [. . .]" [21] (pp. 185-186).

Here, the dynamic instability of deltas interacts with human efforts to stabilize them, and over time this creates the unexpected outcome of massive land subsidence. The delta crisis is thus attributed to a heterogeneous series of actors and relations, from dike and dam construction to groundwater extraction and urban infrastructures, all of which are part of engineering interventions to transform dynamic ecologies into environments habitable by people.

It can be argued that this makes the delta story even more pessimistic than that of climate change. For the latter, it has, after all, been possible to imagine decarbonization of the economy as a potential technological fix, even if it is by now quite unrealistic. However, no analogous technological fix can be imagined for sinking deltas since sedimentation loss is caused by so many fundamental and interlocked technological elements of modern cities [2]. The only obvious solution would be large-scale removal or fundamental alteration of basic infrastructures such as dikes and dams, which is evidently impossible in the foreseeable future.

In a *Science* paper scrutinizing the vulnerability of 48 deltas, Tessler et al. clearly articulate the problem [2]. Conceivably, the vulnerability of deltas to land subsidence could be diminished by very high levels of infrastructural investment, but this is practically impossible due to the "heavy reliance on external financial and energy subsidies." Considering "a future scenario in which infrastructure costs have increased," the authors find that deltas from the Mississippi and the Rhine to Chao Phraya and Yangtze would "disproportionally" increase in vulnerability compared with less-developed deltas [2] (p. 641). Highlighting emergent, unruly interactions between dynamic landforms and the fixed materiality of infrastructures, the analysis depicts unpredicted consequences that now undermine fundamental presumptions of modern infrastructure planning.

Hannah Knox has observed that anthropological discussions of state planning often focus on how societal improvement "is pursued through infrastructural transformations in the built environment" [22] (p. 358). The starting point is a delineation of "the kind of society that is desired by creating material systems (neighbourhoods, electricity networks, roads, waterways, railways) that might enable that society to be brought into being."

Presently, the delta crisis challenges this modern infrastructural imagination in two ways. First, the stable demarcation of society and infrastructural systems is undermined by the dynamic nature of deltas. Infrastructures such as dams and dikes, for example, might create a flood-free city. The scale of infrastructure is made to correspond with that of the desired society, and the environment that encompasses them operates as a stable background, which the planners can safely ignore, or define in terms of acceptable "environmental impacts." However, as Earth System science extends its analysis of infrastructural consequences to planetary and geological scales, an increasingly dire set of unanticipated effects become visible. Modern infrastructural planning is badly equipped to deal with these large-scale effects.

The second challenge, therefore, concerns fundamental questions about conventional planning frameworks. The working assumption behind modern infrastructure planning is that engineering methods can be separated from social ends. Engineered structures appear as no more than neutral means for achieving social goods, like flood-free cities. In light of the delta crisis, however, delta infrastructures are no longer neutral. Instead, they appear as *agents* that interact unpredictably with other bio-chemical, ecological and socio-economic agents in complex planetary webs. For these reasons, the anthropological critique of modern planning [23] and infrastructural management [22] finds an unlikely ally in Earth System science.

3. Future Earth and Social-Ecological Systems

It follows from this dynamic view that sustainability science must encompass the interfaces between ecologies, infrastructure, and society. This new research agenda has potentially significant implications for sustainable management of the planetary environment as a whole. At the forefront of this process of reimagination has been the expansive interdisciplinary field Earth System science, which grew out of the Global Environmental Change programs created in the 1980s.

Originally aiming to analyze "the entire Earth System on a global scale by describing how its component parts and their interactions have evolved, how they function, and how they may be expected to continue to evolve on all timescales" [24] (p. 4), Earth System science is mostly composed of natural science approaches with a particular emphasis on the analysis of large-scale remote sensing data collected by satellites. While the significance of human activities for the Earth system was recognized early on, various forms of social science—notably institutional theory, but also bits of sociology and anthropology—have only more recently become integral to the research agenda [25]. In 2015, most of the Global Environmental Change programs were consolidated under a new platform called Future Earth.

The framework document "Future Earth: Research for Global Sustainability" describes a situation where humanity faces unprecedented risks due to "more rapid and complex global interactions between social and environmental components of the Earth system and clear indications of significant shifts in climate, biodiversity, pollution loads and other critical factors" [26] (p. 1). The delta crisis, which stems from disturbances of sediment transport and the water cycle represents one of these shifts. Amidst such unprecedented Anthropocene syndromes [27], humanity finds itself with no "adequate answers as to how to safeguard prosperity and development" [26] (p. 2). Accordingly, Future Earth designates a new kind of research "co-produced with society." The notion of co-production originates in the STS literature, where it is used to conceptualize the de facto inseparability of domains such as science and policy, conventionally viewed as sharply separated [28–30]). In contrast to STS, Future Earth depicts co-production as a normative aspiration towards "seamless integration" of natural and social science. As we shall see, this is a point of tension with the 'sophisticated conjunctions' between knowledge practices that we suggest the delta crisis calls for.

There is, of course, nothing very new about interdisciplinary collaboration in environmental studies. In the early 20th century, anthropologists including Boas in the United States, Forde in the United Kingdom and Imanishi in Japan explored connections between social and cultural forms and the environment based on the Humboldtian tradition of natural history. Later, in the 1960s, the development of ecosystems ecology and cybernetics had a profound impact. Future Earth's vision of seamless integration, however, takes a distinctive form.

Since the 1970s, the ecologist Holling has argued that the recurrent failures of natural resource management can be ascribed to its presumption of a stable environment [31]. This image, Holling proposed, had to be replaced by one in which human disturbances bring about complex and unpredictable ecosystems behavior.

In a pathbreaking paper, which originally had limited influence but steadily grew in importance, Holling [31] argued that the then dominant ecosystems theory could only approximate the behavior of "a self-contained system that was fairly homogenous and in which the climatic fluctuations were reasonably small" [31] (p. 6). Unfortunately, "real world examples" of such systems are rare or non-existent. In reality, Holling wrote, "we are dealing with a system profoundly affected by changes external to it, and continually confronted by the unexpected" [31] (p. 1). Hence, the constancy of system behavior "becomes less important than the persistence of the relationships," and accordingly resilience was defined as an ecosystem's capacity to absorb disturbance while adapting to a changing environment [9,32,33]. Replacing the idea of a single ecological equilibrium, systems were now seen as having many possible equilibria and thus as "multi-stable" (an idea originating in [34]). Contrary to earlier ecological assumptions of "stationarity" — "the idea that natural systems fluctuate within an unchanging envelope of variability" [35] (p. 573), the successor image is one of planetary unpredictability and fundamental *instability* [8] (p. 1).)

Over the past few decades, resilience has become a key notion in fields as diverse as natural resource management and sustainable development, disaster prevention and international security. The key implication is a shift toward a new form of governance called adaptive management [32]. Rather than employing rational planning to achieve maximum sustainable yield, for example, adaptive management aims to adjust to constantly changing ecosystems by monitoring feedback loops and changing strategies. The approach thus foregrounds interactions between human interventions—such as commercial fishing—and dynamic ecosystems.

In parallel, there has been increasing attention to the interdependence between environmental processes and social institutions such as property regimes and the organization of industry. To analyze such relationships, natural resource management scholars developed the framework of "social-ecological systems," defined as "a bio-geophysical unit and its associated social actors and institutions" [36] (p. 4).

These ideas have become prominent within Earth System science and related discourses [15] (p. 2). In a proposal for a revised planetary boundary for freshwater consumption, for example, Gerten et al. argued for linking biophysical and social-ecological analysis of food and water security and environmental sustainability [37] (p. 556). Similarly, Pahl-Wostl et al.'s analysis of environmental flows and water governance aimed to increase "the capacity of social-ecological systems to deal with uncertainty and surprise" [38] (p. 345). Thus, Holling's original call for adaptive management has been placed in the context of systems that are both social and ecological.

In turn, this has led to various extensions and transformations of the concept of resilience. While the original definition centered on the capacity of a system to absorb shocks while maintaining basic functions, Pahl-Wostl et al. [38] speak of dealing with uncertainty and surprise. The environmental scientist Folke [9] (p. 253) characterizes resilience as a "capacity for renewal, re-organization and development." Additionally, a brochure published by Stockholm Resilience Centre defines the term as a "the capacity of a system to deal with change and continue to develop" [10] (p. 3). As Folke summarizes: "the concept of resilience in relation to social-ecological systems incorporates the idea of adaptation, learning and self-organization in addition to the general ability to persist disturbance. In this sense, the buffer capacity or robustness captures only one aspect of resilience" [9] (p. 259).

Through these translations, resilience has helped to introduce a new figure of the social into environmental science.

4. Social Ambiguities

Within Earth System science, the social operates in several registers. Conceptually, it is defined as quantifiable system components. For research, it functions as an opening to particular kinds of collaboration. Finally, in terms of consequences for management, policy and governance, it is elicited as a set of problems.

As resilience expanded and came to encompass social learning and ways of dealing with surprise, it became integral to Future Earth's novel approach to sustainable development, in which social and environmental processes are imagined as seamlessly integrated [39]. The framework document represents this view in a "simple conceptual model." The model shows two boxes, "human well-being" and "environmental changes," both of which generate "drivers" of change. Research into these transformations is visualized as a circle with themes—from modeling and forecasting the Earth system to understanding and maintaining diversity, analyzing government and institutions, and understanding human behavior and culture—plotted on the perimeter.

At first glance, this diagram appears innocuous, however it has some rather curious features. For one, "the social" is not necessarily amenable to the same kinds of research, modeling, or analysis, as the environmental components. Governance and water flows, for example, can obviously both be studied, but hardly in the same manner. More generally, it is not clear how "modeling the Earth system," and "understanding human behavior and culture" can be rendered compatible as modes of understanding social-ecological systems. Rather than solving the issue, putting these topics in adjacent boxes simply makes the basic incongruence invisible and impossible to address (see also [15] (p. 4)). It becomes impossible to gauge what is "lost in translation" [40] (p. 65).

As noted, the Earth Systems research agenda covers very important problems including planetary boundaries, environmental risk, and climate disruption, and it is hardly surprising that scientists attempt to influence policy-makers. These endeavors, however, are fraught with difficulties. Considered not as an object of research but rather as a context for the promotion of environmental policy, quite another version of the social emerges.

With reference to this other scene of the social—not abstract and conceptual but political and practical—frustrations are manifest, and they practically echo one another. Stafford-Smith et al. register "a growing gloom that global decision-making is failing to keep up with the pace of change" [41] (p. 3). Although science has made "giant strides in expanding knowledge on how our Earth system functions ... we are failing in our new role as planetary stewards, a role that is now crucial to sustaining human development and, even, the survival of civilization." Pahl-Wostl et al., similarly, argue that: "missing links in the trajectories of policy development is a major reason for the relative ineffectiveness of global water governance" [42]. There are calls for a "transition from knowledge to action" [43] (p. 708), which will depend on "coproduction of knowledge with stakeholders" [43] (p. 709), "cosmopolitan perspectives" [43] (p. 713) and a willingness to reach consensus, which is so far clearly lacking. Evidently, the co-production and "seamless integration" of knowledge and action is fraught with problems.

As this suggests, the science-policy interface is a prominent location of "the social" for Earth system scientists. Their own science, moreover, is recursively implicated with this interface (see also [8] (p. 2)): it is part of its "co-production." Yet, while various social topics, from legal frameworks and property regimes to community organization and resource management are all studied as part of social-ecological systems, the science-policy interface where Earth system scientists encounter major social obstacles appears to fall outside the scope of analysis. Thus, "the social" in Earth System science takes on a double aspect: it is located at once inside and outside its own research framework.

There is good reason the aspiration of Earth System science is not only to *understand* social-ecological dynamics but also to promote sustainable ways of inhabiting the planet. As we have indicated, however, Earth System science is marked by deep ambivalence with respect to the social. While drawing on Holling's [31] notions of resilience and adaptive management—which challenged rational planning—a very different view of the social as a practical obstacle, emerging from concrete difficulties encountered at the science-policy interface, leads to the revival of dubious technocratic ideals [11] from the supposedly disbanded paradigm.

5. Into the Delta: The Social as Figure and Ground

The very term social-ecological systems gestures at a qualitative difference between two distinctive domains. However, while the hyphen connects the two, it does not obviate their difference. Accordingly, two questions emerge: What is gained by the combination and what is lost in translation?

The ambiguity of the social reappears in social-ecological studies of specific delta systems. This is exemplified by the previously mentioned large-scale interdisciplinary project, which, comparing the Mekong, the Ganges Brahmaputra and the Amazon deltas [21], alternates between taking the social as *object* of social-ecological analysis and as the problematic *context* of intervention. While the former calls for quantitative modeling, the latter entails managing complicated relations with regional organizations by hosting co-production workshops "focusing on vulnerability and risk" [21] (p. 182). In this section, we probe this shifting status, and its conceptual and pragmatic consequences, in the context of the two Southeast Asian deltas that are the focus of our own STS-oriented anthropological research on the Mekong (in Cambodia and Vietnam) and the Chao Phraya in Thailand.

Already in 1963, the geographer Gilbert White had argued that adequate planning and management of the Mekong river basin development would depend on recognition that the basin was shaped by a mixture of physical and political factors [44]. Without taking into consideration interlinked social and ecological dynamics, he surmised, it would be impossible to achieve the triple goal of flood control, power production, and wildlife conservation.

More recently, Earth system scientists entered this scene equipped with social-ecological systems and models. Van Staveren et al. examined "controlled seasonal flooding in long-term policy plans for the Vietnamese Mekong delta" [45]. Inspired by David Biggs et al.'s depiction of the Mekong as a giant hydro-agricultural machine [46], they explored delta trajectories as a result of interacting social-political, technical, and environmental systems. More macroscopically, Szabo et al. compared the environmental vulnerability of the Mekong, Ganges-Brahmaputra and Amazon regions from the perspective of population dynamics [47]. Bringing together analysis of ecosystem services, environmental hazards, and demographic changes, they concluded that rising sea levels and an aging population calls for rethinking public health and good environmental governance. Barbosa et al. used time-series data to identify rapid economic development, changing land-use practices, and salinity intrusion as the key drivers of change in the Mekong, which are "progressively putting more pressure on the delivery of important provisioning services, such as rice and inland aquaculture production" [48] (p. 555). The Mekong social-ecological system, they concluded, "may have moved outside safe operating spaces into unsustainable configurations" [48] (p. 568).

Meanwhile, Ha et al. drew on resilience theory to analyze the "Governance Conditions for Adaptive Freshwater Management in the Mekong" [49]. Adaptive management structures are described in terms of social learning, experimentation and flexibility, and the study advocates governance that is "polycentric and horizontal with broad stakeholder participation" [49] (p. 117). It is also observed, however, that this mode of governance is unlikely to be adopted, since the conditions for success are not met. However, when it comes to *why* the conditions are not met and *what* makes the implementation of adaptive governance in the context of Vietnamese environmental policy virtually impossible, the authors have nothing to say.

Like social-ecological systems research, political ecology also emphasizes socio-political and human-environment relations. However, in contrast to the former, which evokes social and policy challenges without saying much substantial about them, the institutional contexts of river management are central to political ecologists working on Southeast Asian deltas. The aim "to identify and understand the mechanisms that underpin the transformations of aquatic socio-environmental systems" [50] (p. 358) is exemplified by Lebel et al. who examined management, decision-making and science as a "joint production of social and biophysical processes" [51], and by Sneddon and Fox who analyzed transboundary water flows with a focus on how to "design and sustain institutions for equitable sharing" [52] (p. 182). Centrally, ecohydrological dynamics are shaped by river basin institutions that "construct the object of co-operation" ([52] (p. 183). This inseparability between 'ecohydrology' and decision-making is captured by the notion of "critical hydropolitics." Käkönen and Hirch depict the scientific facts propagated by the Mekong River Committee as shaped by "inherently political processes" [53] (p. 351) that are often environmentally unfriendly.

Over time, the socio-political dimensions of water governance have thus become increasingly visible in integrated water resource management. By 2008, a Special Issue of *Ambio* described Mekong as "at a crossroads" [54] due to rapid social, economic and environmental transitions. Considering sustainable "future routes" [54] (p. 146), the editors identified a lack of political transparency as major obstacle to good governance and called for stakeholder participation in order to 'combat fragmentation' [54] (p. 147). In the same issue, Hoa et al. concluded that flooding is positive for agriculture in the Vietnamese Mekong delta but negative for regional planning! [55].

While modeling has convincingly shown that the uncoordinated building of dam cascades in the Mekong region will have dire consequences for sedimentation flows, livelihoods, biodiversity, and the delta in general [56], political ecology has shown, equally convincingly, that this scientific consensus is of almost no consequence due to national and transboundary politics. Laos, which aims to become 'the battery of South-East Asia,' has little interest in the Mekong delta in distant Vietnam, and although the Cambodian population is highly dependent on fish for protein, and decreasing fishing populations is a well-documented consequence of dam cascades, the country continues to build dams for other reasons. These situations testify to a range of divergent economic and political interests, captured by terms like critical hydropolitics. Such interests and their effects, however, are too diffuse to quantify and model, and the information needed to even make the attempt is carefully guarded by businesses and government institutions, whose modes of operation do not remotely conform to Western ideals of accountability and transparency [57].

From this juxtaposition of social-ecological systems analysis and political ecology emerges an illuminating figure-ground reversal. Social-ecological analyses show the complex relationship between bio-geochemical and institutional processes, but avoids critical analysis of the broader social and political landscape, and of the patchy science-policy interface itself. In consequence, its social analyses offer little assistance when it comes to handling the concrete problems confronting sustainable policy. Political ecology, in turn, beams a light on this shaded area. It dislocates the ambition to speak truth to power by depicting scientific claims and recommendations as fundamentally entangled with institutions and politics. However, while it convincingly shows the integral relation between science and policy, it has comparatively little to say about the role of changing material environments in societal change [39].

Even though they appear superficially complementary, social-ecological systems and political ecology thus do not "add up." The forms of knowledge and analytical insights cannot be "seamlessly integrated" since society and science appear in both, but in incongruent versions. The problem, however, is less with the incongruence than with the idea of integration. For more pragmatic and imaginative responses to the delta crisis, the notion of a systemic integration must be replaced with sophisticated conjunctions of only partly coherent knowledges.

6. Cosmo-Ecology: Towards Sophisticated Conjunctions

Enabled by big data sets and new models, Earth System science has generated a compelling new image of the planetary delta crisis, according to which delta transformations are effects of interlocked processes involving everything from population dynamics and agriculture to dam development and coastal engineering. When it comes to imagining solutions, Earth Systems scientists put faith in adaptive governance. Yet this is curious, given that the analyses show the problems to be well-nigh ungovernable. Given that governance shows few signs of adaptability, the curiosity compounds.

As noted, this lack of adaptability and responsiveness is the subject of complaints from frustrated environmental scientists experiencing "growing gloom" [41] (p. 3). It can also lead to the revival of a problematic technocratic imagination ([11], see, e.g., [7] (p. 545), [12]). Here, we detect a tension—with significant political and democratic implications—between the commitment to social learning and the aspiration to make governance more objective in terms more or less exclusively defined by environmental and sustainability sciences.

Once again, the unstable location of the social within Earth System science and social-ecological systems research provides a vantage point for understanding the situation. One dimension pertains to modeling assumptions about internally coherent dynamics and determinate boundaries between system components, which are fundamentally challenged by the prevalence of incoherent dynamics and indeterminate boundaries in hybrid domains like deltas [58] (p. 92). This is vividly illustrated by the notion of "delta machine," which consists of numerous unpredictably interrelated elements, from management schemes and technical solutions to water governance, and incongruent ideas of adaptation and of disaster response [3,46]. To this we have added the complications that arise as Earth System science becomes recursively implicated with patchy, heterogeneous science-policy interfaces that, not unlike Holling's [31] multi-stable ecological systems, are many-stranded, conflictual, and significantly uncontrollable.

As this indicates, the fundamental problem for the ambition to "seamlessly integrate" the social and the ecological—and science with policy—is the incongruence between the social as a domain of research (a system) and the co-productions of relations that entangle the practice of research at every point. Rather than knowledge integration, solutions to the delta crisis requires inventing sophisticated conjunctions of knowledge, which are attentive to heterogeneity and cognizant of the recursive relations between science, policy, society, and environments. In lieu of "seamlessness," it is incumbent to work with diverse methods, epistemologies, and concepts, knowing full well that they do not add up. Rather than observing clearly defined social and ecological systems, the delta crisis places us amidst emergent and hybrid socio-natures. An image of cosmo-ecology comes to the fore [59].

In contrast to the systems imagination, the guiding assumption of cosmo-ecology—exemplified by analyses of the delta machine [46] and delta ontologies [5]—is uncontrollable heterogeneity and recursive relations between research and practice. Different from social-ecological approaches to policy, where the frustrations of adaptive governance can morph into calls for the revival of technocracy, but also different from political ecology, where institutional power games always overdetermine environmental outcomes, cosmo-ecological research and practice centers on "learning attentiveness to the infinite ways of being affected and of affecting" [59] (p. 35). Sophisticated conjunctions of many forms of knowledge and practice are needed: not only to adequately characterize the multi-faceted delta crisis but also to simultaneously imagine and work towards inventive responses in many incongruent contexts; from biodiversity protection, urban design and agricultural production to river infrastructures and political deliberation. In terms of cosmo-ecology, diverse delta knowledges necessarily exist in a relation of mutual, constructive complication [60].

From this point of view, it is not simply that the diverse delta studies we have examined do not form a total system; it is that they cannot form such a system, either individually or in combination. Since science is not a meta-perspective floating freely above policy and practice, but rather a set of practices among others, this is not bug but a feature. However, precisely because research is always entangled with other forms of knowledge and action, it becomes possible to experiment with new relations, perspectives, and conjunctions. Different approaches reveal aspects unseen, or impossible to see, from others. Destabilizing what appears as near-certainties, they pose mutually challenging questions with the potential to provoke new research questions and agendas.

Earth System science's articulation of the planetary delta crisis offers a good illustration of just this effect. Due to its spatial and temporal scale, it has vividly shown that the delta crisis can only be dealt with by taking seriously the consequences of large-scale interlocking biophysical and infrastructural processes. By highlighting the adverse long-term social and economic effects of modern water management, it has underscored the necessity of developing far more decentered modes of analysis than those to which social scientists—typically focusing on particular institutions or mechanisms of participation and deliberation—are accustomed. To the extent that it is solvable at all, the delta crisis will only be solved by a radical undoing of modern infrastructures, along with their distinctive modes of management and planning.

This means that it is possible to evaluate the accomplishments of Earth System science in quite different ways. One might emphasize its relative ineffectiveness in transforming environmental policy. It can be argued, however, that this failure is less significant than its successful widening of interdisciplinary debates about the delta crisis. Thus, its depiction of the delta crisis as the slowly unfolding and basically unavoidable consequence of large-scale infrastructure building and the trapping of sedimentation across river basins, can also be seen as an experimental effort to "learn to become affected" by planetary dynamics [61]. Given the unlikelihood that adaptive governance would be able to solve the crisis anyway, we can hardly take Earth System science to task for 'merely' providing new stories, new knowledge, and richer articulations of what needs to be taken into consideration.

We have *also* emphasized, however, that Earth System science does not perfectly exemplify the sophisticated conjunctions of knowledge and action required by cosmo-ecology. It is unable to deal with the constitutive hybridity of the domains it models, and it faces considerable problems analyzing its own social location at the science-policy interface [39]. At the most general level, there is a latent contradiction between its own delta analyses, which clearly show the insurmountable problems of modern water infrastructures, and its relatively meek recommendations for changing policy. The latter contrasts starkly with the evident need to imagine radical changes — "well beyond existing practice" [8] (p. 1).

This means that the delta crisis calls for experiments with new relations between science and policy, knowledge and practice. As noted by Lave et al., it will be central to bring the different concepts and categories through which diverse scientists and other practitioners "'see' the world into conversation" [15] (p. 7) in a way that respects their differences. Here, there are many cosmo-ecological possibilities (see also [62]). One example is provided by the research on Bangkok's urban delta ecologies carried out by the landscape architect Danai Thaitakoo and the urban designer Brian McGrath. We conclude by highlighting some pertinent differences between this collaboration and the approach of Earth System science and by considering their implications for sophisticated conjunctions, which include—but go considerably beyond—interdisciplinary scientific collaborations and science policy.

7. Bangkok's Delta Ecologies: A Cosmo-Political Exemplar

Drawing on landscape ecology, urban design, history and ethnography, Thaitakoo and McGrath [17] study the relations between life in Bangkok, and the ecological and hydrological aspects of urban planning. Although they seriously engage with both society and ecology, the aim is not to comprehensively model Bangkok's complex urban ecologies. Instead, they show how entanglements and dynamic interactions between ecologies, forms of life, governance and infrastructures create Bangkok's hybrid socio-natures and their "infinite ways of being affected" [59] (p. 35). The distinctiveness of this approach relates to the design orientation of both collaborators. Due to their respective backgrounds as a landscape architect (Danai) and an urban designer (McGrath), this exploration of how urban Bangkok is shaped by delta ecologies is inseparable from pragmatic speculations about possible material interventions. By documenting patches of sustainability amidst

Bangkok's chaotic landscapes, they provide a catalogue of ways of thinking about and doing sustainable water-centered urban landscapes [63].

Compared with Earth System science and social-ecological systems, this collaboration exemplifies some quite radical shifts in how the relation between knowledge and practice is conceived. First, akin to Serres' [60] (p. 128) vision for a "new rationalism," it is premised on empirical multiplicity and conceptual heterogeneity rather than aiming for systemic integration. While the latter embeds an (implicit or explicit) idea of epistemic hierarchy in which all knowledge must conform to the demands of systemic modeling or be relegated to the realm of subjective opinion, the former assumes that knowledge of many kinds—from careful descriptions of the co-production of urban infrastructures and ecologies and narratives of peoples' life-situations to in-depth analyses of how diverse political institutions draw on, manipulate, or reject scientific claims as part of making decisions—are all necessary in order to understand the delta crisis and its possible solutions.

A second point follows. Contrary to assuming the position of an external and neutral observer of social-ecological systems, Danai and McGrath depict plural knowledges as emerging from interactions of multiple nonhuman and human actors, including scientists, policy-makers, designers, and urban dwellers. This locates scientific collaborations as part of the networks, or in their words, "design ecologies," they study. With the recognition that knowledge practices themselves make up a patchy ecology of theories, models, methods, always fully immersed in material and social relations [64], it becomes impossible to maintain that the role of science is simply to provide 'the facts' to policy. Objectivists are always likely to mistake this description for an attack on the credentials of science. In reality, it paves the way for more fruitful interdisciplinary collaborations as well as more capacious ways of imagining relations between science, politics, and society. Immersed in knowledge ecologies, scientists do not float above the ground, and thus they are required to deal openly and reflexively with their own blind spots, as exemplified by the inability of social-ecological analyses to deal with their own social location. Meanwhile, it stimulates experiments to weave together many kinds of knowledge—each known to be partial—for specific purposes and in particular contexts.

Third, this creates significant opportunities for scientists and researchers to expand their collaborative *and* imaginative horizons. As we have discussed, Earth Systems researchers tend to concentrate on macroscopic analyses intended to inform regional or planetary environmental governance. However, there are, after all, many more relevant actors and constituencies than those found in policy settings: agricultural cooperatives, landscape artists, speculative designers, not to mention the innumerable citizens variably affected by the delta crisis. Beyond enhancing interdisciplinary collaborations and the science-policy interface itself, research engagement *with* such collectives is urgently needed; not least since it is their "transitory futures" [8] (p. 5) that are at stake as the delta crisis unfolds.

We have argued that this crisis is cosmo-ecological. Empirically, its features are not amenable to integration in a single, comprehensive system. Politically, no one, Earth System scientists included, has either a clear view of what must be done, or the right to assume a position of spokesmen for the deltas. Finding themselves among unsustainable, deteriorating, modern water infrastructures, and amidst incongruent, competing knowledge ecologies, both social and natural delta scientists need to move out of their epistemic and political comfort zones. At this moment in time, they (we) need to take risks with collective learning and speculative forward-looking scenarios (see also [65]). How else will it be possible to create pathways to seriously different delta futures, not to mention planetary sustainability?

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