



Synthesis

Hydrosocial rupture: causes and consequences for transboundary governance

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ABSTRACT. Unsustainable models of growth-based development are pushing aquatic ecologies outside known historical ranges and destabilizing human activities that have long depended on them. We develop the concept of hydrosocial rupture to explore how human-water resource connections change when they are exposed to cumulative development pressures. The research analyzes stakeholder perceptions of hydrosocial ruptures in two sites in Southeast Asia: (1) peatlands in Riau Province, Indonesia, and (2) Tonle Sap Lake, Cambodia. In both contexts, capital-driven processes have reconfigured human-water resource connections to generate transgressive social and environmental consequence that cannot be contained within administrative units or property boundaries. Our findings show how these ruptured hydrosocial relations are perceived and acted upon by the most proximate users of water resources. In Cambodia, a policy of resettlement has sought to thin hydrosocial relations in response to biodiversity loss, chronic pollution, and changing hydrology in Tonle Sap Lake. By contrast, in Indonesia's Riau Province, efforts are underway to thicken human-water relations by hydrologically rehabilitating peatlands drained for agricultural development. We argue that in both of these contexts hydrosocial ruptures should be understood as phenomena of transboundary governance that cannot be addressed by individual groups of users, sectors, or jurisdictions.

Key Words: *hydrosocial relations; rupture; Southeast Asia; transboundary water governance*

INTRODUCTION

Analyses of disruptions in human-water interactions, or hydrosocial ruptures, have shown how development pressures fundamentally change water outcomes (Swyngedouw 2015, Vos and Hinojosa 2016). In spatial terms, the impacts of hydrosocial ruptures are transboundary in the sense that they cannot be contained within individual jurisdictions, regulatory regimes, and property boundaries (Hobbs et al. 2014, Zeitoun et al. 2017). Temporally too, growth-based development agendas and water technologies such as dams, canals, reservoirs, and commercial fisheries are moving human-water relations into uncharted territory (Wolkovich et al. 2014, Micheaux et al. 2018). Although recent political ecology scholarship has made advances toward understanding the spatio-temporal complexities of hydro-modernity processes, the full consequences of water's unintended redistributive effects remain unknown and largely undocumented.

We are concerned with local stakeholder (defined here as water resource users and community-level decision makers) perceptions of destabilized hydrosocial relations. We developed the concept of hydrosocial rupture to denote moments of profound change in human-water relations that traverse administrative boundaries and exceed the governance capacities of jurisdictions, sectors, and individual groups of resource users (Wilson 2014, Lund 2016, Philippopoulos-Mihalopoulos 2017). The most physically proximate users of water resources tend to bear the cumulative socioeconomic burden of capital-intensive development, while higher-level actors often exploit power asymmetries to their advantage (Armitage et al. 2015, Busilacchi et al. 2018). We argue that it is important to understand local perceptions of ruptures generated by these dispersed power relations and environmental impacts. This is because place-based perceptions inform ecological behaviors at higher organizational scales of

governance, just as they shape compliance with, or resistance against, policy choices that shape water's unequal and transboundary material effects (Hamilton 2018).

Our investigation draws evidence from Southeast Asia, a region rich in water bodies where hydrosocial relations have been fractured, disassembled, and reconfigured by the integration of place-based water practices and ways of life into wider development processes. The research focuses on two sites in which hydrosocial relations have been transformed over the past four decades by transitions to market-based economies: (1) peatlands in Riau Province, Indonesia, and (2) Tonle Sap Lake in the Cambodian province of Kampong Chhnang. In each context, we interviewed local stakeholders about their perceptions of government-driven responses to major ruptures in intensively productive aquatic environments. The results highlight the policy failures that produce hydrosocial ruptures and the opportunities to shift transactions with water resources in more ecologically sustainable and socially inclusive directions.

HYDROSOCIAL RUPTURE

Hydrosocial ruptures are "open moments" when anthropogenic disruptions of human-water relations may create opportunities to reform the spatial, social, and biophysical organization of governance (Lund 2016:1202). Although this concept resonates with recent work on water crises as co-governance opportunities (Baltutis and More 2019, Groenfeldt 2019), we take our analysis in a slightly different transboundary direction. Drawing from earlier work on rupture (Wilson 2014, Lund 2016) and hydrosocial literature that places the movement of water within the power relations and institutions that shape its material flows (Linton and Budds 2014, Damonte 2019), we treat hydrosocial ruptures as cross-border phenomena that are differentially perceived and acted upon at varying scales of governance.

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We locate our hydrosocial analysis of rupture within the realm of transboundary environmental governance, understood as the full range of state, civil society, and corporate perceptions and decision-making processes that (re)distribute social-ecological costs and benefits across territories and timeframes (Miller 2020). In spatial terms, hydrosocial ruptures realign territorialized water resource regimes to create new forms of ecological knowledge, power, and authority (Damonte 2019). We see how dams, canals, and roads reconstitute hydrosocial spaces by opening up new frontiers for mega-hydraulic development (Boelens et al. 2019). These transboundary transformations may displace local knowledge, rural livelihoods, and intergenerational adaptive capacities (Miller 2021 *a*). How people perceive and respond to these redistributive inequalities depends on their proximity to the material effects of hydrosocial changes in addition to their relative position of advantage or disadvantage within a stratified social order.

More propitiously, hydrosocial ruptures might open up opportunities to pursue socially inclusive forms of resource distribution (Miller et al. 2020). Transboundary water governance strategies to heal “metabolic ruptures between society and nature” (Wittman 2009:805) have included community-based networks to co-produce ecological knowledge about migratory fish quotas through to catchment or basin-level cooperative frameworks (Baltutis and Moore 2019). However, there is a need to better understand how transboundary governance regimes might address the temporal and spatial dimensions of hydrosocial ruptures. Recent hydrological models (Räsänen et al. 2017, Basheer et al. 2018) have shown how mega-hydraulic infrastructures critically undermine the stability of aquatic ecologies in some areas while enhancing water, food, and/or energy security in others. The cascading disruptions caused by these capital-driven processes could be thought of as a “continuity of ruptures” (Philippopoulos-Mihalopoulos 2017:124).

There are at least two oppositional ways of understanding these modifications of terrestrial and atmospheric circulations of water driven by capitalist processes. First, infrastructures such as roads, embankments, dams, and ports are designed to (re)introduce greater certainty into hydrologic cycles (Mollinga 2014) by taming waterscapes to maximize resource efficiency within a controlled environment (Savenije et al. 2014). In the rapidly developing countries of Asia, there is a clear (geo)political dimension to this stabilizing view of constructed water environments. Hydraulic infrastructures tend to be portrayed in national development narratives as emblematic of the transition from unpredictable, volatile, and backward societies into well-regulated, modern nation-states (Baghel and Nüsser 2010). Second, conversely, the more expansive human-centred ambitions for aquatic environments become, the less likely they are to be sustainable. We see this when major dams divert large volumes of water for drainage and irrigation, increasing the predictability of variations in water levels in some areas while simultaneously raising the precarity of livelihoods and food insecurity in other areas. The hydrosocial power relations imbued in these processes transform not only the vernacular knowledge and adaptation strategies of dam-affected communities, but also “migration decisions and migratory outcomes across significant spatial distances” (Parsons and Chann 2019:10).

In these ways, the hydrosocial rupture is distinguishable from broadly consonant concepts of social-ecological systems that frame environmental crises within a balance-of-nature paradigm rather than the flux-of-nature paradigm applied here. For example, when hydrological systems are exposed to sustained market pressures, they eventually reach social and ecological tipping points (Milkoreit et al. 2018) or thresholds of change (Walker and Meyers 2004), at which point disruptions in the ecological health of water resources fragment or disassemble social relations. This in turn necessitates a fundamental shift in governance to recreate or rehabilitate a different but still socioeconomically and ecologically functional system (Callicott 2002). Unlike the allied concept of the social-ecological trap, which involves mutually reinforcing cycles of negative social and ecological feedbacks that are difficult to break out of (Cinner 2011), ruptures afford opportunities for collective environmental action across administrative and property boundaries precisely because they are so difficult to contain jurisdictionally and affect shared and overlapping resource interests. This spatial and temporal reorganization of human-resource connections also departs from the irregular disturbance cycle (Snapp 2017), which suggests that ecosystems and societies are capable of bouncing back (Hamilton 2018) to prior conditions after disturbance events such as extreme floods, droughts, and wildfires (Callicott 2002).

Our theorization thus offers an expanded optic for analyzing the unintended and cascading spatio-temporal consequences of acute instability in human-water relations that are most often catalyzed by capital-intensive processes of change. This analytical lens is useful for identifying linkages between complex environmental problems that, at first glance, appear to be disconnected from situated human-water relations. It has utility in understanding the cross-border governance implications of hydro-modernity processes that push aquatic ecologies beyond sustainability levels and which demand multi-scaled forms of cooperative redress because they cannot be addressed at a single scale of human interest.

METHODS

Data and analysis

Our analysis is based on qualitative fieldwork undertaken in 2018 and 2019 by two groups of collaborators, each comprising researchers who individually possess linguistic proficiency in the two study areas. The first author undertook field work in Cambodia and Indonesia and coordinated the negotiation of complementary research questions using different interview techniques suited to each context. Collectively, the co-authors span the physical and social sciences, applying their multi-disciplinary knowledge to the vexed question of how to address complex development pressures in aquatic environments.

We selected sites according to the research experience of our individual authors in each area and the transboundary geographies of hydrosocial rupture that underpin both contexts. Our fourth author has led several graduate student field investigations to the floating village of Chhnok Tru on Tonle Sap Lake in Cambodia and has forged long-standing relationships with some of its residents. In Riau, we relied on the networks of our second author, who is based in the provincial capital of Pekanbaru, where many NGOs with operations in our three

selected villages (Sepahat, Buruk Bakul, and Tanjung Leban) in Bengkalis Regency have headquarters.

Both of our governance contexts are broadly representative of the wider environments in which hydrosocial transformations occurred. Chhnok Tru village in Cambodia's Kampong Chhnang Province is demographically representative of the substantial populations of stateless ethnic Vietnamese living on Tonle Sap Lake (Parsons and Lawreniuk 2018) and of the emerging pattern of Cambodian government-driven resettlement onto dry land (Haefner 2016). Residents of our three selected villages in Bengkalis are better connected with the outside world than the majority of peatland communities in Riau owing to long-standing academic and NGO interest in the regency's rich biodiversity found in its Giam Siak Kecil-Bukit Batu Biosphere Reserve. Peatlands account for over 70% of the total extent of Bengkalis (Syahza et al. 2019) and their clearance and drainage for agriculture mirrors a similar pattern of conversion that is taking place elsewhere in Indonesia. Similarly, the diversity of peatland restoration activities in our three selected villages corresponds with the Indonesian government's nationwide 3R approach (rewetting, revegetation, revitalization; BRG 2019).

Our timeline of rupture begins in 1979 in both case studies. In Riau, 1979 marked the beginning of an intensive period of state-driven development into peatlands that led to the realignment of agrarian livelihoods in the service of national food security and agro-export growth. In Cambodia, 1979 saw the collapse of the ultra-Maoist Khmer Rouge regime (1975-1979) that allowed Chhnok Tru residents to move (back) onto Tonle Sap Lake after an extended period of forced land-based labor. We trace these early decades of rupture using background literature to show how accumulating development pressures have shaped current social conditions, public perceptions, and environmental outcomes.

The findings in the *Results and discussion* section mainly draw from semi-structured interviews that are suited to analyzing perceptions of change. A total of 38 semi-structured interviews (19 in each context) were used to assess stakeholder perceptions of government responses to destabilized hydrosocial relations, the focal point of comparison between the two cases. In Riau, respondents were interviewed in Pekanbaru and Bengkalis in May, August, and December 2018 using a combination of purposive (selective) sampling and snowball sampling (recruiting people recommended by interviewees; Appendix 1). Respondents in and around Chhnok Tru were selected through random sampling (chance encounters) in addition to purposive and snowball sampling techniques (Appendix 2). Fieldwork in Tonle Sap Lake and a resettlement area in February 2019 coincided with a period of deep uncertainty for Chhnok Tru residents, who were either in the process of being relocated to non-riverine areas by the Cambodian government, had already moved onto dry land, or lived in fear of imminent displacement from their traditional water-based livelihoods.

Questions that guided the semi-structured interviews were underpinned by two unifying themes: (1) memories of environmental disruptions; and (2) perceptions of transboundary governance. Our questions about environmental disruptions among farmers and fishers focused on sudden or gradual changes to crop and/or fish yields, livelihood transitions, adaptive strategies, and perceptions of government responses to

environmental change. Questions to NGO representatives and government officials in Riau explored policy decisions and programs aimed at mitigating the negative impacts of hydrosocial transformations. In Cambodia, we were only able to interview one government official (the village head) and no NGO representatives, who, according to the community doctor, had left Chhnok Tru under pressure from the provincial government due to political sensitivity regarding the resettlement program. We tried to fill this gap through media content analysis, but these policy positions are less comprehensively covered than in our Riau case. In Bengkalis, peatland community residents and small farmers who benefited from NGO support and were connected to wider social networks were generally outspoken in identifying large plantation companies as the transboundary drivers of environmental change. By contrast, in Chhnok Tru, when we prompted interviewees to discuss outside factors responsible for local change, respondents preferred to discuss their immediate concerns about government-driven resettlement rather than the distant and less tangible driver of hydropower dam construction.

Because of the political sensitivity of developments and policies in our field sites, we anonymized our interviews. These were supplemented with comparative analysis of publicly available documents including news articles, relevant legislation, and NGO reports. We triangulated our document analysis where possible by consulting experts and academics working on transboundary water governance issues in Southeast Asia.

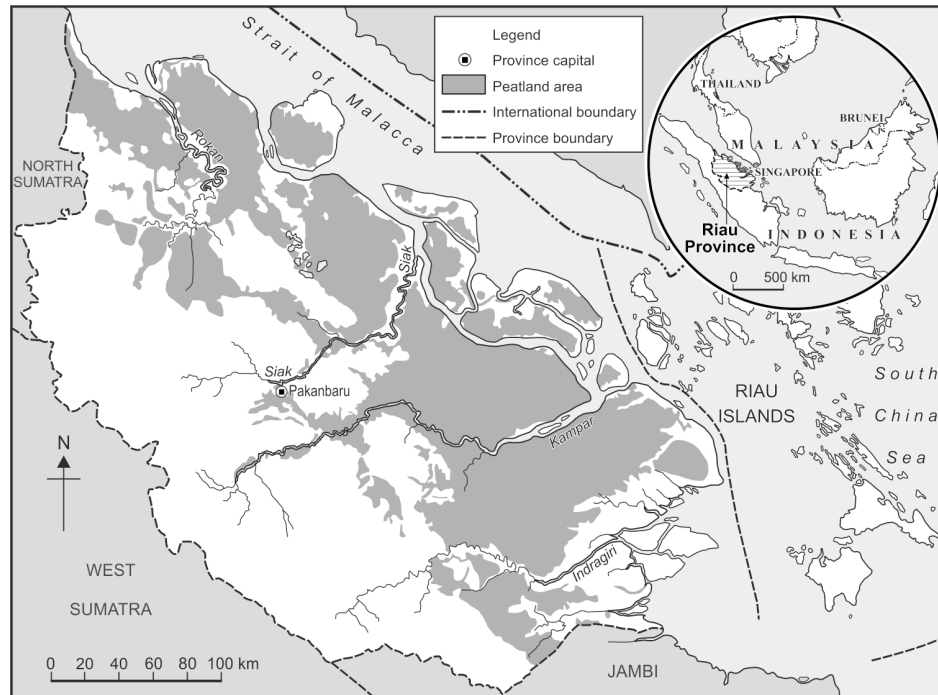
Governance context of the cases

Riau Province, Indonesia

Disruptions in human-water relations in Riau Province on Sumatra island (Fig. 1) are set against a backdrop of intensive peatland development. Peatlands account for 54% of Riau's surface area (4.9 million hectares (mha); Tanjung 2020) and around 20% of Indonesia's total peatland extent (Warren et al. 2017). The drainage and clearance of these naturally saturated areas for agricultural production are the leading drivers of Indonesia's soil-based carbon emissions and its substantial contributions to transboundary air pollution, known legally and colloquially as "haze" in Southeast Asia. An elaborate network of around 70,000 km of canals in Riau's peatlands (UGM 2017) has destabilized their natural hydrological properties and flood control functions (Lupascu et al. 2020). As a result, transboundary disputes around air pollution from biomass fires in cleared and drained peatlands, inequalities regarding water access, and water pollution from pesticides and palm oil effluent have become commonplace.

Three phases of capital-driven peatland development have contributed to the transboundary scale of these ruptures in Riau's eastern regency of Bengkalis, where ethnic Malay (57%) and Chinese (18%) residents in particular have peatland-based livelihood traditions centred on rubber cultivation and wet rice agriculture dating back to the 19th century (Masuda et al. 2016). From 1979, however, President Suharto's developmentalist New Order regime (1967-1998) introduced a five-year plan (known as REPELITA III, 1979-1984) to enhance rural food self-sufficiency while promoting agro-export growth through large-scale plantation development (Kuniyasu 2002). Commercial logging in Bengkalis accelerated during this period as agriculture shifted

Fig. 1. Map of Peatlands in Riau, Indonesia.



toward oil palm production and the area expansion of rubber plantations owned by outside plantation companies rather than by peatland communities themselves. Much of this peatland conversion was undertaken by migrants from the province of North Sumatra and Java island as part of the New Order's inter-island migration policy that involved the movement of around five million people from densely populated parts of Indonesia to more sparsely populated forested areas, driven by the search for new lands to cultivate. Assisted by the construction of the Trans-Sumatran Highway and branch roads into Riau Province, some 524,000 people migrated into Riau under this scheme between 1979 and early 1998 (Masuda et al. 2016).

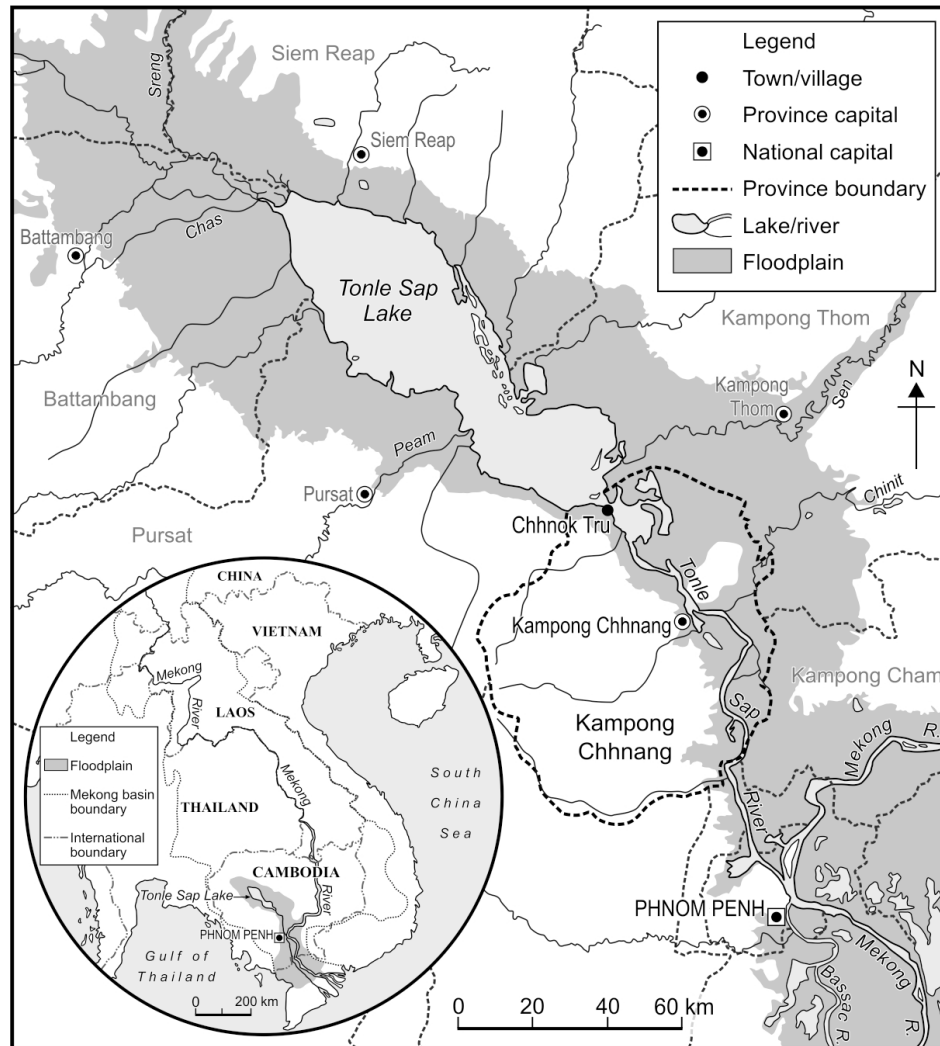
The second phase, marked by a shift away from state-driven development (Gellert 2015), followed the collapse of the New Order in 1998 and the initiation of a nationwide process of neoliberal democratic decentralization. Local authorities in Riau were encouraged to compete for external loans, investments, and access to markets, resulting in foreign investors, mainly from Malaysia and Singapore, operating an estimated 40% of oil palm plantation concessions in Riau (RiauPos 2013). In Bengkalis, the three villages of Sepahat, Buruk Bakul, and Tanjung Leban, which had been mostly covered in forest until the late 1990s (Suzuki et al. 2016), became surrounded by large palm oil and acacia (pulpwood) plantation companies. Smallholders in each of our three villages also converged on cheap and "empty" peatlands under the provincial government's poverty reduction program to cultivate palm oil, in addition to growing other cash crops such as pineapples, betel nut (*Areca catechu*), rubber, rice, and chili.

These first two phases have folded into the third and current period that includes partial efforts to mitigate the cumulative

ruptures generated by major peatland-based plantations. Indonesia has endeavored to reduce its soil-based peatland carbon emissions as a climate mitigation strategy in accordance with its Nationally Determined Contributions to the 2015 *Paris Agreement*, with financial and technical support for REDD+ pilot programs provided by the World Bank, the Netherlands, Australia, Norway, and Germany (Gunawan and Kobayashi 2016). With less than 4% of peat swamp forests remaining in pristine condition on the entire island of Sumatra (Sutikno et al. 2019), rehabilitation efforts in Riau have focused on a flexible interpretation of paludiculture (wetland cultivation) on rewetted peatlands (Uda et al. 2017). Paludiculture is legislatively supported by Government Regulation No.57/2016 on the *Protection and Management of Peatland Ecosystems*, which articulates general guidelines for the commercialized rehabilitation of drained and degraded peatlands using the national government's 3R approach (BRG 2019). Currently seen as the most ecologically sustainable pathway to peatland development, this model promotes socioeconomic inclusivity through its articulation as a social forestry program, which, in Indonesia, refers to a suite of programs that have historically sought to alleviate rural poverty through community-driven development (Rakatama and Pandit 2020).

As a sustainable growth strategy, paludiculture-based social agroforestry plots are spatially marginal to high-yielding oil palm and acacia (pulpwood) monocrop plantations that occupy almost two-thirds of Riau's peatland area (Miettinen et al. 2016). These monocultures complicate efforts to spatially expand paludiculture through their reinforcement of resource exclusions, especially in the form of unequal water-sharing arrangements between plantation enclosures and surrounding peatland communities

Fig. 2. Tonle Sap Lake and location of Chhnok Tru village, Cambodia.



that expose the latter to heightened dry-season fire risks and rainy season floods. At the same time, these regenerative activities can be understood as an emergent form of hydrosocial resourcefulness that seeks to balance the competing demands of peatland development with more sustainable and inclusive pathways to distribution in the longer term.

Tonle Sap ecosystem, Cambodia

Located in Cambodia's central plains (Fig. 2), Tonle Sap is Southeast Asia's largest freshwater lake and is connected to the Mekong River. The seasonal rise and fall of the Mekong partially drive the lake's expansion to 15,000 km² during the wet season (May-October) and contraction to 2600 km² in the dry season (November-April; Arias et al. 2014). Hydropower dams along the Mekong and terrestrial (urbanization and mechanized agriculture) development processes around the lake have changed the flow and level of this flood pulse system, altering the transfer of water, sediment, nutrients, and fish that maintain biodiversity and productivity (Campbell 2009). Some 1.7 million fishers and farmers who directly rely on the Tonle Sap's resources experience

these transboundary transformations as flood regime irregularities (onset, duration, water levels) and in-flowing plastic and pesticide pollutants that deplete fish stocks, degrade aquatic ecologies, and disrupt seasonal aquaculture and farming activities (Grundy-Warr and Lin 2020).

Chhnok Tru village was (re)established after a major rupture in hydrosocial relations. Due to the Khmer Rouge's cultural purge that forcibly returned Cambodian society to "ground zero," there is sparse evidence of the village predating this revolutionary regime, which cancelled all commercial fishing lots and prioritized rice production. Some older residents, however, remembered fishing ways of life dating back to the 1960s (interviews 35, 38). There are also historical records of the significant influence of ethnic Vietnamese fishers on the Tonle Sap Lake at the start of the 20th century (Keskinen 2003); stateless ethnic Vietnamese, who are both fishers and farmers, comprise around half of Chhnok Tru's 1700 households (Ishikawa et al. 2017). In 1989, when Cambodia embarked on its transition toward a market economy, the Chhnok Tru floating community became integrated into a

system that divided Tonle Sap Lake into large, medium, and small-scale privatized fishing lots, a system first developed during Cambodia's French Protectorate period (1963-1953). Under this competitive regime, tensions between subsistence and large-scale commercial fishers frequently descended into violent encounters over fishing rights and boundaries, illegal poaching, and the use of environmentally destructive yield-enhancing methods. To curb the perceived "anarchy in fisheries" (Resurreccion 2008:157), the government eventually disbanded the fishing lot system in 2012, but this did not resolve tremendous challenges related to lake-wide sustainability. The problem of over-exploited fisheries was exacerbated by the effects of large hydropower dam construction and the associated clearance of floodplain forests around Tonle Sap Lake that provide important habitats for fish (Middleton and Un 2018).

This backdrop of hydrosocial transformation has informed the Cambodian government's current policy of relocating Chhnok Tru residents as part of its long-term strategy to move all floating villages onto dry land. Incrementally implemented in the wider Kampong Chhnang province since late 2015 (Chin 2016) and in Chhnok Tru since October 2018 (Chandran 2019), involuntary resettlement is a cornerstone of the provincial five-year plan (2015-2019) for *Integrated Urban Environmental Management in the Tonle Sap Basin* (ADB 2014). By 2019, 10,081 people, including 2188 Khmer families and 2397 ethnic Vietnamese were in the process of being forcibly resettled (Special Rapporteur 2019). State representatives have argued that involuntary resettlement is necessary to provide redress for overfishing and water pollution while improving livelihoods, restoring biodiversity, and, eventually, beautifying the waterfront to promote tourism (Mom 2019). However, resettlement has been politically mediated to the detriment of ethnic Vietnamese who have lived in Cambodia for generations but lack citizenship rights to own land or attend public schools (Chandran 2019).

More systemically, the case of Chhnok Tru follows a pattern of moving Cambodia's water-dependent communities without public consultation to make way for transboundary development schemes. In 2015, the Cambodian government relocated riverine communities along the Sesan and Srepok rivers in northeast Cambodia to facilitate construction of a dam at their confluence, threatening biodiversity and migratory fisheries (Haefner 2016). The Sesan and Srepok rivers are tributaries to the Mekong River, and thus ultimately connect to Tonle Sap Lake. In a similar vein, the resettlement of Chhnok Tru residents has ruptured place-based human-resource connections while concealing the transboundary drivers of these changes, which remain noticeably absent from official sustainability narratives.

RESULTS AND DISCUSSION

Our findings direct attention toward local stakeholder perceptions of two types of government responses to hydrosocial ruptures. Perceptions show how people differentially prioritize the costs and benefits of altering water environments that inform corresponding behavioral adjustments (Hamilton 2018). Both of our contexts entail an extraordinary heterogeneity of state, civil society, and corporate actors and institutions with different worldviews and competing development agendas. Their perceptions diverge within as well as between sectors and scales of interest. At the household level, no two people or families

register the lived effects of hydrosocial rupture in exactly the same way, with variations in savings, health, and access to community support networks shaping attitudes and abilities to cope with shocks. Mindful of this diversity, we do not homogenize the perceptions analyzed below, but, rather, locate these hydrosocial relations in everyday struggles over resource access, control, and the meaning of development.

Perceptions of the causes of hydrosocial rupture

In each of our contexts, hydrosocial ruptures did not happen overnight. Because development impacts accumulated gradually over decades, interviewees in both sites had initiated livelihood transitions well before government authorities formulated policy responses. In Riau, peatland community NGO representatives spoke of the gradual disappearance of fishing livelihoods along rivers in the Giam Siak Kecil-Bukit Batu Biosphere Reserve, which traverses Bengkalis and Siak regencies in Riau (Qomar et al. 2016), due to pollution and the activities of illegal loggers (Interviews 8, 10). In Bengkalis, where people continued to fish in peatlands in addition to working as farmers and laborers (Interviews 2, 3), traditional water resource dependencies were ruptured and re-patterned by expanding monocrops and related canal infrastructures (Astuti 2020). Fishers had to restrict their peatland fishing to dry season months (January-March and June-September) owing to the severity of wet season flooding (Aldrian and Susanto 2003). Annual fish catches declined because canals restricted the movements of migratory fish and limited the replenishment rate of stocks (Interviews 4, 8). Apart from depleting this locally important basis for food security, the seasonal shift in peatland fishing inadvertently contributed to air pollution. Many fishermen (who combined fishing trips with wild honey harvest) were smokers who discarded their cigarettes in highly flammable biomass, which, in dry season conditions, sparked haze-forming wildfires (Interviews 2, 3, 4). During the wet season, too, peatland farmers expressed concerns about the destruction of their crops due to prolonged flooding episodes (Interview 1). Inundation and permanent flooding are likely to become growing problems as peat drainage further lowers the surface elevation of surrounding peat areas (Hooijer et al. 2012).

In the Tonle Sap ecosystem, too, both aquatic and terrestrial developments transformed human-water connections. Many fisher and farmer respondents periodically out-migrated in response to declining fish stocks and chronic water pollution. Some sent their children, or they themselves traveled, to work in factories and construction sites in urban centres (Interviews 21, 22, 23, 24), or even abroad to South Korea or Thailand (Interviews 32, 33). Others moved their floating homes to different locations in the Tonle Sap River during times of fishery stress (Interviews 25, 30). Many supplemented their resource-dependant livelihoods by taking on extra work locally as boat or truck drivers (Interview 31), opening provision shops (Interviews 36, 37), or by seasonally migrating to other parts of the lake to farm, fish, or sell homemade products such as ladders for stilt houses (Interview 29). Traditionally, these forms of livelihood diversification had been regarded as forms of resilience to withstand shocks and flexibly adapt to the lake's seasonal rhythms. However, almost all of our respondents perceived these new forms of labor household management to be an imposition forced upon them by deteriorating ecological conditions and outside political processes over which they had little or no control.

Perceptions of transboundary drivers of hydrosocial transformations

Our respondents understood the localized and transboundary drivers of these hydrosocial ruptures very differently in each context. Whereas interviewees in Bengkalis identified at least some transboundary dimensions of human-induced environmental change, none of our Chhnok Tru respondents ventured to connect localized environmental impacts with geographically distant processes. Instead, they spoke of a gradual decline over many years in amplitude of the Tonle Sap's flood pulse system, except in irregular "very high water" La Niña years (Interviews 29, 32). No respondents articulated causal connections between this hydrological shift and the construction of large dams along the Mekong River, with some half-joking that the lake was sick (Interviews 29, 34). Similarly, fishers attributed their combined reduction in wild catch yields (from around 300-400 tonnes of fish per day in 2014 to just 20 tonnes daily in 2019; Interviews 21, 22) to illegal over-fishing (Interviews 20, 23, 24, 31, 38). Although fear of government reprisals may have shaped these responses, they contrast with hydrological studies (Arias et al. 2014) and popular media discourses (Roney 2020) that link these changes to basin-wide developments, including hydropower dams (Whittington 2018).

By contrast, farmers and peatland community interviewees in Bengkalis were relatively well-connected to the outside world, as reflected in their articulation of causal connections between changes in peatland hydrology and the expansion of foreign-owned agricultural plantations and hydraulic infrastructures. Most of these respondents benefited from NGO and private industry support, information technologies, and access to a relatively free press. They also tended to interpret transboundary water disputes as a negative consequence of capital-driven peatland development (Interviews 10, 13, 16). Indonesian legislation seeking to mitigate haze pollution and hydrologically rehabilitate drained and degraded peatlands (Government Regulation No.57/2016) has institutionalized competition over water by stipulating that peatland concessionaires must maintain a water table depth of 40 centimetres on their properties. Large plantation owners who hold the balance of power in peatland property relations can afford the technologies required to control the movements of large volumes of water in their concession areas, whereas surrounding smallholders and peatland communities typically cannot. Non-governmental organization respondents spoke of an unwillingness by government officials to intervene in addressing these water exclusions that expose peatland communities adjacent to large plantations to dry season hotspots of heightened fire risk and severe wet season floods (Interviews 6, 7, 10, 12). Although local government officials said they play a mediating role in encouraging plantation corporations to release critical dry season water supplies by opening the sluice gates on their dams (Interview 14), peatland community representatives contended that such negotiations repeatedly failed (Interviews 6, 7) because outside concessionaires "never honour their promises" (Interview 4). In a similar vein, community respondents spoke of disputes arising from the leakage of pesticides/herbicides across property borders that contaminated shared water resources, killing fish and vegetation and reducing crop yields (Interviews 4, 5, 6).

Local perceptions of government responses to hydrosocial rupture

In our contexts, responses to hydrosocial ruptures comprise policies to thicken water resource connections (Riau) and thin hydrosocial relations through out-migration and forced resettlement (Tonle Sap). In Riau, government agencies, NGOs, agro-export corporations, and peatland communities have all promoted paludiculture-based social agroforestry as an inclusive pro-small farmer strategy to develop the dual productive and protective functions of peatlands (World Agroforestry Centre 2017). By contrast, controversy has mired the Cambodian government's policy to restore the ecological balance of Tonle Sap Lake by thinning human-water relations (Chin 2016, Dara 2018). Chief among the perceived failures of the resettlement policy is its punishment of the most physically proximate and socially vulnerable users of water resources at the expense of addressing other drivers of hydrosocial change responsible for eroding social-ecological stability at the basin scale.

Thickening hydrosocial relations in Indonesia's Riau Province

Community-led and government-supported social forestry programs in Riau have begun to explore the restorative properties of paludiculture on peatlands. Social forestry trial plots are set within a broader trajectory of otherwise deteriorating hydrosocial relations. What is noteworthy about this initiative to establish "common ground" around a "water-based economy" (Syakriah 2020), however, is the multi-sector and multi-scalar support that paludiculture has garnered (Miller 2021b).

If conducted on a large scale, paludiculture could repair the biophysical and ecological properties (by rewetting biomass and replanting species suited to wet conditions) of peatlands that have been drained, cleared (often by fire), and severely damaged through human-induced disturbances (Budiman et al. 2020). Mixed social agroforestry that combines endemic and adaptive species, such as gelam (*Melaleuca cajuputi*) and illipe nut (*Madhuca longifolia* var. *latifolia*), with commercially viable non-endemic species (for example, liberica coffee and coconuts) could also safeguard carbon-rich peatlands by minimizing emissions that contribute substantially to global warming (Jauhiainen et al. 2016). For these reasons, in 2017, Indonesia's Peatland Restoration Agency (Badan Restorasi Gambut, BRG) set aside 5600 km² of abandoned or degraded peat areas that do not fall under a single jurisdiction or property regime for social forestry activities (Jong 2018). In Riau, BRG officials have conducted field schools with 79 peatland communities with activities focusing on building dams to re-saturate drained peatlands, making organic compost, and providing seeds and training programs to grow wetland taxa such as sago (*Cycas revoluta*), areca nut (*Areca catechu*), and illipe nut (Interviews 14, 18). A farmer in Buruk Bakul village noted that apart from learning about species that will thrive in undrained peatlands, "these are actually local trees that were common during our childhood" (Interview 1). Peatland community NGOs say their ecosystem approach (Interview 35) prioritizes seasonal planting and ongoing experimentation with growing species suited to different water depths (Interviews 5, 6, 12).

Despite its perceived benefits, many respondents rightly pointed out that the hydrosocial ambitions of paludiculture-based peatland development face serious constraints. Bureaucratic delays in issuing 250,000 ha of peatland social forestry permits for paludiculture development (Nugraha and Arumningtyas

2019) and budgetary limitations hampered efforts to expand beyond pilot projects (Shahab 2018). Although the government has promoted paludiculture as a pro-small farmer strategy, smallholders in Bengkalis, who typically farm up to 25 ha (Interview 12), have asked “how will this bring benefit to us” when “the peatland replanting program is only a few hectares?” (Interview 1).

This seemingly intractable problem of size has impeded efforts to connect with distant markets. As a BRG official in Jakarta explained, “buyers in Europe are interested [in swamp products], but farmers cannot meet demand” (Interview 19). Even when they can produce sufficient goods, “there are hardly any middlemen [quality controllers] who are trained to certify peatland products like pineapples for export” (Interview 19). Convinced that the future sustainability of paludiculture depends on its profitability, peatland community NGOs in Riau have invested in hiring consultants “to come up with a more sustainable method of agriculture, but with profitable commodities that will attract communities” (Interview 9).

General confusion about what paludiculture means in an Indonesian context raises questions about whether it can reverse the hydrological impacts of peatland growth. With paludiculture research concentrated on temperate peatlands, the complexities of preparing varying tropical peatland water tables, acidity, and nutrient levels for planting remain poorly understood (Jauhiainen et al. 2016). Only one of our respondents possessed intergenerational knowledge of paludiculture-based farming (Interview 1), while the majority flexibly defined the concept to encompass crops grown on relatively dry peatlands such as rubber, coconuts, and pineapples. The incorporation of these crops into mixed agroforestry programs reflects the challenges involved in finding markets for little known swamp commodities such as gelam and illipe nut (Interview 14).

Paludiculture is generally perceived to constitute a remedy for the transboundary problem of haze pollution, but its efficacy in reducing fire risks is limited by its small extent relative to that of surrounding monocrop plantations on fire-prone drained peat (BRG 2019). To provide redress for this problem, one senior BRG official controversially proposed reorganizing hydrosocial relations in Riau around paludiculture-based monocrops. “If we want to make paludiculture work, we have to create a system that is as big as the two other [peatland plantation] industries: palm oil and pulp and paper,” he argued, ideally “in the next four decades” (Interview 18). Yet, it is also unlikely that paludiculture crops will ever commercially compete with high-yielding monocrops that are the product of several decades of intensive research (Gewin 2018). Although existing plantation monocrops have lowered water tables across almost two-thirds of peatlands in Riau (Jelsma et al. 2019), the ability of paludiculture crops to retain large volumes of water remains untested. Moreover, our peatland community respondents overwhelmingly perceived paludiculture-based intercropping to be the most socially inclusive means of sustaining local food security.

Notwithstanding the potential for monetarizing nature to incubate new forms of social conflict, assigning a material value to carbon stocks in Indonesian peatlands could enhance the scalar agency of paludiculture as a means of reducing hydrosocial ruptures and ensuring more sustainable forms of development.

Indonesia has yet to value its peatland carbon stocks (Interview 19), estimated to constitute 28 billion tonnes, the equivalent of almost three years of global fossil fuel emissions (Warren et al. 2017). According to the BRG, non-paludiculture farming produces over twice the annual rate of carbon emissions (110 tonnes CO₂eq per hectare) compared with paludiculture plots (around 50 tonnes CO₂eq per hectare; BRG 2019). Carbon monitoring and payment/credit schemes could incentivize farmers and plantation owners alike to keep carbon in rewetted peatlands along similar lines to the European Union’s peatland agriculture climate strategy (EU 2020). At this nascent stage, however, the lack of knowledge about carbon markets among all peatland stakeholders means that their integration into sustainable livelihood programs entails substantial risks.

Ironically, although paludiculture-based development emerged in response to the cumulative ruptures catalyzed by modernized peatland hydrology, its future capacity to revitalize hydrosocial relations and mitigate transboundary haze and water pollution will demand additional infrastructural expansion. Dams will need to be built and canals will require in-filling to retain large volumes of water in areas affected by artificial drainage. These infrastructures are expensive (Rp12 million, or US\$860 per hectare), raising concerns about the capacity of peatland communities to secure outside funding to fulfil the criteria for obtaining paludiculture-based social forestry permits (BRG 2019). As the inverse of dry peatland agriculture, paludiculture will need different types of machinery to plant and harvest crops, including the construction of roads on raised embankments to transport agricultural produce from waterlogged farms. Paludiculture could make peatland development more sustainable than dryland monocultures in the longer term, but it will invariably further modify peatland hydrological systems in ways that will exert new and as yet unanticipated redistributive social and ecological effects.

Thinning human-water relations in Cambodia’s Tonle Sap Ecosystem

In misdiagnosing the root causes of environmental degradation in Tonle Sap Lake, the Cambodian government’s resettlement policy has laid the groundwork for at least two cascading ruptures. The first concerns unaddressed sources of environmental unpredictability. Transboundary dam projects, reservoirs, and large irrigation projects that contribute to ecological instability are excluded from the resettlement plan. Localized drivers, such as pollution and illegal fishing, have similarly been overlooked. Illegal fishing is conducted on a commercial scale by fishers who can afford to live away from the lake and pay substantial bribes (up to US\$1000 per night) to allow continuation of their activities (Interviews 29, 31, 36). A second form of rupture concerns the fracture or dissolution of relocated floating communities. The majority of Chhnok Tru residents lack savings to plan for transitions to land-based livelihoods. Stateless ethnic Vietnamese residents face heightened socioeconomic risks on land due to their historical experience of marginalization from Cambodian society that originally drove many to live on the lake (Dara 2018).

It is worth noting that in the case of Chhnok Tru, this process of community fragmentation began long before the initiation of involuntary resettlement, but it influenced the geographically dispersed pattern of out-migration that followed. A village elder

dispelled notions of social cohesiveness that are often uncritically transposed onto local communities in donor-driven agendas and development industry discourses by claiming that no self-organization took place around community fisheries, traditional water ceremonies, or to pool risk through sharing labor and lending practices (Interview 38). Internally divided and forced to compete with outside (usually wealthier and larger-scale) fishers over declining water resources, Chhnok Tru residents were further disunited by the government's differential treatment of ethnic Vietnamese residents, who were moved onto dry land well before their Cambodian Cham Muslim and Khmer Buddhist counterparts (typically six months to a year before our interviews).

This staggered resettlement and inability to self-organize created a complex picture of transboundary mobility. Without exception, respondents who moved to the government's designated settlement site encountered tremendous difficulties in adapting to their new living conditions. Social media correspondence with some of the relocated Khmer villagers since our fieldwork indicates that they continue to face harsh conditions, particularly during the long dry season, with poor sanitation and problems of access to clean water. This has led many, especially ethnic Vietnamese who were required to pay rent in the resettlement site because they lacked Cambodian citizenship rights to own land (Interview 30), to abandon their allotments and travel in search of employment in Phnom Penh and other urban centres. Their abandonment is a serious indicator that (forced) relocation is not necessarily a sustainable solution to multi-scalar hydrosocial changes and can lead to people becoming environmental refugees or impoverished in their new location. As environmental uncertainty deepens, there is a likelihood that younger people will decide to move away from the Tonle Sap area, which may not necessarily mean escaping poverty and could lead to negative feedbacks as their families use remittances to pay accumulating rural debts (Parsons 2017). Aside from these considerable material challenges, respondents lamented losing connections with their ancestors as their cultural ways of being "river people" became attenuated (Interviews 26, 28).

Others, unable to adapt to life on land, returned to the lake for work and/or to pay for the protection of their boats, rituals that were both costly and time-consuming (Interviews 25, 27). A farmer who had lived on Tonle Sap Lake from 1979 until her relocation in September 2018, commuted to cultivate pumpkins on an island in the lake for six months each year (November-July) because her allotment was small with poor soil quality and lacked running water, which she had to buy from vendors (Interview 34). Not only was the resettlement area arid and dusty in the dry season, but it became inundated with floodwaters up to 4.5 m deep in the wet season, leaving once highly mobile Chhnok Tru residents who were accustomed to moving their floating houses with the lake's ebbs and flows critically unprepared to cope with inundation on land. One Cham Muslim couple took out a microfinance loan to move their floating house into a fixed position and purchase a sugar cane juice-making machine to ease their livelihood transition, which they feared would leave them indebted for years to come (Interviews 26, 37). Witnessing this unfolding crisis added to the anxieties of Chhnok Tru residents on the lake awaiting resettlement. Summarizing this sentiment, a resident who had seen the relocation site for himself, said he did

"not want to go to an environment where there is no job and no toilet" (Interview 38).

This reluctance to move did not mean that Chhnok Tru residents saw life on the lake as optimal or even desirable. With development pressures pushing aquatic ecologies well outside healthy ranges, illness and infant/child mortality were widespread. The community doctor, who had lived in Chhnok Tru since 1979, saw between 35 and 60 patients per day all year round with diarrhea, stomach ailments, respiratory complaints, and skin conditions linked to water pollution (Interview 35). People spoke of their own children dying from disease (Interviews 33, 36) and family members falling ill three or four times annually (Interviews 20, 29).

The health of human-water relations will likely further deteriorate without a comprehensive policy remedy. Chhnok Tru respondents spoke of the provincial government's inefficient response to addressing water pollution by limiting the outsourcing of plastic waste collection to a private contractor during dry season months, when plastic is visible, which is then burned rather than recycled (Interviews 22, 34). Meanwhile, illegal fishing has reportedly increased as residents have left the lake (Interview 36). Amidst these developments, it is little wonder that rumors abound that the government's real motivation for moving floating communities is to pursue its long-standing goal of exploiting the Tonle Sap as a new frontier in oil and gas exploration (Interviews 31, 34), or, as a form of spatial capture, to create a commercial arena for future tourist ventures and port activities (Falby 2002).

CONCLUSIONS

When hydrological systems are exposed to sustained market pressures, they can become damaged and degraded in some areas and dysfunctional in others. This research has shown how governments and users of water resources think and act when aquatic ecologies are pushed past known historical ranges to rupture human-water dependencies. Hydrosocial ruptures, as breaches in human-water relations once assumed to function within a sustainable and self-regenerating system, thus describe conditions of perpetual uncertainty that are becoming normalized in human interactions with water. As has been demonstrated, hydrosocial ruptures propagate further ruptures, the cascading effects of which link individuals, communities, and ecosystems in ways that can no longer be regarded as geographically and temporally separated nor limited to a particular jurisdiction.

As a transboundary concept, hydrosocial rupture contributes to an understanding of the complex challenges involved in governing the unintended social and ecological consequences of hydro-modernity. Specifically, our findings have highlighted what these transgressive effects mean for the most physically proximate and socially vulnerable users of water resources, whose voices tend to be obscured or overlooked in state and corporate narratives that find acute expression in hydraulic infrastructures such as dams, canals, and commercial fisheries. Our focus on local perceptions of government responses to major ruptures signals the need to better account for the unequal redistributive effects of water. These tend to disadvantage rural populations closest to the material effects of modernization processes, while enhancing the food, water, and energy security of socioeconomically affluent populations in distant urban centres.

Reimagining the relationship between the “socio” and “hydro” realms of water governance to reduce the frequency and prevalence of ruptures is both an opportunity and a challenge. As an opportunity, crises in human-water connections can transform perceptions about water resources to (re)value them beyond financial measures and catalyze collective activities around more coordinated, inclusive, and sustainable development pathways. As an ongoing challenge, hydrosocial ruptures create winners and losers that reflect prevailing power geometries. Further research is needed to assess the different scales at which perceptions of water-connected development translate into ecologically unsustainable behaviors, and how targeted interventions at specific organizational scales of governance could be deployed to address them.

Responses to this article can be read online at:
<https://www.ecologyandsociety.org/issues/responses.php/12545>

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Data Availability:

The data that support the findings of this study are available on request from the corresponding author, [MAM]. None of the data are publicly available because of restrictions containing information that could compromise the privacy of research participants. Ethical approval for this research study was granted by the Institutional Review Board of the National University of Singapore (IRB No. S-18-183).

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Appendix 1 Interviewees in Riau, May, August, December 2018 and October 2019

1	Male	Farmer	Buruk Bakul Village, Bengkalis, Riau
2	Male	Farmer, Village Head	Buruk Bakul Village, Bengkalis District
3	Male	Farmer, Village Head	Sepahat Village, Bengkalis
4	Two Males	Farmer, Volunteer Firefighters	Tanjung Leban Village, Bengkalis
5	Male	Peatland community NGO	Pekanbaru, Riau
6	Male	Peatland community NGO	Pekanbaru, Riau
7	Male	Environmental NGO	Pekanbaru, Riau
8	Male	Environmental NGO	Pekanbaru, Riau
9	Male	Environmental NGO	Siak, Riau
10	Male	Conservation NGO	Pekanbaru, Riau
11	Two males	International conservation NGO	Pekanbaru, Riau
12	Male	Civil servant	Pekanbaru, Riau
13	Male	Civil servant	Pekanbaru, Riau
14	Female	Civil servant	Pekanbaru, Riau
15	Males and Females	Division of Pollution and Environmental Degradation, Department of Environment and Forestry	Pekanbaru, Riau
16	Male	Academic	Pekanbaru, Riau
17	Male	Peatland Restoration Agency	Pekanbaru, Riau
18	Male	Peatland Restoration Agency	Jakarta
19	Female	Peatland Restoration Agency	Jakarta

Appendix 2 Interviewees in Chhnok Tru, Kampong Chhnang, February 2019

Interviewee	Gender	Occupation	Place of interview
20	Female	Fisher	Chhnok Tru, Tonle Sap lake
21	Male	Fisher	Kampong Chhnang Port
22	Female	Fisher	Kampong Chhnang Port
23	Female	Fisher	Chhnok Tru, Tonle Sap lake
24	Male	Fisher	Chhnok Tru, Tonle Sap lake
25	Male	Fisher	Resettlement site 2km from lake proper
26	Male	Fisher	Resettlement site 1km from lake proper
27	Male	Fisher	Resettlement site 1km from lake proper
28	Male	Fisher	Chhnok Tru, Tonle Sap lake
29	Male	Fisher/ Stilt house ladder maker	Chhnok Tru, Tonle Sap lake
30	Female	Aquaculture specialist/ Fisher	Resettlement site 2km from lake proper
31	Male	Boat driver	Chhnok Tru, Tonle Sap lake
32	Two females	Farmers	Phum R. Poum Mareas Village, Tonle Sap Lake
33	Male and female	Farmers	Island on Tonle Sap Lake
34	Female	Farmer	Island on Tonle Sap Lake
35	Male	Doctor	Chhnok Tru Health Centre
36	Female	Convenience shop owner	Chhnok Tru, Tonle Sap lake
37	Female	Convenience shop owner	Resettlement site 1km from lake proper
38	Male	Village head/ Fisher	Chhnok Tru, Tonle Sap lake