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Disrupted Sand Flows, Artisanal Fishers, and the Making of Coastal Protection in Southern India

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Abstract

Flowing parallel to the sea, sand is subject to erosive, accretive, and extractive processes and is intertwined with the socio-ecological dynamics at the land–sea interface. Human interventions, climate change, and societal responses to it are constantly reshaping the morphology of coastal areas and thus disrupting sand flows, for example, through the construction of harbours or groins to prevent erosion. In this article, we ask how disrupted sand flows shape the interaction and social dynamics between different coastal actors in the making of coastal protection. Empirically, we ground our research in the Pondicherry region of southern India, characterised by a sandy morphology and numerous fishing communities. Building on the literature on "geosocialities," we argue that engaging with the materialities of ocean sand and the social implications of sediment loss for artisanal fishers is crucial to reducing maladaptation. Following sand as a non-human actor unravels the social entanglements with ocean sand that underpin the implementation of protective measures and that shape access to sandy beaches for artisanal fishers. By exploring these contestations, we show how the reclamation of sand through groins is embedded in unequal power relations over shrinking beaches. While migration to other sandy beaches becomes a necessary means of adaptation, this leads to local conflicts over coastal space. We conclude by highlighting the need to understand coastal adaptation as a geophysical and socially intertwined process, in which ocean sand must be critically considered for future adaptation strategies.

Keywords

artisanal fishers; climate change adaptation; coastal protection; fishing communities; geosocialities; India; maladaptation; sand resources

1. Introduction

As Jimi Hendrix (1967) poetically reflects on the transience of human endeavours, he notes that "castles made of sand fall into the sea eventually." While human constructions and monuments are of a very temporary or at least uncertain nature until consumed by the ocean, to continue the lyrical metaphor by Hendrix, the tidal forces of the sea that move coastal sands outlast but are not unaffected by such anthropogenic activities. Often overlooked, but ubiquitous, sand resources supplied by rivers and tidal currents sustain and help build coastal areas where more than a billion people live worldwide (Intergovernmental Panel on Climate Change [IPCC], 2019). The link between sand and climate change is significant but complex. On the mitigation side, the extraction of marine sand releases (directly) the greenhouse gases sequestered in the sediments (Sun et al., 2023), while the production of concrete releases (indirectly) huge quantities of CO_2 (United Nations Environment Programme [UNEP], 2022). On the adaptation side, as a key driver of geomorphological processes together with ocean currents, sand not only sustains livelihoods and the marine ecosystem but also protects coastlines that are increasingly vulnerable to the impacts of severe weather events (Pilkey et al., 2022).

Given this interconnectedness, looking at coastal sand resources provides an important entry point for understanding climate and coastal adaptation and protection not as something external "out there" we adapt to, but as (re)produced through our lived environments as part of the social and biophysical forces (Taylor, 2014). In the era of the Anthropocene, characterised by persistent human impacts on a planetary scale, it is imperative to focus more social research on the various entanglements with sand in the context of numerous human interventions, such as dredging of navigation channels, the sand extraction for land reclamation, or the construction of coastal defences (Gustafson, 2021; Hein & Hilder, 2023). The implementation of hard and static coastal protection measures to coastal hazards (e.g., seawalls or groins) not only often demand huge quantities of sand but also takes place in highly dynamic and contested coastal environments, where sand resources are crucial but largely overlooked in governance processes. As such, coastal adaptation interventions are common examples of shifting vulnerabilities, not least due to overlooked power relations that are reshaped by infrastructural and technical interventions and result in maladaptation (Eriksen et al., 2021; Schipper, 2020). Formerly and as this work shows, coastal measures to a large extent were referred to as coastal protection. While the measures often remain the same, funding and framing increasingly fall under coastal adaptation to climate change. However, in the literature, both terms are categorized as adaptation strategies (Mamo et al., 2022). Considering its multiple uses and functions for the marine ecosystem, sand in particular is situated in contested arenas with multiple actors (Jouffray et al., 2023; Lamb et al., 2019; Torres et al., 2017). Climate change and societal responses to it are constantly reshaping the morphology of coastal areas and thus affecting marine sand fluxes, for example through the construction of seawalls and groins to prevent erosion. However, the social implications of sand loss for coastal communities remain a conspicuous blind spot in both adaptation planning and governance of resources. This article aims to fill this gap and contribute to the body of work on "geosocialities" by showing how disrupted sand flows shape the making of coastal protection and hence adaptation outcomes.

In a specific context in India's south-eastern coast, the construction of a harbour interfered with the littoral drift that resulted in the loss of livelihoods for thousands of artisanal fisheries that depend on sandy beaches for boat parking and storage. The traditional fishing techniques of the many fishing communities in the area have evolved over centuries around the sandy beach ecosystem, which provides a variety of functions, from maintaining fish habitats to providing space for boat parking. Access to sand and space for the seasonal beach formation is therefore critical to the livelihoods of fish workers who depend on sandy beaches to access the sea. In this article, we argue that the (re)distribution of ocean sand is embedded in unequal power relations that make some populations more vulnerable to climate and environmental change than others. More specifically, we focus our analysis on how the disruption of sand flow shapes the interaction and social dynamics between different coastal actors in the making of coastal protection and future adaptation strategies.

In answering this question, we explore the contestation and struggle over access to sandy beaches, which contribute to adaptation to coastal risk, and identify a vicious cycle of maladaptation (Barnett & O'Neill, 2010; Schipper, 2020). Empirically, we ground our research in a case study of the Pondicherry region of southern India, a coastal environment characterised by a sandy morphology and numerous fishing communities. We argue that it is crucial to engage with the materialities of ocean sand to understand the contexts of social vulnerability. Our analysis focuses on the disruption of sand flows caused by coastal infrastructures. To this end, human agency is understood as shared with other non-human actors, such as sand and ocean currents, that shape the world and human history (Latour, 2005; Sayes, 2014). The implementation and functionality of coastal infrastructure in turn is shaped by the interactions between humans and non-humans and is an inherently political process with competing interests (P. Harvey et al., 2016). By exploring these human–sand relations, this article contributes to the emerging scholarship on "geosocialities" (Carse & Lewis, 2017; Dawson, 2021; Palsson & Swanson, 2016), which aims to engage more with the materialities of ocean sand as a non-human force. Coastal adaptation strategies herein are understood as a geophysical but also socially entwined process upon which access to sand is contested. The article is structured as follows. We begin by bringing together the importance of sand in adaptation processes in terms of coastal hazards and adaptation measures, before engaging with the literature on "geosocialities" and sand as a non-human actor. From this, we derive our methodology, which guides our fieldwork on the Coromandel Coast in southern India. Tracing the sandy morphologies found there, we investigate the disrupted sand flows that have led to coastal erosion and the social implications for artisanal fishing communities. We find that the construction of groins, in particular, is embedded in a cycle of fish workers' protest, rock extraction, and the constant northward shift of erosion, leading to the construction of more groins. After making these human-sand entanglements explicit in the empirical case, the article concludes with a call to integrate shifting ocean sands into future adaptation policies to reduce the risk of maladaptation.

2. Why Does Sand Matter for Adaptation?

Contrary to the common perception that sand is abundant, sand resources are declining worldwide for several reasons. Sand is the second most consumed resource after water with the main uses being the construction sector and coastal development (UNEP, 2019). As the world's most in-demand construction material, sand is the main component of urban development and the physical backbone of the built environment (UNEP, 2019). Its extraction causes severe socio-environmental damage and political-economic frictions, especially along the world's coastlines (John, 2021). For example, the unprecedented demand for sand is fuelled by the expansion of ports and coastal cities through land reclamation or beach nourishment, leading to a "looming tragedy of the sand commons" (Torres et al., 2017, p. 970; UNEP, 2022). Especially, in countries of the so-called Global South the regulation and enforcement of laws to prevent illegal sand extraction operations is complicated because of limited resources and governance capacities to monitor affected sites (Rangel-Buitrago et al., 2023).

2.1. Diminishing Sand and Its Impact on Coastal Risk

Sand is essential not only for booming urbanisation, especially in coastal areas, but also for the marine ecosystem. With an ever-increasing demand as an aggregate in concrete and as a nourishment for beaches or hard infrastructure in the coastal environment, sand resources are becoming increasingly contested and depleted far beyond their replenishment rate (Rangel-Buitrago et al., 2023). In particular, coastal development and urbanisation contributed to an accelerated rate of sand extraction that far exceeds the supply from rivers, coastal dunes, and beaches. At the same time, maintaining sand resources as a coastal barrier may be the most cost-effective adaptation strategy against more frequent climate risks, such as cyclones or slow-onset risks, including coastal erosion and sea-level rise. For example, the costs of rebuilding infrastructure after coastal hazards (e.g., flooding) due to the loss of protective beaches do not outweigh the profits generated from extracted sand resources (Rangel-Buitrago et al., 2023). Sand acts as a natural buffer at the land–sea interface between the terrestrial and marine ecosystems, but also stabilises the coastline. As such, sand resources play a critical role in protecting land and property from coastal erosion and severe weather events.

Interventions that alter the flow of coastal sediments or extract sand resources are associated with the production of risks or disasters. Given the risk of sea level rise due to climate change, sandy coasts are particularly at risk in terms of the projected demand for sand resources (Jouffray et al., 2023). A coastline that has been lowered by mining is more vulnerable to sea-level rise and flooding. In addition to climate risks and coastal hazards, human activities such as sand mining in rivers for construction purposes or hydropower dams that prevent sand from reaching the coast are a major driver of coastal erosion (Zografos, 2017). Disrupted sediment flows from rivers accelerate erosion processes, threatening coastal infrastructure and assets (Jouffray et al., 2023; Rangel-Buitrago et al., 2023). Reduced shoreline stability also contributes to the vulnerability of coastal environments to storm surges, flooding, and sea level rise, the latter often leading to the salinisation of coastal aquifers. In southern India and Sri Lanka alike, for example, both sand depletion from dunes and reduced sediment replenishment from rivers have exacerbated the effects of the tsunami in 2004 (Namboothri et al., 2008).

2.2. Sand in Coastal Adaptation Strategies

The coastline is never fixed on a map but dynamic and in constant interaction through erosion and accretion. Therefore, beaches are rivers of sand that flow parallel to the coast. As such, many coastal adaptation measures, including the construction of seawalls or groin fields, interfere with the natural transport of sand caused by coastal morphodynamics including tidal currents, wave energy, wind, and sediment transport (Rangel-Buitrago et al., 2023). Interferences that alter the flow of sand result in changes to the coastal environment. For example, the construction of groins is likely to result in a large reduction of sand supply to adjacent beaches and dunes because they block the littoral drift (Sundar et al., 2021). Ironically, such structures are often perceived as protective by coastal communities, even though they disrupt sand flow and increase erosion up or down the coast (Klöck et al., 2022). The removal of beach sand then again increases the demand for coastal infrastructure such as groins, sandbags, or breakwaters. In addition, the future demand for aggregates is predicted to increase as climate change threatens coastal infrastructure (Torres et al., 2021). This, in turn, will require careful coastal adaptation planning to redirect investment in coastal infrastructure.

Whether triggered by a groin or a dam, the disruption of sand flow causes damage downstream, for example, in the form of increased erosion or loss of protective features, and thus increases the risk of maladaptation to climate change (Magnan et al., 2016; Sovacool et al., 2015). The unintended effects of adaptation measures are embodied in the concept of maladaptation understood as "actions or inactions that may lead to increased risk of adverse climate-related outcomes, increased vulnerability to climate change, or diminished welfare, now or in the future" (IPCC, 2014, p. 857). Other definitions address the wider underlying drivers of vulnerability which are conflicts, marginalization, or economic restructuring that are embedded in socio-environmental processes (Magnan et al., 2016). For the purpose of the argument made here, the notion of maladaptation points to the possibility that disrupted sand flow unintentionally may increase the vulnerability of other social groups. A case study examining (mal)adaptation in Ghana's Volta River Delta shows how climate policy discourses legitimise hard engineering measures to deal with coastal erosion in isolation from the social-economic activities (e.g., sand mining) that exacerbate maladaptation (Owusu-Daaku, 2017). The construction of a seawall, for example, may reduce exposure in the short term, but may ultimately have negative impacts due to a false sense of security or the loss of sediment that causes erosion beyond the spatial scale of the intervention (Grothmann & Patt, 2005; Table 1).

Although considered a soft measure, beach nourishment for land reclamation and beach restoration, which consumes large quantities of coastal sand, is another prominent strategy to counter sand erosion that is increasingly framed as climate adaptation (Qiu & Gopalakrishnan, 2018). To increase the width of a beach, large quantities of sand are added, mainly by dredging sand from nearshore or offshore borrow sites (Bisht, 2021). Often referred to as "building with nature" or categorised as a nature-based solution, beach nourishment is increasingly preferred to hard coastal infrastructure as it is comparatively less disruptive to natural sand flows. However, the seasonal (re)nourishment of beaches, such as on the luxury tourist island of Sylt in Germany, only periodically prevents erosion but requires the continuous relocation of sand and financial resources (Hinrichsen, 2009). The redistribution of sand resources thereby affects the marine ecosystem by shifting currents and changing wave patterns, resulting in habitat destruction or loss of biodiversity (de Schipper et al., 2021).

Table 1. Sand-dependent coastal adaptation strategies.

	Adaptation strategy	Sand use	Pitfalls
Coastal Risks: • Flooding • Sea-level rise • Erosion	Seawalls	Construction material	Interference with sand accretion and beach lowering
	Groinfields	Construction material and trapping of sediment transport	Downdrift erosion of adjacent beaches and livelihood impacts
	Beach nourishment	Offshore mining of sand deposits and relocation through dredging	Loss of marine habitat and seasonal erosion
	Artificial dune building	Fences to stimulate sand capture and planting of sand-trapping species	Regulate sand extraction and uninhabited areas
	Sandbagging	Mined with shovels from sourcing sites	Emergency measures and short duration

In the context of climate and environmental change, sand in its various functions and uses is at the very heart of coastal adaptation processes and coastal risk management measures (see overview Table 1). Coastal adaptation strategies within (sub)national institutional frameworks fail for a number of reasons (cultural, economic, or poor implementation). However, the critical role of ocean sand in coastal governance processes and the relationship between multiple dimensions of maladaptation is a major cause that remains unexplained in the literature. The ability to access, use, and relocate sand resources is crucial for adaptation strategies and overlapping climate-related and human-induced environmental risks potentially confound adaptation outcomes (Taylor, 2014; Work et al., 2018). Therefore, this article aims to address the aforementioned research gap by conceptually and empirically integrating a sand focus into coastal adaptation and governance processes to unravel how human–sand relations are intertwined with shifting vulnerabilities, social needs, and unequal power relations. To this end, the next step is to lay the conceptual groundwork by locating disrupted sand flows within the concept of "geosocialities." This means understanding sand as a non-human actor that, for example through coastal morphodynamics, is intertwined with the social process of adaptation to climate and environmental change.

3. Disrupted Sand Flows and Sand as a Non-human Actor

Climate change adaptation to date has primarily focused on a narrow range of economic and technological outcomes, lacking engagement with the materialities that shape social vulnerabilities, such as increased conflict over the resources needed to adapt (Juhola et al., 2016; Kuhl et al., 2020). Here we argue that the integration and analysis of disrupted sand flows and their embedding in the making of coastal governance is fundamental to the success of adaptation strategies of the various actors that shape environmental change in coastal environments. For this purpose, we engage with the notion of ocean sand as highlighted by Jouffray et al. (2023). The notion of ocean sand is used here to refer to sand from near and offshore deposits, including beaches, bays, lagoons, estuaries, tidal wetlands, and coastal quarries, thus recognising ocean sand as an "interconnected and dynamic complex social-ecological system at the land-sea interface" (Jouffray et al., 2023, p. 9). Focusing on ocean sand helps to grasp the broader context of its embeddedness beyond the technicalities of sand as a construction material, and thus allows us to think of sand as a non-human actor in the coastal environment. This is crucial because, as a non-human actor, sand actively shapes, for example, aquatic habitats and is a key entity of important geomorphological processes not least because of its supply from rivers and tidal currents that sustain liveable coastal areas.

Our understanding here is based on the assumption that human intentionality is not the only determinant of action but also non-human world-making entities such as sand and sediment (Dürbeck et al., 2015). Ocean sand is active in the sense that it is subject to natural and anthropogenic erosional and depositional processes at the coast, often driven by dynamic sediment transport. In other words, ocean sand has agency as an organism that makes workable the "living arrangements" upon which human interventions materialize and thus demonstrates that "making worlds is not limited to humans" (Tsing, 2015, p. 22). The focus of this article is on disrupted sand flows along the Coromandel Coast of southern India where ocean sand is mainly used by small-scale fishing communities (e.g., boat parking and fish drying) or tourist activities, and disruptions are caused by the construction of groins and seawalls to stabilise the coastline or to protect against coastal erosion and cyclones. The agency of fish workers thereby is part of the broader spectrum of non-human agencies (Sayes, 2014). Ruled by tides, waves, and currents, the movement of ocean sand expands and contracts beaches. The continuous erosion and accretion then influence the locations of breaking waves. The formation of beaches thereby protects the coast by adapting to wave conditions. In other words, sand is readily exchanged by these morphodynamics, resulting in the formation of sandbars offshore or dunes onshore. However, the resulting seasonal currents and the uneven movement of billions of tonnes of sand per year make the coastline vulnerable to the disruption of sand flows (e.g., by seawalls), resulting in an imbalance of sediment within a given sediment cell (Ramesh et al., 2011). Also known as littoral cells, a sediment cell encompasses the intertidal and nearshore movement of sediment at the shore including zones of erosion, transport, and accretion (Herman & Zhang, 2015). Particularly along the Coromandel Coast, sediment cells can extend for hundreds of km, crossing politically determined state boundaries, as is the case between Pondicherry and Tamil Nadu, which share the same sediment cell. Surrounded by the state of Tamil Nadu, coastal disturbances in the territory of Pondicherry materialise across states due to a shared sediment budget. Thus, sand actively produces coastal space beyond state jurisdiction.

Conceptually, we engage with the growing literature on "geosocialities" (Palsson & Swanson, 2016; Yusoff, 2018), which builds on and extends the concept of the "social life of sediment." Broadly speaking, the term "geosociality" encompasses the society-nature entanglements of the geological and the social, as well as the ways in which "humans in specific localities perceive and make sense of the geophysical environment" (Flitner et al., 2018, p. 47). It thus encompasses the making of the meaning of adaption efforts that reshape coastal geomorphologies but also the actors (e.g., fishing communities or local authorities) who manage vulnerabilities associated with coastal hazards. More specifically, the concept of the "social life of sediment" suggests that social needs, values, and activities are intertwined with the movement, or the mere existence, of sediment (Parrinello & Kondolf, 2021). By drawing on sediment metabolism for urban political ecology, Gustafson (2021) showed how sediment dynamics are linked to power relations in the production of uneven geographies. For this work, power is understood as relational in the sense that power arises from making connections across space and is generated between humans and non-humans as actualised power (Latour, 2005; Müller, 2015). In the Anthropocene, characterised by human influence on a planetary scale, sediment requires greater attention in social enquiry, given the multiple ways in which human activities directly intervene in sediment movement, such as through dredging or construction projects. Deforestation, for example, leads to soil erosion, which increases the sediment load of rivers, which in turn causes flooding and the reshaping of the morphology of coastal areas (McNeill & Winiwarter, 2010).

While the "social life of sediment" concept is mainly applied to the alteration of sediment fluxes in rivers, this article investigates human–sand relations with the aim of extending it as an analytical tool for ocean sand. For example, coastal land loss due to sediment starvation has received little attention in the literature. Similarly, the role of sufficient sediment supply for coastal restoration remains largely under the radar of policy debates (Parrinello & Kondolf, 2021). Building on the "social life of sediment," the integration of ocean sand recognises its critical role and the linkages between sand extraction, either through mining protective features or by altering coastal morphodynamics (e.g., tidal currents), and coastal hazards such as erosion from flooding. It allows us to examine the relationship between people and sand, where livelihoods depend on active sand bodies that are intertwined with the functioning of the marine ecosystem. Ocean sand therefore has non-human agency and is intertwined with social practices, coastal spaces, and needs that cannot be separated from the processes of adaptation. In the vein of co-produced natures and societies in the Anthropocene, a focus on geosocialities seems timely, where humans themselves have become a geological force to which they are now adapting. Climate change itself shows "how dangerous geologic intimacies have long been in the houses and factories of Europeans—the glowing red coal fires entangled with industrial capitalism and 'modern' life" (Palsson & Swanson, 2016, p. 153). Moreover, this argues for recognising non-humans as implicated in webs of world-making and overcoming environmental determinism. Such an approach is in line with current calls for research to focus on more than human sociality (Krøijer, 2021; Tsing, 2013) and the goal of investigating the intersections between life and non-life (Povinelli, 2016).

4. Methodology: Following Ocean Sand

The methodology underlying this article is derived from the conceptual underpinnings of a more-than-human approach and is inspired by studies that "follow-the-thing" (Appadurai, 1986; Cook, 2006; Haegele, 2024; D. Harvey, 1990; Marcus, 1995). However, rather than following sand as an object back to its origins, we follow sand in the regional context of the Union Territory of Pondicherry, a former French enclave, and Tamil Nadu along the Coromandel Coast in southern India. This method aims to unravel human–sand relations by following multiple sites, or in a more Marxist fashion, tearing aside the veil to expose power relations and reveal underlying vulnerabilities of coastal adaptation (Hulme, 2017). Previous studies have mainly uncovered social relations behind the veil of commodities to make non-human actors visible. In our case, instead, we follow sand not in the logic of sought-after construction material, but as a crucial "thing" in dealing with issues of coastal erosion and infrastructure and the sustenance of coastal communities. Using qualitative methods, including semi-structured interviews, informal discussions, and direct observation, we engage with a range of coastal actors and ground our research in the everyday situations of artisanal fishing communities. Through these methods, we aimed to understand their perspectives on sand, disappearing beaches, protective measures, and the causes of coastal erosion. We mainly asked the same open questions to the same actors but changed the framing of our questions with respect to other actors. Fieldwork was carried out on the Coromandel Coast, particularly in Pondicherry and neighbouring fishing villages, between October 2023 and March 2024 as part of a research fellowship at the French Institute of Pondicherry. In total, $n = 33$ semi-structured interviews were conducted with fishing communities but also NGOs, involved in coastal protection and beach restoration, scientists from the National Centre for Coastal Research, locals involved in tourism, and government authorities, including the Public Works Department, the Port Department, the Pondicherry Coastal Zone Management Authority, the Pondicherry Climate Change Cell, and the Fisheries Department. For detailed location, the fishing villages of Bommayiarpalayam and Pillaichavady were selected, both of which are critically affected by coastal erosion, frequent cyclones, and the ongoing construction works of groins and seawalls to prevent the loss of beach sand (Figure 1).

Bommayiarpalayam is in Tamil Nadu state, while Pillaichavady is divided between the state of Tamil Nadu and the Union Territory of Pondicherry (still called French Pillaichavady by the elders). Respondents were identified following human–sand interactions and snowball sampling techniques starting from the Pondicherry Harbour northwards. Interviews were recorded, in some cases translated from Tamil into English, and transcribed where possible. The data was supplemented by field notes and transect walks along the coast. The transcribed material, consisting of interviews, field notes, informal discussion, and relevant policy documents was then coded using ATLAS.ti. Codes were derived inductively in the process of identifying key themes by following ocean sand. Key themes include sand as an actor (e.g., littoral drift), hard infrastructures (e.g., harbour and groins), spatial implications for fish workers, as well as rock extraction for coastal protection and are illustrative of the quotations in the discussion section.

Figure 1. Map of the study area.

5. Results and Discussion

5.1. Disrupted Sand Flows Along the Coromandel

The city of Pondicherry and the state of Tamil Nadu are located on the south-eastern coast of India, which is characterised by extensive sandy beaches, dunes, and other coastal landforms such as lagoons, estuaries, mudflats, marshes, and deltas (Figure 1). About 100km south of Pondicherry lies the Cauvery Delta fed by the Cauvery River, which deposits large quantities of sand and silt, forming wide sandy beaches through the forces of the littoral drift. Dunes and beaches, which are significant sand accumulations, make up a large portion of the Coromandel Coast and play a crucial role in shaping the coastal morphology and influencing land use planning in the studied coastal zone. The entire coast of India is shaped by the natural movement of sand (littoral drift). In particular, the coastal stretch along Pondicherry shows a substantial net transport of sediment along the coast, which implies that the sand moves predominantly in one direction (Lakshmi et al., 2012). During 8–9 months of the year from March to October, the southwest monsoon moves sand northwards, while during the remaining winter months (3–4 months) sand is transported southwards by the northeast monsoon (Figure 4). The coastal region of Pondicherry and Tamil Nadu is one of the most vulnerable states to coastal hazards in India, particularly due to more frequent cyclones and storm surges in the face of climate change (Black et al., 2019). Sea-level rise due to climate change is another major challenge for the low-lying coastal areas of the Coromandel. Due to increased climate variability, coastal areas are projected to experience higher tides and more intense storms arising from a warmer sea. These weather extremes generally occur during the monsoon season. During this period, sand is transported from the beach to the offshore sandbank, reducing wave energy. With the end of the northeast monsoon winds, the sand moves shoreward, driven by the waves. The natural movement of sand is therefore necessary to reduce the intensity of more frequent coastal hazards.

Providing a large number of functions—from sustaining fish habitats to providing space for boat parking—the traditional fishing techniques of the many fishing communities in the area evolved over centuries around a sandy beach ecosystem (Figure 2). In Tamil Nadu, some fishing communities have an unbroken tradition of over 2,000 years of occupying the space closest to the sea (Madhanagopal, 2023). In fact, the local ecosystem is associated with the particular fishing caste, the Hindu *Pattinavar* on the Coromandel Coast, who dominate this part of the coast. Traditionally, the *Pattinavar* have relied on strong self-governance through the evolution of institutions (e.g., *uur panchayats*), sometimes beyond state jurisdiction, to maintain social control and access to the use of fish resources and community management (Bavinck, 2001; Singh & Chellaperumal, 2014). Houses are built close to the coastline to ensure visibility of the sea to locate shoals of fish (e.g., changes in sea colour or wind direction). With the liberal and uncontrolled distribution of fishing equipment through private humanitarian aid after the tsunami in 2004, artisanal fishing has mainly switched to mechanised gear, although traditional craft is still used, especially close to the shore. In this, the lines between economic development and humanitarian aid were blurred and post-tsunami emergency reliefs by the government were tied to the inland relocation of artisanal fishing communities (Cohen, 2011; Wright et al., 2021). Being more labour-intensive, the artisanal fishing sector requires the largest number of fish workers who use coastal common areas, particularly sandy beaches, for the following purposes: boat landing and storage, boat repair and maintenance, catch drying, net mending and maintenance, and fish auction and sale. Coastal communities also need beach space for cultural purposes such as during the Maasimagam festival in which the local deities of nearby temples are carried to the sea for a ceremonial bath. Access to sand and the space for the seasonal formation of beaches is, therefore, critical to the livelihoods of sand-based fishing communities.

Figure 2. Artisanal fish workers along the Coromandel and Pondicherry in the 1950s. Source: PondyCAN (2008).

5.2. Historical Accounts of Shifting Sands and the Construction of Social Vulnerability

Along the Pondicherry coast, the first coastal structures to interfere with the natural movement of sand date back to the 1860s (Figure 3), when a 1.5km seawall was constructed to protect what is now known as the French Town, which was built over the sand dunes. From there, large granite boulders were continuously dumped along the beach road to strengthen the wall against erosion (Figure 3). However, it was a commercial harbour built by the Pondicherry government in 1986 at the mouth of the Ariankuppam River, about 1.5km south of the main town, which caused the most rapid erosion (Figure 4). Two massive breakwaters were built within the littoral zone of the coast to act as an artificial entrance. As a result, this artificial channel blocked the natural movement of sand and deposition of sediment, starving the coast to the north of the harbour and causing severe erosion due to the disrupted sediment budget. The construction of the harbour not only drastically exacerbated the erosion, but also set in motion a vicious cycle of coastal protection measures that resulted in the fortification of the coastline with seawalls and the trapping of sand resources by groins north of Pondicherry.

Figure 3. (a) Fortified Pondicherry (18th century); (b) Old Pier (1950s); (c) Seawall along beach road (1970s). Source: Lakshmi et al. (2012).

The construction of a 6km seawall between 2002 and 2003 further shifted the erosion from the Union Territory to Tamil Nadu. In the process, several km of beach and village land of fishing communities were lost to the sea. Guided by the narrative of taming nature, when the tsunami struck the coast in 2004, another push for hard infrastructure legitimised the enlargement of seawalls and the construction of groins to defend from and fight against the sea. Although other coastal areas outside the study site were more strongly affected by the tsunami due to different elevations, an abundance of funds was made available by the government for the implementation of new projects to protect the coast. A similar reactive dynamic unfolded in the aftermath of Cyclone Thane in 2011 (Punithavathi et al., 2012). Following this, proposals for groins by the Public Works Department on both sides (Tamil Nadu and Pondicherry) were passed without the environmental impact studies as demanded by NGOs or without obtaining Coastal Regulation Zone (CRZ) clearance. According to the CRZ Notification 2019, the area where groins were built falls under CRZ IV (water body) and CRZ IB (intertidal zone), wherein any construction is prohibited without CRZ clearing from the Coastal Zone Management Authority of Tamil Nadu (National Centre for Sustainable Coastal Management & Ministry of Environment, Forest and Climate Change Government of India, 2024). The CRZ include the coastal area up to 500m from the high tide line and falls under the governance of CRZ rules that demarcate coastal areas in different zones, for example, no development zones. As a result, the flow and distribution of sand resources have been drastically altered, with disputes between various coastal actors and devastating impacts on the artisanal fishing communities in northern Pondicherry.

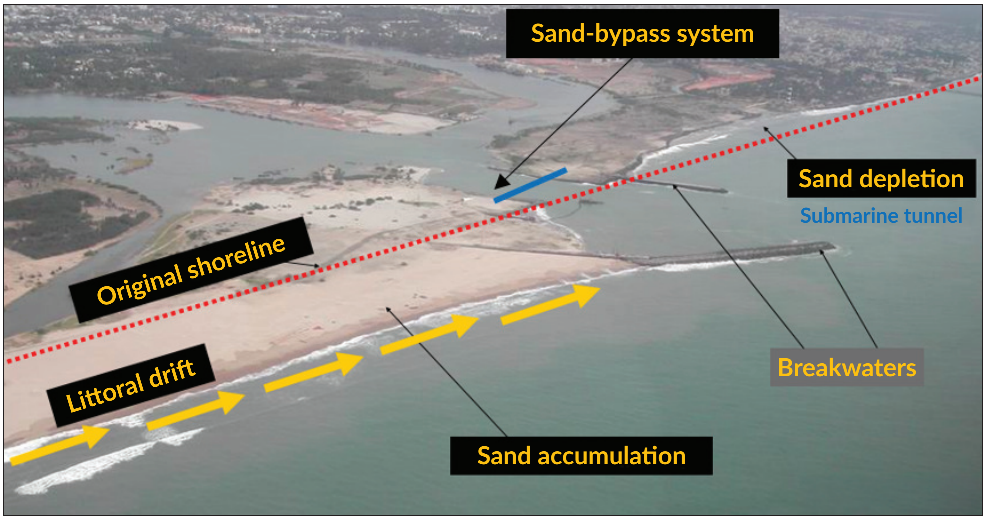

Figure 4. Aerial view of the Pondicherry harbour blocking sand at the mouth of Ayriankuppam River. Photo: PondyCAN.

To date, more than 80 hectares of the beach have been lost along the study area, affecting 20km of coastline, with more than 7,000 fishermen losing their livelihoods and at least a dozen fishing villages wiped out (Bautès et al., 2023). Artisanal fishers are still affected by the increasing loss of working space due to the loss of beaches. As beaches are lost and extended seawalls impede access to the sea many are forced to launch their boats from distant beaches outside their village or find new employment in urban areas. In addition, shoals of fish coming close to the shore have diminished, making artisanal fishers more vulnerable by pushing them further out to the sea where reportedly storms become more unpredictable as the Bay of Bengal is getting hotter. The disappearance of sandy beaches, which are closely linked to the livelihoods of fishing communities, has therefore contributed significantly to their social vulnerability. In response to man-made erosion, several fishing communities have made numerous attempts, including protests, road blockades, and hunger strikes, to reach out to their respective government to demand compensation, and protection of their villages and the beach in front of their homes.

5.3. Dammed Rivers of Sand and the Impact of Groin Fields

We follow ocean sand by unpacking the human–sand relations in the coastal development of a harbour, the construction of groins for coastal protection that led to the damming of sand rivers and the creation of a cycle of maladaptation. Although hidden and sometimes invisible in the sea, shifting ocean sand exerts agency over its use and is significantly involved in the social web that produces winners and losers in the making of coastal protection. It does so primarily by co-shaping the coastal morphology with humans who, for example, perceive and make sense of the loss of a beach in different ways. This notion of the "geosocial" is illustrated by the following quote from a respondent:

> Of building groins, you just see the land area, how much of beach we have lost. You can see that the beach has no value. Because it is public property or it is not private, so it has no value. (NGO interview, 2024)

Under the pressure to reclaim the lost sand resources, but without the approval of the environmental authorities, the Tamil Nadu government has constructed a series of about 12 groins reaching as far as Bommayiarpalayam, thereby diverting the erosion back into the Union Territory of Pondicherry (Figure 5). Groins are impermeable walls, usually made of rock, that extend vertically from land into the sea. Along the Coromandel Coast, groins are used to trap the sand as it moves northwards. While small beaches have formed along the structures, like the breakwater at the harbour (Figure 4), the groins have deprived adjacent shorelines of sand and rapidly accelerated northward erosion (Figure 5). A protesting fisherman states: "Don't allow Pillaichavady to make the groins, because if they make the structures, then we are gone" (Fisherman interview, 2023). The engineering of groins implicitly carries a logic of sacrificing the beach zones on which artisanal fishing depends. At the same time, the neighbouring fishing villages demand these measures as a last resort to preserve some of the lost ocean sand to protect their homes.

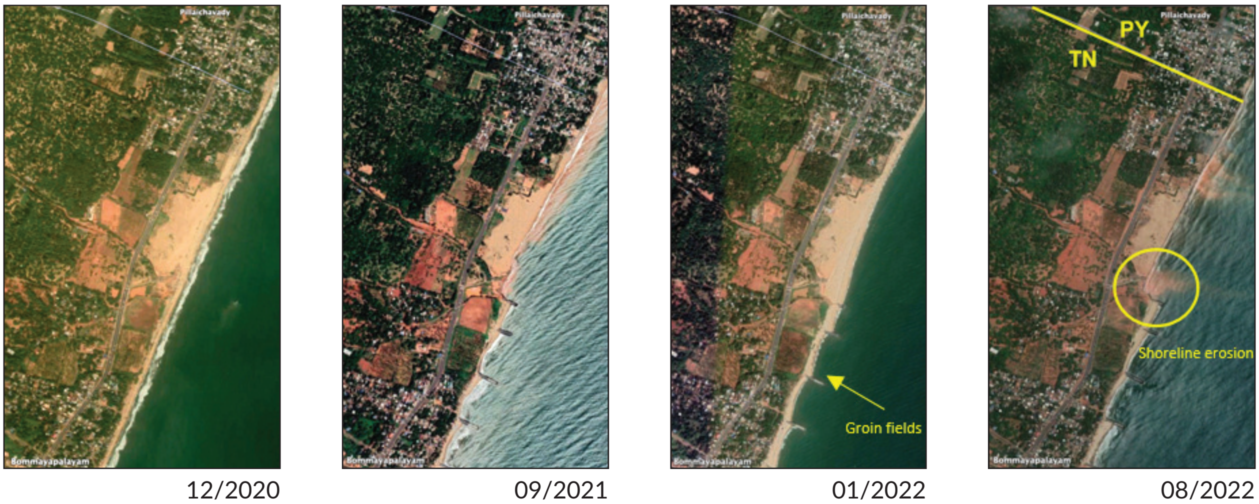

Figure 5. Time-lapse of satellite images documenting the construction of groin fields. Note: "TN" refers to Tamil Nadu and "PY" refers to Pondicherry. Source: Google Earth.

Artisanal fishers are forced to adapt to these spatial changes by moving where ocean sand newly accumulates on which they can safely store their gear. Faced with coastal pressure from all sides, the migration of fish workers often leads to conflicts with other self-governed fishing communities, mainly because of the interference in their livelihoods and the restrictions they face due to more boats that need to be parked on the sandy shore. Several interviews with affected fish workers highlight the constant mode of survival linked to their livelihood (e.g., seasonality and availability of fish or lucky catches), which leads to the urgency of quick solutions with short-term security. Reportedly claimed to be an emergency measure, the government builds hard infrastructure when it is too late, e.g., after a cyclone, and the "natural" disaster has already unfolded. A scientist at the National Centre for Coastal Research puts it this way:

> Suppose you have a stomach pain, what do you need? You need medicine to eat because you don't know. You don't have time to think about your pain, why it happens. What is the cause? So exactly the same. This groins and everything. I find it is a temporary measure without understanding the dynamics of the sea. (Coastal scientist interview, 2023)

In the long term, however, groins create dammed rivers of sand that, like a river dam, interrupt the flow of ocean sand and thus also redistribute who has access to ocean sand resources (Figure 6).

Figure 6. A groin in Bommayiarpalayam village is blocking sand movement northwards.

The starvation of ocean sand in Pondicherry was not unexpected when the harbour was constructed in 1986. After the decision in favour of groins, another human–sand entanglement needs to be unravelled, the dysfunctional sand bypass system and the failure to dredge the unevenly accumulated sand for beach nourishment: “What if I tell you, that you use that money not for dumping stones but for dredging? Because if they dredge, the sand will come and you don’t have to put stones” (Civil society organization interview, 2023).

Instead, the design included a sand bypass system that allows the accumulated sand to be dredged and pumped to the other side, restoring the natural movement of sand and mitigating the effects of erosion (Figure 4). In the absence of regulatory monitoring and poor harbour revenue generation, lack of funding and political will led to the failure of maintenance dredging which would have been crucial for beach nourishment and de-silting of the harbour channel (interview, 2024). In the end, dredging was mainly carried out when the mouth of the harbour became clogged with sand to allow commercial fishing vessels, such as trawlers, to pass through. The allocation of ocean sand by the deepening of the channel here prioritises the trawler association of commercial fishers over the artisanal fish workers who depend on access to the sandy beaches of northern Pondicherry. The lack of access to the beach due to the disruption of seasonal sand movement forces fish workers to relocate their gear to newly formed beaches where boats can be parked safely (Figure 7). These dynamics show the underlying vested interests and unequal power relations over the distribution of sand resources, also given that fish workers from Tamil Nadu are not allowed to use the Pondicherry harbour and its construction which was done without prior consultancy of the affected fishing communities.

Figure 7. Fish workers relocate their gear to a coastal space with wider beaches.

However, a critical question remains regarding the adaptation to coastal erosion by artificially creating sandy beaches: “If they can spend so much money in building groins, why can you not spend money and just reactivate this sand bypass system and your problem is solved?” (NGO interview, 2023).

To a large extent, such decisions by government authorities can be answered by understanding the vicious cycle of hard measures that have been created, underpinned by strong modernist narratives of flood control and defence *against* the sea rather than *with* the sand. Grains of sand in the coastal environment are like “free spirits” that never stand still (interview, 2023). However, as in many other Indian coastal cities, and at a cost of several crores of rupees, the Public Works Department has facilitated large-scale operations to dump massive rocks, extracted and trucked in from quarries in the Tamil Nadu hinterland, to stop the movement of sand and fortify the coast, as it was conducted by the French in colonial times (Lakshmi et al., 2012): “Whenever we face the sand problem, we will engage some cranes and Hitachi machines to pick up the stones buried into the sea that is development work” (Coastal authority interview, 2024). The continuous movement of ocean sand causes the rocks to sink further and further, requiring new hard materials to maintain the hard coastal defences. Consequentially, continuous northward erosion has created a “sustainable business model” (interview, 2023) in the sense that there is a never-ending demand for more rock to adapt to the disrupted sand flows created (Figure 8).

While climate change is not discussed as a cause of erosion at the local level, projects proceeding under the outlined status quo of coastal protection are increasingly framed as climate change adaptation. The National Bank for Agriculture and Rural Development, for example, has been accredited to the Green Climate Fund and by the Adaptation Fund Board of the United Nations Framework Convention on Climate Change to implement climate change adaptation and mitigation programmes, particularly through the Rural Infrastructure Development Fund. With a focus on technocratic measures, the construction of groins falls under the category of rural infrastructure projects for flood protection and projects benefit from new

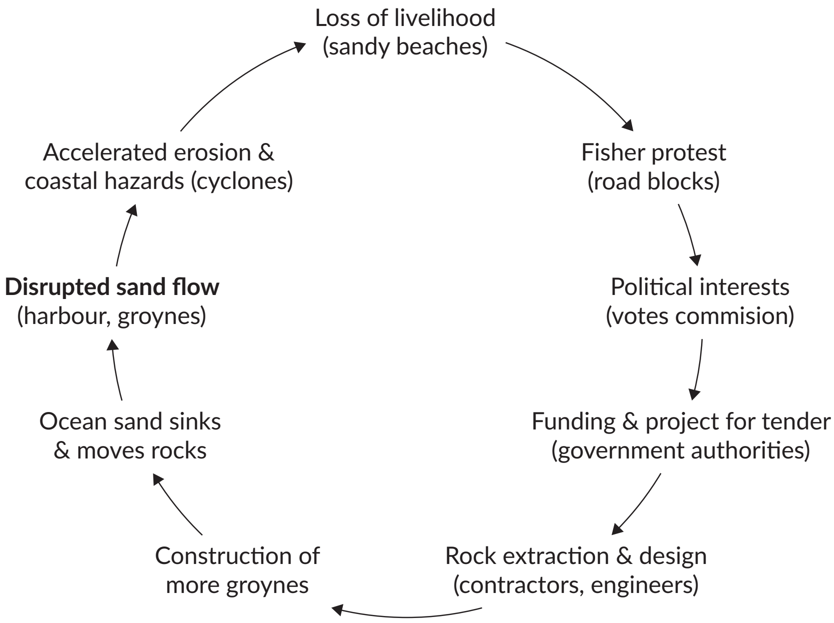

Figure 8. Cycle of coastal maladaptation.

sources of funding. An interviewee from a local NGO complains, "Because of this whole emphasis on climate change it almost kind of makes you helpless on the local level" and "today every funding comes only with a climate change tag." This re-labelling overlooks the materiality of sand and thus sidelines an investigation of the root causes of sand loss (Connell, 2003). Moreover, coastal interventions in the sandy intertidal marine zone play into the pockets of political parties that have seized the opportunity to create new coastal protection or adaptation projects:

> It is a continuous money-making thing, because on the one hand these stones will sink, and you have to keep more stones and secondly you have to keep extending. Politicians are happy to produce this kind of projects. These are big-budget projects. So, the moment Pillaichavady makes groins they will need a contractor to start mining the stones, procuring the stones. There are so many levels. At every level, money has to be given. If you don't give money, you don't get your groins. (Interview, 2023)

The failure of soft adaptation measures, such as dredging for beach nourishment, is linked to the vested interests of various actors ranging from coastal engineers and quarry owners to the transporters and contractors who are paid to transfer rock, not sand, from one ecosystem to another. Repeatedly, the implementation of such infrastructure suffers from poor planning, with little of the planned budget left over after the funds have been allocated and the projects commissioned. Corruption also often delays the implementation of protective measures, increasing vulnerability during the monsoon season. In this way, local politicians who need votes to stay in power respond to the demands of the protesting fish workers without having enough time to consider more holistic approaches to long-term coastal management. For example, the engineering of interventions that trap sand faces the increasing unpredictability of how much sand will actually move. As more and more structures are built along the coast, it becomes almost impossible to calculate back the "natural" transport of sand and therefore to model the potential effects of shifting erosion. In addition, the relocation of large quantities of ocean sand for beach nourishment makes monitoring even more difficult:

> What happens when the dredger comes? The meter will tell you how much sand is going out. The first thing they will do is break the meter because if the meter is not there, you make five hundred metre cubes and you sell them for five thousand. How do you check? (Coastal authority interview, 2024)

Inherent in the materiality of ocean sand future adaptation projects and past coastal protection are bound up with the difficulties of monitoring sand loss, predicting sand movement and, ultimately, allocating a fair share of sand to the communities that depend on it. The materiality of ocean sand, in particular, its unruliness across political boundaries and its agency in social processes, such as adaptation, raises complex issues for coastal governance and the appropriateness of the demarcations it proposes in different coastal zones. Geosocialities scholarship thus opens up new avenues for interdisciplinary research to deepen our understanding of forms of geomorphological agency, here ocean sand, and society. While this article has attempted to do so by exploring the coastal dynamics around artisanal fishers and coastal protection strategies, this approach is limited to capturing the broader global environmental governance architecture related to climate change adaptation. Thus, one of the major challenges is not only to extend the time scale of ocean sand observations but also to trace the global in the local by extending the spatial scale of the analysis. This will require future work that goes beyond the material implications and considers, for example, the broader politics of knowledge production that guides and legitimises future adaptation strategies.

6. Conclusion

This article reveals the complex (non)human relations between ocean sand, artisanal fishers, and the making of coastal protection at multiple spatial and temporal scales. Tracing human–sand entanglements along the Coromandel renders visible the governance challenges inherent in dynamic coastal environments. Through its movement and accumulation, ocean sand has the power not only to adapt to hard infrastructure but also to interact with the actors who depend on it (Kothari & Arnall, 2020). Adaptation outcomes depend not only on the material conditions of how ocean sand shapes the coastal environment but also on how different actors negotiate its (re)distribution. From a livelihoods perspective, zooming in on ocean sand highlights the pitfalls of property rights that focus solely on land-based livelihoods and overlook shared beach spaces. Future adaptation measures must therefore treat mobile ocean sand as a secured public good that actively forms the basis of coastal environments and the fisheries that depend on them. Following the locations of disrupted sand flows permitted the unpacking of human–sand relations and brought to the fore a situation of sediment starvation caused by a harbour or the attempt to dredge and pump sand for its accumulation to mitigate coastal erosion. In this case, the narrative of protection from a violent sea guided the implementation of groins, resulting in the disruption of sand flows and the loss of livelihoods for thousands of artisanal fishers. Similarly, as Anand et al. (2018, p. 2) point to infrastructure as a “terrain of power and contestation,” the implementation of coastal infrastructure in particular, such as groins, is embedded in unequal power relations. This raises questions of environmental justice in future adaptation efforts: To whom will ocean sand resources be distributed and from whom will they be taken?

To address this question, we conclude that recognising ocean sand as a non-human agent offers new perspectives for addressing coastal erosion and sea-level rise in the context of coastal adaptation strategies. Acknowledging the agency of non-humans helps overcome the long-established Western notion of modernity underpinned by dominating nature through technology and hard coastal infrastructures (Arnall, 2023). We show how adapting to coastal hazards through static measures that ignore the dynamics of ocean sand deepens the vulnerabilities and inequalities of some populations more than of others. Engaging with the fluid materiality of ocean sand therefore provides a lens through which to analyse the hidden complexities of different coastal actors in managing coastal risk. Our empirical study also relates the construction of a destructive harbour to the cycle of constant hard solutions to prevent further erosion to the north. It thus opens up new relevant avenues for a case of undoing the coast in future adaptation-making with the aim of preventing the disruption of sand flow and reducing the risk of maladaptation. The concept of "geosociality" here helps to imagine new forms of agency to reshape the entangled geographies of static coastal development policies. It forces policymakers to be aware of the trade-offs between prioritising development and economic growth (e.g., harbour) over transformative coastal adaptation strategies. Uncertainties in adaptation planning and the making of coastal protection design are hereby linked to the materiality of ocean sand and therefore need to be investigated as such when understanding the local vulnerability contexts in which climate change adaptation projects materialise.

Because of the shifting boundaries of the shoreline, which are neither water nor land, coastal adaptation processes are accompanied by a less clear legal framework than on land. In addition, these processes must take into account different competing actors and their interests in the use of coastal resources (Alexander, 2021; Bavinck et al., 2017). In the case of Pondicherry and Tamil Nadu in particular, adaptation to ocean sand flows also requires recognising them as a vital political entity that operates across politically determined state boundaries, but within large sedimentary cells. Ignoring this has transferred and exacerbated coastal erosion to neighbouring jurisdictions where self-governed fishing communities compete for shrinking beach space. The complexity of coastal adaptation stems not only from the uncertainties of climate change impacts but also from vested interests in the use of diminishing sand resources and the unruly character of continuously moving ocean sand (Hein & Thomsen, 2023). Ultimately, ocean sand in its various functions and uses is at the very centre of coastal adaptation processes and coastal risk management policies. Our case links to other work showing how livelihoods dependent on sand resources are forced to adapt to changes in sand availability (Lamb & Fung, 2021). The ability to access, use, and relocate sand resources determines winners and losers in these processes. We conclude by borrowing from the phrase: Not to bury our heads in the (ocean) sand by ignoring the very foundations of the land–sea interface!

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Conflict of Interests

The authors declare no conflict of interests.

Supplementary Material

Supplementary material for this article is available online in the format provided by the author (unedited).

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