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Shoring Up

Climate Change and the Indian Coasts and Islands

Rohan Arthur

As the science fiction prophet Douglas Adams well knew, the secret to invisibility was magnitude. The only way to reconcile the cognitive dissonance of immensity is to deny its existence. As an undefined force that acts at scales inconceivably larger than typical ecological, social, economic, or historical processes, accepting that climate change is now one of the primary drivers of these processes is not easy. A similar cloak of invisibility shrouds the global oceans. Our knowledge of ocean processes declines exponentially as we dive below the photic zone, rendered more than metaphorically invisible. It is scarcely surprising then that in public discourse in India, the impact of climate change on the oceans is an invisible force acting on an invisible space.

In reality, the ocean is a central regulatory organ of climate; anthropogenic modifications of oceanic processes can result in major disruptions in this regulatory function. On coasts and oceanic islands, these disruptions are being experienced first-hand, even if it

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is difficult at smaller scales to link them back to a changing climate. Coasts are naturally dynamic, but their resilience is quickly unravelling as oceanic currents, surface temperatures, weather patterns, and ecosystem function all respond to rapid environment change. Populations congregate thickly within 100 km of the coast (Small and Nicholls 2003), placing coastal communities at the highest risk. Low-lying oceanic islands are at one extreme of this vulnerability and are the first to experience the first and higher-order impacts of climate change (Barnett and Adger 2003; Duvat et al. 2017; Storlazzi et al. 2015). India's coastline stretches for more than 7,500 km and coastal districts house roughly 17 per cent of its population. More than 250 million people crowd within 50 km of the coast, a fifth of it concentrated in the megacities of Mumbai, Kolkata, and Chennai (Sudha Rani, Satyanarayana, and Bhaskaran 2015). While coastal cities present a unique set of problems, the entire coastline is subject to the impacts of climate change.

I will briefly describe the essential services that coastal ecosystems supply and the principal climate-related threats to them. I will then explore policy responses to climate vulnerability. Using a case study from Lakshadweep archipelago, I will examine the responses of low-lying atolls to climate change. Finally, I will discuss what mainstreaming coastal climate vulnerability in public policy would require.

Coastal Ecosystems and the Services They Provide

Humans flock to coastlines for a reason. Coastal systems are rich in resources, offering a wide array of provisioning services that sustain livelihoods. Marine fisheries are completely dependent on the productivity of these systems. India extracts about 3.63 metric tonnes per year of fish, squid, and shrimp from its exclusive economic zone—the third-largest capture fishery in Asia, the seventh worldwide (Fishery Resources Assessment Division [FRAD] 2017). From being largely artisanal in the 1950s, the fishery has rapidly industrialized and diversified with intensive mechanization. As near-shore ecosystems deplete, mid-water and deep-sea communities are being increasingly targeted. The boundaries between small-scaled artisanal and large industrial fleet fishing are fuzzy as the sector connects to international markets.

From daily subsistence to factory production, the fishery is completely dependent on the services that ocean and coastal ecosystems provide. In addition though, these systems support important regulatory, supporting, and cultural services vital to coastal livelihoods, summarized in Table 29.1. Many coastal and pelagic ecosystems are important carbon sinks, capturing atmospheric carbon, burying it in sediments or transporting it deeper. Seagrasses, mangroves, and salt marshes have some of the highest sequestration rates globally. They are, therefore, important organs in the global biosphere, helping offset greenhouse gas emissions. When they are lost or degraded, they lose centuries of carbon reservoirs along with their sequestration abilities. Worse, they may even become net emitters of carbon and methane, compounding climate change impacts.

Impacts of Climate Change on Coastal and Marine Systems

We are still relatively new colonizers of the sea. While anthropogenic species' extinction started almost 100,000 years ago on land, only in the last few centuries have we been exterminating marine species sufficiently to be noticed. This is no reason for complacence—marine defaunation has increased dramatically in the last decades as we rapidly industrialize the sea (McCauley et al. 2015). How much this loss can be attributed to climate change alone is difficult to ascertain. Climate change is one among several interacting drivers defining the characteristically human signature of the Anthropocene. Mapping the global human footprint on oceanic systems, Halpern and others identify only 3 uniquely climate-related drivers (sea-level rise, ultraviolet radiation, and ocean acidification) among the 17 they list (Walbridge et al. 2008). However, apart from being a distinct agent of environmental variation, climate change pervades non-climate drivers as well. In turn, many of these factors contribute to positive feedbacks in climate trajectories, further destabilizing the self-regulatory capacity of whole-earth system dynamics.

Species and Ecosystem Responses

It is difficult to completely disentangle the influence of climate change from non-climate drivers in determining current

Table 29.1 Major Coastal and Marine Ecosystems in India, Their Principal Threats, and the Services They Provide to Human Communities

System	Distribution	Threats and Status	Ecological Goods and Services		
			Provisioning	**Regulatory and Supporting**	**Cultural**
Landward					
Mangrove forests	In pockets on both coasts and in island systems. Extensive in the Sundarbans.	**Threats:** Habitat conversion, logging, pollution, overfishing, sea-level rise, other climate-related effects. **Status:** Drastic reduction across India, restoration efforts at several locations.	1. Fish and shellfish 2. Timber 3. Mixed agriculture, aquaculture	1. Coastal protection 2. Erosion control 3. Pollution control 4. Carbon sequestration 5. Fish nurseries 6. Nutrient cycling	1. Sacred sites 2. Tourism 3. Large channels used as waterways for transport
Sand dunes and beaches	1. Beaches abundant on coasts and islands. 2. Dunes are patchily distributed, more on east coast.	**Threats:** Habitat conversion, beach hardening/coastal development, vegetation loss, sand mining, sea-level rise. **Status:** Dunes largely destroyed/converted, beaches still abundant.	1. Sand and minerals 2. Agriculture on landward side	1. Coastal protection and wind breaks 2. Erosion control 3. Water catchment 4. Pollution control 5. Small carbon sequestration ability when vegetated 6. Turtle nesting sites	1. Boat landing sites 2. Post-harvest areas (sorting, drying, packaging, and so on) 3. Beach tourism

Salt marshes	Limited distribution, mostly Gujarat, but also Tamil Nadu and Andhra Pradesh.	**Threats:** Habitat conversion, aquaculture, cattle grazing, hydrological and salinity changes, invasive species, pollution, sea-level rise, other climate-related effects. **Status:** Limited information.	Cattle fodder	1. Coastal protection 2. Erosion control 3. Pollution control 4. Extremely high carbon sequestration capacity 5. Nurseries for crustaceans, fish 6. High bird diversity	Bird watching tourism
Seaward					
Sedimentary habitats	Extensive on continental shelf.	**Threats:** Trawling, pollution. **Status:** Limited information despite high dependence.	1. Shrimp, other invertebrates 2. Bottom-dwelling fish	1. Potentially high carbon sequestration 2. Pollution metabolism and burial 3. Filtering can help water clarity 4. Nutrient cycling	None
Seagrass meadows	Gulf of Mannar/ Palk Bay; Andaman & Nicobar Islands; Lakshadweep. Patchy meadows elsewhere.	**Threats:** Sedimentation, fragmentation, pollution, invasive algae, climate change impacts equivocal. Status: Major decline across India.	Fisheries	1. Coastal protection 2. Erosion control 3. Potentially very high carbon sequestration capacity 4. Fish and invertebrate nurseries 5. Nutrient cycling	Tourism benefits equivocal (seagrass cast often disliked by tourists)

(cont'd)

Table 29.1 *(cont'd)*

System	Distribution	Threats and Status	Ecological Goods and Services		
			Provisioning	**Regulatory and Supporting**	**Cultural**
Coral reefs	Atoll and fringing reefs on oceanic islands, Gulf of Mannar/Palk Bay; patch reefs in Gulf of Kutch; smaller reef formations elsewhere; unexplored banks off west coast.	**Threats:** Overfishing, sedimentation, pollution, climate-related increases in sea surface temperatures, ultraviolet radiation, ocean acidification. Status: Highly threatened globally and in India.	1. Fisheries (about 12% of global production) 2. Octopus, sea cucumber, shellfish, and so on. 3. Aquarium species 4. Calcium carbonate for construction	1. Coastal protection 2. On atolls, critical for island formation and maintenance 3. Unclear if net source or sink of carbon 4. Fish nurseries 5. Nutrient cycling 6. High diversity	Tourism
Pelagic waters	Widespread	**Threats:** Overfishing, pollution (oil spills, ship transport, plastics, etc), changing ocean currents, other climate change effects. **Status:** Slated for exponential increase in exploitation.	Pelagic fisheries	1. High carbon storage capacity 2. Pelagic phytoplankton, main engine of primary production in the sea 3. Nutrient cycling 4. Habitat for iconic pelagic species	1. Religious, mythological, and literary symbolism 2. Global transport 3. Cruise and sport tourism

Source: Banerjee et al. (2017), Barbier et al. (2011), Holmlund and Hammer (1999), Moberg and Folke (1999), Patro et al. (2017), and Snelgrove (1999), among others.

environmental and socio-ecological trends. The uniquely climate-related drivers on marine and coastal systems include: (i) sea-level rise; (ii) increasing sea surface temperature; (iii) oceanic current disruption; (iv) ocean acidification; and (v) intensity and frequency of unusual weather events. These interact in complex ways, amplifying or dampening each other's influence. Together they trigger a host of first-order effects—directly influencing species physiologies, life histories, survival rates, population trends, movement and migration patterns, species interactions, and habitat condition. Species cope differentially with the intensity and rapidity of these changes, creating winners and losers as better-adapted opportunists outcompete specialists. For instance, with increasing tropicalization of subtropical and temperate waters, ranges of tropical fish, coral, algae, and other invertebrates are expanding rapidly; freed from their usual predators and competitors, these invaders can quickly transform these new environments (Vergés et al. 2014). More typically though, ocean and coastal waters are witnessing alarming declines. Over the last six decades, phytoplankton have reduced by up to 20 per cent in the Indian Ocean—caused by increased stratification in ocean layers as a result of ocean warming (Roxy et al. 2016). This warns of a rapid expansion of a marine desert in the Indian Ocean as the principal engine of ocean productivity shuts off. At the other extreme, highly eutrophic and hypoxic dead zones are spreading across the world's oceans, including the Bay of Bengal, caused by land-based fertilizers and other chemical pollutants pouring into the sea (Bristow et al. 2016; Diaz and Rosenberg 2008). Between declining productivity and hypoxia, the Indian Ocean is showing evident signs of stress. These decadal trends become dramatically obvious as global oceanic patterns break down—the clearest being the increasingly erratic El Niño Southern Oscillation (ENSO). This current of unusually warm water pouring in from the Pacific is caused by changes in oceanic winds, with pan-tropical impacts. Since the 1990s, the Indian Ocean has experienced at least four high-intensity ENSO events; apart from being a strong driver of the Indian monsoon, it results in mass coral mortalities in tropical reefs (Baker et al. 2008; Descombes et al. 2015).

Interconnectedness

The coast is an area of busy transitions, an abundance of ecosystems, often part of a connected matrix of habitats. There is a constant transfer of material and energy within this fluid matrix. While a large part of this flow is because of oceanographic connectivity, much of it is transported by marine biota—both mobile and sedentary species move between ecosystems at some time in their life cycle. For instance, a fish may start life in the plankton in open pelagic waters, recruit in coastal mangroves, migrate back again to pelagic waters as an adult, occasionally visiting coral reefs to feed. Birds, turtles, and other marine megafauna can connect otherwise highly separated ecosystems—nesting, travelling, and foraging in locations hundreds or thousands of kilometres apart (Lundberg and Moberg 2003). This unique connectedness also links their ecological fates; impacts on one system can have significant flow-on consequences for several others.

Non-linear Ecosystem Properties

Many marine and coastal ecosystems do not respond in predictable, linear ways to increasing stress (Hewitt, Ellis, and Thrush 2016). Coral reefs, rocky beds, and pelagic systems all show complex dynamics that, under normal conditions, are held together with negative feedbacks—internal regulatory mechanisms that prevent the system from careening off on hard-to-control trajectories (Holbrook et al. 2016; Holling 1973). When these homeostatic feedbacks are disturbed, the natural buffer capacity of the system is compromised—beyond a threshold, the system collapses, often catastrophically, without much hope of recovery. We are only just coming to grips with non-linear ecosystem behaviours and are yet unable to predict system shifts before they occur.

Review of Indian Research on Climate Change Impacts

There is little first-hand research from India directly addressing climate-change consequences on marine ecosystem dynamics. The bulk of Indian research documents changes to sea-level and weather patterns, and evaluates coastal vulnerability. These studies indicate a 3.2 millimetres per year ($mm.yr^{-1}$) increase in mean sea-level along the coast (tracking global averages), with the Bay of Bengal experiencing approximately 5 $mm.yr^{-1}$ increase over the last two decades (Nidheesh et al. 2017; Unnikrishnan and Shankar 2007). This is linked to a weakening monsoon (documented since the 1950s), which causes oceanic heat retention, thermal expansion, and a consequent sea-level rise in the northern Indian Ocean (Swapna et al. 2017). The weakening monsoon rides tandem with fewer cyclones that are significantly more destructive when they do occur. Recent unusually severe cyclonic activity in the Arabian Sea has a distinct human signature that is quickly becoming the new normal (Murakami, Vecchi, and Underwood 2017). Coupled with sea-level rise, this makes Indian coastal zones increasingly vulnerable to strong storm surge activity.

The tsunami of 2004 severely tested India's coastal defences and found it seriously wanting (Sudha Rani, Satyanarayana, and Bhaskaran 2015). In its wake, a host of studies emerged, mapping coastal vulnerability to storm surges and sea-level rise. Typically, these studies combine satellite imagery, hydrography, and (less frequently) field surveys to map coastal habitats and built-up areas. These maps are modelled against projected rates of sea-level rise, coastal erosion, and storm surge intensity/frequency to determine the relative susceptibility of different parts of the coastline to climate (and related) drivers. The findings are meant to feed into development plans at state and national levels. How much they actually influence on-ground policy is an open question.

We know little of how ocean acidification influences systems in India. Increased atmospheric carbon dioxide (CO_2) changes ocean chemistry, causing an overall decrease in pH. By depleting carbonate ion concentrations and lowering carbonate saturation states, acidification reduces the accretion of species with external skeletons of calcium carbonate ($CaCO_3$) (plankton, crustaceans, molluscs, coral, and so on). This makes them particularly vulnerable to breakage. With structural species like coral, this translates to increasingly fragile reefs that crumble with every storm. Recent studies have shown that even non-calcifiers are likely to be affected by increasingly acidic environments, seriously affecting the chemosensory and visual responses of fish, increasing their predation risk (Ferrari et al. 2012).

As discussed, these drivers interact with non-climate drivers, influencing near-shore and oceanic ecosystems. While it is difficult to disentangle their effects, it is naïve to ignore them when attempting to understand climate change consequences to the coast. One important reason to pay attention to non-climate drivers is to overcome the resigned paralysis of scale that climate change tempts us to retreat to. Regional/local management can seldom tackle the magnitude of climate change, but it is clear that social–ecological resilience to climate variability is strongly mediated by local factors. For instance, reef recovery after catastrophic coral bleaching is strongly linked to sedimentation caused by land use change. Reducing sediment stress may not address the underlying climate-related drivers of bleaching, but may make the difference between reefs succumbing or recovering from bleaching events. While climate change is global in its causes, its impact is always experienced locally—and locally contingent factors are vital to how the system responds. Managing for climate change, then, is best imagined as an enterprise in enhancing the resilience of every sector of the coast and its ecosystems, with climate variability as a critical (often capricious) driver influencing the overall buffer capacity of the system.

India's Climate Change Preparedness

The all-pervasive nature of climate change requires a coherent, planned, and integrated coast-wide response to be effective. When evolving a regional climate change strategy, two factors should be kept front and centre. First, climate and non-climate drivers are intrinsically interconnected; oceanographic ecological and socio-political processes interact in complex ways. Second, human ecological systems are inherently non-linear in behaviour; it is seldom easy to predict future trajectories based merely on past and present performance. These characteristics make linear symptomatic approaches ineffectual; resilience planning instead requires understanding stability dynamics and reimagining the spatial and temporal scale of management to match them. For example, stabilizing structures may not address eroding beaches if natural sand depositional patterns function at much larger scales. Resilience planning requires particular vigilance for telltale signs of criticality, that is, behaviours that presage imminent shifts in human ecological systems (Andersen et al. 2009; Carpenter et al. 2013; Rothman 2017; Thrush et al.

2009). These indicators would ideally alert regional managers to take proactive steps to address the local stressors pushing systems towards potentially catastrophic shifts.

How far is this vision from reality in India? Climate change is only relatively recent in India's policy debate. The country is still evolving a unified response, with one eye on the international community and another firmly on its own developmental agenda. With other nations, namely, Brazil, South Africa, and China, India's stance has evolved from an initially prickly and defensive one to a considerably more nuanced stand that attempts to resolve the trilemma of meeting environmental, developmental, and equity requirements (Dubash 2016). India's policy is outlined in the National Action Plan on Climate Change (NAPCC) and state-level action plans, that is, State Action Plans on Climate Change (SAPCCs). The focus is clearly on technological fixes, market mechanisms, and sustainable development, building a climate change response around eight national missions (see Dubash and Ghosh, Chapter 19 in this volume). Himalayan ecosystems and forests feature prominently as separate national missions; the oceans and coasts are conspicuous by their absence. This blind spot is alarming given how disproportionately climate change is likely to impact ecosystems and communities along the coast. The NAPCC provides for coastal protection only as part of 'other initiatives', listing setback lines recommended in the Coastal Regulation Zone (CRZ) notification as a guidance instrument. The better part of the strategy, however, is linked to investments in coastal defences, salt-tolerant crops, and coastal afforestation. Fisheries merit no mention whatsoever, either within the sustainable agriculture mission (within whose ambit it could likely fall) or in the coastal protection provisions.

As envisioned, most sectors likely affected by climate change are state subjects, and most coastal states (with the exception of Goa and Daman and Diu) have developed their own action plans (SAPCCs).[1] While these plans come within the purview of the Ministry of Environment, Forest and Climate Change (MoEFCC), little clarity exists on how states should coordinate strategies and responses. It is even less clear how the MoEFCC will realistically steer independent

[1] See http://www.moef.nic.in/ccd-sapcc.

ministries towards a common climate-change mandate. It is argued that the SAPCCs could be crucibles of locally contingent creativity, adapting the vision of the NAPCC to local resilience needs. However, this vision is very far from the hastily produced reality of the SAPCCs accepted by the centre.

While (unlike the NAPCC) all states explicitly highlight coastal vulnerability, the means identified to tackle it is by advancing developmental agendas even further. In evaluating coastal vulnerability, SAPCCs rely either on sparse locally relevant information or on coarse global projections. Sea-level rise, storm surges, saline ingress, and coastal erosion are common themes identified in most coastal SAPCCs, but few have good current estimates of how these will influence their coasts. For instance, without local sea-level rise estimates, Gujarat defaults to global estimates to frame its vulnerability (Government of Gujarat 2014). Tamil Nadu relies on a single (wrongly cited and interpreted) source (Cheung et al. 2009) to project a 50 per cent *increase* in near-shore pelagic fish productivity (Government of Tamil Nadu 2014) and to develop a strategy to track this bonanza: promoting deep-water fishing; mid-water processing units; and other intensification strategies. This, in fact, is not unique to Tamil Nadu. In my reading of SAPCCs, every coastal state proposes to deal with potential climate change impacts on fisheries with two broad strategies: enhancing and maximizing catch by upgrading fisheries technologies and infrastructure; and actively promoting aquaculture and mariculture. Thus, while tropical fisheries are poised on the brink of ecological collapse, SAPCCs would see a further intensification (rather than restricted harvesting) of these resources. Like most other provisions in the SAPCCs, this represents an uninterrupted expansion of growth trajectories that each state was already on, flying in the face of most scientific evidence. A similarly unifying theme is the reforestation/afforestation of mangroves and coastal forests, as coastal shelter belts, nurseries for fisheries, and as carbon sinks. Although refurbished with the language of climate change, this is merely an extension of an unchanging forest department strategy (Mukherjee et al. 2010); without careful thought and implementation, they often do more harm by interfering with natural processes (Feagin et al. 2010).

Between the narrow sector-wise framing of current policy reflected in the SAPCCs and our laggard climate science, it is difficult to imagine how India's response can translate to a cogent climate-resilient strategy. However, given the uncertainty of climate change responses, a coordinated resilience response is our best hope for managing current and future change to oceans and coasts.

Case Study: The Lakshadweep Archipelago as a Harbinger of Things to Come

The Lakshadweep archipelago is a bellwether of future climate change impacts. As low-lying densely populated coral islands, it is a perfect prism to examine how coastal ecosystems, human communities, and local governments are responding to ongoing climate change. Composed almost exclusively of coral sand, the islands rely on a constantly growing atoll framework to ensure that lagoons remain calm even during the stormy monsoons. Calm lagoons also protect fresh groundwater lenses from saline intrusion (Storlazzi et al. 2018). Therefore, for Lakshadweep, habitability is dictated by reef health.

Lakshadweep reefs have been subject to increasingly frequent ENSO events, resulting in large-scale coral bleaching and mortality. Within the last two decades, the archipelago has witnessed three catastrophic mass mortalities, in 1998, 2010, and 2016 (Arthur 2000, 2015). The overall observations over the last 20 years are indeed sobering. Even without significant local impacts, fish communities have changed radically, with many top predators disappearing rapidly from all except the most stable reefs (Alonso et al. 2015; Karkarey et al. 2014). Alarmingly, reefs have declined by nearly 78 per cent since 1998 and at current rates, may no longer have the capacity to keep up with natural erosion. This means that the reef frameworks that sustain calm lagoons, land stability, and groundwater supplies are already significantly compromised. Long before sea-level rise, the Lakshadweep Islands may become uninhabitable once land and freshwater become limiting. Supporting dense human populations may no longer be viable and the Lakshadweep populations may well be among India's first climate refugees.

What are local community and government responses to this unfolding crisis? Most Lakshadweepans will have heard about climate change, but for most, fishers included, its impacts are understood in vague terms. There certainly isn't any sense of urgency in the discourse over climate change, nor the sense that their own choices can influence the trajectories their human ecological system takes (Kelman et al. 2017). Islanders seem unable or unwilling to link their own day-to-day experiences or decisions with the imminent climate disaster that mills around them. A sign of this disconnect is a recent rise in commercial reef fishing at a time when reefs are reeling from major coral mortalities. The exponential growth of this fishery threatens to unravel the already fragile resilience of the Lakshadweep reefs. Confronted with visible signs of climate change impacts, like eroding beaches, reducing fresh water, or declining reefs, the community sees this as a problem for the government to fix. Despite recent attitudinal shifts, the surrender of individual agency to government institutions derives from a long subsidy culture on which government–community relationships are constructed. This serves to disconnect local communities from their social–ecological system, and facilitates the nebulous understanding islanders have towards climate change.

The response of the administration is equally ambiguous. While every government department lists climate change as a priority, their responses are reactive, often pulling in different directions. The Lakshadweep Action Plan for Climate Change (LAPCC) reflects this ambiguity. Acknowledging reef vulnerability, the document proposes further increasing fisheries capacity without any mechanisms for regulating harvest. All other strategies dealing with climate impacts rely on technological fixes, such as beach stabilization measures, desalination plants, and reef restoration. Climate change has seriously reduced the safe operating space for further development in Lakshadweep, but while government policy acknowledges the problem, it barrels on its own developmental paths—only with greater intensity. As it stands, Lakshadweep is hurtling towards disaster with climate change sitting doggedly in its blind spot.

Building Climate Resilience for Indian Coasts and Islands

Even if the Paris treaty does not get unstuck by global politicking and inefficiencies of implementation, anthropogenic climate change will still be the dominant agent of environmental and social change.

The proposed cap of 1.5°C (even if achievable) will not give marine ecosystems like coral reefs sufficient time to adapt (van Hooidonk et al. 2016). Already, the return time of ENSOs has reduced to once in every 6 years, signalling a shift to a new normality for marine systems (Cai et al. 2014; Hughes et al. 2018). The difficulty of mainstreaming climate change in public discourse is one of making the self-evident visible. Intergovernmental responses have been exercises in political accountancy, yet, while India carves out its global stance, asserting its right to emit and 'sustainably' develop, little serious thought has been invested in how to establish social–ecological safeguards to address the impacts of developmental trajectories on coastal systems. As discussed earlier, while the forces of global change (both climate and non-climate driven) are apparently inexorable at local levels, resilient systems resist, recover, and adapt better in the face of rapid environment change. Resilience is highly contingent on local situations and needs to be understood and managed at ecologically or socially relevant scales. Rather than absolving coastal managers of responsibility, climate resilience places the onus on them to protect and enhance the social–ecological resilience of coastal and oceanic systems.

Managing social and ecological interface areas is seldom easy. Coasts are where the needs of ecosystem protection collide with local livelihoods, fisheries, shipping, development, mineral exploration, and national defence. Climate change affects each of these in potentially unpredictable ways; and the way states have chosen to address this is by parcelling out responses to relevant government departments, without explicit mechanisms of aligning mandates or coordinating responses between departments or across state boundaries. This is particularly relevant for ecosystems and species that span multiple states, traversing multiple legislative and policy boundaries. While it may appear unreasonable to expect a radical shift in inter-departmental coordination under current governance structures, the central properties of complex coastal systems—non-linearity and interconnectedness—make coordination inescapable to adequately build climate resilience into policy. The challenge for coastal planners is to translate these system properties into workable government plans. The contours of a climate-ready plan require a set of phased strategies to support natural buffer capacity and to improve recovery when disasters do occur. While maximizing social–ecological resilience should be central to a climate-ready strategy, it will also need adequate back-up strategies in case these first-line measures fail.

Maximizing Social–Ecological Resilience

A useful way to conceive how social–ecological resilience can inform management is to think of climate change and ecosystem integrity as defining the safe operating space within which all human activities—extractive and non-extractive—need to be managed. Often, departmental mandates over the same resource space differ widely, as the need to conserve and safeguard these resources confronts the urge to intensify production or maximize use. Finding a negotiated middle ground between departmental goals is essential. However, these departmental mandates and developmental goals need to work within the boundary conditions set by the social–ecological system itself. These are non-negotiable system boundaries, beyond which the social–ecological system behaves erratically, becoming prone to sudden shifts and inevitable surprises. In real terms, this could mean reefs shifting to algal dominance, a fishery collapse, a disease outbreak, a violent resource conflict, or a sudden migrant rush. As can be imagined, none of these happen in exclusion—they are often multi-sectoral problems that require a multi-sectoral response. Thus, a coral reef regime shift (the mandate of local environment departments) may trigger a fisheries collapse (the mandate of fisheries departments), which could result in conflict between fishers (a law-and-order matter), leading to a host of other societal problems with unforeseen consequences. Sufficiently healthy social–ecological systems will have enough self-corrective properties to buffer such disturbances without showing radical system shifts.

Maintaining systems within regimes of stability is central to resilience management. Resilience thinking needs to underlie policy directions of every concerned coastal institution. Of course, this assumes that we understand how climate change is modifying system boundary conditions—knowledge currently lacking for most coastal and marine systems in India. In addition, central to any resilience management is a monitoring designed to alert managers of approaching criticalities, and a clear mechanism of prophylactic response before thresholds are breached. While a lot of attention focuses on governmental responses, the communities most directly affected often have effective institutions and mechanisms to monitor and adapt to change. Identifying these institutions and giving them a stronger voice in decision making can often be more effective than top-down governmental initiatives. Where these formal and informal local institutions have eroded, it may require active efforts in rebuilding them and giving them agency over their coastal resources.

Back-up Strategies for Climate Change

Resilience planning works with the assumption that healthy ecosystems and communities will deal better with inevitable climate change. However, a set of back-up strategies is critical in case this first line of defence fails. These are not mutually exclusive with resilience planning, but need to be deployed with much more caution. This includes:

1. *Climate defence strategies*: Designing ecologically sensitive and reliable engineering solutions to protect communities from climate change impacts. For instance, severe coastal erosion requires coastal stability measures, but exactly where those efforts should be employed should be informed by a deeper understanding of coastal sediment dynamics. In considering defence strategies, working *with* rather than *against* natural dynamics should always be the preferred option. In this context, mangrove afforestation/restoration (a strategy proposed by all coastal states) makes sense only if the initial causes of degradation have first been adequately addressed. Typically, when this is done, many coastal systems (mangroves, dunes, seagrasses, reefs, and so on) appear to be quite capable of restoring themselves without further engineering. Only when these efforts fail or are inadequate should more invasive artificial measures be considered—these typically work against natural dynamics, resulting in an unravelling of a host of system properties that are difficult to determine a priori.
2. *Retreat strategies*: In the long term, near-shore areas of coasts and islands will become progressively uninhabitable due to

sea-level rise, storm surges, cyclones, and erosional processes, among others. Over the next century, coastal retreat will be unavoidable. This could happen gradually as individual families find conditions increasingly inhospitable, or as large-scale migrations of entire communities to less-vulnerable areas. In the case of oceanic islands like Lakshadweep, the horizon for retreat is much shorter since the processes of reef erosion, land loss, and saltwater intrusions have already begun. What may be a necessity within three to four generations on the coast may be a more immediate concern for Lakshadweep populations (see the case study). This large-scale population redistribution will require careful planning if it has to be managed without chaos. It is unclear if current policies on internal migration take full cognizance of the scale of human movement that climate change could imply—and whether inland areas are adequately prepared (infrastructure, societal carrying capacity, and so on) to receive this huge influx of people.

3. *Disaster management*: The coast already faces increasingly frequent and intense weather events. India woke up to the need for disaster management after the 2004 tsunami that showed how unprepared the coast was to large-scale disasters. In its wake, coastal states made serious attempts to review their own disaster preparedness. In the climate regime we are heading towards, we will employ these disaster plans much more frequently as flooding events, storm damage, disease outbreaks, and air pollution increase in coastal areas. While meagacities will face the brunt of these disasters, isolated areas face unique challenges since getting first-response and rescue material to them is seldom easy.

The Nation with Its Back to the Sea

Climate change is already a major agent of change on India's coasts and islands, and its ecosystems and local communities are struggling to cope. Our oceanic islands may already be outside safe operating spaces, and they are poised for imminent collapse. Shifting urgently towards a rational, inclusive, and coordinated resilience response is critical. Our current response is as far from this as it is possible to be: it is incoherent, fractured, uncoordinated, and pulling in different directions. If national policy is any indicator, we are a nation with its back to the sea. Before we can make climate resilience central to the management of ocean and coastal systems, we will first have to address this blind spot and embrace the connectivity and non-linearity of these systems. Islands and coasts are where the impacts of climate change first manifest. If we learn to handle it here, it may have important lessons for climate readiness across India.

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