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Changing the Paradigm: A Requisite for Safe and Sustainable Coastal Societies

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The Gravity of the Coastal Zone

Human beings have settled along shores ever since we emerged as anatomically modern *Homo Sapiens* in Africa 200,000 years ago [1]. The coastal zone provides us with livelihood opportunities, facilitates flows of people, capital, goods and services, and is generally a place of beauty and recreation. About 10% of the population and 10% of the world's GDP are concentrated within 10 meters above mean sea level [2]. However, the coastal zone is not only an area of opportunity, but also the riskiest place on earth [3]. It presents particular challenges to human settlements and activities, such as coastal floods, erosion, cyclones, saltwater intrusion, etc. The coastal zone is in other words drawing human beings to settle there, requiring us to address the challenges of living there.

The Future Is Not an Extrapolation of the Past

The challenges for safety and sustainability of coastal societies are not stable, but rapidly transforming through various ongoing processes of change. Climate change is expected to raise global sea levels substantially [4] and is already exacerbating coastal floods and erosion [5], cyclones [6], saltwater intrusion [7], etc. The global population exposed to coastal flooding has been projected to increase from 40 to 140 million between 2005 and the 2070s, and the exposed economic assets to rise from US\$3 trillion to 35 trillion during the same period [8]. Many of the coastal challenges are also aggravated by human activity more directly, such as intensified coastal erosion due to extraction of sand and gravel, reducing sedimentary inputs through dams, building jetties and breakwaters that interfere with long-shore current sediment transport, and destruction of dunes to construct buildings, marinas, etc [9]. Population growth and urbanisation is, in other words, affecting the coastal zone disproportionately [4], and the increasing complexity of society is making it progressively more difficult to grasp and address the challenges [10]. Hence, it is important for coastal societies to stop imagining the future as an extrapolation of the past. For instance, communities must stop focusing solely on reducing the risk of recent catastrophic events reoccurring, which is clearly visible in the immense investments in tsunami early warning systems in the Indian Ocean after the 2004 tsunami. Especially since other coastal hazards are more -- and increasingly -- frequent and cumulatively damaging.

Static Measures in a Dynamic World

Coastal societies are complex and dynamic human-environment systems with tight relationships between social and natural elements and processes. Traditional notions of and interventions for safety and sustainability are often untenable for such systems. For example, efforts to hold the coastal line through hard erosion protection are often aggravating coastal erosion by disturbing sedimentary processes and low-lying land reclamation is increasingly problematic in the face of rising sea levels. It is thus increasingly acknowledged that complex and dynamic systems must be resilient in order to be safe and sustainable [11-14]. Resilience is here an emergent property of a human-environment system based on its ability to anticipate, recognise, adapt

to and learn from variations, trends, disturbances, disruptions and disasters [15]. In short, coastal societies must have requisite flexibility over time in order to implement measures that are as dynamic as the world around them.

Working with Nature

It is increasingly recognised that we are fighting a losing battle in our attempts to control nature, especially as processes of change are continuously transforming the risk landscape [16]. In order for coastal societies to be resilient, they must recognize that they cannot control nature and instead work with nature [17]. For example, it has been shown that eroded sediments may deposit and protect other locations from coastal floods, leading to significant benefits in mitigating flood risk. Hence some coastal communities are now allowing previously protected cliffs to erode naturally [5]. Similarly, relocating flood defences further inland and restoring previously converted saltmarshes has proven a cost-effective way to mitigate coastal erosion and flooding [18], as the restored area and vegetation absorb wave energy, bind sediments, and retain and diffuse floodwater. The "Delfland Sand Engine" is an innovative approach to traditional beach nourishment that has also recognised the benefits of working with nature. The traditional design of sand nourishment has the primary objective of shoreline maintenance using a medium volume of sand (2-5 million m³). The lifespan of such nourishment is approximately five years. This means that every five years the nourishment has to be replaced, resulting in a frequent disturbance of the ecosystem. In the case of the "Delfland Sand Engine", 20 million m³ of sand was introduced into a single location, reaching 7 m above mean sea level [17]. Then, allowing the natural processes to occur, the sand was distributed over the shoreface replenishing sand levels across the beach and dunes. This utilization of natural processes is less expensive, longer lasting and far less disruptive to the ecosystem [17].

Another Requisite Paradigm Shift

To summarise, the coastal zone is of momentous importance for human beings and coastal societies must be resilient to be safe and sustainable. Coastal societies must thus let go of the paradigm of imagining the future as an extrapolation of the past and instead put

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trust and invest in our analytic capacity for anticipating potential future scenarios. They need to explicitly acknowledge the particularly dynamic character of the coastal zone and focus on measures that are as dynamic as the context they address. Coastal societies must also stop attempting to control nature and instead focus on working with natural processes. Without such fundamental paradigm shift there is a grave risk that sustainable development becomes increasingly unfeasible in the rapidly transforming coastal zone, as the cost of maintaining a status quo is likely to skyrocket in both economic and ecological terms.

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