Pathways to coastal retreat
The shrinking solution space for adaptation calls for long-term dynamic planning starting now

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There is an urgent need to take coastal retreat more seriously as an option for adapting to sea level rise (SLR) and as a strategy capable of providing positive outcomes, if planned ahead. Early signs of such thinking are emerging. We demonstrate how exploring pathways to managed retreat adds value in the context of irreversible long-term SLR. Retreat is typically framed and understood as a single action, largely used after events rather than preemptively, and considered as a last resort. However, implementing managed retreat constitutes a multidecadal sequence of actions (i.e., across pathways) including community engagement, vulnerability assessment, land use planning, active retreat, compensation, and repurposing. This Policy Forum advances practical knowledge on what pathways to coastal retreat may look like and how they can pave the way for flexible and positive transformational adaptation, if started now.

SHRINKING SOLUTION SPACE
SLR globally accelerated from 1.4 mm/year (1901–1990) to 3.6 mm/year (2006–2015) and will continue to do so during this century (10 to 20 mm/year in 2100) (1). Sea levels could rise between 0.43 and 0.84 m generally by 2100, relative to 1986–2005, as a median estimate under low and high emission scenarios, respectively. However, a rise of 2 m by 2100 cannot be ruled out (1). There is also a clear commitment to SLR centuries into the future due to inertia in both the climate and ocean systems; for every degree of warming, sea levels will eventually rise ~2.3 m (2).

Inexorable SLR makes some degree of relocation of coastal residents, buildings, infrastructure, and activities inevitable, even if global warming is mitigated to 1.5°C or 2°C. The necessity of paying more serious attention to pathways to managed retreat is becoming urgent (3). To begin with, observed coastal flooding is already reaching unacceptable levels for communities and infrastructure in many low-lying coastal settlements around the world (1), and unless adaptation starts now, in a few generations, more regions (e.g., small islands, parts of the US coast, major deltas) will be at risk of coastal flooding (1). Additionally, retreat requires decadal lead time to plan and implement equitably (3, 4). Furthermore, many decisions taken today have a long legacy effect and create path dependencies, closing off some options in the future. For example, coastal defenses last for many decades and protected areas attract people and assets, which lead to expectations of further protection. On the other hand, creating space for wetlands to grow as sea levels rise provides a temporary buffer, keeping future options open for later development or a lower barrier to retreat.

Ongoing and accelerating SLR, compounded with other climate-related changes (e.g., intensification of extreme events such as storms, heavy rainfall, and river flows) and increasing population at the coast, is already progressively shrinking the solution space of available adaptation options. Accommodation options (e.g., elevated buildings, early warning, and shelter) will not be enough to reduce coastal risks to acceptable levels under SLR-induced flooding and erosion. As sea levels rise, groundwater salinization will render water supplies unusable and limit food production to salinity-tolerant crops. Nor will nature-based solutions, such as offshore reefs or wetland restoration, be likely to keep pace with combined climate change impacts (1) and human pressures that have reduced space and sediment supply to the coast. Such responses are therefore expected to be only temporary adaptations in many places (5).

Hard protection, either through holding the line (protect) or advancing seaward (advance) using levees, barriers, or artificial islands, can be beneficial, for example, in resource-rich megacities but also has limitations, as sustained and rapid SLR would make it increasingly difficult to extend infrastructure within available time frames (6). Also, hard protection will not be an affordable long-term solution for...
every community, nor will it address the impacts of rising groundwater and river flows in every coast (6) or the existing and increasing residual risks (e.g., when levees fail). In low-lying coastal areas across different geomorphologies and levels of development, retreat offers an alternative option (see the first figure) that ultimately removes vulnerability and risk in situ.

**A DYNAMIC STRATEGY**

Retreat is not easy, for various reasons, including attachment to place, high costs, lack of risk awareness, impacts on inland settlements, and political resistance (3). For example, retreat means sunk costs of existing investments in public infrastructure and private property and does not address the risk to cultural assets that cannot be relocated. However, among the reasons that make managed retreat beneficial is that it enables long-term change at the coast to be anticipated and planned for in an orderly way, which can minimize both stress on people and agencies and inequitable outcomes.

Exploring pathways can support staging retreat and help to break retreat into manageable steps over time, align it with maintenance or other social goals (e.g., economic development or environmental conservation), and implement retreat depending on how the future unfolds. This could help to overcome the societal resistance to retreat. Dynamic Adaptive Policy Pathways (DAPP) (7) planning is a practical approach developed to do exactly this and is increasingly used to support climate change adaptation decision-making. To date, DAPP planning has been used to address adaptation to SLR in several locations, including the Netherlands, the UK, the US, and New Zealand, where measures have included no-build zones and community and assets relocation (5, 6, 8). The long-term perspective puts retreat on the table next to protection and accommodation measures (see the first figure), avoiding increasing investments that eventually become higher sunk costs.

A first step in pathways planning is to assess the hazard, vulnerabilities, and uncertainties and to identify adaptation options. An adaptation option may fail to achieve objectives and/or may reach a performance limit or threshold (also referred to as an adaptation tipping point) as conditions change (e.g., SLR); a new or additional measure is then needed. Similarly, opportunities may arise (e.g., when infrastructure needs replacing or when people cannot tolerate SLR impacts and the need for retreat becomes obvious). The first figure presents some thresholds and opportunities for adaptation to SLR that change the solution space.

Next, by sequencing options, starting with low-regret and preparatory actions that can and/or need to be taken in the near term, pathways are designed while also testing options for their sensitivity to a range of SLR increments and to their path dependency. Pathways design is often done in a staged manner, with increasing depth of analysis. For part of the city of Miami, Florida, potential pathways were first developed using narratives, by asking stakeholders: What could be short-term, mid-term, and long-term adaptation options? What is the next option? Promising options and pathways were then further assessed using detailed models. In the Netherlands, a study assessed the solution space for multiple meters of SLR before exploring pathways. The study concluded that spatial planning that recognizes the consequences of long-term SLR is needed, because of the uncertain, potentially high SLR.

Monitoring is typically used to evaluate success of implementation but is also needed for detecting early warning signals on approaching thresholds and windows of opportunities for preemptive actions (e.g., new insights on future risks or new social values). This helps to identify when a decision to shift to another action is necessary. For adaptation to SLR, signals can be derived from climate drivers (e.g., mass loss from Antarctica, local SLR), impact signposts (e.g., flooding or freshwater availability) based on observations, and scientific studies and assessment (e.g., the Intergovernmental Panel on Climate Change (IPCC)) and, maybe more critically, from social, economic, and cultural signposts (e.g., insurance withdrawal, increased costs, and others developed with communities). Monitoring levels of (in)tolerable risk, increasing exposure to
damage through population changes, and infrastructure aging could warn about potential lock-in or lock-out situations. Potential signals need to be evaluated for timeliness and reliability, while considering the required lead time for planning and implementation of next actions. This is problematic in a context of increasing and accelerating coastal risks, where physical and societal thresholds occur close together, with limited time left for implementation, and where communities are dependent on critical infrastructure, the functioning of which is already threatened. For example, in Florida, several water infrastructure thresholds are close or have been reached, where nuisance flooding is observed and the septic systems are being compromised by rising groundwater tables. New infrastructure with pumps and drainage can only buy a limited amount of time (8).

Beyond mapping the solution space that includes retreat, pathways thinking is also critical to supporting the design and implementation of the transition to retreat, as presented with the nested pathways in the second figure.

PRACTICAL PATHWAYS INSIGHTS
Although the relevance, extent, rate, and modalities of managed retreat will vary depending on SLR and local context, three generic steps can be highlighted across coastal settlements: preparation, active retreat, and cleanup (5). Enabling decision-makers to progressively prepare includes engagement to gain community understanding of the risks and to understand social values and vulnerabilities; planning to identify options, exploring pathways, and establishing monitoring plans to detect signals of opportunities (e.g., early moves, end of lifetime of infrastructure); funding for property acquisition and infrastructure provision in alternative areas; and adjustment of land use plans and regulations. These preparatory actions support active retreat, which comprises the acquisition of property, buyout, and removal of structures or relocation of houses, people, and economic activities. The last step, cleanup, comprises land rehabilitation and repurposing (e.g., for coastal amenity and recreational uses that can relocate readily) until that land is permanently flooded by the sea.

Because implementing managed retreat can take decades, it needs to be considered well ahead of any climate-induced societal and physical thresholds (9). The time needed depends on each society’s willingness and ability to anticipate the climate risks and to act on them before observed impacts. Time is also needed to plan and engage with those affected about the urgency to start the retreat process now, so that individuals can make relocation decisions as opportunities arise. For example, in the Netherlands and New Zealand, retreat to enable river floodplain restoration was signaled well ahead of project implementation in anticipation of the effects of climate change (5, 10), which gave time (25 and 10 years, respectively) for eventual removal of houses and purchase of at-risk properties on a voluntary basis. This contrasts with instances where retreat has been triggered after damaging climate events (e.g., after hurricanes Sandy in New York and Katrina in New Orleans (4, 10); where protection proved ineffective and retreat was forced, creating additional community stress and costs [e.g., after a storm and mudslide in New Zealand (11)]; or where forced retreat to a flood-safe area was unsustainable because work was unavailable in the new location [e.g., in the Philippines (12)]. These examples illustrate the social consequences of retreat if it does not take a planned and staged pathways approach.

To determine when to start active retreat, one can assess under what conditions retreat is required because of limitations of other strategies, indicating the latest moment at which active retreat should be realized. Another way is to assess the conditions under which retreat becomes more beneficial than

Indicative adaptation pathways of retreat
Retreat is presented as a nested pathway within a broader pathways map, including advance, protect, and accommodate. Retreat comprises three stages: preparation, active retreat, and cleanup. Engagement and monitoring support planning and implementation (gray lines). After designing a plan, land use regulations and temporary measures can be implemented, followed by buyout. Enabling investments and regulations are precursor actions.

![Indicative adaptation pathways of retreat](image-url)
other strategies accounting for flood risk, alignment with social goals, and costs. For example, Kool et al. (14) worked backward from an infrastructure threshold for SLR of 30 cm, at which point a gravity-based stormwater and wastewater system would need to be replaced by a pumped system. Before that point, the costs for a new system, its lifetime, and the opportunity costs to the community would need to be assessed against the costs and benefits of a retreat option that helps remove the ongoing impacts from SLR. Using pathways for adjacent locations, they identified opportunities for drainage system redesign to buy time for engagement with the community before eventual retreat. Such a strategy consisting of progressive steps can result in a beneficial transition that is supported by the community.

An increasing number of studies (3, 5, 10, 15) provide lessons for developing robust pathways to coastal retreat: (i) engaging early with affected communities to build understanding of their risk tolerance, vulnerabilities, and values; (ii) enhancing the policy and public understanding of higher risk levels than in the past; (iii) early design of and contributions to design of funding mechanisms and regulations that can enable implementation of retreat; (iv) avoiding developments in places recognized as risky and where existing urbanization trends can be reversed through no-build zones and prohibited land uses; (v) considering locations for new developments or designing them to be movable; and (vi) considering whether buying time through temporary accommodation, protection, or nature-based measures will trigger greater risk exposure and therefore worsen the problem over time, or whether these approaches facilitate a transition to retreat.

NECESSARY ENABLERS
Inexorable SLR that will continue for centuries means that for many low-lying coastal areas worldwide, retreat is an inevitable adaptation action. If planned now and integrated with social, economic, and cultural goals, the anticipatory and dynamic pathways to retreat can be a positive approach to reduce coastal risks and minimize regret of investments and social inequities.

To allow retreat to be considered a serious option and implemented where appropriate, there are a number of necessary enablers that require further attention by the research and policy communities. These include: (i) improved understanding of how SLR is a changing risk over time that requires a shift from static to dynamic pathways decision-making and how this affects communities differently now than in the past; (ii) improved understanding of what managed retreat comprises and how it can be staged over time through monitoring and sharing experiences; (iii) development of policies and regulations that are grounded in anticipatory planning supported by sustainable funding arrangements; (iv) further development of analytical methods relevant to changing risk, such as for mapping the shrinking solution space and identifying if and when retreat will be needed; (v) further assessment of the effectiveness of the range of adaptation responses under alternative futures and how retreat can be integrated with wider societal goals; and (vi) enhancement of the role of political leadership in building community trust in preparation for managed retreat, and embedding commitment devices to maintain the long-term dynamic approaches for reducing SLR risks.

Notably, the development and the implementation of any retreat pathway fundamentally depends on the past trajectory of coastal risks; the present situation (governance, coastal strategy, observed impacts, individual and institutional values and attitudes toward climate-related risks); the envisioned future; and when and under what conditions adaptation opportunities and limits appear. Whatever the context considered, it is increasingly evident that the shrinking solution space for adaptation in low-lying coastal areas calls for long-term dynamic pathways planning now.

REFERENCES AND NOTES
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