Policy Brief

Climate change impact chains in tropical coastal areas

Tropical coasts are highly vulnerable to climatic pressures, the future impacts of which are projected to propagate through the natural and human components of coastal systems. One single event (e.g., intense storm) or gradual changes (e.g., upland deforestation or sea-level rise) can have multiple direct and indirect impacts in coral reefs, seagrass meadows, mangroves and human settlements and can compromise the resilience of the whole system.

Risks related to climate change are frequently examined in isolation through the assessment of a single economic sector or ecosystem. However, this approach may lead to the indirect impacts, mal-adaptation risks and feedback loops being overlooked. Alternatively, impact chain maps offer a way of illustrating the potential impacts of climate change in a holistic and systemic way. An impact chain represents how a pressure propagates through a system via direct and indirect impacts. This brief summarises the climate change impact chains in tropical coastal areas based on a literature review of 289 papers. Impact chains are presented for five climate-change-related pressures.

> The impact chain concept is used by the Climate Impacts: Global and Regional Adaptation Support Platform (ci:grasp) to structure climate-related information on impacts. ci:grasp is a web-based climate information service developed by the Potsdam Institute for Climate Impact Research (PIK) and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). It is funded by Germany's Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) as part of its International Climate Initiative (IKI).

Ocean acidification

Ocean acidification primarily affects coral reefs and marine organisms, with subsequent effects on people and other ecosystems. It leads to changes in the marine carbonate chemistry, which can directly cause declines in coral reef calcification and growth.[1] Erosional processes might then overcome coral growth, weakening reef stability and coral competitiveness for space and light. As a result, fleshy and non-calcifying algae will dominate, damaging biodiversity and weakening the ability of reefs to recover from disturbances.[2]

Any reef degradation and coral mortality will lead to losses in provisioning and protective (or regulating) ecosystem services.[3] Coral reefs serve as breakwaters, protecting shorelines and creating quiet habitats for other ecosystems, such as mangroves and seagrass beds. They are also an important habitat for reef fish. The loss of these ecosystem services will increase the overall vulnerability of people living in coastal areas.

Acidification is projected to have a direct impact on fish communities also. Increased CO_2 dissolution in ocean waters has long-term effects on the metabolic functions, growth, and reproduction of fish, with subsequent alterations in population and species levels.[2] Seagrass beds, by contrast, are expected to benefit from the increased levels of CO_2 for their photosynthesis.

To slow down acidification and minimise its impacts, mitigation measures are needed to limit anthropogenic CO_2 emissions. Developing adaptation measures to minimise or delay the impacts will require additional research, such as biogeographical surveys of the range shifts of economically and ecologically critical species to adjust harvesting practices for resilience.[2] Either way, minimising human pressures constitutes a 'no-regrets' measure for increased resilience.[2]

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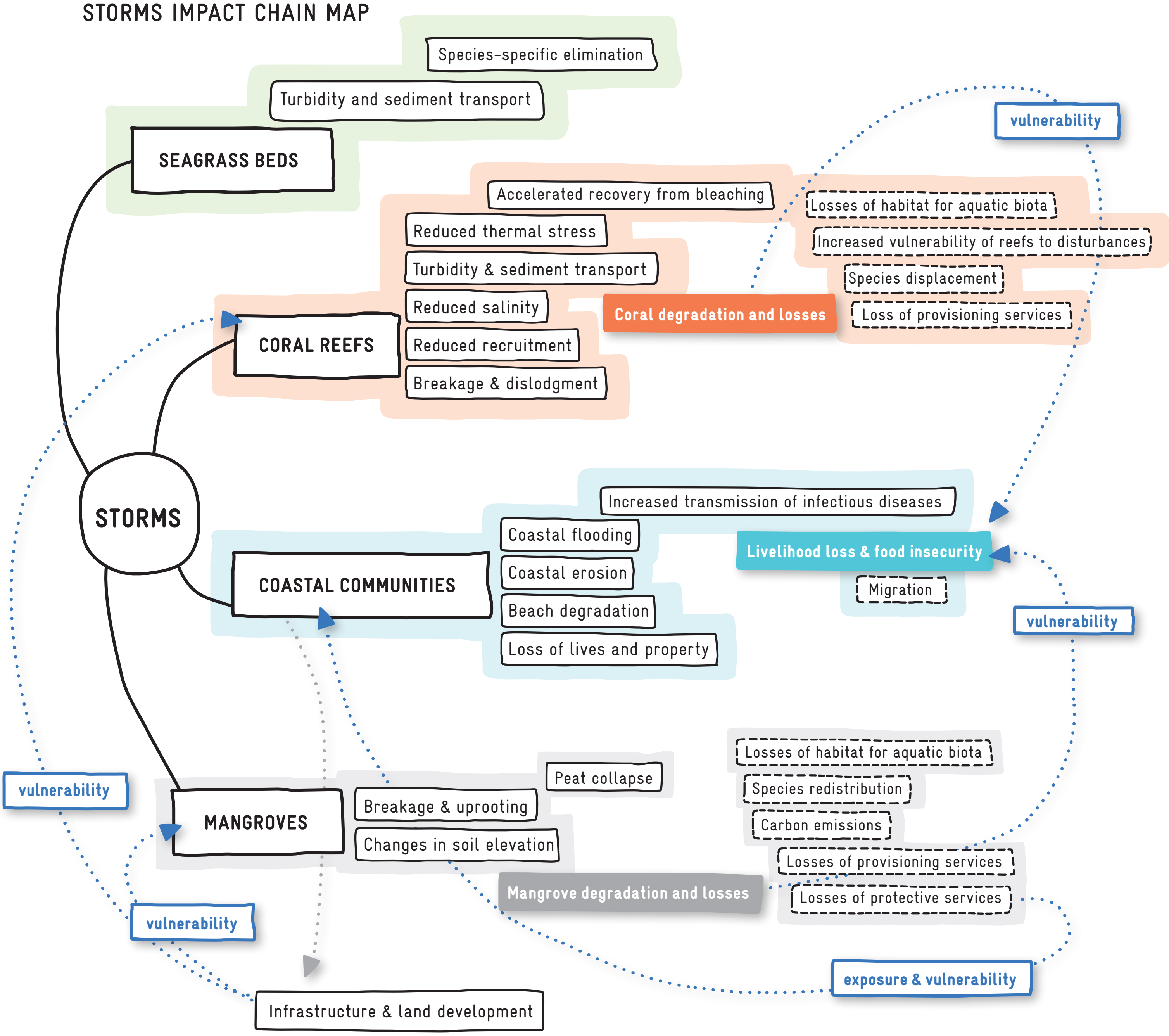
STORMS IMPACT CHAIN MAP



Ocean warming and sea-surface temperature increases

Ocean warming, including increases in sea-surface temperatures, has a direct impact on reef-building corals as it decreases their growth rates[4] and induces bleaching. For example, the 1998 ENSO events led to the bleaching of many Indian Ocean coral communities, with up to 90% mortality in shallow areas.[5] The delayed effects of coral bleaching include predator concentration, increased bio-erosion, susceptibility to disease and parasites, and decreased capacity for wound healing.[6]

The direct socio-economic effects of bleaching on coastal communities include decreases in diving tourism[7], declines in reef fish stocks[8] and general losses of coral ecosystem services (e.g., regulating) because of the decline in coral cover. Coastal erosion also increases because the reefs can no longer serve as protective barriers.[5]

Declines in coral cover will reduce the habitat available for reef fish, which will also be directly affected by ocean warming because it will weaken their physiological performance and change their behaviours, especially in early life and reproduction phases.[8] Range shifts are expected to occur for subtropical and temperate species.[9]

Fish can potentially adapt through acclimatisation over multiple generations, but this adaptation ability may be compromised by other pressures such as overfishing. Coral reefs also have the potential to adapt through the acquisition and maintenance of more thermally tolerant symbionts (algae living in symbiosis with corals).[10] However, anthropogenic pressures such as nutrient enrichment and overfishing can greatly affect coral tolerance of and recovery from thermal stress.[11, 12] Coastal management should better account for the cumulative, synergistic and mounting stresses arising from climate change and concurrent human activities.

Changes in precipitation

Decreases or increases in rainfall and associated extreme events (e.g., drought, flooding) will affect coastal areas in different ways. In mangrove ecosystems, drought could lead to increased salinity, which in turn results in growth decline, altered competition between species and the conversion of upper tidal zones to hypersaline flats.[13] In coastal settlements, major crop losses can be expected under drought because of the lack of fresh water for irrigation, especially in small islands. Such events have already weakened food security in the South Pacific Islands.[14]

On the other hand, increases in rainfall (both in coastal areas and in upland areas) will have an impact not only on coastal communities and wetlands, but also on coral reefs. Inland flooding can cause sediment discharge into coral reefs, which can be detrimental to their health.[15] Prolonged rainfall and flooding can also cause freshwater-induced bleaching, especially in reefs located further from the open ocean (e. g., in lagoons).[16]

Localised coastal flooding and inland/riverine flooding both have impacts on downstream coastal communities, as such events lead to the mass transportation of sediments and pollutants, and cause direct physical damage to settlements and agriculture.[14, 17] Limiting pollution and sediment discharge is the first step towards reducing ecosystem and community vulnerability.

Although extreme floods can have adverse impacts on mangroves, moderate increases in rainfall can be beneficial for coastal wetlands. To minimise any negative impacts from changes in rainfall and enhance any potential positive effects, sustainable management at the broader watershed level is needed.

Sea-level rise

Sea-level rise (SLR) is one of the most certain outcomes of climate change. Relative SLR that exceeds mangrove sediment accretion and elevation is a substantial cause of recent and predicted reductions in mangrove areas and health, as it leads to sediment erosion, inundation stress and increased salinity at landward zones.[13] Even when mangroves have the possibility of migrating landwards (i. e., no barriers are present), conservation concerns are not eased, because it is the seaward fringes that provide the most valuable ecosystem services for fisheries and coastal protection.[18] Any degradation or loss of mangroves will also result in substantial carbon emissions.

Accelerating SLR can also have an impact on coral reefs through increases in energy and sediment resuspension, and drowning. Sediment particles that settle on coral surfaces interfere with photosynthesis and feeding, and turbidity induced by suspended sediment reduces incident light levels.[19] As mentioned above, coral reef degradation will have detrimental effects on reef fish, and subsequently on the coastal communities that depend on them for their livelihoods. Mangrove ecosystems also provide important habitats for fish and crustaceans and any losses in their extent will increase people's vulnerability. Furthermore, alterations in tidal patterns and increased turbidity and salinity will directly lead to modifications of fish habitats and, in turn, to changes in the distribution of many fish species, especially estuary species.[17]

Following mangrove losses, and hence the protective services they provide, coastal communities will experience the negative impacts of SLR and tropical storms more strongly. The SLR impacts of inundation and shoreline erosion have been exacerbated along many coasts in the Pacific by the clearance of coastal vegetation, the mining of sand and the construction of artificial structures that fail to take into account coastal dynamics.[20]

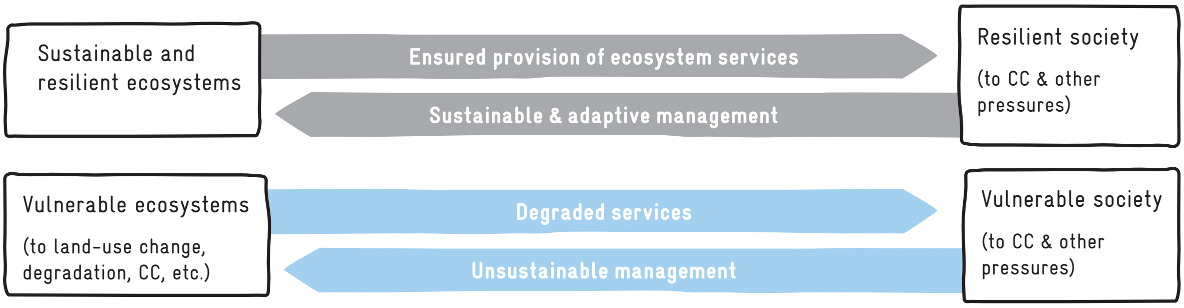
SLR will have both direct and indirect impacts on coastal settlements and agriculture. Indirect impacts are associated with the loss of ecosystem services caused by the inundation and degradation of ecosystems. Direct impacts are inundation and erosion of land, saline water intrusion and coastal flooding. The losses of land, livelihoods and property caused by SLR are projected to be significant and to force many coastal communities to migrate.[21]

Sea levels will continue to rise even under the strictest mitigation scenarios, and measures should be taken to protect coastal communities and ecosystems. However, ecosystem management should be done at the landscape level to manage sediment and other inputs that can induce further stress on coastal ecosystems. Activities can be conducted within the mangrove catchment to maintain or enhance elevation.[13]

Tropical storms

Tropical storms (e.g., cyclones, hurricanes and typhoons) first have direct impacts on both ecosystems and people, followed by cascading effects. The physical force of

ECOSYSTEM-BASED ADAPTATION



hurricanes, for example, can directly degrade and kill mangroves. By changing the space available to different species, hurricanes can also reset succession and thus alter species composition.[22] Storms influence mangrove sediment elevation through soil erosion, soil deposition, peat collapse and soil compression.[13] However, an increase in soil elevation can have a positive impact on mangrove ecosystems as it can counterbalance the effects of relative SLR.

Positive impacts can occur for coral reefs as well. At broad spatial scales, tropical cyclones can cool the upper ocean, which reduces thermal stress for bleached corals and accelerates their recovery. Moderate storms can transfer sediment particles that uplift reef layers without breaking the corals[23] and can aid larvae dispersal from and onto reefs. Strong storms, however, induce physical damage through breakage and dislodgement, adversely affect coral recruitment and reduce salinity levels to points that can be lethal.[24] They also cause large sediment blowouts that can clear seagrass meadows, leading to long-term effects such as the colonisation of the cleared space by macroalgae.[25]

Again, degradation and losses in ecosystems affect coastal communities through the loss of ecosystem services. The loss of storm-protection services of mangroves, for example, renders people progressively more vulnerable to climate stressors. By contrast, settlements protected by mangrove ecosystems have been shown to suffer significantly less damage during past cyclone events than unprotected ones.[26, 27]

As climate change progresses, tropical storms are predicted to become more intense and frequent. In the absence of coastal protection, direct impacts such as coastal flooding, erosion and beach degradation will become even more severe, as will the loss of life, property and livelihoods. In addition to ecosystem conservation activities, actions must be taken to minimise disaster risk. Such actions include constructing or modernising early warning systems, developing shelters and evacuation plans, constructing coastal embankments, raising awareness at the community level, mapping high-risk areas, and establishing and enforcing appropriate building codes.[28]

Conclusion

Impact chain maps can improve understanding of the direct and indirect effects that can be triggered by climate-related pressures at different levels in socio-ecological systems. However, whereas the maps illustrate potential impacts, the actual impacts will depend on specific socio-economic and ecological factors, such as disaster preparedness and geomorphology. In addition, decision making for adaptation should take into account the effects of multiple interacting stressors.

Nevertheless, impact chains make it apparent that the resilience of each system component is interconnected: the more resilient the ecosystems, the greater the resilience and adaptation of the people that depend on them. In turn, people must manage ecosystems appropriately to ensure their resilience and the ongoing delivery of important ecosystem services, as degraded ecosystems are more vulnerable to stressors and recover more slowly (if at all) after a disturbance.

Ecosystem-based adaptation, defined as the use of biodiversity and ecosystem services to help people to adapt to climate change, offers one approach for achieving this, if planned and implemented appropriately and according to local conditions. However, it should be supplemented by additional measures such as preparedness activities (e.g., early warning systems), infrastructural measures and capacity building.

Download the full study report "Climate Change Impact Chains in Coastal Areas (ICCA)" and the Annex.
Access the individual impact chain maps on ci:grasp:

- Ocean acidification
- Ocean warming
- Changes in precipitation
- Sea-level rise
- Tropical storms

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