Chapter 9

Coastal and island zones: areas under anthropic pressure

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Isla Maragarita, Venezuela.

Coastal zones are in the front line as regards physicochemical changes in the oceans. The rise in sea level is pushing back coastlines. The warming and acidification of seawater also disturb ecosystems that are under marine influence. However it is very difficult for researchers to separate climate effects from those—more numerous—that result directly from human activities. Coastal areas pay a high price for their attractiveness, with increasing urbanisation and exploitation of resources. But one thing is certain: these environments have often become fragile and future population growth and changes in ways of life will mean that these direct anthropic pressures will continue to combine with the increasing effects of climate change.

The erosion and submersion of coasts

Marine submersion models are now available for the simulation and forecasting of the movement of the sea into the land according to the rise in ocean water levels. For example, it is estimated in these models that 12% of the islands in the world will be threatened with disappearance. But although projections based on the rise in sea level are sufficient for studies at the global scale, they are not necessarily sufficient for a predictive map of the future submerged areas at the scale of an ocean basin.

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Small island in the Maldives. These islands that are practically at sea level are particularly vulnerable to climate change and the rise in sea level. Coast protection embankments are used to try to limit wave impact during periods of heavy seas.

First of all, the rise in water level is very unevenly distributed. In the Pacific zone, differences in the rise of the level of the sea between New Caledonia and the islands of Micronesia in the past 50 years display a ratio of 1 to 10. More locally, the rise in sea level is also affected by climate disturbances and tectonics. For example, very significant differences in sea level are observed according to the intensity of the El Niño phenomenon.

Box 19

The first 'climate refugees', also victims of plate tectonics

The Géoazur research unit and its partners explained in 2011 why the marine submersion observed in the Torres Islands in Vanuatu is twice as rapid as forecast: the rise in sea level was combined with the sinking of the archipelago as a result of tectonic activity.

The village of Lataw in the Torres Islands in Vanuatu is being invaded by water. In 2004, this small place in the middle of the South Pacific had to retreat by several hundred metres, making the 70 inhabitants the first 'climate refugees' of history according to the United Nations. Were they victims of global warming? Not only that.

In 2011, the Géoazur unit and its partners showed that the archipelago was sinking into the sea at a rate of about 1 cm per year. Vanuatu is at the edge of the Pacific tectonic plates under which the Indo-Australian plate is sliding, causing a lowering of the ocean bed and of the islands at the surface. Over a 12-year period, while the sea level rose by about 15 cm, Torres Islands descended by nearly 12 cm.

The water level thus rose at double the rate forecast by the local authorities. This error of interpretation limited the shift of the inhabitants of Lataw Bay, preventing them from gaining more long-term safety.

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A Lataw villager in the Torres Islands in Vanuatu.

Erosion depends on the local dynamics of environments

The rise in sea level and greater frequency of storms increase the frequency of submersion events and hence coastal erosion. However, erosion also depends on the dynamics of sediment systems. After a hurricane for example, beaches may form again naturally from the stock of eroded sand deposited in the forward part of the beach. In contrast, if the 'stock' of sediment has been reduced by the removal of sand, the beaches exposed to the force of waves and swell will retreat.

Coastal ecosystems also cushion erosion phenomena to a greater or lesser degree. Totalling some 600,000 km^2 along tropical coasts, coral reefs are an effective natural barrier to marine erosion. They cause waves to break, dissipating three-quarters of their power. Islands bordered by a reef thus have excellent natural protection. In addition, growth of the reef and coral sediment can also partially compensate a rise in sea level. For example, the Marshall Islands and Tuvalu still have the same surface area in spite of a rise in sea level of 2 mm per year during the second half of the 20th century.

Coastal erosion in Senegal.
Although the causes of the phenomenon are partially human (sand extraction from the beaches and coastal development) and partially natural (fragile coastal soils), the effects of coast erosion will probably be worsened by climate change and the rise in sea level.

Box 20

Recovery of the Chilean coastline after the 2010 tsunami

The LEGOS unit and its Chilean partners showed that dunes and beaches had become re-established less than a year after the tsunami that hit Chile in 2010. The earthquakes resulted from phenomena totally unrelated to climate but the Chilean coast formed a unique 'natural laboratory' for improving anticipation of the impacts of climate warming on coasts.

In February 2010, Chile suffered a severe earthquake that caused a tsunami with 10-metre waves. It hit a coastline inhabited by millions of people and the earthquake and giant waves also changed the features of the shores: dunes and sandbars were washed away and the coast was lowered by as much as 1 m in places.

The LEGOS international team and its Chilean partners made observations to assess the impact on 800 km of coastline less than a week after the event. Topographical and GPS observations showed that the tsunami had had the effect of a bulldozer, destroying existing structures: dunes, underwater sandbars, beaches, etc.

Bi-monthly monitoring of the natural reconstruction of the coastline was then performed. This showed that the coast responded rapidly to the disaster. Most of the sandy coastal structures had re-formed after a few months but their morphology was different. Unexpectedly, the sedimentary system regained balance in a year but the balance was different to the pre-tsunami situation.

The earthquake also lowered part of the coastline by several tens of centimetres. This lowering caused marine submersion, making the Chilean coast a natural 'laboratory' for anticipation of the impacts of rising sea levels. Until now, projections in models were based on a simple equation called Bruun's Law in which the geometrical parameters of a section of beach are used to predict its erosion in case of a rise in sea level. The observations made by the researchers help to show that reality is more complex than this. Since December 2012, a permanent observation system provides continuous monitoring of the dynamics of the coastline.

Homes destroyed by the earthquake and tsunami of 27 February 2010 in the River Mataquito estuary in Chile.

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The village of Cabrousse in southern Casamance (Senegal).
A rice field in a coastal area hit by a storm-driven tide that took salt into the mangrove and the paddy field.

Soil salinisation: a consequence of rising sea levels?

Seawater intrusion has serious consequences for coastal land ecosystems. In particular, soil salinisation makes previously fertile soils non-productive. The salinisation of ground water also causes difficulties when potable water is required. Drought also aggravates the problem: more marked low water periods in watercourses contribute to a slow invasion of sea water in water courses and the salinisation of farmland.

Nonetheless, the salinisation phenomena observed today are less linked to climate than to human activities. Population growth in coastal areas is accompanied by high water consumption. Urbanisation (concrete and tarmac) makes land impervious and this limits the infiltration of rainwater which is then drained by river systems and no longer recharges ground water. Increased use of water and increased runoff thus result in greater salinity of ground water. Coastal works are also strongly involved in sea water/fresh water exchanges and the consequences are sometimes unexpected (Box 21).

Even in the absence of any human presence, the balance between fresh and salt water in coastal aquifers is both complex and unstable (Box 22).

Box 21

When salinisation upsets the whole coastal system in Senegal

The excavation of a breach to release Senegal River floodwater in 2003 resulted in the formation of an opening to the sea several kilometres long in about a decade. The changes in the ecosystem were such that some locals abandoned market garden crops and are now harvesting salt.

In 2003, a major flood alert encouraged the Senegalese authorities to make a breach in the Saint-Louis dunes so that the excess water could flow into the sea more rapidly. The channel prevented the town from being hit by a flood. However, once it had been excavated, the 4-metre breach became wider and wider. A year later it was 1 km wide and in October 2012 the contact zone with the Atlantic was about 4 km wide.

Fresh water was already scarce and the intrusion of seawater made it more difficult to find and the population had to be supplied by bowsers or travel for several kilometres.
Today, scattered wells abandoned because the water was too saline are a common sight in the region.

The conditions were already fairly difficult for market gardening before 2003 and it was now strongly threatened by the hyper-salinisation of water and soil.
With the decrease in vegetable crops and the disappearance of tourist facilities as a result of erosion, the population—especially the women—have now turned to salt production.

Although the cause of this ecological and social upset has a human cause in this case, this study by the Senegalese partners of the Résilience unit illustrates the vulnerability of coastal systems in the face of salinisation and a rise in sea level.

Box 22

Small Pacific islands: a duel between fresh water and the sea

There is practically no human activity in the islets off Nouméa in the south-west lagoon of New Caledonia. Here, within the framework of the 'Interface' project, scientists studied the distribution of fresh water and salt water in ground water.

The researchers examined the spatial distribution of salinity in underground water using measurements of conductivity.
This work was cross-referenced with hydrogeological models to plot 2D and 3D maps of the distribution of island aquifer salinity and also to assess capacity for recharge by rainfall.

Unexpectedly, underground water was more saline in the centre of the coral islets than at the shore, which is nonetheless the zone of interaction between fresh and saline water. The reason is that vegetation is denser in the centre of the island and uses a large quantity of fresh water.

Furthermore, recharge of fresh water by precipitation is minimal in the centre of the island, again because of the density of the vegetation and more developed soils.
In contrast, maximum drainage is observed in the dunes by the sea.
A dilution of the salt content was thus observed in underground water at the edges of the islet and, conversely, concentration in the centre.

This research will lead to the evaluation of fresh water resources on Pacific coral islands within the framework of the search for indicators of vulnerability in the context of global climate change.

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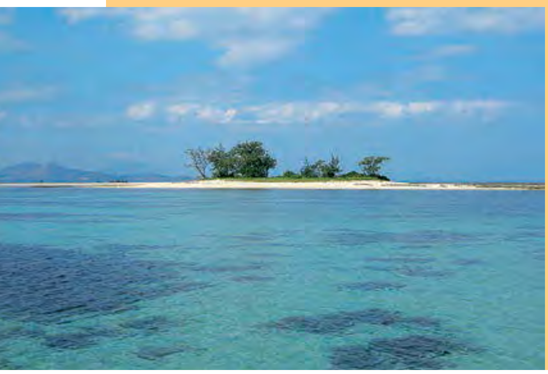

Wooded coral islet in the lagoon at Nouméa, New Caledonia.

Amazonian mangrove swamp in French Guiana.
Human activities are causing the disappearance of 1 to 2% of these ecosystems. Their fragility is increased by climate change.

Mangrove swamp, a vulnerable ecosystem between land and sea

Mangroves cover three-quarters of the coastlines of the tropics and form a specific ecosystem. However, they are currently disappearing at a rate of 1% to 2% per year. The reasons are population growth, the intensification of urbanisation and the exploitation of natural resources. The expansion of shrimp farming in South-East Asia, Central America and East Africa has had a particularly devastating effect. Climate change exerts further pressure on ecosystems that are already fragile. The disappearance of mangroves leads to the loss of certain essential ecological functions. Mangroves are home to rich biodiversity and form a key element in the balance of coastal ecosystems by allowing the return of nutrients, which, without these trees, would have been definitively lost in deep sediment.

The increase in the number and intensity of cyclones could be fatal for these ecosystems. They have a destructive effect on mangroves, which, because of this, rarely colonise the most exposed stretches of coast, preferring quieter areas where sedimentation occurs. According to recent scientific work, if cyclones were to occur too often, mangrove swamps would be incapable of surviving.

Box 23

Mangroves: exemplary adaptation

Mangrove swamps in French Guiana display a natural capacity for compensating massive, repeated destruction caused by marine erosion.

As along all the coasts downstream of the Amazon estuary, the coastline of French Guiana is ceaselessly remodelled by large-scale hydro-sedimentary processes that are the result of the movement of sediment and fresh water flowing from the Amazon into the Atlantic Ocean.
However, the mangroves in Guiana seem to be well adapted to this permanent coastal instability.
Analysis of the evolution of the area of mangrove swamps since 1950 confirms the ability of the ecosystem to compensate repeated massive destruction caused locally by erosion of mud by swell.

Research by the Amap unit and its Brazilian partners shows that the ecosystem is able to maintain itself at a regional scale by rapid and effective re-establishment on newly formed mud deposits protected from swell.
Avicennia germinans, the dominant shoreline mangrove species, is able to colonise new sediment deposits rapidly thanks to its early maturity, floating propagules (seeds that germinate immediately) that are viable for about 100 days, very rapid rooting (5 days) and strong annual growth (up to 2.25 m).

Colonisation is amplified considerably when sediment inflow and tide patterns combine to turn bare mud into a gigantic propagule collector with an area of several hundred hectares. However, these adaptations that are the result of natural selection are sometimes not enough for reconstitution after rapid destruction.

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Mangrove colonisation zone in French Guiana.
Adapted to erosion phenomena, the mangrove species *Avicennia germinans* can colonise a recently formed mud bank very rapidly.

Box 24

Carbon sequestration: reforestation limits for Senegalese mangrove swamps

From 2006 to 2013, an area of 14,000 hectares of mangroves in Senegal was replanted. However, the international visibility of this success should not hide the ecological and social limits of this reforestation. Work by the Paloc unit and its Senegalese partners shows why the multi-functional aspect of mangroves cannot be reduced to carbon sequestration.

Protection policies for mangroves have been run by Senegal for several decades in order to limit the rapid degradation of these ecosystems. Mangrove reforestation campaigns have displayed renewed vigour over the last 10 years thanks to recognition of its exceptional carbon sequestration capacity.

Interested in carbon credits, private enterprise has financed REDD+ projects implemented by NGOs such as IUCN and Océanium. Danone has invested €4 million in mangrove plantations since 2009.

These operations resulted in the replanting of 14,000 ha of mangroves from 2006 to 2013. However, the work carried out by Paloc unit researchers and their Senegalese partners tempers the success of this reforestation.

Artisanal oyster fishing in a mangrove swamp in Siné Saloum, Senegal.

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The scientists focus first of all on the ecological limits of the REDD+ approach that targets first and foremost the volume of carbon credit produced. Only one mangrove species has been planted whereas six grow in Senegalese mangrove swamps. The priority awarded to the quantity and visibility of the plantations is at the expense of agro-ecological criteria.
The researchers have observed in the field that many plants finally do not grow, considerably affecting success in terms of the carbon balance. Quantification of the carbon credit promised is late as the result will depend on the growth of the forest. And the actual calculation of carbon sequestration capacity is still being discussed.

These reforestation operations also raise questions of spatial inequality while the projects do not address the question of the status of the replanted zones, with risks of not including the local users of these areas.
Finally, the scientists insist on the scientific and ethical issues in restoration taking into account the complexity of socio-ecosystems of mangrove—whose multiple functions cannot be reduced to carbon sequestration alone.

Protection against erosion

In the face of long-term changes, it is important to understand how mangroves have managed to adapt to environmental constraints up to now. Work in French Guiana shows the exceptional regeneration of mangroves in the face of strong environmental constraints and their contribution to the stabilisation of sediments (Box 23).

This distinctive ecosystem forms a buffer zone between sea and land and may play a role in the protection of muddy, particularly unstable coasts against erosion. For example, IRD scientists and their partners have shown how a decrease in mangrove swamp would cause large-scale erosion of 370 km of coast in French Guiana. In this South American country, coastal marsh zones have been developed as 'polders' for the development of aquaculture and rice growing. Embankments have been constructed, reducing the 1 km of mangrove fringe to a strip only a few tens of metres wide. But the embankments would not withstand the force of waves and an increase in sea level if the mangroves were to disappear. Furthermore, embankments and rockfill prevent the sedimentation of mud from the Amazon on which mangrove areas are regenerated.

Mangroves also play an important role in the carbon cycle because of their strong capacity for turning atmospheric carbon dioxide into organic matter. Together with primary tropical forest, mangrove forms part of the terrestrial ecosystems that produce most biomass. The quantities of carbon stored in these forests is still a subject for debate among scientists but their sequestration potential means that they are already the subject of protection and reforestation policies within the framework of fighting climate change (Box 24).

The biodiversity of coral barrier reefs threatened

Coral reefs form another tropical coastal ecosystem that is threatened today. Several long-term quantitative studies confirm the degradation or loss of coral communities in numerous reefs. Here again, the causes are to be sought in human activities. Excessive fishing, biological invasions, pollution from the shore, development operations and mechanical damage to reefs are some of the numerous anthropic pressures involved. In some regions and especially in the Caribbean the occurrence of diseases affecting coral in recent years has been attributed to urban development.

Climate change thus has effects in ecosystems that have often been seriously damaged by humans in the past. Coral reefs are sensitive to ocean warming and

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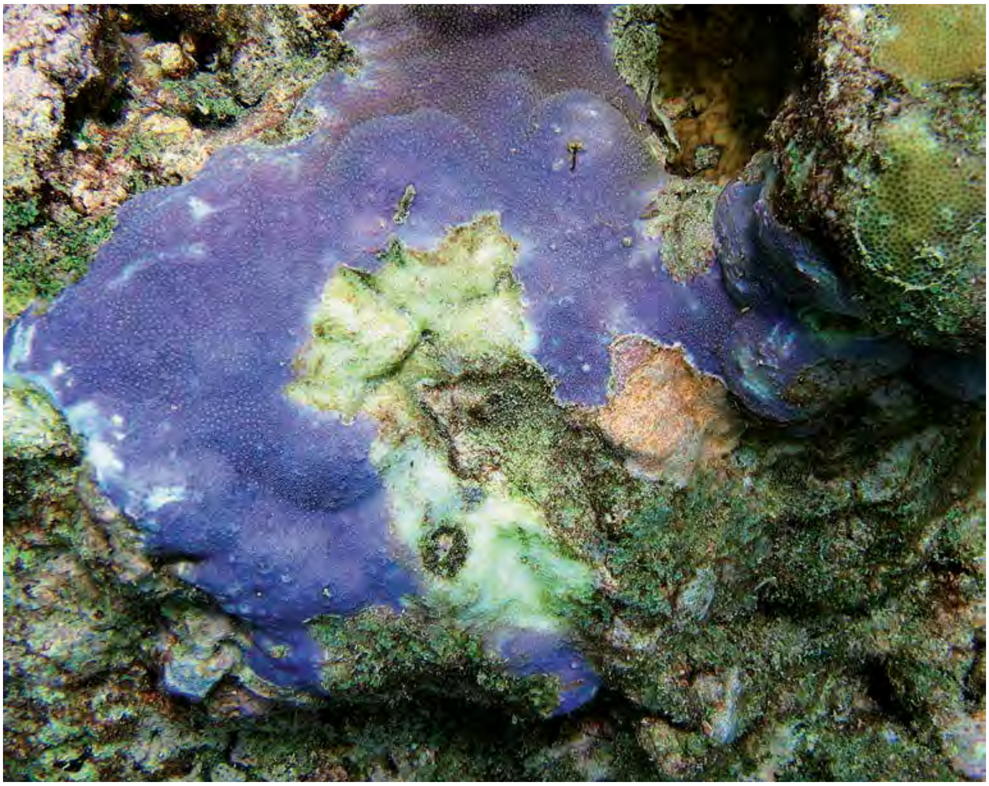

White patch syndrome on a *Porites* colony in Mayotte.
The first report on the health of corals in the south-west Indian Ocean led to the description of the new pathology in 2013.

acidification and have now been made fragile by heat stress and bleaching phenomena (see page 92). Waves caused by cyclones and tropical storms also destroy fragile coral communities. It can take 10 to 20 years for a damaged reef to be reconstituted. However, if the frequency and intensity of climate events and anthropic stress increase, the return to normal will be much slower. In addition, acidification reduces available calcium carbonate in seawater and may also slow the calcification of coral polyps and hence the growth of reefs. However, there are still too many gaps in knowledge of the physiology of these organisms for us to know whether corals are capable of adapting to rapid changes of the environment.

Towards new underwater landscapes

Scientists are addressing evaluation of how the increase in climatic and anthropic pressures will affect coral reefs in the future. Much work carried out in the 2000s on the future of coral reefs was very alarmist. But recent research shows that although numerous coral species have clearly been declining for more than 30 years, others are holding their ground or even becoming more plentiful. A vast international study in which IRD participates has observed the evolution of 7 coral reefs around the world (In the Caribbean and the Indo-Pacific Ocean) for some 15 years. Scientists have shown the spread of certain genera such as *Porites* stony corals that withstand rises in temperature. They also put these recent changes into perspective with regard to past events recorded in fossil reefs; it was seen that the abundance and structure of coral populations had already varied strongly in past millennia. These new data made it possible to revise the projections for the coming decades. As water temperatures continue to rise, a subset of 'winning' species will succeed—those with the greatest tolerance to heat, the best population growth rates or the greatest longevity.

A quarter of known marine fish species

The ecological consequences of the ongoing changes go beyond corals alone as these ecosystems house a quarter of known marine fishes. In collaboration with international teams, IRD studied the impact of coral bleaching on the fish communities housed in this coral. For this, scientists compared coral and fish populations at some 60 coral sites in 7 countries (the Maldives, the Chagos Archipelago, Kenya, the Seychelles, Tanzania and the islands Mauritius and Réunion) before and after massive coral bleaching following an El Niño event in 1998. This scientific work shows that the decline of coral communities is followed by reduction in diversity, a reduction of size and loss of structure in fish populations.

The changes in coral reefs are also preoccupying for food security in numerous southern countries as they provide the protein requirements of neighbouring populations.

Shoal of fish
in *Acropora branchus* coral
(New Caledonia).
Coral reefs provide shelter and are a source of food for numerous invertebrate and fish species.
The degradation of corals causes a decrease in reef biodiversity by a knock-on effect.

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