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HOW CAN NATURE PROTECT PEOPLE AGAINST SEA-LEVEL RISE?

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YOUNG REVIEWERS:

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Almost one third of people on Earth live near the coast where they are at risk from floods. Coastal areas are often protected from flooding by human-built flood-protection structures, like dikes and seawalls. Now that Earth's climate is changing, sea-level rise and storms are becoming more intense and frequent, which increases the risk of flooding. Therefore, we need to develop bigger flood-defense structures to stay safe from flooding. However, this is very expensive. Is there an alternative? It may sound surprising, but nature can help us out. Around the world, ecosystems like mangrove forests, salt marshes, and coral reefs can help to protect our coasts from flooding. They can contribute to greener, more natural, biodiverse coasts, and make living along Earth's coastlines safer and more sustainable. Using these natural systems is called nature-based flood defense. In this article, we explain how it works.

WHY DO WE NEED TO PROTECT OURSELVES AGAINST SEA-LEVEL RISE?

RIVER DELTA

A low-lying area where rivers empty into the sea. Famous examples are the Nile delta in the Mediterranean Sea and the Mississippi delta in the Gulf of Mexico.

The coast is a nice place to live. One third of the people on Earth live along the coast: in small fishing towns, in big cities like New York and Shanghai, or even in entire countries, like the Netherlands. Many of these places lie in areas called **river deltas**, where a river enters the sea. River deltas are great locations for harbors, agriculture, and fishing, but they are also low-lying areas that can easily flood. Half of the Netherlands, for example, is several meters below sea level and would be flooded today if the country's flood protection failed! Living at the coast is risky, and it is becoming riskier with climate change and its consequences, including **sea-level change** and more or stronger storms.

SEA-LEVEL CHANGE

Sea-level is actually quite variable and can even fall in some places. It also does not rise all the time. But for coastal protection, sea-level rise is most relevant.

LAND SUBSIDENCE

The sinking cities at the coast. It happens if we pump water, gas, and oil from underground, and the weight of buildings and houses pushes the emptied soil downward.

RELATIVE SEA-LEVEL RISE

The combined effect of land subsidence and sea-level rise. It increases flood risk more than sea-level rise alone.

As global temperature continues to rise, glaciers and ice sheets, like those in Antarctica and Greenland, are melting. The melted ice flows into the oceans, raising sea levels. At the same time, the oceans capture some of the heat from the atmosphere and, as the water gets warmer, it expands—so sea levels rise even more. But that is not all—some cities are literally sinking. One of the main reasons cities sink is because we pump water, gas, or oil from underground. The weight of buildings and houses then pushes the emptied soil downward. This effect is called **land subsidence**. In some cities, land subsidence makes the water level rise more than 10 centimeters per year, making sea-level rise an even bigger threat! The effect of land subsidence and sea-level rise together is called **relative sea-level rise** (Figure 1A) [1], and it increases the flood risk to coastal areas.

Beyond contributing to relative sea-level rise, climate change also causes more frequent and intense storms. Stronger storm winds can blow more water onto the coast, leading to even higher water levels than are seen with relative sea-level rise alone. Because of this, the waves that reach the coast are also higher. Why? Waves consist of an above-water part and an underwater part (Figure 1B). Normally, when the underwater part of the wave hits the seafloor or a man-made barrier, it collapses and the whole wave breaks. You can see this at sandy beaches. However, when the water level is too high, waves do not break, so they stay large. Storms with such high waves can cause floods, damage buildings, and sometimes even take human lives. How can we protect ourselves against sea-level rise?

IS IT TIME TO UPDATE OUR FLOOD DEFENSES?

GRAY FLOOD DEFENSES

Concrete structures that protect the coast from flooding, such as dikes, seawalls, and breakwaters.

Coastal cities are protected by concrete structures often called **gray flood defenses** (Figure 2A). These defenses include dikes, seawalls, and breakwaters. A breakwater protects the coast from the force of the waves by forming an elevated barrier in the sea. The underwater parts

Figure 1

(A) Relative sea-level rise is a combination of sinking land (land subsidence) and rising sea levels. **(B)** Waves have an above-water part and an underwater part. When the underwater part of a wave hits a barrier, it collapses and the wave breaks.

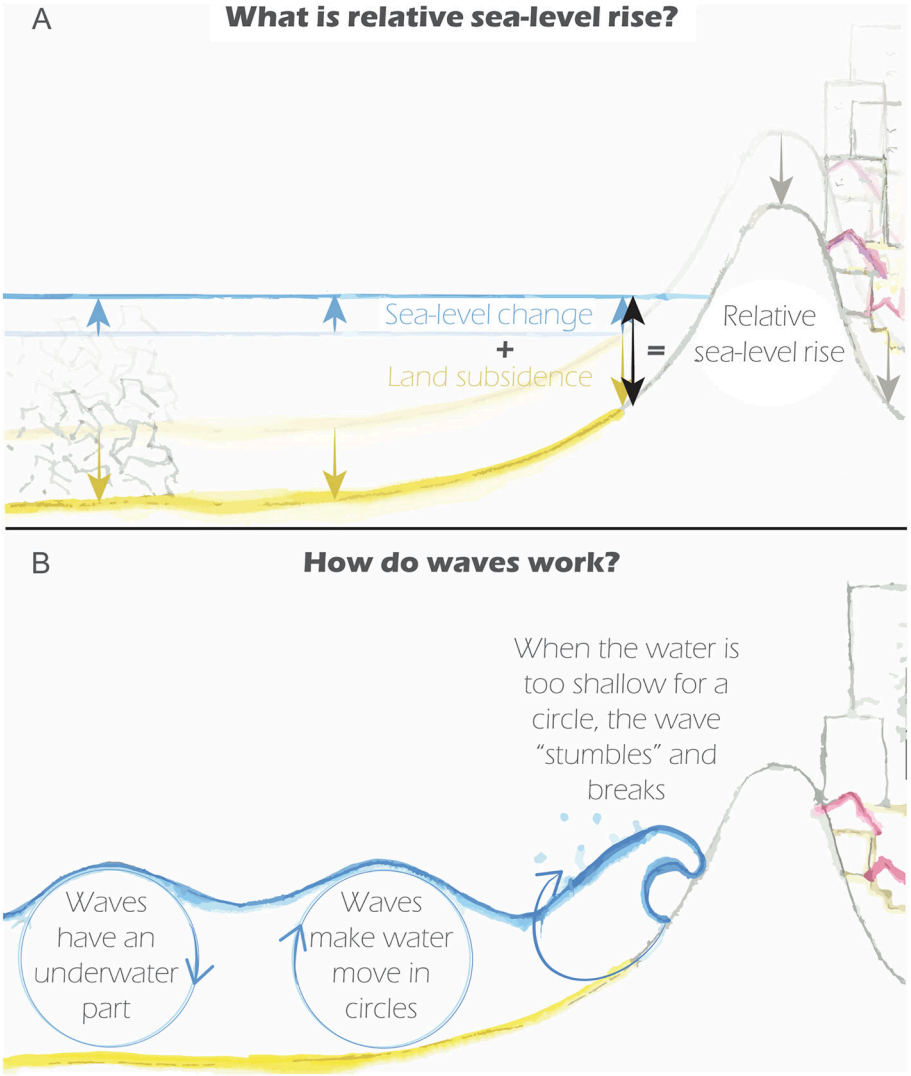

Figure 1

of waves hit this barrier and lose some of their energy, kind of like stumbling over a curb when you run. Dikes or sea walls are barriers on the shore. They protect the land from flooding, especially when the water level is higher than normal, which happens during storms in combination with really high tides.

Gray defense structures are built to survive heavy storms, but they are not so effective when sea levels rise. For example, breakwaters are less effective against sea-level rise because the underwater parts of waves do not hit the breakwater anymore. Instead, the waves have enough space to travel *over* the breakwater and break on the shore (Figure 2A). Dikes and seawalls are also less effective—if relative sea level rises too much, the water level becomes higher than the barrier and the land behind it floods. Also, dikes and seawalls can be damaged by very strong waves and storms, which makes them less effective. Sinking lands, rising seas, and increasing storms mean that we need higher and stronger flood defenses, but that will cost lots of money. What if

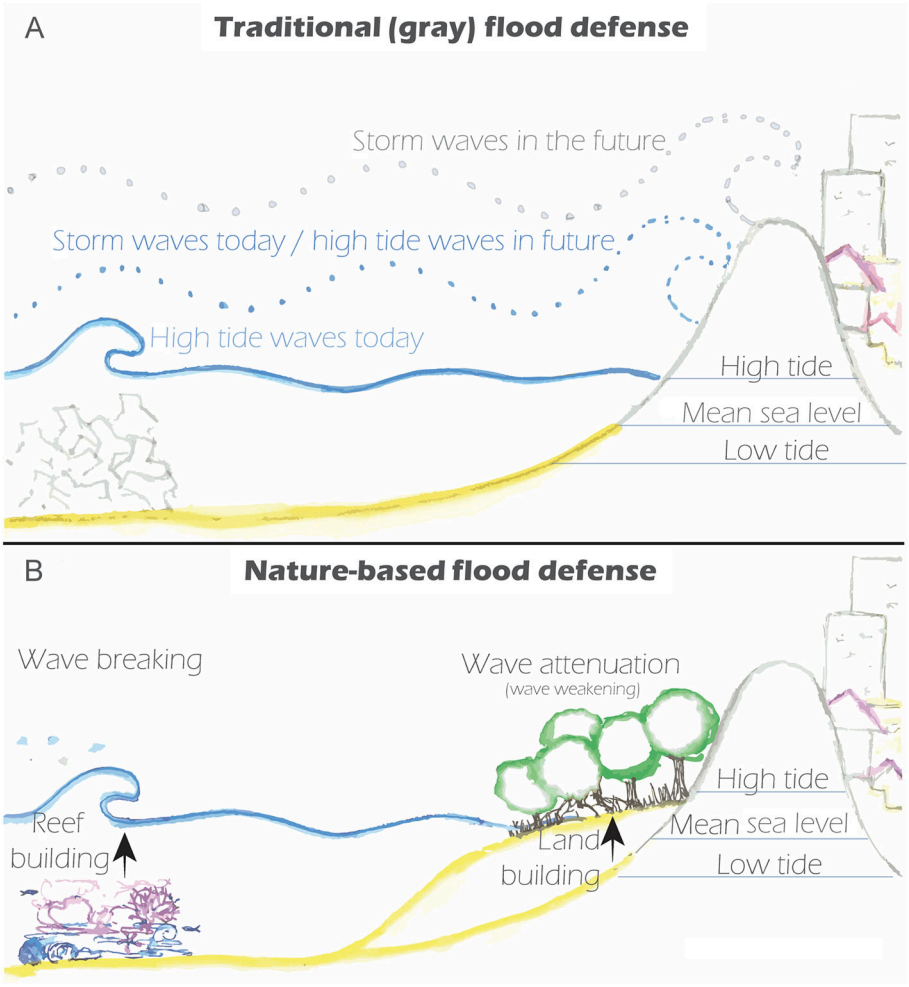

Figure 2

Figure 2

(A) Traditional gray flood defenses protect the land from waves and flooding, but relative sea-level rise makes gray flood defenses less effective. **(B)** Nature-based flood defenses use living ecosystems to help protect the coast. Specific plants and animals can be used depending on the geographical location (see Figure 3).

we could use living systems to help protect the coastline? This is called **nature-based flood defense** (Figure 2B) [2].

HOW NATURE CAN PROTECT US FROM RELATIVE SEA-LEVEL RISE

Coastal **ecosystems** around the world can be used for nature-based flood defense. These ecosystems are made up of plants such as mangrove trees and salt marsh plants, and animals that build "breakwater-like" reefs including oysters, mussels, and corals (Figure 3). These plants and animals are adapted to living in salty seawater. Some can protect us from floods by slowing down waves, others do so by building land, and some can do both!

Coral reefs are not just pretty; they are sturdy and grow close to the coast. Their locations are very similar to those of gray concrete breakwaters and they also work the same way—by forming an underwater elevated barrier that breaks waves (Figure 2B). Oysters and

NATURE-BASED FLOOD DEFENSES

These flood defenses use both concrete structures and coastal ecosystems such as salt marshes or coral reefs to protect the coast from flooding.

ECOSYSTEM

Plants and animals that form a distinct piece of nature. This can be the Amazon rain forest, the Great Barrier Reef, or your local forest.

Figure 3

Global distribution of coastal ecosystems that provide nature-based flood defenses. The colored circles around each picture correspond to the colors on the map. Salt marshes and shellfish reefs are mostly found in temperate regions, while mangroves and coral reefs are found in the tropics [Photograph credits: Jildou Schotanus (mussel reef), Marte Stoorvogel (salt marsh), and Celine van Bijsterveldt (coral reef and mangrove)].

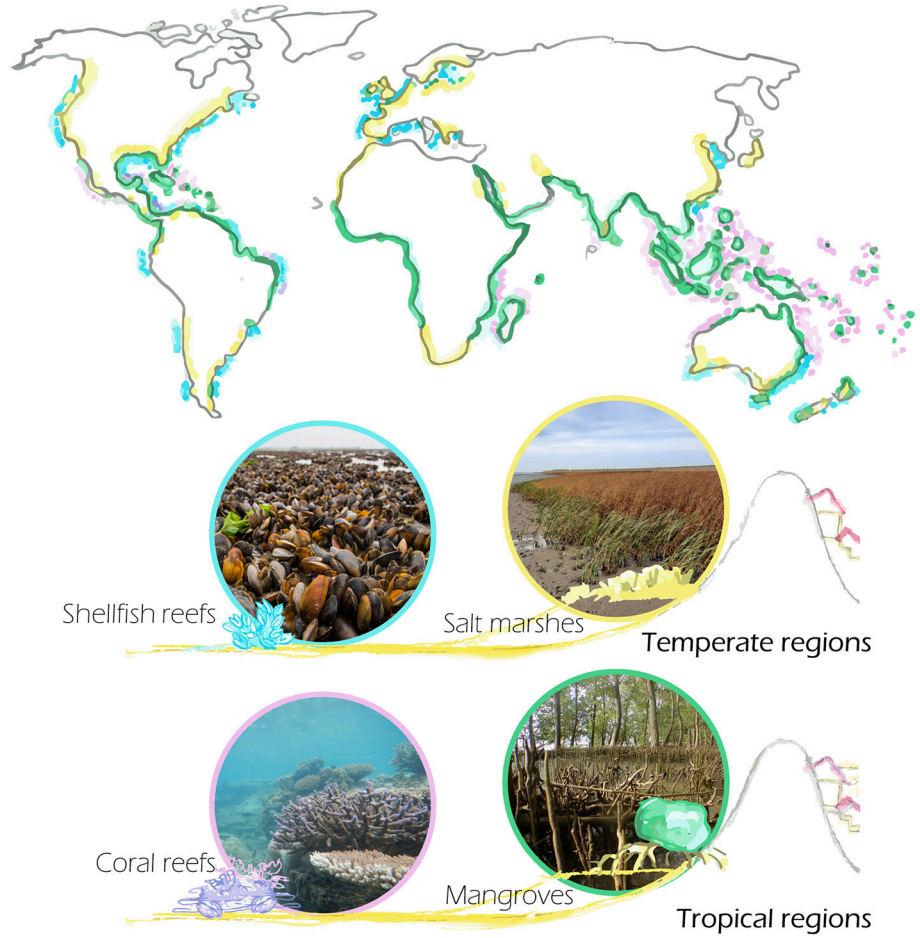

Figure 3

mussels can build shellfish reefs that break waves much like corals do. Although reefs and gray breakwaters protect the coast in the same way, reefs can grow! By growing, reefs can keep up with sea-level rise and stay high enough to keep breaking waves, while breakwaters must be maintained.

Mangroves and salt marshes often grow outside dikes and seawalls. This is helpful, because they can reduce the size of the waves before they reach the gray flood defenses. If a wave rolls into a mangrove forest (or salt marsh), it runs into many obstacles. Every time the wave hits a plant, it weakens and loses a bit of its energy. By hitting all the plants in a marsh or forest, the wave loses so much energy that it becomes a lot smaller. We call this effect **wave attenuation**. If a mangrove forest or salt marsh is large enough, it can reduce wave height a lot. This is so effective that we can build a smaller dike, saving a lot of money!

WAVE ATTENUATION

Every time the wave hits a plant, it loses a bit of its energy. By hitting lots of plants, the wave loses so much energy that it becomes smaller.

Mangroves and salt marshes can also raise the land on which they grow. Without plants, seawater can flow so fast that it can carry mud and sand particles. But when water flows through coastal plants, it slows down and the particles sink onto the soil. Over time, this

makes the soil surface higher. This is very useful for keeping up with sea-level rise [3], and consequently the area is flooded less often. Since mangrove trees and salt marshes like to grow in less flooded areas, they keep building land in those areas and the surface level keeps increasing. The elevated surface level can act like a breakwater, protecting the coast even more [4].

MORE ADVANTAGES OF USING COASTAL ECOSYSTEMS

Besides providing nature-based flood defense, coastal ecosystems have more advantages. As we mentioned, their surface level can rise with the sea [5]. This makes them cheaper because they need less maintenance than gray flood defenses do. These ecosystems can also store large amounts of carbon, which lowers the amount of carbon dioxide in the atmosphere. Lower carbon dioxide levels mean less climate change—so less sea-level rise. Finally, these ecosystems provide a nice area for rare plants and animals to live, which supports biodiversity. People can enjoy these coastal ecosystems, too!

Unfortunately, coastal ecosystems have been declining over the last 50 years. Therefore, scientists are now learning how to protect and restore them. We can do this by studying the preferences of the plants and animals that live there. How often do they like to get flooded? Can they handle lots of waves? How salty should it be? The more we learn about these plants and animals, the better we can protect them—so *they* can protect *us* from floods!

In summary, maintaining gray flood defenses will be very expensive with sea-level rise. Coastal ecosystems can also break waves and even build land to keep up with sea-level rise. In this way, they can help us protect our coasts from flooding all around the world. There are a few ways that YOU can help. First, if you are interested in this topic, you can read more articles—check out these *Frontiers for Young Minds* articles, on sea-level change, global ocean climate change, or seagrasses. You could consider giving a presentation at your school to teach others about nature-based flood defense. To learn even more, you could find and meet your local scientists, or meet them online—For example, Skype a Scientist and Letters to a Pre-Scientist. Finally, if you want to become a scientist yourself, learn as much as you can about biology, mathematics, and physics! Maybe someday you will help to discover new mechanisms of nature-based flood protection!

AUTHOR CONTRIBUTION

RH, CB, CC, and MS collaboratively contributed to the conception and writing of the manuscript. RH coordinated the project. CB designed the figures, supported by MS. RH, CB, CC, MS, and TB contributed to manuscript revision, read, and approved the submitted version.

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YOUNG REVIEWERS

HELENA, MOMO, AND TATI, AGES: 10–11

This fun-loving trio enjoys science and writing. They love to explore new topics and are especially intereseted in eco-friendly ways to combat climate crises to create a brighter future for our planet. Helena likes to hike and paly soccer. She also adores her two cats. Momo enjoys being in nature, especially in city parks, because urban ecology shows her how strong nature can be. She has blue hair. Tati loves dogs. She is an amazing sewer and builder.

AUTHORS

ROSANNA VAN HESPEN

I am Ph.D. student at NIOZ marine research institute in Yerseke, in the Netherlands, and I love studying nature. As a kid, I enjoyed playing with water and mud; and secretly, I still like it! Also, I think plants are really cool. That is why I did a bachelor's degree in biology and later a master's degree in ecology. Now I get to study the muddy mangrove systems in my Ph.D. project, to learn how we can use mangrove forests for flood defense. *rosanna.van.hespen@nioz.nl

CELINE E. J. VAN BIJSTERVELDT

My name is Celine, and I have been fascinated by marine life since I was little. I loved being in and around the water. So, I started snorkeling and later scuba diving, to be able to look at all the cool marine life up close. During my studies, I learned that coastal ecosystems are not only "a nice place to go" but can also be useful. For example, mangroves provide clean water and fish. During my Ph.D. at NIOZ, I studied how we can restore mangrove ecosystems. I am now working as a marine ecology teacher at Wageningen University to teach a new generation of scientists and managers all about the cool things that marine ecosystems can do.

CAROLINA M. L. CAMARGO

Growing up close to the sea, I was always curious to understand how the oceans move: waves, tides, and currents. That is why I decided to study oceanography—not only did I get to spend more time at sea, but I also got to learn how the oceans work. Now, as a Ph.D. student at NIOZ, I use satellite data to see how and why sea levels are changing across the world. Unfortunately, this means I do not go to the sea so often, but I hope my research will contribute to keeping us safe from sea-level rise.

MARTE M. STOORVOGEL

In 2020, I started my Ph.D. at NIOZ, after obtaining a bachelor's degree in soil, water, and atmosphere, and a master's degree in soil geography and earth surface dynamics, both from Wageningen University. During my studies, I discovered that I am very interested in how soils develop and how they can be used for things like agriculture and nature development. Now I am mainly researching how soils become strong over time, and how this can help to protect humans from the sea.

TJEERD J. BOUMA

Personally, I get energy from contributing to solving important societal problems. Hence, I work both on how to preserve and restore nature (to counter biodiversity loss), and on learning how nature can be sustainably used to help humanity. In studying nature-based flood defense, all these topics come together. I work at both the NIOZ and Utrecht University, which gives me the opportunity to do this kind of research around the globe. As a kid, I did not know whether I wanted to study engineering or biology—so you can see why I like this topic!