BRIVAL **Coralie** & GARCIA PEREZ **Martin**

JACQUES ROUGERIE FOUNDATION
SPACE AND SEA GENERATION
INSTITUT DE FRANCE

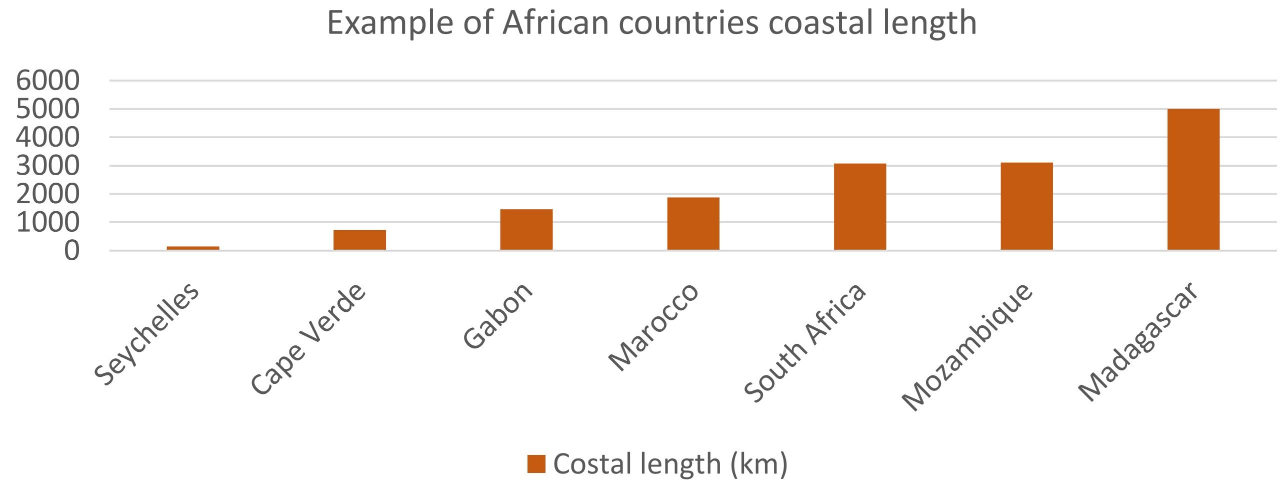
# NOSY LAVAKA

## RISING FROM DEFORESTATION

# NOSY

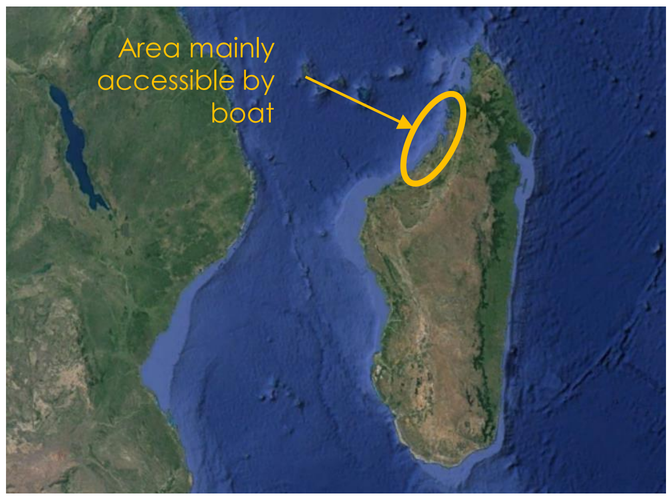
# LAVAKA

In Malagasy **NOSY** means island. This word is iconic for this country. First, because Madagascar is the fourth biggest island on earth. With its 5 000 km of coastline, Madagascar is by far the African country with the higher coastal length.




*Hinkel and al., Sea level rise impacts on Africa and the effects of mitigation and adaptation : an application of DIVA, 2011*

Throw the years, this isolated characteristic has made Madagascar a melting pot, where different cultures meet, exchange and create history. Plus, Madagascar is surrounded by small islands. Most of them have names starting by Nosy and each has particularities, special customs, and economic activities. For instance, NOSY BE is a touristic island while NOSY FALY, at 15 km from NOSY BE, is well known for its fishing activity and especially for the MAHALOUKY (small fish similar to sardine) season. Madagascar population is mainly rural and lives on the coast or islands near the mainland. Thus, the Malagasy way of life is attached to the sea and its resources. For instance, various villages are accessible only by boat. Cut from the countryside, only the sea seems to connect people living in those villages.


*Google Earth, 2019*

In Malagasy **LAVAKA** means literally "hole". It is defined as a very steep-walled excavation that brutally digs the topographic surface (Brenon, 1952). More broadly it is a type of erosion mainly found in Madagascar, due to a combination of natural and anthropogenic factors. LAVAKA has an average size of 80 meters long by 40 meters wide and 15 meters deep.

*Alizé Carrère, National Geographic, 2013*

Climate has an important part in LAVAKAs formation. Indeed, they are presented in Madagascar highlands, near Antananarivo. The weather of there is particularly aggressive with two distinct seasons :

Dry season, during the southern winter

Mid-wet season, including 80 to 90% of annual rainfall

This contrast has an important impact on the soil by first drying it and, during the wet season, quickly floods the region. Also, the existence of tropical cyclones brings very large amounts of rain over a very short period. Human activities and more precisely deforestation have also an impact nonnegligible on erosion phenomena like LAVAKA. Without dense vegetation, the soil hardens, becomes compact more or less impermeable during the rainy season, More than geologic formation, LAVAKA is a symbol of Madagascar deforestation scars inscribed on a burnt soil used now for agriculture.

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# SEA LEVEL RISE

Climate change and especially sea level rise will have an important impact on Madagascar coasts and the people living there.

Considering the scenario with an increase of 4°C by 2100, sea level will rise between 64 cm to 126 cm in the period 1995 - 2100 (Hinkel et al., 2011). Madagascar is particularly vulnerable because of tropical storms and its intensification that cause more important flooding (Nicholls, 2006).

Rapid sea level rise can destroy coastal habitats, cause (United States Environmental Protection Agency, 2019). :

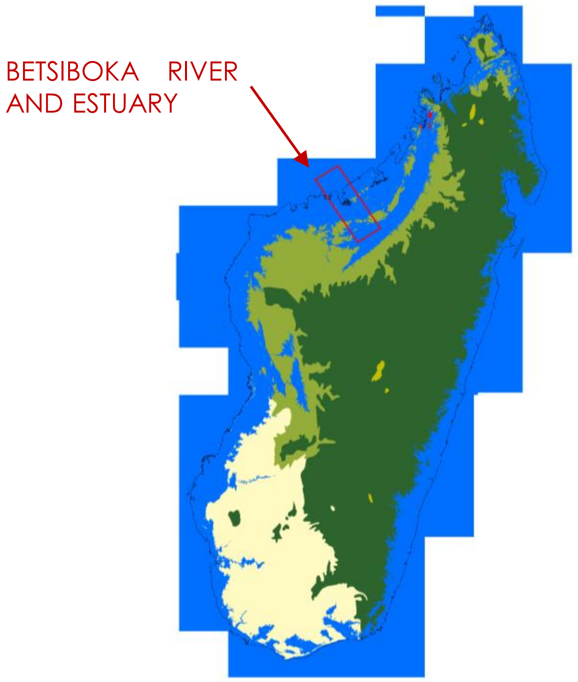

massive erosion


agricultural soil contamination with salt


lost of biodiversity (natural habitat, fish, birds and plants)

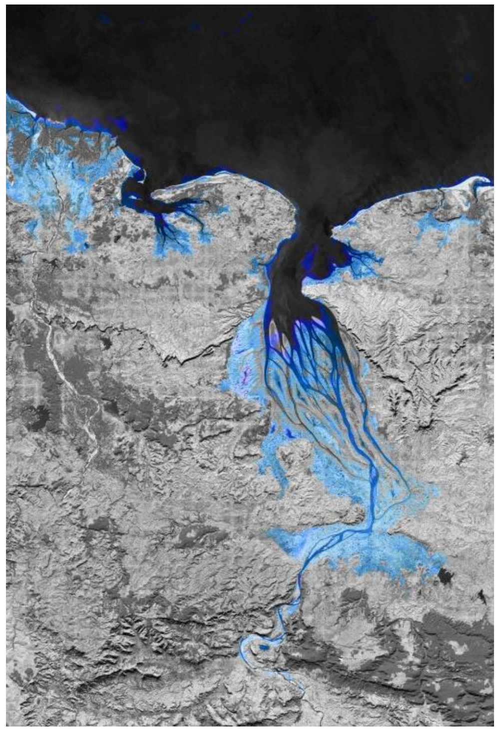

flooding

Estuaries and delta, because of their localization next to the sea and their important population, are more vulnerable to flooding due to increasing rates of sea-level rise (Ratliff and all., 2018). It is the case of Betsiboka estuary located near Mahajanga city (one of the six largest cities on the island), on Madagascar Northwest coast. In this region, the coast, the riversides and the delta bank are threatened by sea level rise. It will lead to massive erosion, agricultural soil contamination with salt, flooding and lost of biodiversity like mangrove forest.




*Sea level rise in Madagascar ESA, 2019*

**BETSIBOKA RIVER AND ESTUARY**



*Sea level rise in Betsiboka estuary*

**Key**

Sea level rise in 2100

Floods during hurricane

# DEFORESTATION

Deforestation is old news in Madagascar (Alizé Carrère, National Geographic, 2013). Since the end of the 20th century, deforestation has accelerated natural erosion. Indeed, without roots to retain sediments and an absorbing soil during big flooding, Madagascar will keep bleeding sediments. After heavy rains and hurricanes the red soils are washed from the hillsides into rivers to the coast.

*Betsiboka: Madagascar's Red River, NASA, 2012*

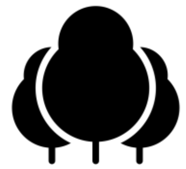
*Betsiboka: Madagascar's Red River, NASA, 2012*

Being an island has allowed Madagascar to develop its own particular nature throw the years. That is why 80% of Madagascar species cannot be found anywhere else on the Planet (US Agency for the International Development - USAID). However, deforestation phenomena is threatening this biodiversity. The demand for land and natural resources is more and more important degrading the environment. Slash-and-burn agriculture, fuelwood and illicit logging are the major cause to this deforestation.


**0.5%**
of global land mass


**80%**
of species found **NOWHERE ELSE ON EARTH**


**40%**
Projected population growth


**99,000**
Hectares of forest lost **EACH YEAR**

*USAID, 2019*

**BETSIBOKA RIVER AND ESTUARY**

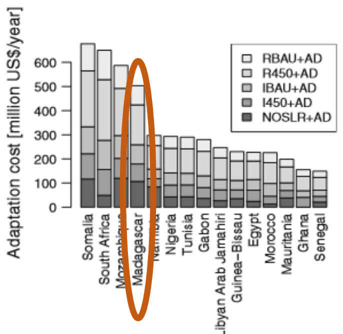
The Betsiboka Estuary is the perfect example of deforestation and erosion effect in Madagascar. It is the mouth of the country's largest river and one of the world's fast-changing coastlines (NASA, 2012). In less than 100 years, forest and mangroves logging and slash-and-burn agriculture have cleared Madagascar lands and caused one of the highest rates of erosion in the world (NASA, 2012).

# COASTAL EROSION - CONTAIN SEDIMENT

Coastal zones are exposed to a range of coastal hazards including sea-level rise and stronger hurricane with their related effects such as erosion. At the same time, they are more densely populated than the hinterland. Thus, fighting against sea level rise has become a worldwide priority. Different solutions can be developed and some of them have already been set up in the developed region threatened by sea level rise.

*Dyke on the port of Brest, France*

*The Oosterschelde storm surge barrier, Netherlands*




*Hinkel et al., 2011*

However, considering Madagascar coastal length, the cost of heavy infrastructure such as dyke and the fact that many African countries have more immediate issue (Neumann et al, 2015), those solutions may not be adapted for all Madagascar coastline. Indeed, comparing the annual adaptation cost to climate change for the 15 highest African coastal countries in 2100, Madagascar is fourth.

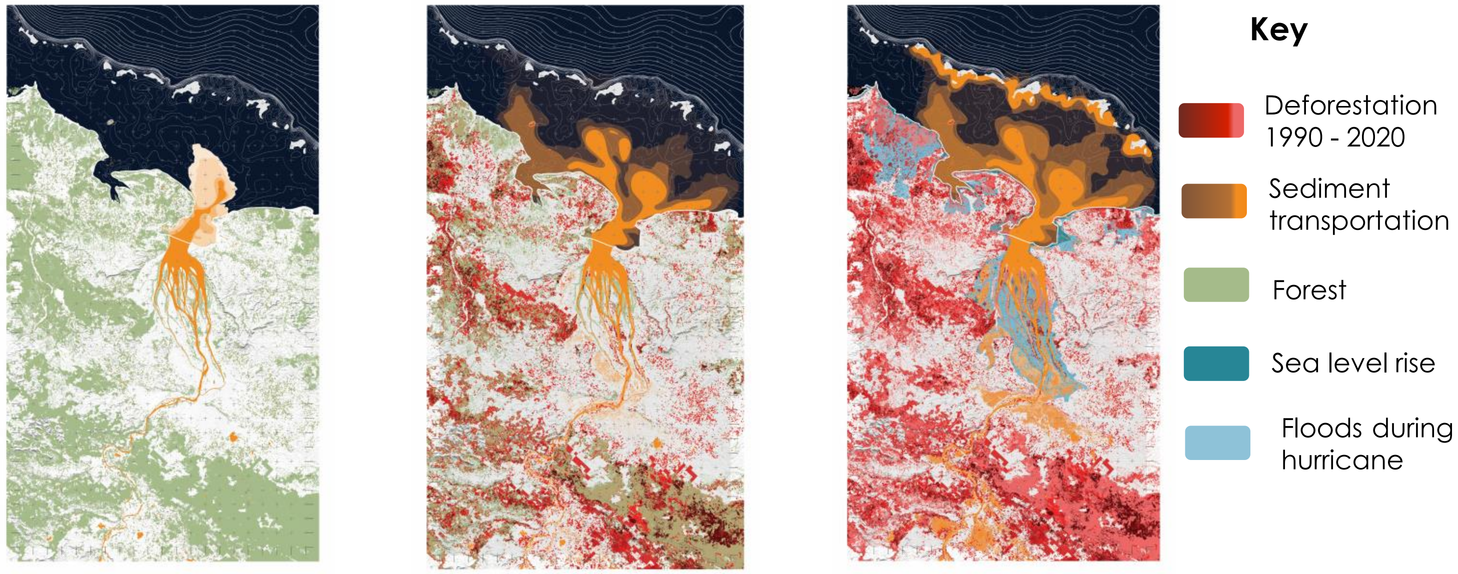
Resettlement is another type of climate change adaptation. It is the transfer of refugees from an asylum region or country to another State or district. This solution is a more extreme measure because it affects drastically people's livelihoods. Indeed, it does not always acknowledge social, political and environmental characteristics (Elkin, 2018).

**78%** of rural population (PNUD of Madagascar, 2019)

Surrounded by water, Madagascar has always oriented its economic and cultural activities towards the sea. Also, most of the population of the Malagasy coast is spread over villages scattered along the coast. Each of them has adopted a specific way of life and carries a cultural and historical heritage from generation to generation.

In this way, resettlement without recognition to the cultural, environmental and economic byproducts of the post-settlement landscape, in another term: retreat (Elkin, 2018), is not suitable for Madagascar sea level rise adaptation. The solution for adapting to sea level rise, considering the above elements, must combine resilience, (financial) feasibility and preservation of the social and cultural environment of the Malagasy coasts.

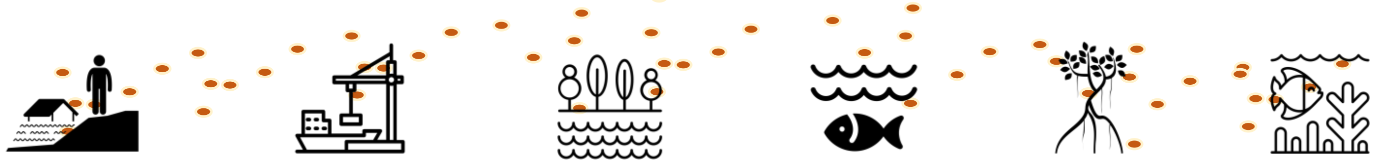
Betsiboka is stretching 600 km from the highlands to the northwest coast on the Mozambique Channel. It is a major conduit for transporting soils and sediments derived from the highlands of Central Madagascar to the sea (Raharimahefa, 2010). Soil losses observed along the Betsiboka have grown exponentially in the past 30 years. With soil erosion contributing about $3\,600 \cdot \text{t.km}^{-2}.\text{a}^{-1}$, Betsiboka River is among the largest recorded in the world (Chaperon et al.,1993; Roche and Rodier, 1984; Aldegheri, 1964; Roche, 1963). If the situation does not change, in 2100 the consequences of this enormous erosion will be tragic.




*Sediment evolution in the Betsiboka estuary (1990, 2020, 2100)*

Soil erosion and sedimentary transport and suspension into the river and the bay to the sea are affecting not only biodiversity but human activities as well.

## SOIL LOSSES IMPACTS



With sediment accumulation into the river, the shape of this later has changed, being narrowest. During heavy rains, water does not have enough space and escape from the riverbed, flooding the closest lands.

Majunga port is the second most significant port for the country. It has been moved directly on the ocean because of the sediment accumulation that prevents ships from going up into the estuary.

Farmlands and grasslands have become muddy swamps due to high sediment deposition driven from deforestation and irrigation with muddy water (Raharimahefa, 2010)

A high level of sediment in rivers reduces solar penetration and water oxygenation. This has a strong impact on biodiversity (animal, fungal and plant) and reduces fishing yields

Sediments cover mangroves slowing their development. Mangrove is one of the most important natural habitat providing food, coastal protection and capturing carbon.

Sediments, by clogging the pores, prevent polyp larvae from settling on the reef. The coral population is therefore not renewed and the coral reef decreases.

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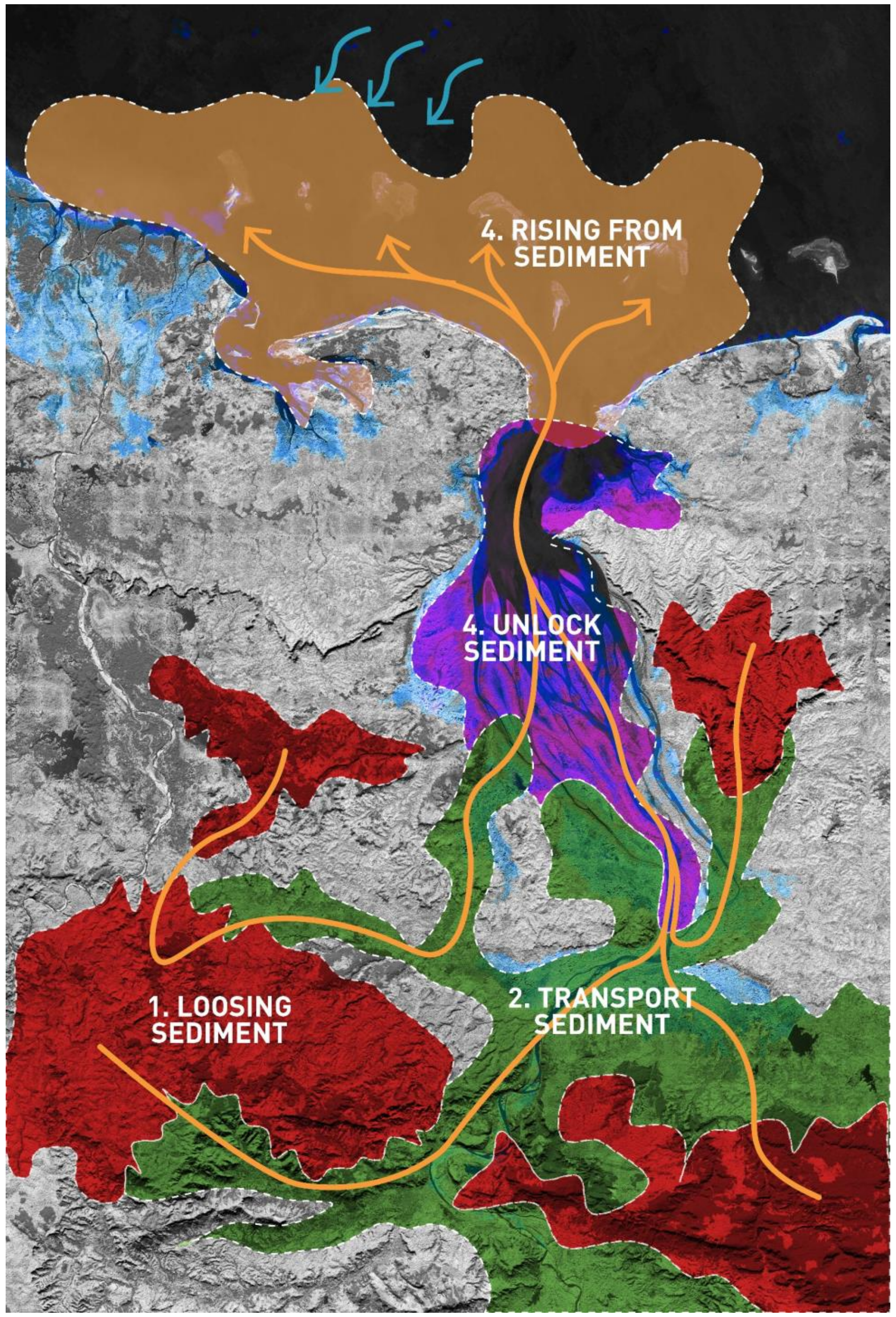
# RISING FROM DEFORESTATION

WHAT IF WE COULD FIND A SOLUTION THAT ANSWER BOTH SEA LEVEL RISE AND EROSION ISSUES IN MADAGASCAR?




LOOSING **SEDIMENTS**

Aim : regulate sediment flow into the river to reach normal flow rate

Environmental challenge: Deforestation and erosion due to non fixed soil creating sediment

Corrective measures : reduce the sediment flow going into the river

Preventive measures : Control deforestation in order to keep the sediment into the soil

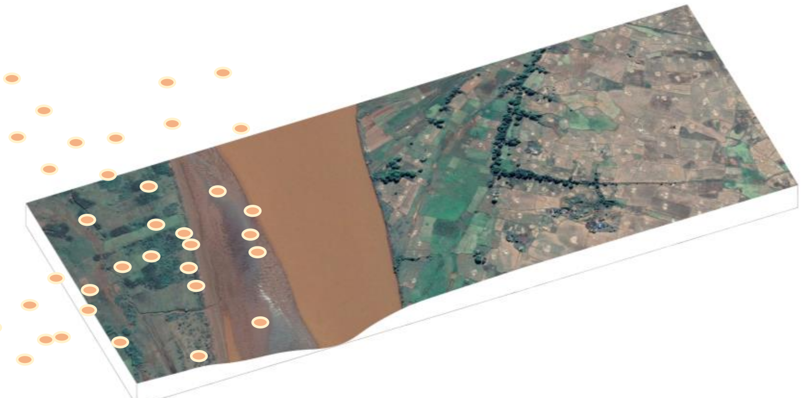
TRANSPORT **SEDIMENTS**

Aim : Maintain sufficient depth in the river to guarantee the sediment transportation and continue activities like navigation or ecological continuity

Environmental challenge: Flooding and clogged river due to sediment accumulation

Corrective measures : Reduce the sediment locked into the river

Preventive measures : Maintain riverbed shape and water depth to keep a water flow necessary for sediment transportation until the delta



UNLOCK **SEDIMENTS**

Aim : Unlock the delta by reducing the sediment accumulation area and accelerate the water flow rate

Environmental challenge: Flooding and clogged delta due to sediment accumulation

Corrective measures : Reduce the sediment locked into the delta

Preventive measures : Maintain delta shape and water depth to keep a water flow necessary for sediment transportation until the sea

RISING FROM **SEDIMENTS**

Aim : Use sediments from deforestation, transported by the river, to protect villages from sea level rise

Environmental challenge : Flooding, sea level rise, erosion, hurricane, biodiversity destruction

Corrective measures : Maintain the sediment between the coast and the coral reef

Preventive measures : Build protection against flooding, sea level rise and hurricane

Mainly due to deforestation and high periods of erosion, a large amount of sediment is found in the river and the estuary. These sediments are transported naturally or mechanically to the shoreline to be used for the construction of coastal protective island barriers. This solution addresses not only the effects of sea-level rise but also the excess of sediment present in the river. Resilient, accessible and local, this system makes it possible to build protection against sea-level rise from the consequences of deforestation: RISING FROM DEFORESTATION

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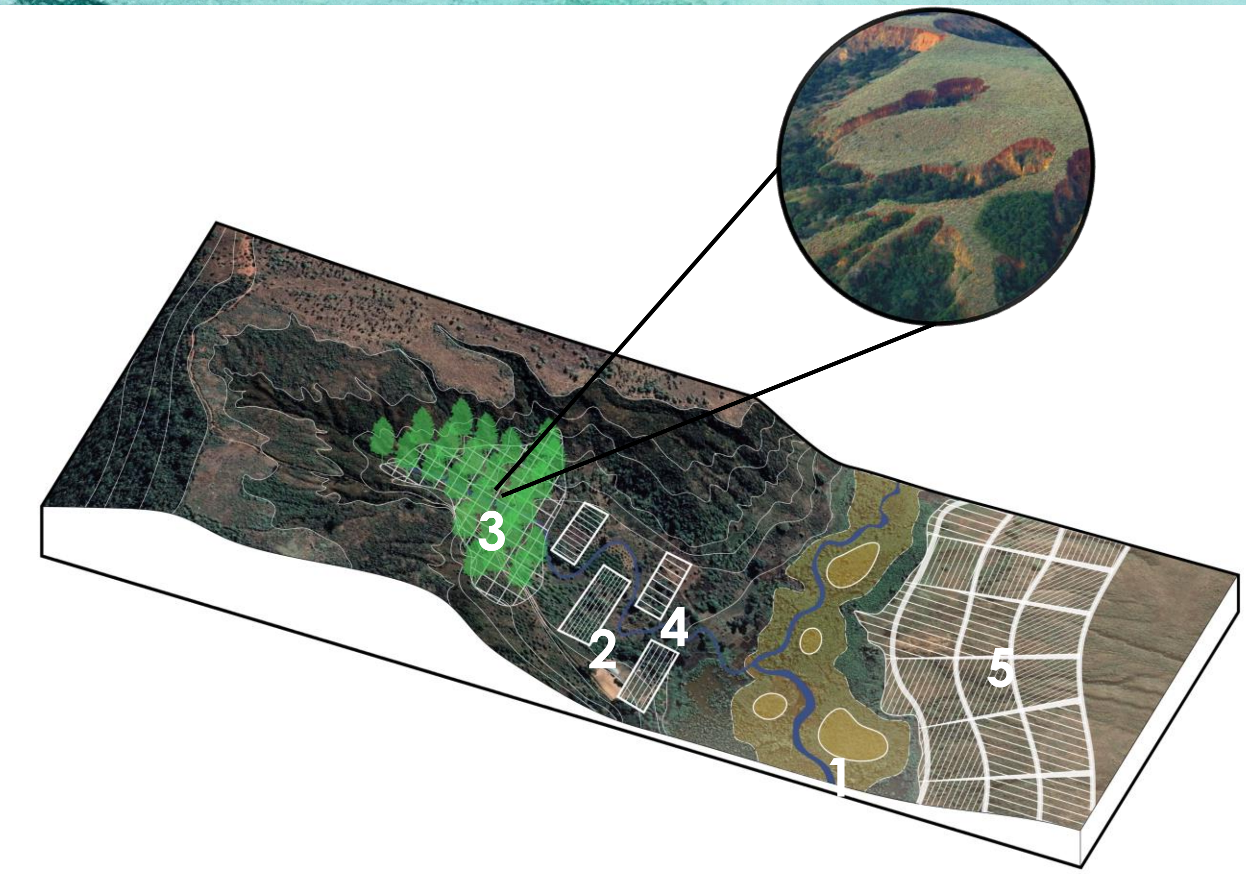
1. **LOOSING**
2. TRANSPORT
3. UNLOCK
4. RISING WITH

# SEDIMENTS




## 01.

**NAME :** Settling Basin
**ENVIRONMENTAL CHALLENGES:** Floods, erosion and locked streams by sediments
**DESCRIPTION:** Artificial structure that stops runoff water in a basin during floods and then slowly discharged only water retaining the sediment. Locked sediments can be used a posteriori for construction and barrier islands.

**IMPLEMENTATION TIME :**

**TIME BEFORE SUCCESSFUL OUTCOME:**

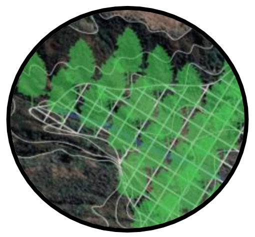
## 02.

**NAME :** Contour plowing
**ENVIRONMENTAL CHALLENGES:** Floods, erosion and land destruction
**DESCRIPTION:** Crops plant in contours, i.e. perpendicular to the slope. It favors water infiltration and reduces erosion. The vetiver plant is an ideal crop because it maintains the soil. Plus, we can produce essential oil.

**IMPLEMENTATION TIME :**

**TIME BEFORE SUCCESSFUL OUTCOME:**

## 03.



**NAME :** Reforestation
**ENVIRONMENTAL CHALLENGES:** Deforestation and erosion
**DESCRIPTION:** Tree plantation restoring ecologically devastated forest area. Agroforestry can be realized in the lavakas. It provides soil stability, natural habitat, and local job.

**IMPLEMENTATION TIME :**

**TIME BEFORE SUCCESSFUL OUTCOME:**

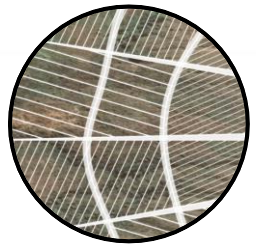
## 04.

**NAME :** Terrace fields
**ENVIRONMENTAL CHALLENGES:** Floodings and erosion
**DESCRIPTION:** Terrace is limiting soil erosion by reducing the runoff flow rate.

**IMPLEMENTATION TIME :**

**TIME BEFORE SUCCESSFUL OUTCOME:**

## 05.



**NAME :** Fields in fallow
**ENVIRONMENTAL CHALLENGES:** Erosion
**DESCRIPTION:** Fallow land has proven its effectiveness in water quality, biodiversity, erosion control and soil restoration. The grassed strip can intercept runoff transversely, slow down the water, retain sediment and act as a diffuser.

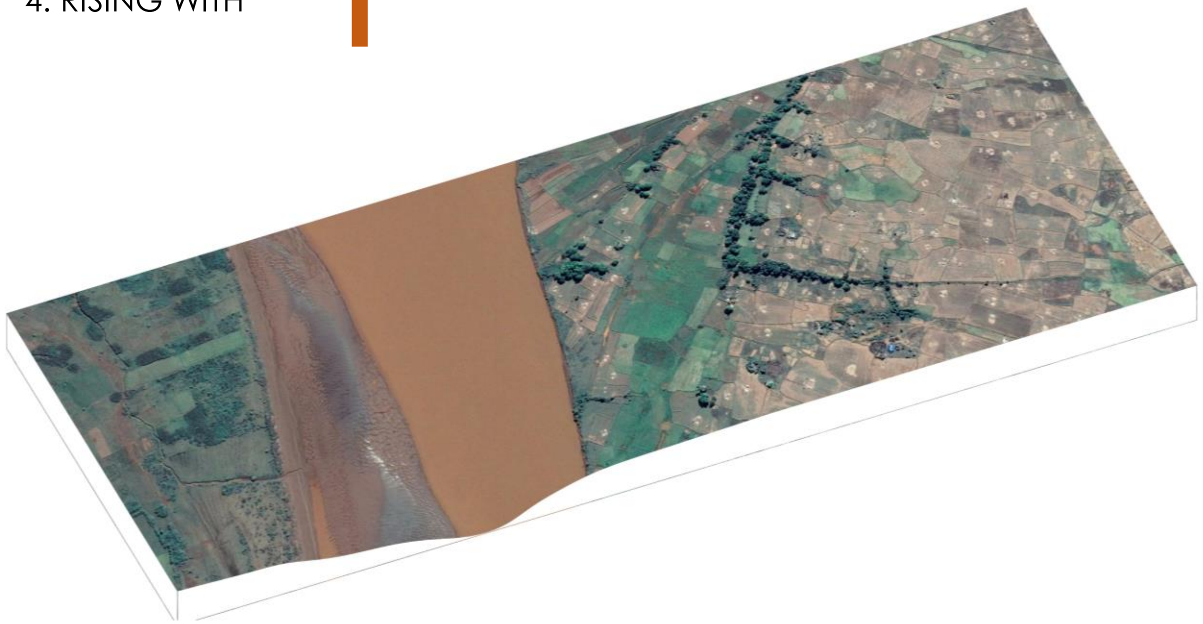
**IMPLEMENTATION TIME :**

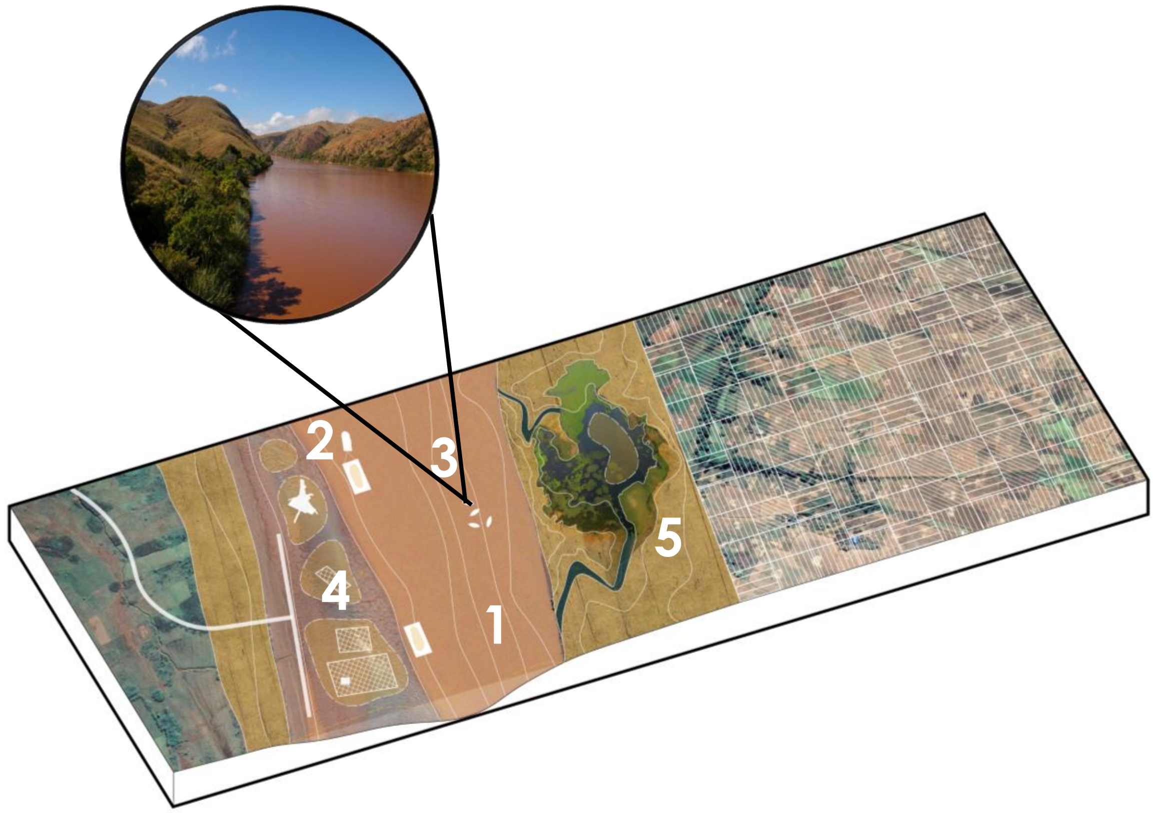
**TIME BEFORE SUCCESSFUL OUTCOME:**

# TRANSPORT SEDIMENTS

1. LOOSING
2. **TRANSPORT**
3. UNLOCK
4. RISING WITH

# SEDIMENTS



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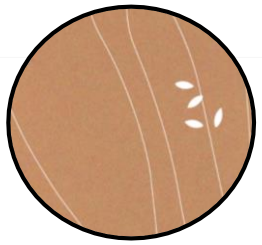


**NAME :** Natural Transportation
**ENVIRONMENTAL CHALLENGES:** Floods and locked river by sediments
**DESCRIPTION:** With the natural river rate flow, sediments are transported. Heavier materials roll to the bottom of the river without taking off (thrust). Lighter materials are transported in the mass of the stream (suspension)

**IMPLEMENTATION TIME :**

**TIME BEFORE SUCCESSFUL OUTCOME:**

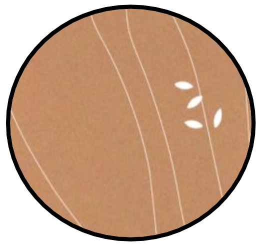
## 02.

**NAME :**Mechanical transportation
**ENVIRONMENTAL CHALLENGES:** Floods and locked river by sediments
**DESCRIPTION:** Mechanical cleaning to maintain water depth and natural sediment transportation. Sediments discharged from the river will be used for barrier island construction.

**IMPLEMENTATION TIME :**

**TIME BEFORE SUCCESSFUL OUTCOME:**

## 03.



**NAME :** Riverbed remodeling
**ENVIRONMENTAL CHALLENGES:** Floods, erosion and locked river by sediments
**DESCRIPTION:** Restructuration of the riverbed in order to maintain a constant water flow rate and transport sediments until the delta avoiding sediment accumulation area.

**IMPLEMENTATION TIME :**

**TIME BEFORE SUCCESSFUL OUTCOME**

## 04.

**NAME :** Riversides landscaping
**ENVIRONMENTAL CHALLENGES:** Floods, erosion and locked river by sediments
**DESCRIPTION:** Adapt existing construction and install simple infrastructure on the riverside in order to maintain the river shape.

**IMPLEMENTATION TIME :**

**TIME BEFORE SUCCESSFUL OUTCOME:**

## 05.

**NAME :** Water retention basin
**ENVIRONMENTAL CHALLENGES:** Floods, erosion and locked river by sediments
**DESCRIPTION:** Artificial structures that control water flow and sediments quantity into the river. Soil is retained into the retention basin and water is discharged in the river. Sediment stock can be used for barrier island construction.

**IMPLEMENTATION TIME :**

**TIME BEFORE SUCCESSFUL OUTCOME:**

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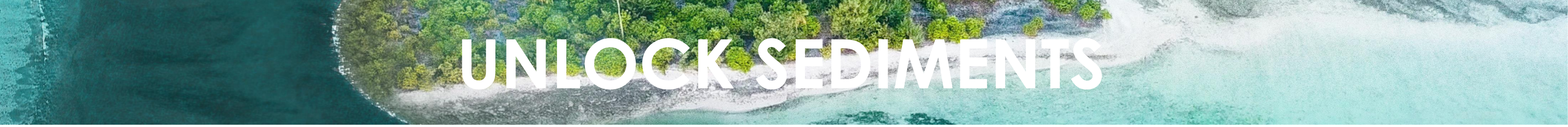
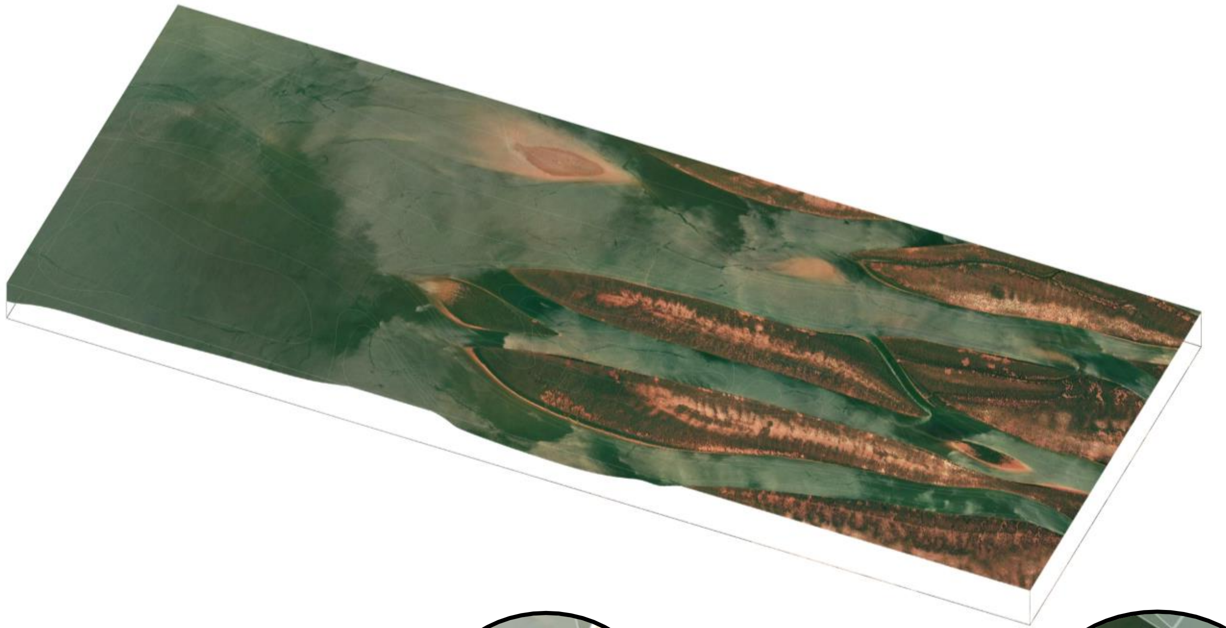
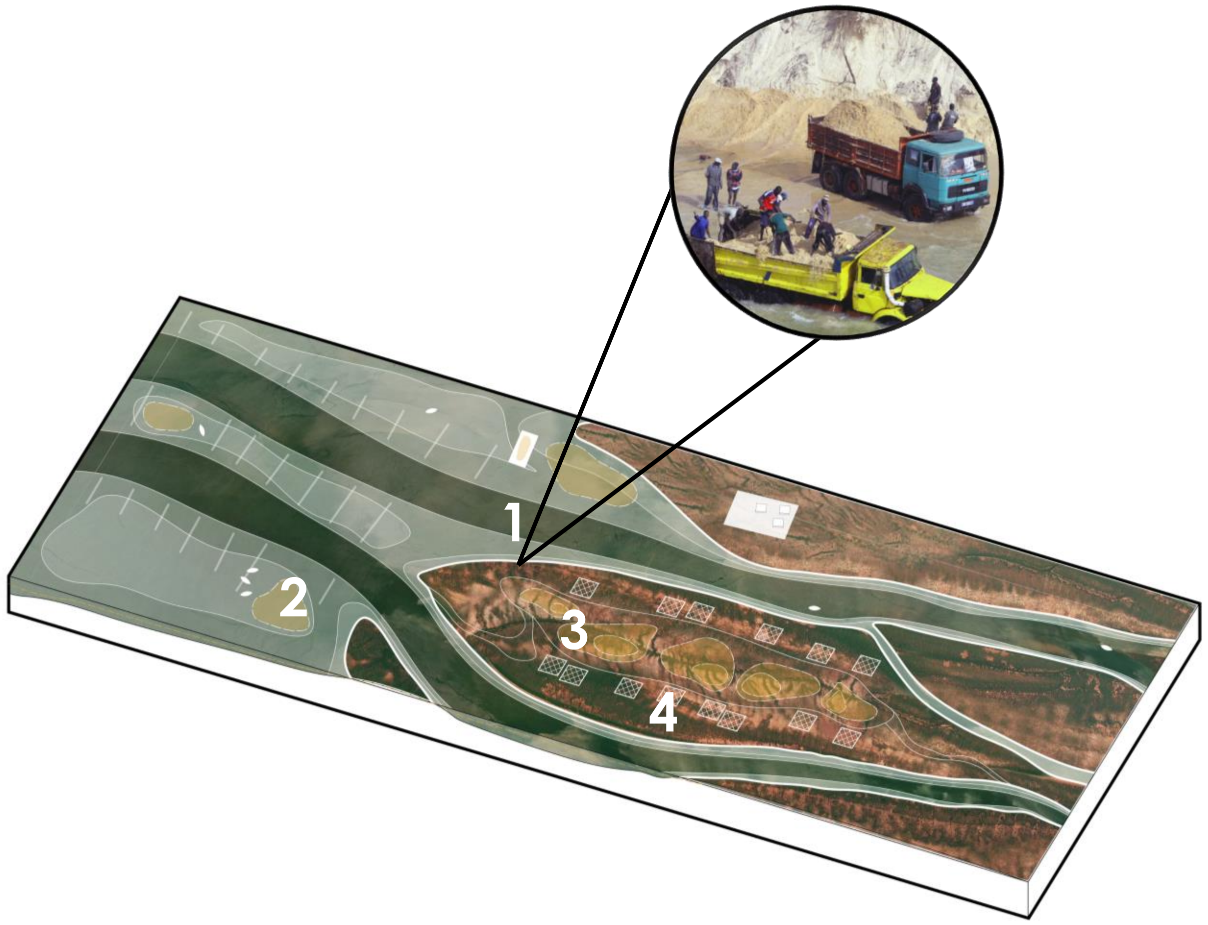



1. LOOSING
2. TRANSPORT
3. **UNLOCK**
4. RISING WITH

# SEDIMENTS



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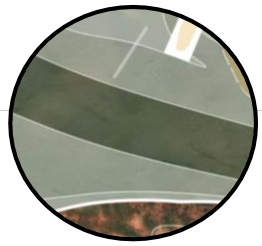

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**TIME BEFORE SUCCESSFUL OUTCOME:**

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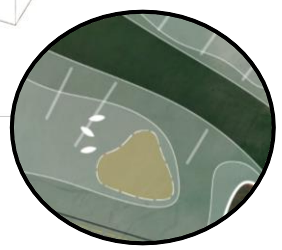

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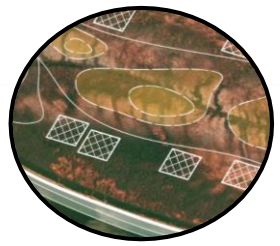
**ENVIRONMENTAL CHALLENGES:** Floods, erosion and locked delta by sediments
**DESCRIPTION:** Restructuration of the delta and islands shape in order to maintain a constant water flow rate and transport sediments in the sea avoiding sediment accumulation area.

**IMPLEMENTATION TIME :**

**TIME BEFORE SUCCESSFUL OUTCOME**

## 04.



**NAME :** Delta landscaping
**ENVIRONMENTAL CHALLENGES:** Floods, erosion and locked delta by sediments
**DESCRIPTION:** Adapt existing construction and install simple infrastructure on the delta bank in order to maintain the delta shape.

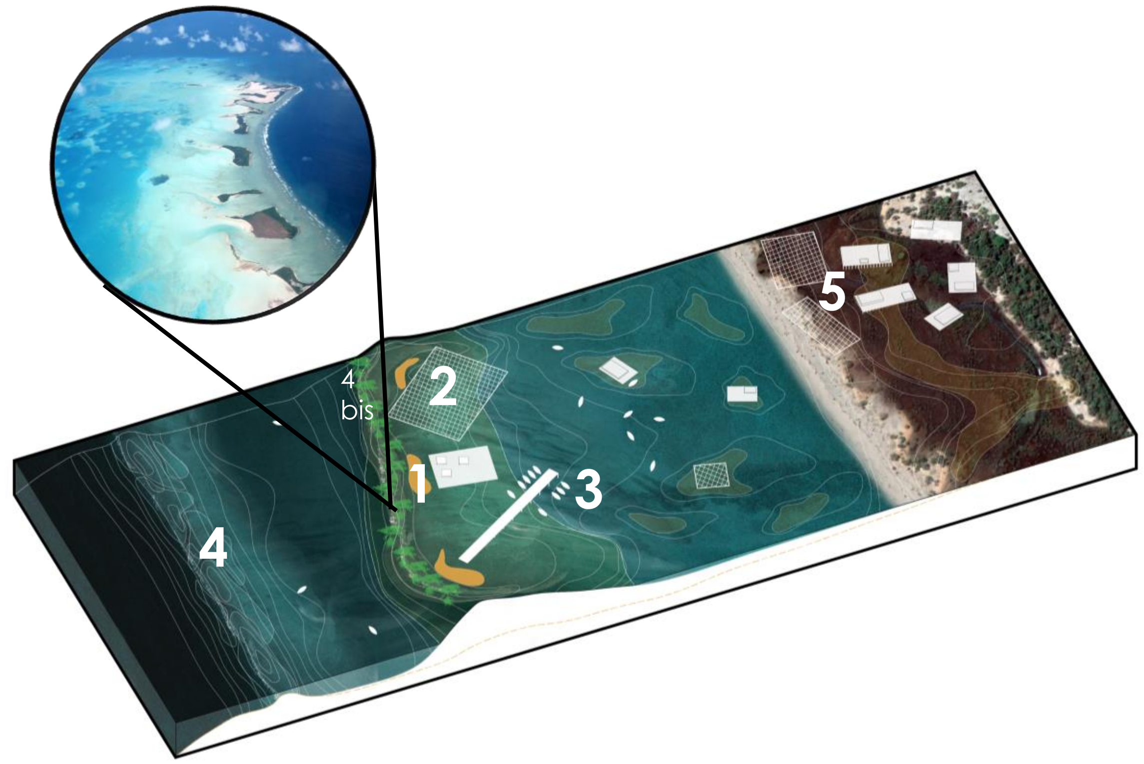
**IMPLEMENTATION TIME :**

**TIME BEFORE SUCCESSFUL OUTCOME:**

# RISING WITH SEDIMENTS

1. LOOSING
2. TRANSPORT
3. UNLOCK
4. **RISING WITH**

# SEDIMENTS

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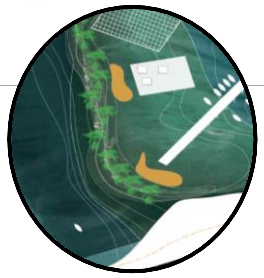
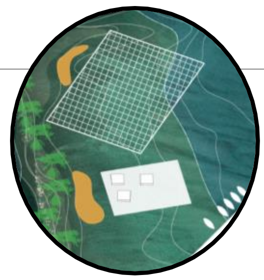


**NAME :** Artificial barrier island
**ENVIRONMENTAL CHALLENGES:** Sea level rise, beach erosion, hurricane
**DESCRIPTION:** System developed by the MIT of underwater structures that use wave energy to create sand the accumulation. Over time, accumulation of sand will grow into new islands protecting from rising sea levels. (MIT, 2019)
**IMPLEMENTATION TIME :**

**TIME BEFORE SUCCESSFUL OUTCOME:**

## 02.



**NAME:**Sea cucumber aquaculture
**ENVIRONMENTAL CHALLENGES:** Sea level rise and beach erosion
**DESCRIPTION:** Sea cucumber is an overfish sea product in Madagascar. This animal cleans sediments of their bacteria and favors seagrass growth that retains the sand on the seabed. Aquaculture can provide income for the local communities
**IMPLEMENTATION TIME :**

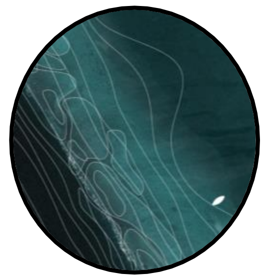
**TIME BEFORE SUCCESSFUL OUTCOME:**

## 03.

**NAME :** Fishery activities
**ENVIRONMENTAL CHALLENGES:** Sea level rise, beach erosion, hurricane
**DESCRIPTION:** Relocation of the fishery activities in the barrier island. This latter shape protect infrastructures (ex: port) and provides naturally fishery resources
**IMPLEMENTATION TIME :**

**TIME BEFORE SUCCESSFUL OUTCOME**

## 04.



**NAME :** Biodiversity preservation
**ENVIRONMENTAL CHALLENGES:** Sea level rise, beach erosion, sediment accumulation, hurricane
**DESCRIPTION:** Retain the sediment into the barrier island to protect the coral reef. Reforestation of mangroves that maintain the sediment, provide natural habitat and fishery resources.
**IMPLEMENTATION TIME :**

**TIME BEFORE SUCCESSFUL OUTCOME:**

## 05.

**NAME :** Retreat
**ENVIRONMENTAL CHALLENGES:** Sea level rise, hurricane
**DESCRIPTION:** Relocation with recognition of cultural, environmental and economic aspects. All coastal activities are maintained thanks to floating facilities (ex: fish market) even if the village is no longer located on the beach itself.
**IMPLEMENTATION TIME :**

**TIME BEFORE SUCCESSFUL OUTCOME:**

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# MADAGASCAR LITTORAL IN 2100

**CORAL REEF :**
The sediment rate on the coral reef is lower. The polype population can be renewed and the coral reef is bigger providing fishery products and economics to the local people.

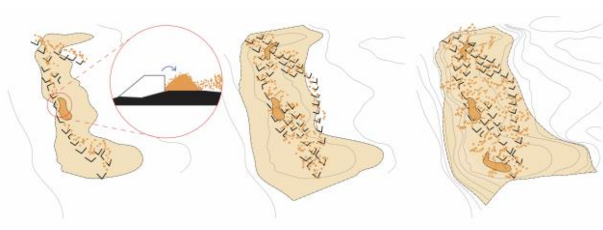
**MANGROVE:**
Mangroves protect the rest of the barrier island against a hurricane. They also represent natural habitats essential for marine animal reproduction. Thus, they maintain the local fishing industry.

**FLOATING FACILITIES :**
Coast lifestyle has been extended to the barrier island. Different facilities have been set up. For example, sea cucumber aquaculture provides exosystemic services and income for local communities.

**SEA GRASS CULTURE:**
Alga and seagrass marine crops are essential to maintain sand and stabilize the bathymetry around barrier island. Plus, algae and seagrass capture $CO_2$ and provide income for local communities.

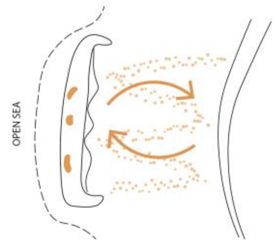

## PRINCIPLE

System developed by the MIT of underwater structures that use wave energy to create sand accumulation in strategic locations. Sand accumulation will grow into new islands. Those structures are bladders made of canvas and biodegradable material that is filled with sediment coming from the river (naturally and mechanically). (MIT, 2019)

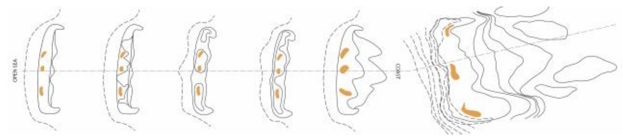


## FORMATION

Bladders are triangle-shaped to optimize sediments capture. There is a double accumulation: sediments coming from the river and sand coming from the open sea. The proximity of the barrier islands to the coast reduces the amplitude of sand movement between the coast and the sea. The sand "back and forth" is shorter and there is less sediment loss in the open sea. Also, the level of the seabed in this area is more constant and less impacted by wave erosion.



## HURRICANE PROOF



1 2 3 4 5 6

1. Short term barrier island evolution
2. Barrier island under strong weather event
3. Barrier island worst case scenario
4. Barrier island recovery after strong erosion
5. Barrier island general trend
6. Long term barrier island evolution

## EXPANDABLE

The Betsiboka estuary is not the only one suffering from sediment problems butalmost all of the estuaries derived from the highlands of Madagascar are also suffering similar issues. Other African countries may face the same problem like Mozambique which is threatened by sea-level rise and hurricane as well.

Madagascar rivers and estuaries (ESA,2019)

Madagascar fires in 2019 (Global forest watch)

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