

Assessing the buffering function of coastal systems in the face of tropical cyclones: insights from Tubuai Island, French Polynesia



Need for alternatives to hard-engineering structures for coastal protection: relying on « **natural barriers** »? (Defeo et al., 2009; Salgado & Martinez, 2017; Spalding et al., 2014)

Salt Marsh



Coral



Mangrove



Oyster



Dunes

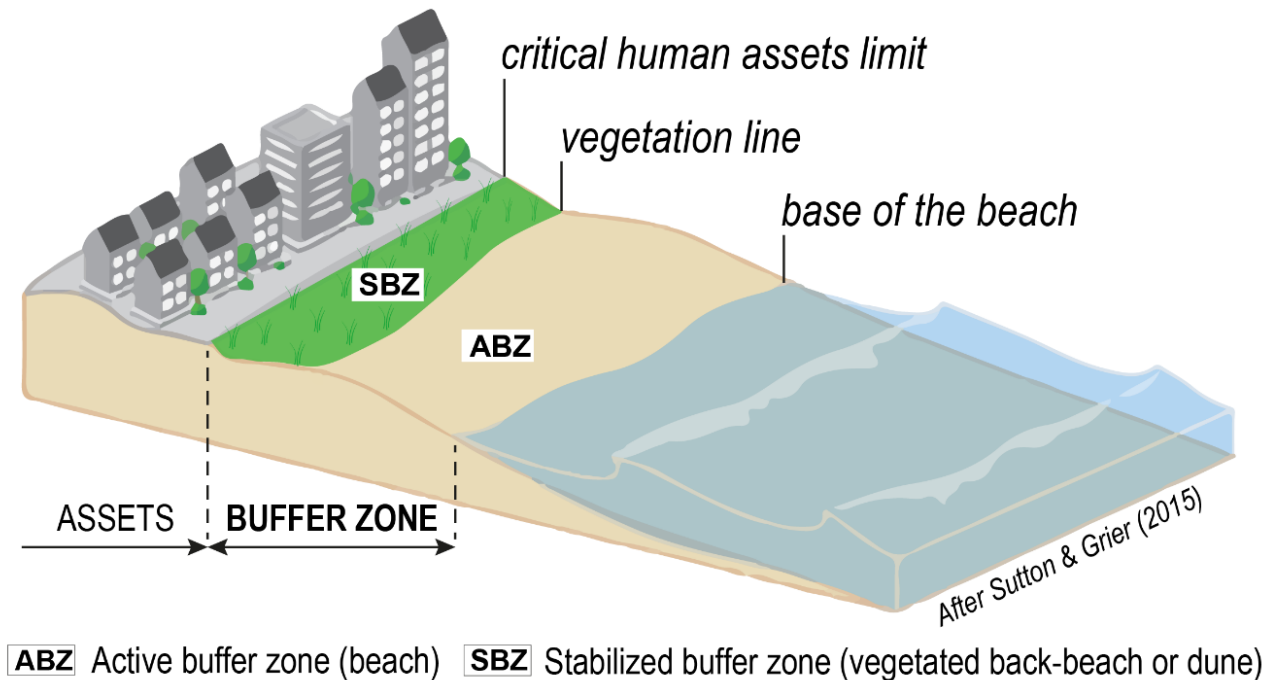


From Sutton & Grier (2015)

Buffer zone definition

“natural” area located between the **base of the beach** and the **first human assets** (roads, buildings, infrastructures)

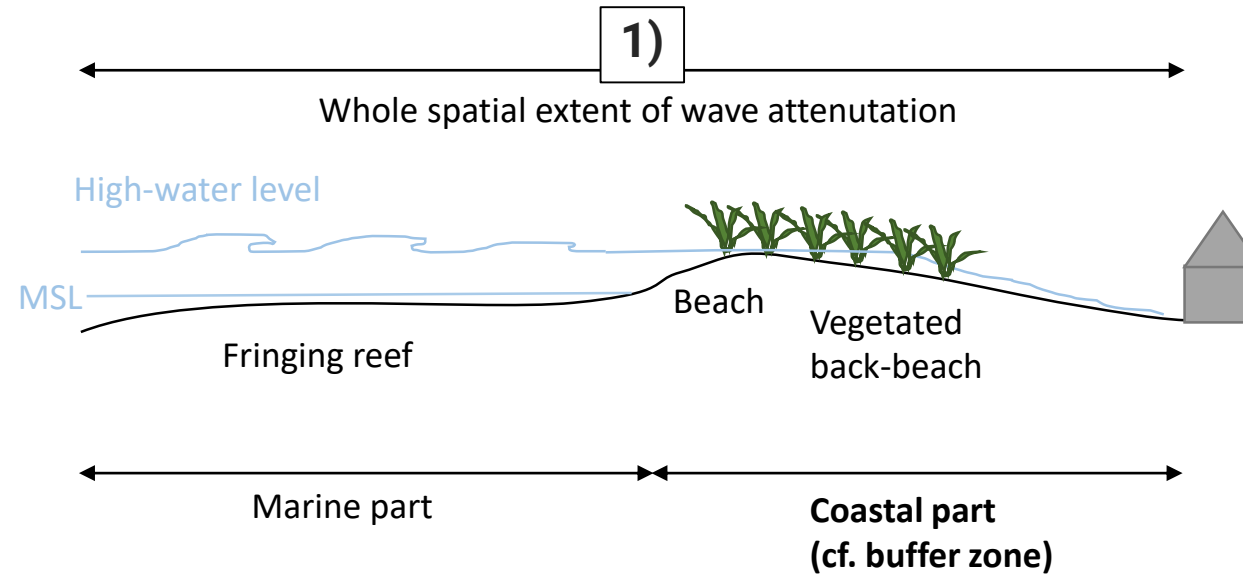
Composed of an active part (beach) and a stabilized part (the vegetated back-beach), separated by the **vegetation line** or **coastal defences** (= stability line)



Buffering function: service offered by natural features (morphological features, vegetation) which results in the damage reduction in face of a hazard (e.g. tropical cyclones). This coastal protection service depends notably on:

1) Attenuation of wave energy:

- No or less blocks projections
- No or less destructive waves
- Less shoreline retreat



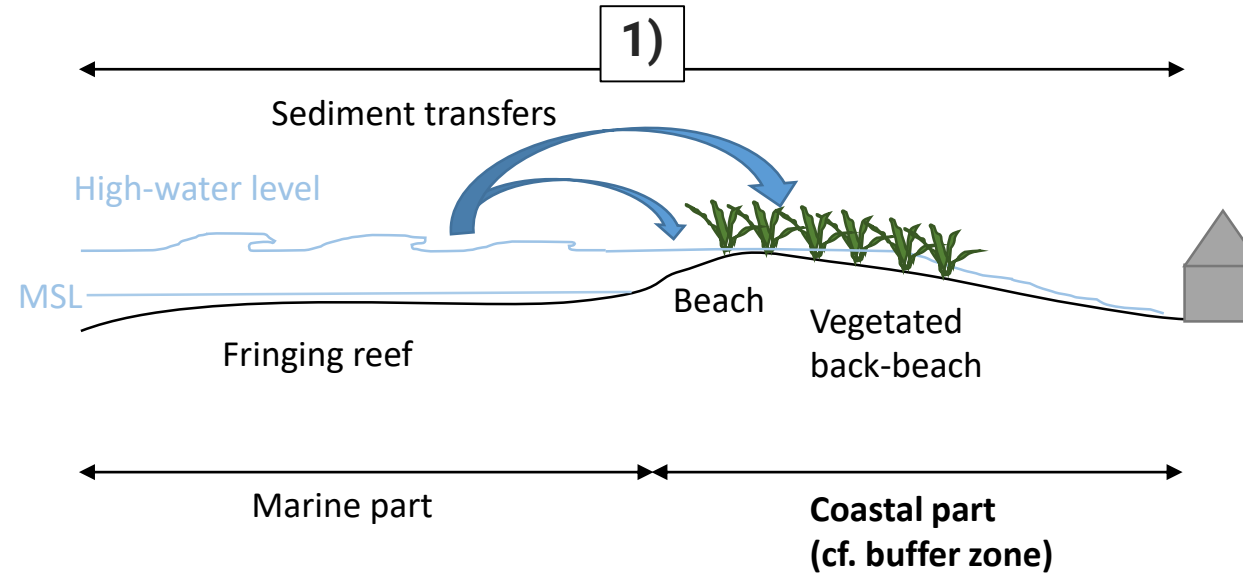
Key parameters of the buffer zone

- Width**
- Structure**
- Vegetation characteristics**
- Elevation**

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- Washover deposits (vertical accretion)



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Elevation

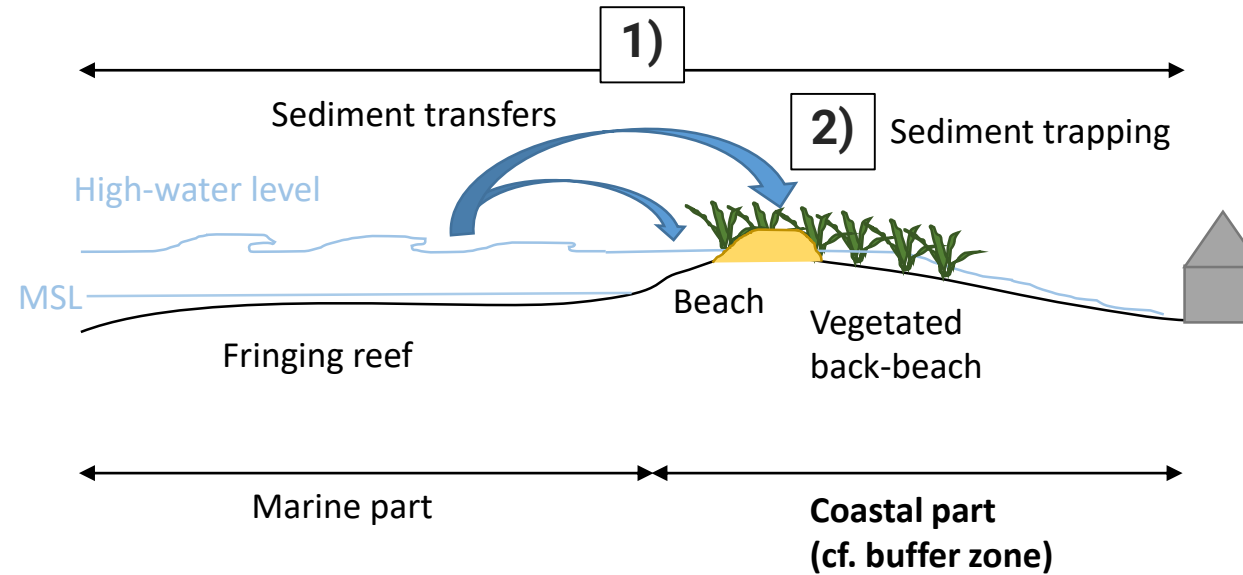
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- vertical accretion (rise in elevation)



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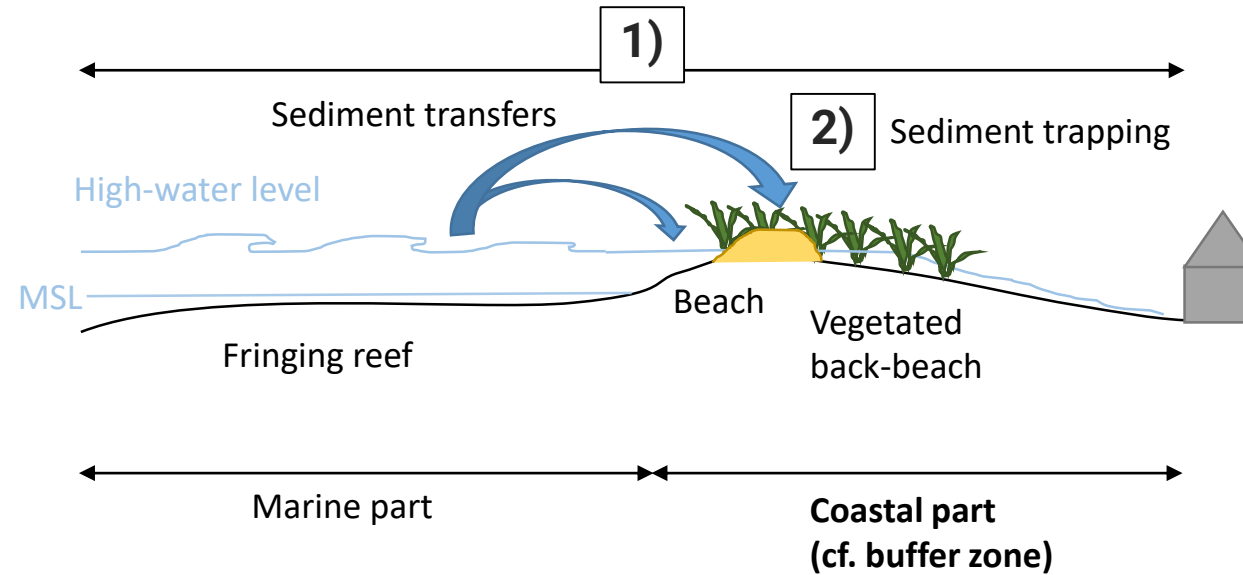
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3) « Natural barrier » against marine inundation:

- No inundation of human assets

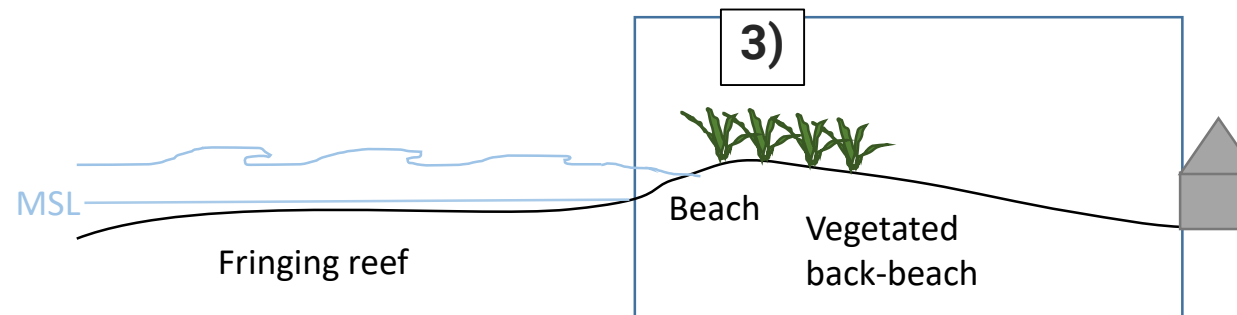


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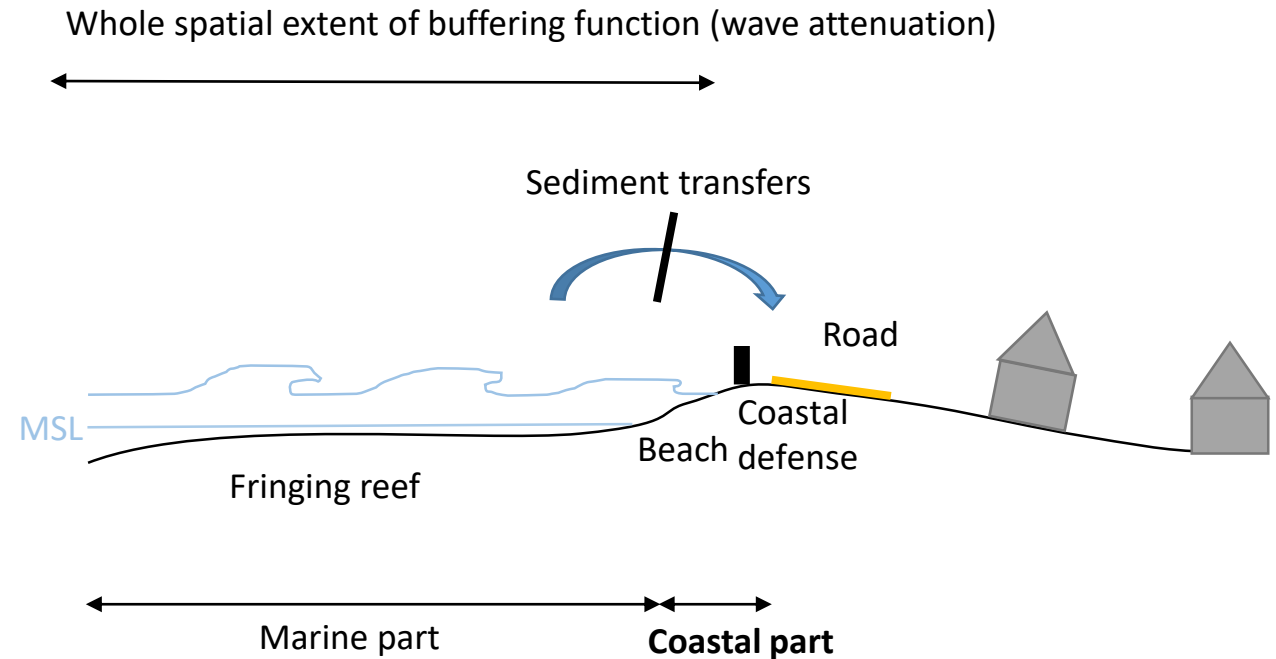
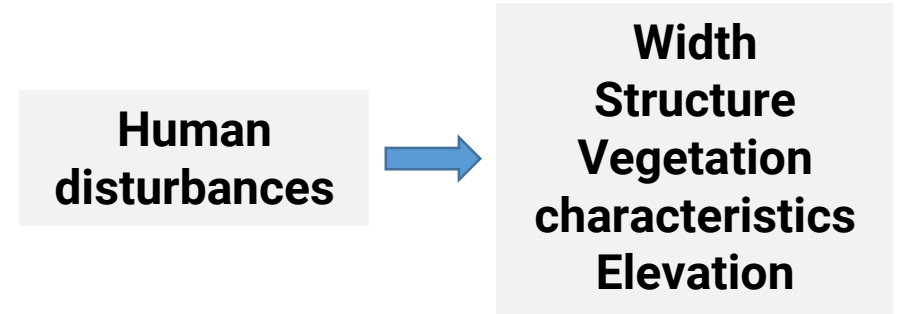
Human activities alter the buffering function: degraded coastal systems



- Urbanization
- Land reclamation
- Sediment transfers interruption due to hard-engineering structures (transversal and longitudinal)
- Sand mining / extraction
- Removal of vegetation

Processes (1, 2 and 3) are disturbed and negative impacts are:

- Contraction of the buffer zone (coastal squeeze)
- More blocks projections
- More destructive waves
- Destabilization (accelerated shoreline retreat in places and advance in others)
- Washover deposits do not remain in the natural system (no vertical accretion)



Scientific question / objective:

Is buffering function restoration of degraded coastal systems a relevant solution for risk reduction?

Case study: Tubuai Island (Pacific ocean)

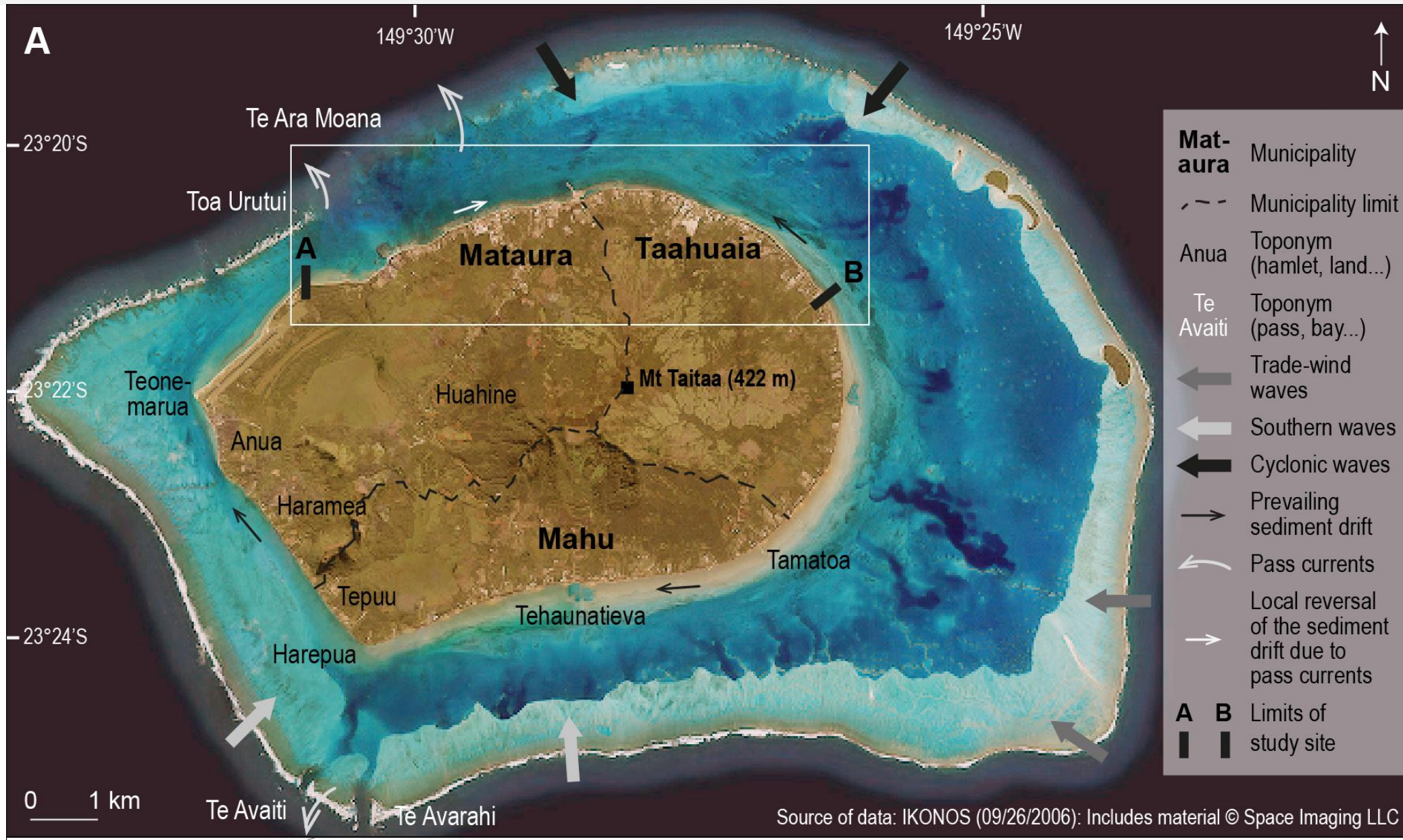
High Volcanic island of 45 km²

Lagoon / barrier reef / fringing reef at the north

Large coastal plain / Barrier beaches (coral sand)

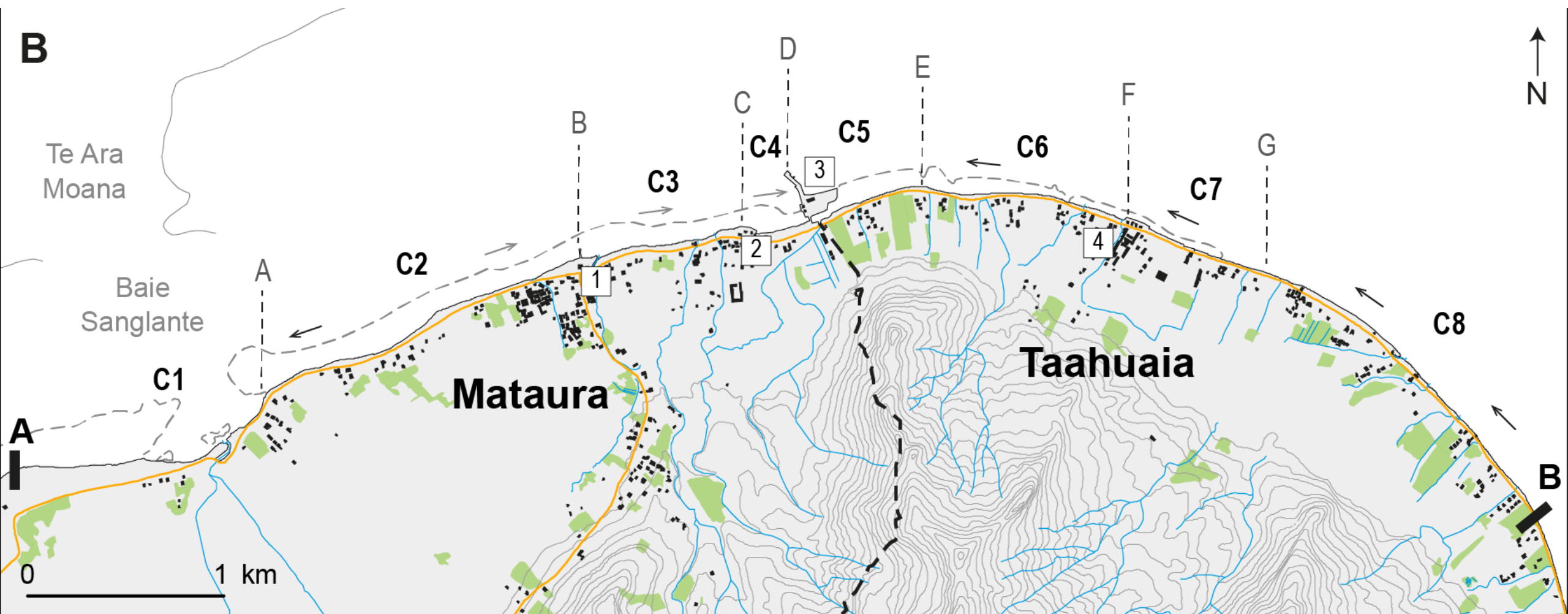
Study site = 8.6 km of shoreline

Northern coast: most populated and most exposed to cyclonic events!



Degraded coastal systems (despite low population density, i.e. 48 inhabitants/km²):

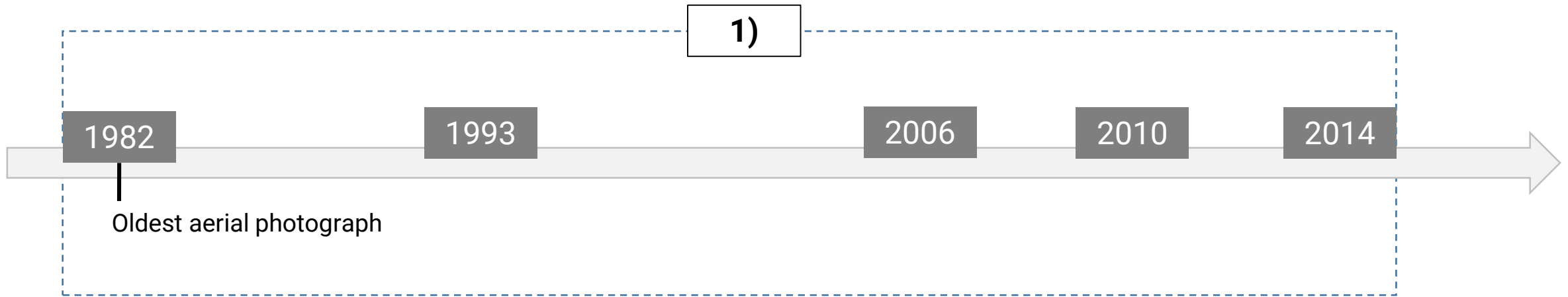
- Coastal urbanization (coastal road very close to the shore)
- Almost no indigenous coastal vegetation anymore: consists of narrow and discontinuous *casuarina* belt with *crinum asiaticum*
- Fragmentation in sub-cells by transversal human-built structures



Barrier reef	Prevailing sediment drift	Building	Sub-cell limit	1 City hall	3 Harbour
Fringing reef	Local reversal of the sediment drift due to pass currents	Main road	E Sub-cell number	2 Meteorological center	4 High school
River		Agricultural plots	C6 Sub-cell number		

Material and Methods: methodological protocol

Two different approaches: **1)** documenting multi-decadal changes (1982-2014) in the buffering function based on a GIS analysis and fieldwork;



Objective

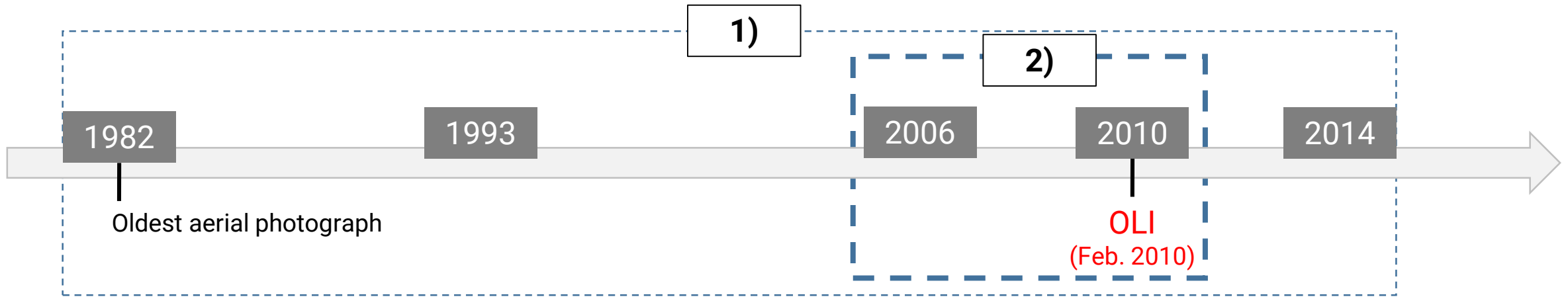
- First theoretical assessment (based on a simplified theoretical index)
- Spatio-temporal variability?
- Quantify the degradation process

Data source

- Aerial photographs, satellite imagery: **French Polynesian Government**
- Data were digitized from imagery, improved and completed with fieldwork (e.g. coastal defences)

Material and Methods: methodological protocol

Two different approaches: **1)** documenting multi-decadal changes (1982-2014) in the buffering function based on a GIS analysis and fieldwork; **2)** then focusing on the TC Oli event in 2010 to assess this buffering function in the face of a strong disturbance



Objective through a more detailed analysis (more variables)

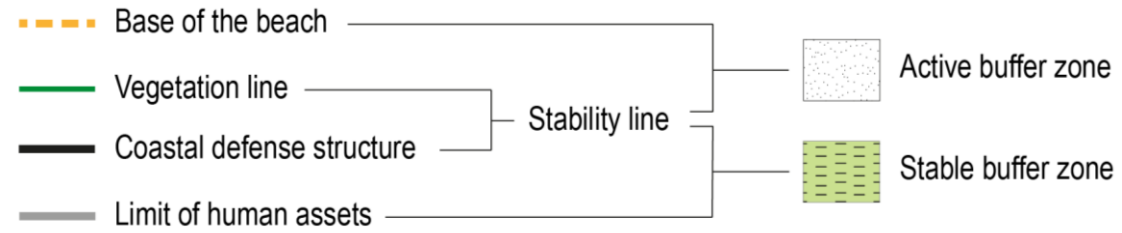
- What really is the buffering function in case of this high-energy event?
- To compare the impacts with the buffer zone characteristics to assess their contribution
- To discuss what could be the lessons for the future

Data source

- Reports, papers, fieldwork, etc. to document the impacts
- 2006 theoretical index (cf. **approach 1**)
- 2006 and 2010 satellite imagery + DEM (2006): French Polynesian Government

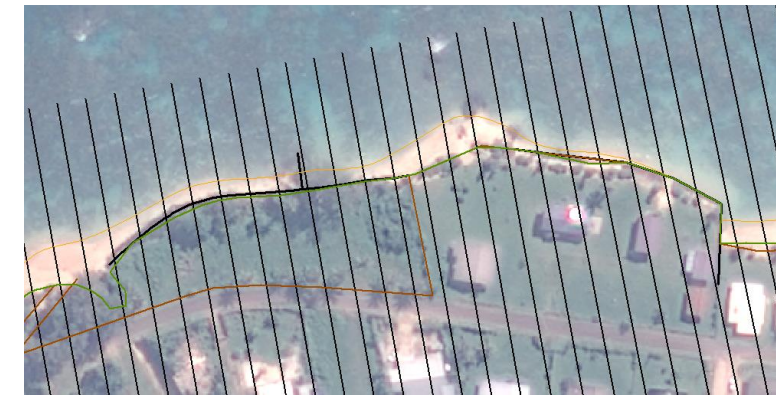
Material and methods: 1) multi-decadal assessment

1. buffer zone limits digitization



2. Spatial framework of the GIS analysis

10m-interval transects cast perpendicular to the shore. 860 transects from west to east



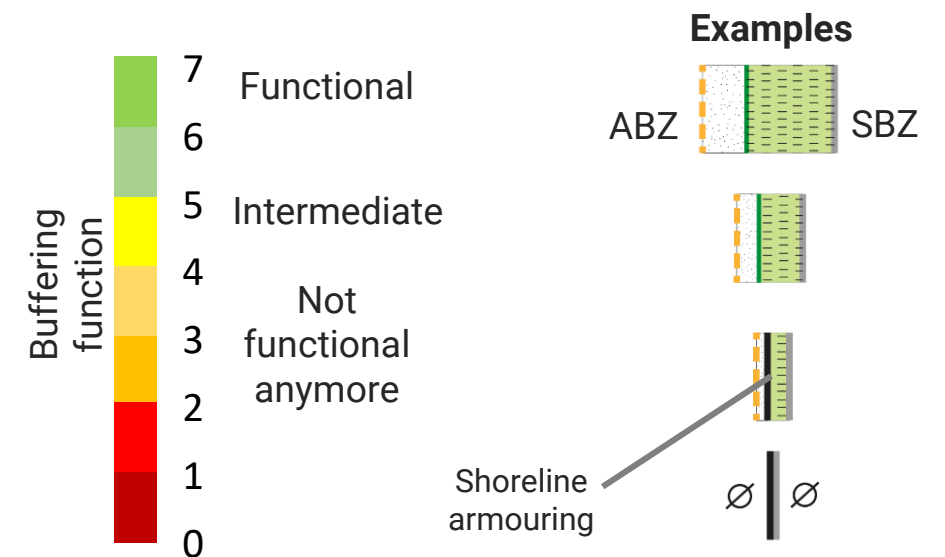
3. Variables available at transect scale

Transects intersected the GIS layers enabling to document the following variables:

- Structure (active vs. stabilized buffer zone)
- Width (active, stabilized, and total buffer zone width)
- Shoreline armouring

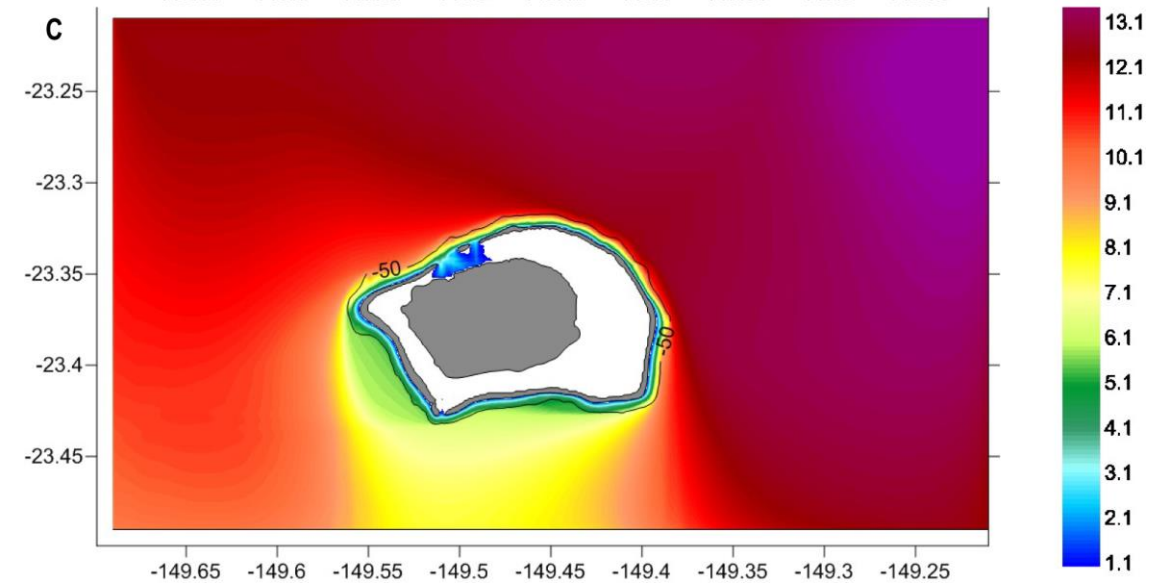
4. Aggregation to an index (scoring)

Width	Structure	Armouring
more than 60m, score 5	complete, score 1	without, score 1
between 30-60m, score 3	truncated, score 0	with, score 0
less than 30m, score 1		



Material and methods: 2) Zoom on TC Oli (feb. 2010)

- February 4-5, 2010
- Hit the northern coast
- Category 4 (gusts of 198 km/h)
- Waves reaching 6-8 m / storm surge of around 2 m)
(Barriot et al., 2016)



GIS Data

Data creation based on DigitalGlobe image taken 9 days after TC Oli landfall

Digitization of the **landward extension of washover deposits** = **minimum extent of marine inundation!**

Crossing (transects) with buffer zone characteristics (from **2006**)

- Theoretical assessment: buffering function score
- Max Elevation
- Vegetation width before the event

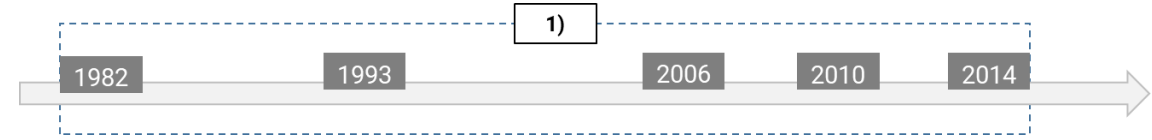
What were the impacts of TC Oli on the northern coast of Tubuai?

How was the buffering function during this event?

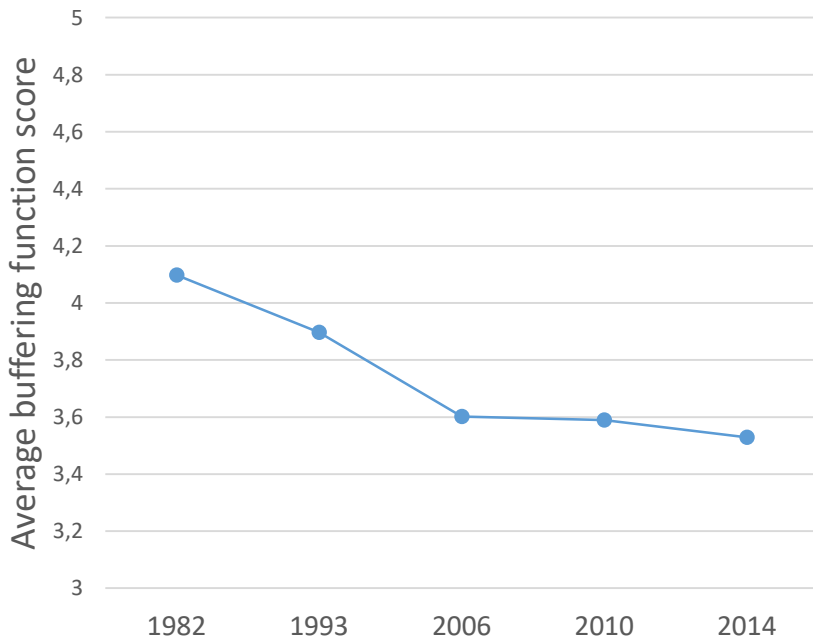
Which lessons learnt for the future?



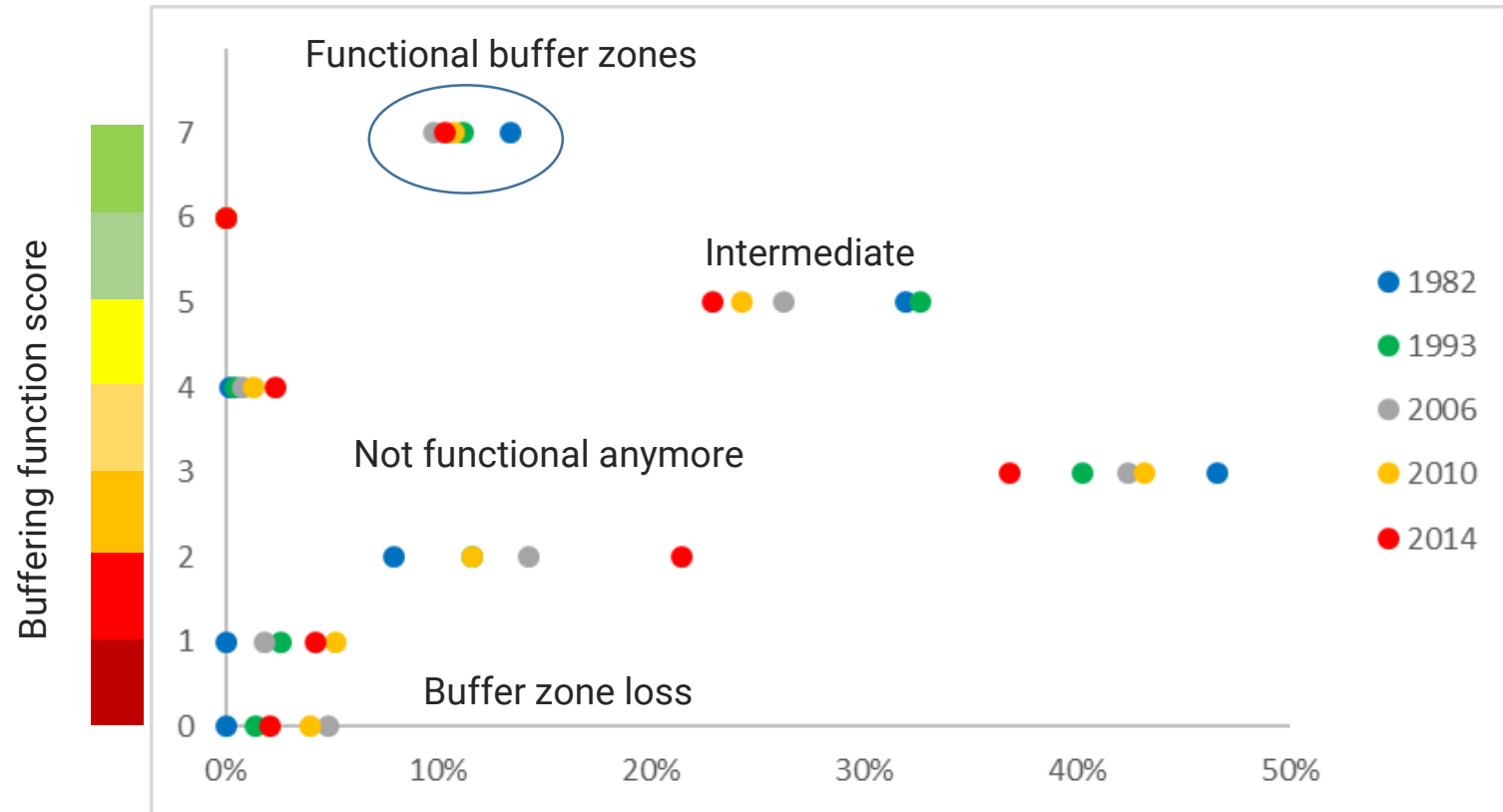
Results



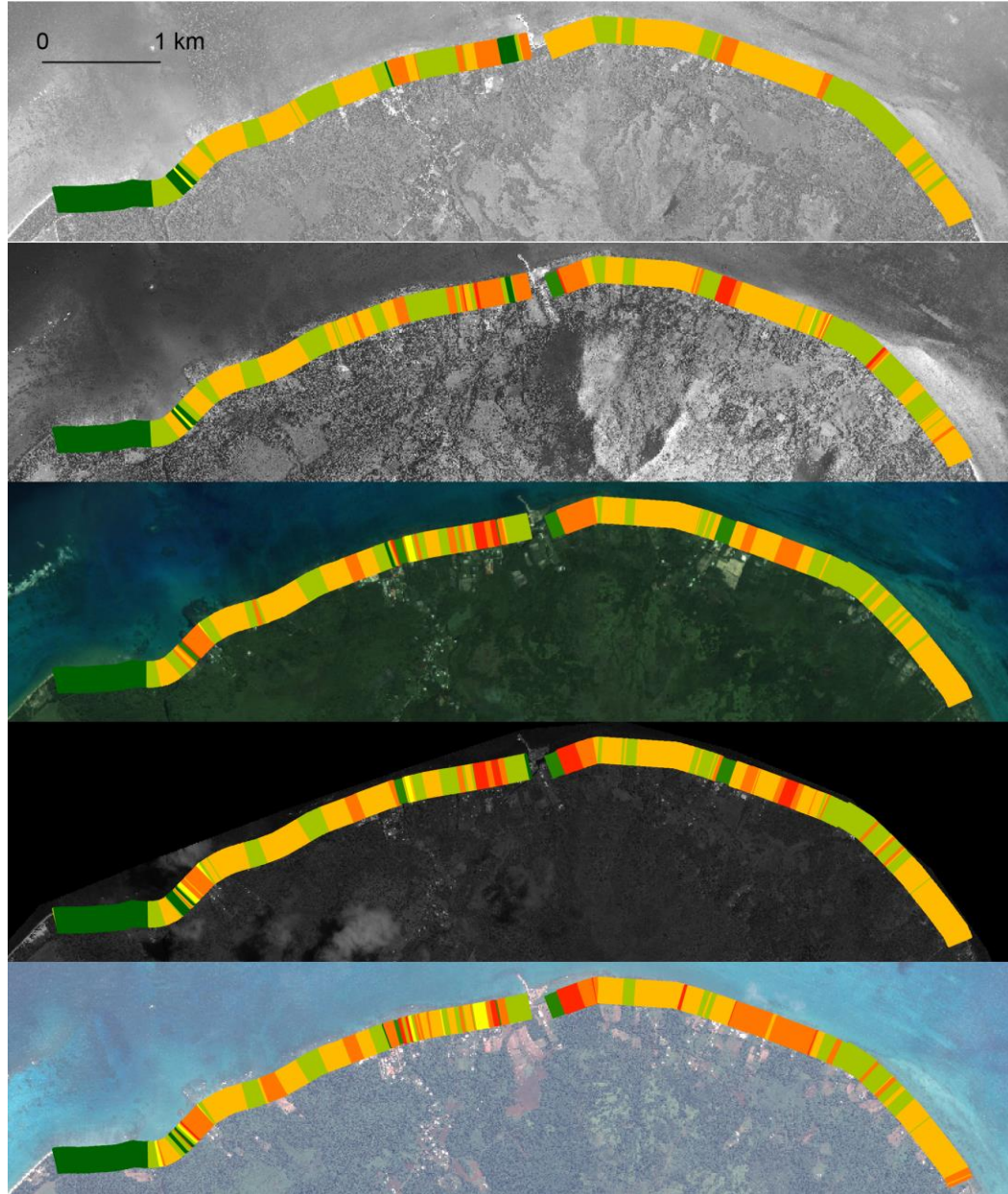
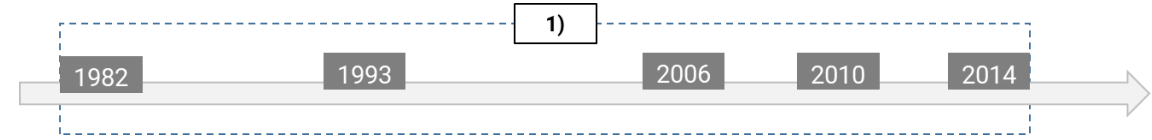
Decreasing in buffering function average score (-0,6 between 1982 and 2014)



Diminution of high scores of buffering functions (5-7)
Augmentation of very low scores (0-2)



Results

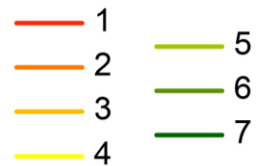


High spatial variability?

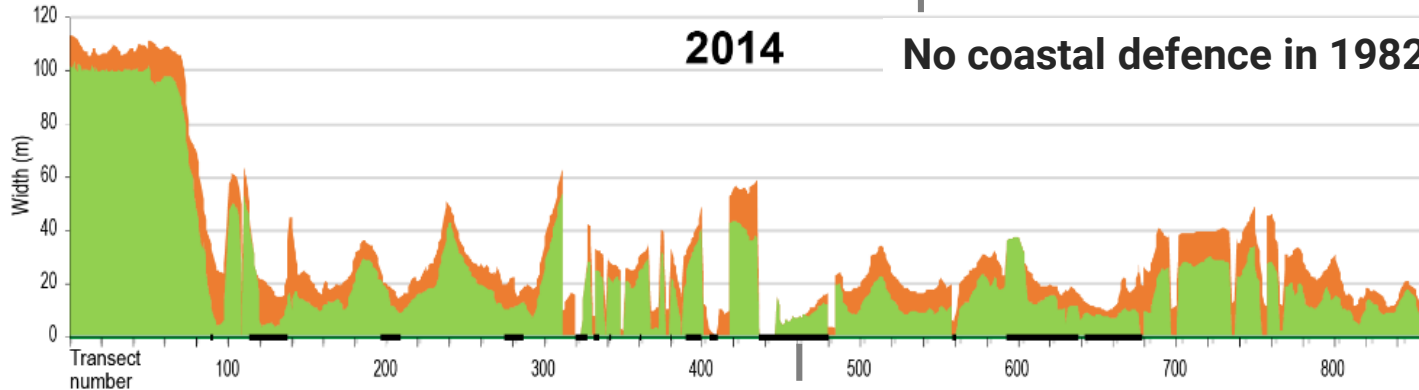
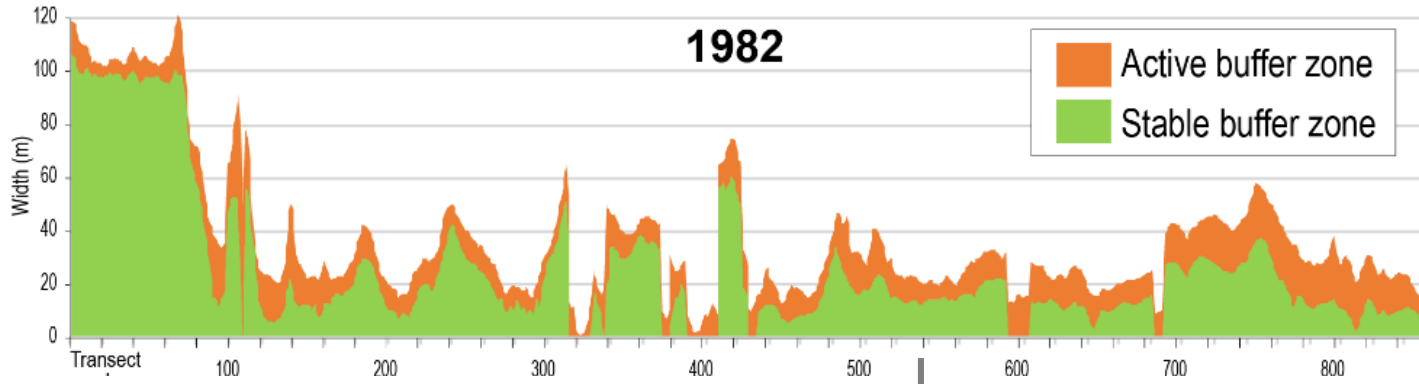
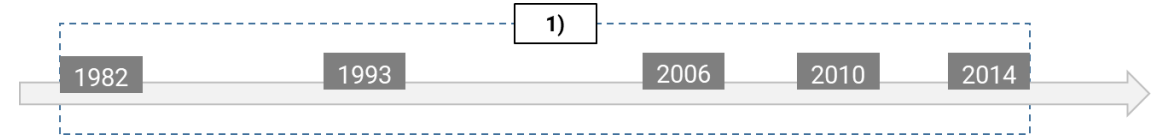
Western part of cell 1: most preserved area

Except this: low functionality because of high human pressure

Buffering function score



Results



Coastal defence

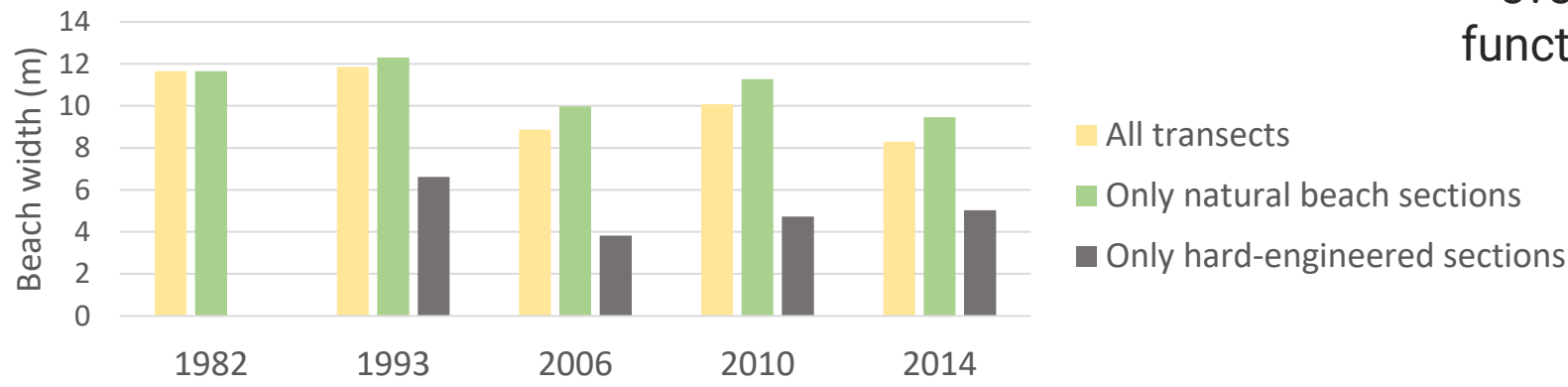
Contraction (even if moderate)

Large **extension** of **shoreline armouring** (thick black line)

Disparition of entities (e.g. **beach loss**)

Fragmentation of the buffer zone

= even spatial variability, low buffering function, especially since 2006



Results: Impacts of TC Oli (feb. 2010)



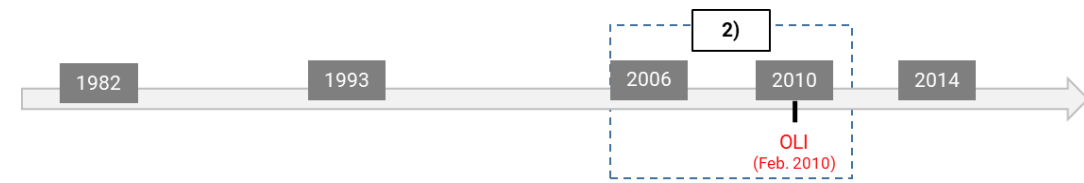
- Marine inundation: major impacts and damages (Etienne, 2012; Barriot, 2016)
- Coastal erosion: moderate impacts (Salmon & Duvat, submitted)



- Numerous damaged buildings and road sections
- Destruction of vegetation
- Washover deposits (30-50 cm thick on the road) (Etienne, 2012)



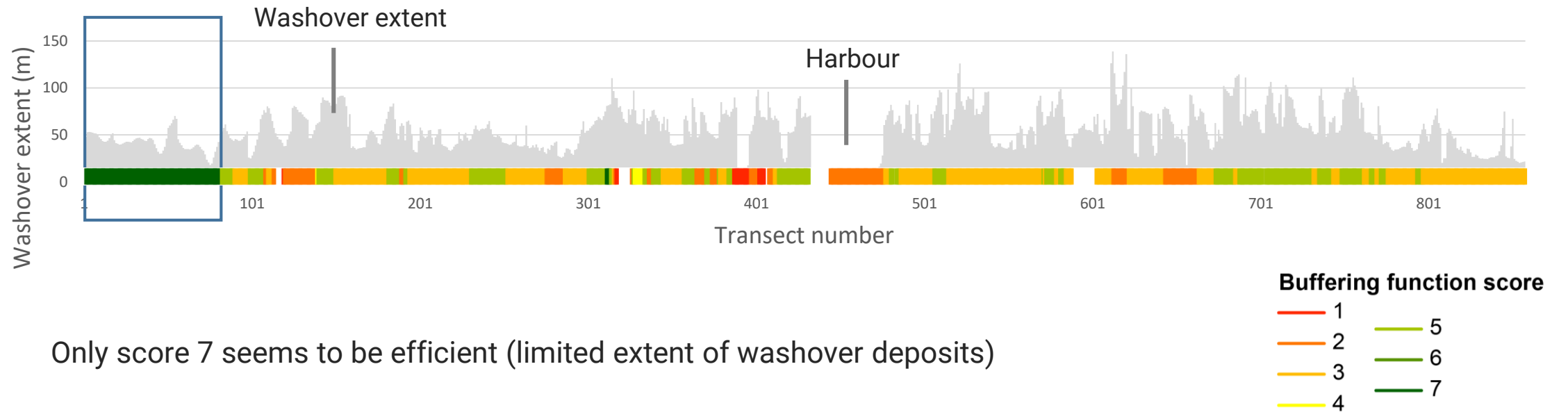
Results: Zoom on TC Oli



The severity and extent of damages are explained, first, by the **cyclone parameters**

Contribution of the buffer zone characteristics?

Crossing the index with the washover extent:

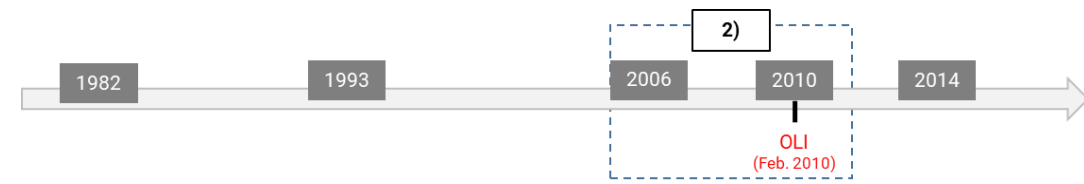


Only score 7 seems to be efficient (limited extent of washover deposits)

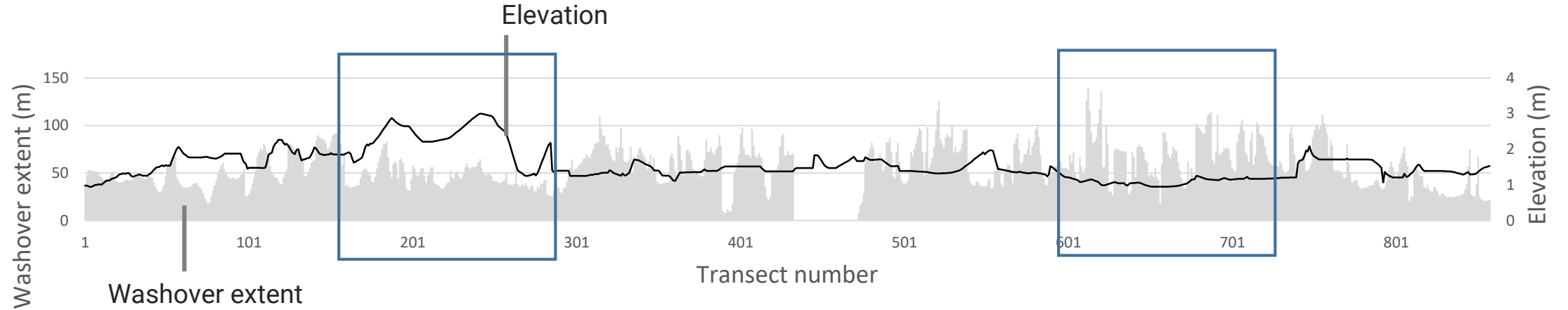
Score 5 did not show any protective role

For the rest, no visual correlations

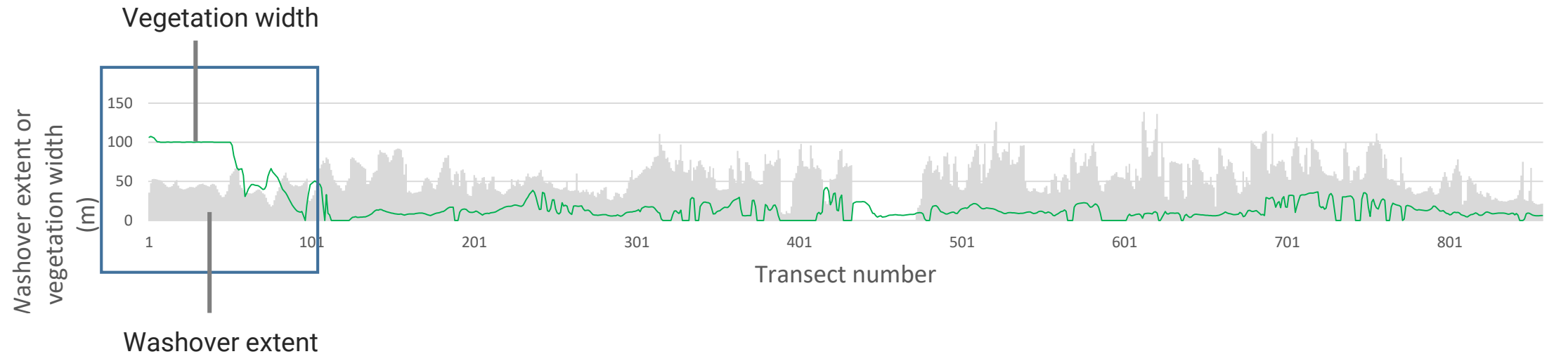
Results: Zoom on TC Oli



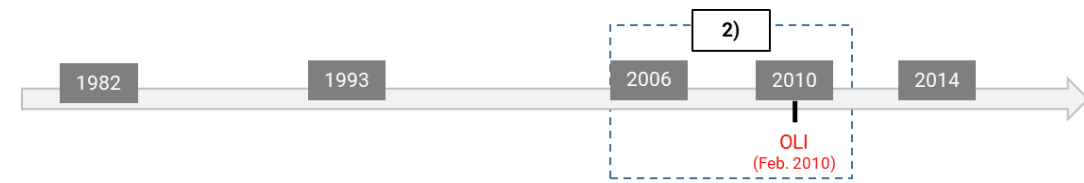
Washover deposits went further inland when elevation was low



Washover deposits went further inland when vegetation width was low



Results (impacts of TC Oli)



What about the buffering function to TC Oli?

Function against marine inundation? > **NO**

> **Elevation is too low** (max = 3 m)

Function of wave attenuation? > **Very limited**

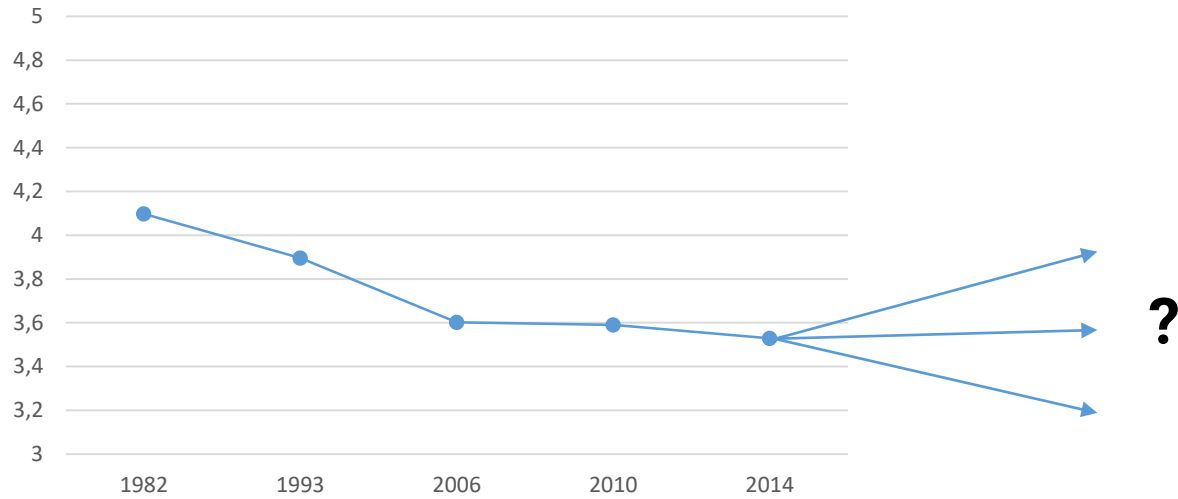
Function of sediment trapping? > **Very limited**

> Buffer zone **width** and **vegetation characteristics** (introduced species, narrow and discontinuous belt) are not adapted

What is next?



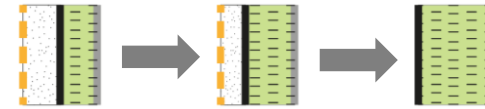
Based on these results, what are the implications for the future?



Shoreline armouring all along the coast?

Need for major financial means

Continuation of the degradation (e.g. beach loss)



Restoration of the buffer zone?

TC Oli revealed the weakness of the buffer zone

Work on these variables to improve its buffering function

What is next?

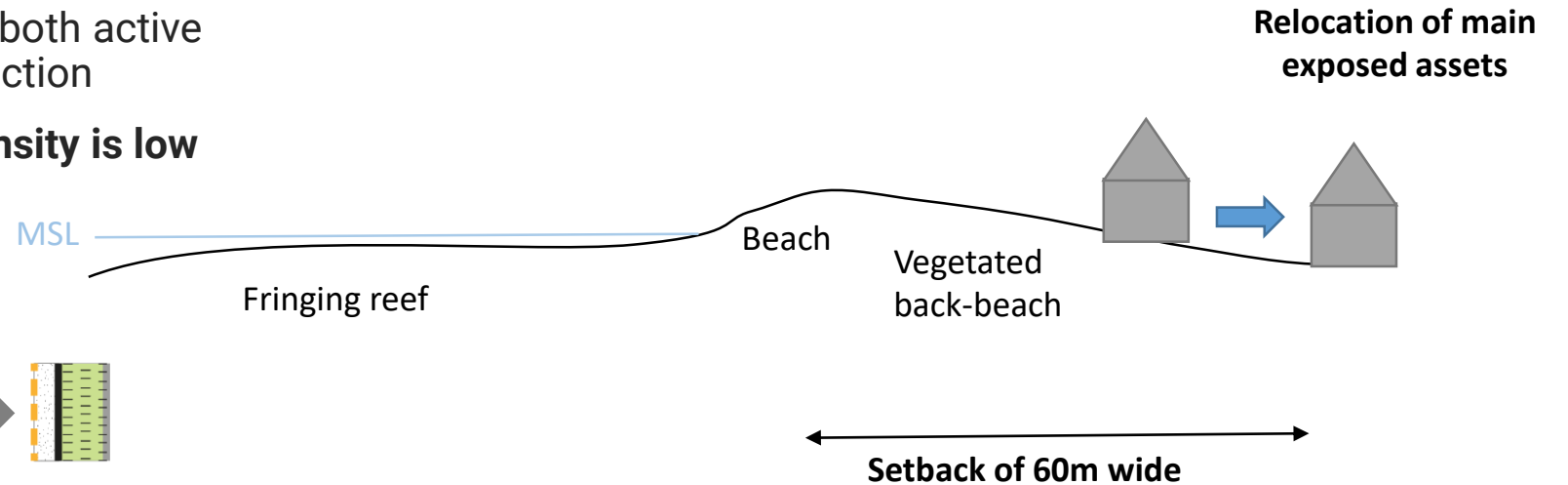


Relocation of the main exposed assets

Since Oli, coastal urbanization **started to slow**

We observed some areas **where assets were relocated elsewhere inland** = buffer zone extension (both active and stabilized parts) due to building destruction

Tubuai has a **wide coastal plain** and **its density is low**



Change in perceptions and behaviours!

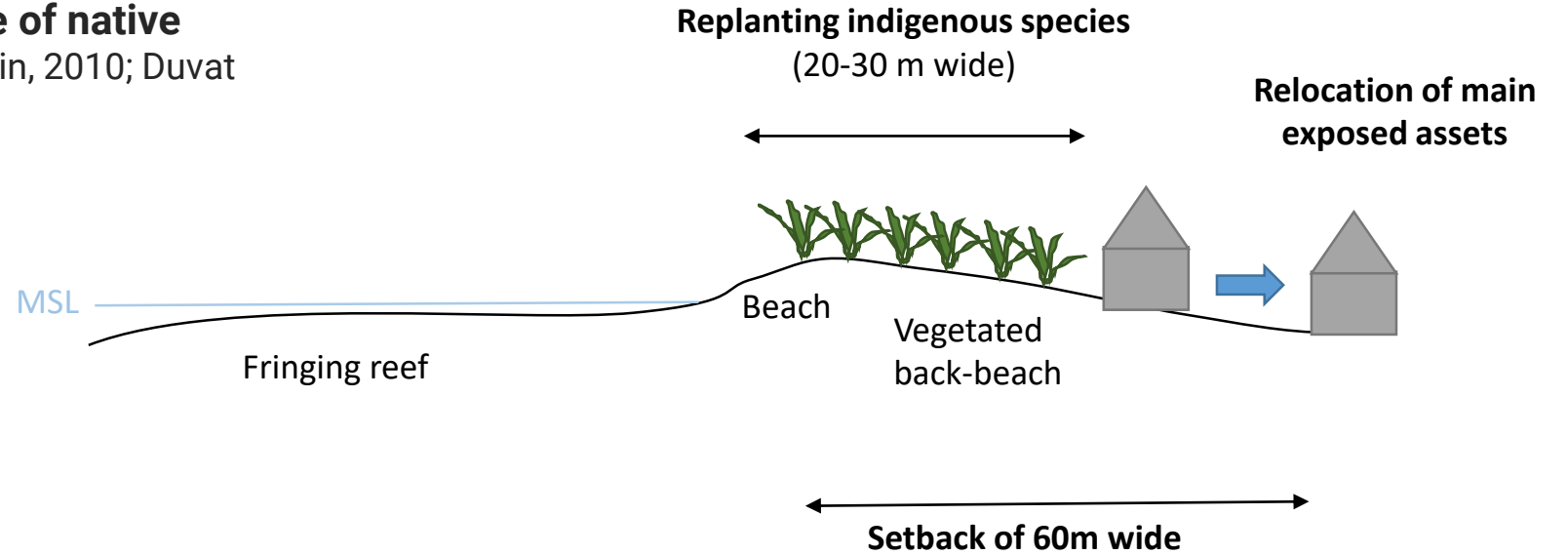
The municipality advocated for a **60m wide coastal strip without any new constructions**

What is next?



Replanting indigenous species

Several studies indicated **the buffering role of native species** (Stoddart, 1963; Woodroffe, 1983; Feagin, 2010; Duvat et al., 2017, 2018)



Stopping with casuarina equisetifolia which prevent from other species to grow (cf. Mon Choisy project in Mauritius)

A **30m-wide belt** appears to be effective to stop cyclonic waves (Duvat et al., 2018)

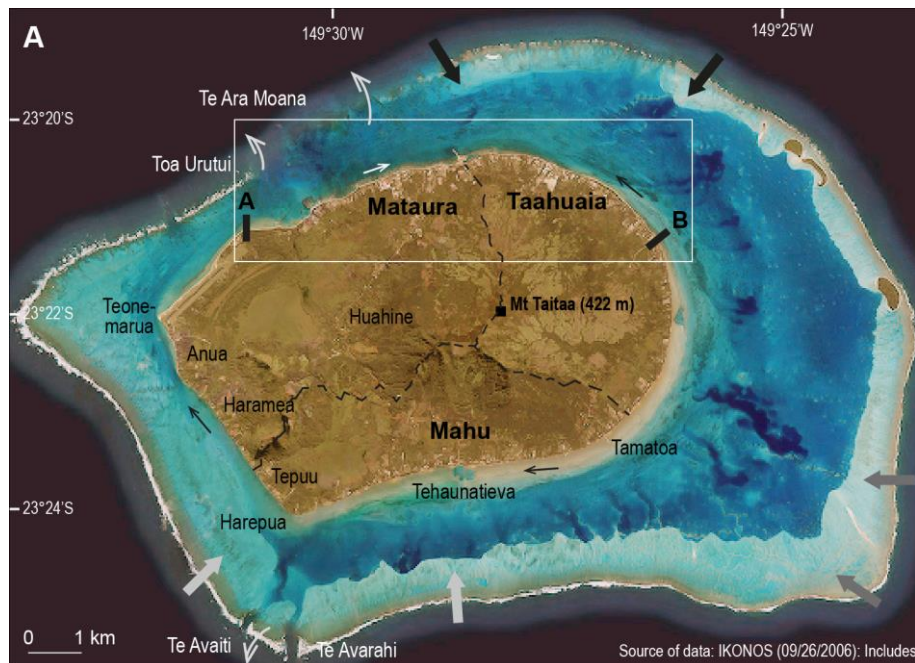
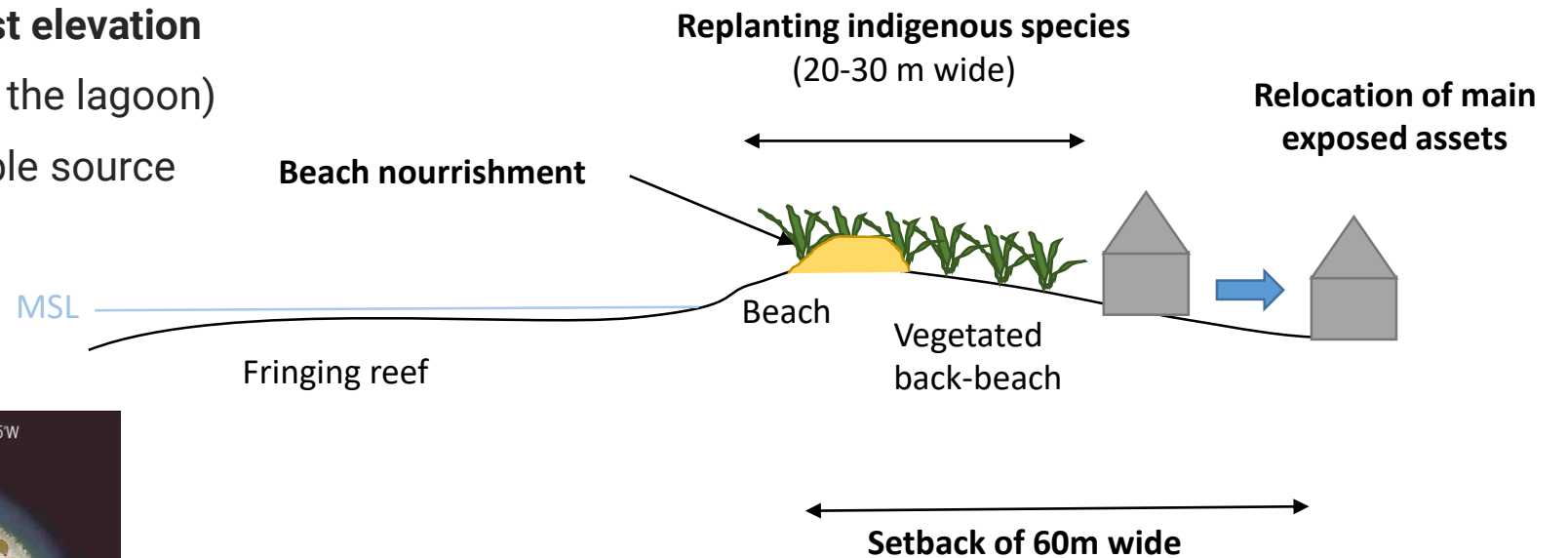


What is next?



Beach nourishment

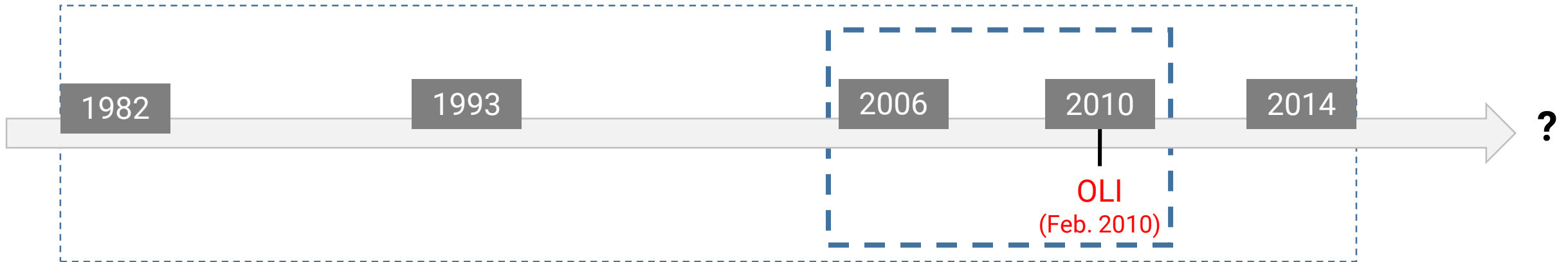
It seems crucial to **increase the beach crest elevation**
In Tubuai, sediments are available (e.g. from the lagoon)
Studies are necessary to find the most viable source
But this solution needs to be considered



Conclusions

Multi-decadal change revealed and quantified the **degradation** of the buffering function

The most significant changes occurred between 1982 and 2006



TC Oli stroke the islands **generating severe damages**, revealing the **weakness points of the buffer zone**: very low **elevation, narrowness, vegetation patterns** not adapted

Although these types of events seem to be too intense to do anything, **working on these parameters to attenuate the negative impacts remains a possible action**

Tubuai seems to have many characteristics enabling to consider alternatives to shoreline armouring, in order to adapt to climate variability and change

Our analysis suggests it is not too late for buffering function restoration in this territory

References

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