DRIVERS OF SHORELINE CHANGES IN THE NORTHERN TUAMOTU REEF ISLANDS, FRENCH POLYNESIA

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1. STUDY AREA

- 111 reef islands distributed among four atolls located between 14°51’S and 15°30’S
- Contrasting geomorphic (size, shape, structure) and human features (urbanised vs. uninhabited and unexploited islands)
- Including the islands concentrating human assets, i.e. major infrastructures, main villages and economic activities
Avatoru urban area, Rangiroa Atoll

- 176,273 ha, 241 islands
- Land area: 66 km²
- 2,567 inhab.
- Tourism, fishing, Agriculture

Tuherahera village, Tikehau Atoll

- 44,885 ha
- 30 km²
- 540 inhab.
- Tourism, fishing

8 densely populated islands concentrating most human assets

A Study area
B Reef flat and shallow lagoon
C Reef Islands

Tiputa Main village
- 1 Airstrip
- 6 Island number

Main village (Tuherahera) and nearby islets (14 islands)
Mataiva Atoll

4,735 ha, 13 islands (2 > 300 ha)
Land area: 17 km$^2$
272 inhab.
Tourism and agriculture

Takaroa Atoll

11,735 ha, 20 km$^2$
1,256 inhab.
Pearl farming

South-eastern side of Mataiva Atoll

South-western side of Takaroa Atoll
2. MATERIAL AND METHODS

- Aerial imagery (33- to 52-y time period)

1. Georeferencing of aerial photographs, using ground control points extracted from the 2013/2014 high-resolution satellite images (RMS error: 0.26-1.72 m)

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B/W photographs: Topographic Section of the Town Planning Division of the Government of French Polynesia; Pleiades satellite imagery 2013 and 2014 from the French National Centre for Spatial Studies (CNES)
2. Digitization of the “stability line” (SL) + base of the beach (BB)

SL: seaward edge of the vegetation or of the stabilised beach ridge in non-vegetated areas along natural coastline; seaward edge of human-built structures along modified coastline.
3. Total shoreline position error (image resolution + georeferencing + shoreline digitization): <4 m (±4 m = stable)

4. Generation of shoreline change statistics using DSAS extension (NSM + EPR)
Coral reef data collected since the beginning of the 1980s

1. Detailed descriptions of the impacts of the 1983 TCs on the reef outer slopes (% of coral destruction, processes at work), based on the comparison of pre- and post-cyclone data

2. Coral reef monitoring data collected since the establishment of permanent stations in the early 1990s
Information on the impacts of the 1983 TCs on shoreline position and island morphology
Generation of data on human pressures (coastal developments, engineered structures, mining, dredging in reef flats, etc.), based on image analysis and fieldwork.
3. RESULTS

CHANGES IN ATOLL AND REEF ISLAND LAND AREA

- No significant change in the total net land area of the study atolls (-1.12 to +1.66%)

- 78 (77%) islands exhibited no significant change in area, while 15 islands (15%) increased and 8 islands (8%) decreased in size

- The smallest islands recorded the highest rates of change (±14.64% per decade)

- 7 out of the 8 islands that decreased in area are very small (<3 ha); and the islets that disappeared were tiny (<0.6 ha)

- All of the islands (16) larger than 50 ha were stable in area, including 5 capital islands out of 6

Reef islands are robust landforms
- Ocean shorelines are more dynamic than lagoon shorelines: 33 islands (31%) showed changes in ocean shoreline position – 19 advance/14 retreat vs. 11 islands (10%) showed changes in lagoon shoreline position – 5 advance/6 retreat

- 90 islands (85%) were stable in position while 16 islands (15%) migrated

- Migrating islands: 10 islands <5 ha; 3 islands are 5<x<10 ha; 3 islands are 15.7<x<36.2 ha. The largest islands (>60 ha) are the most stable in position

- Lagoonward migration: 5 islands out of 6 are located on the southern and south-eastern margins of Tikehau, Mataiva and Takaroa atolls, suggesting that the trade winds contribute to island migration

- Oceanward migration: 9 islands out of 10 are located on the south-western side of Takaroa Atoll

Most reef islands are stable in position
- **Sea-level rise**

- **Storms:** TCs + distant source swells

- **Coral reefs**

- **Human disturbances**

![Map of reconstructed sea level trends (1950-2009)](image)

*Becker et al., 2012*

*Northern Tuamotu: 2.5 ± 0.5 mm > Majuro, Tarawa, but < Funafuti*
**1983 TCs**

- **Atmospheric pressure**
  - < 971 hPa
  - 971 – 995 hPa
  - > 995 hPa

- **Tropical Cyclones 1983-2010**
  - TC of interest
  - Other TC

- **Study atolls**
  - T: Tikehau
  - R: Rangiroa
  - T: Takaroa
  - M: Mataiva

- **TC category (SS scale)**
  - Ta

- **Stability line**

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**Impacts of the 1983 TCs Reva (March) and Veena (April) on Mataiva Atoll**

- **Position toutes les 6 heures**
  - 50 km
  - 100 km

- **Vitesse de déplacement**
  - < 10 km/h
  - 10 à 20 km/h
  - 20 à 30 km/h
  - > 30 km/h

- **Direction et hauteur de la houle significative**
  - 4 m (Veena)
  - 7-8 m (Veena)
  - 10 m (Veena)

- **Stability line**

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**Data source:** Aerial photographs, Service de l'Urbanisme Gouvernement de Polynésie Française
Marked retreat of the Stability Line: erosional impact of the cyclonic waves
On the ocean side of islands, the **Base of the Beach** mainly exhibited either stability, or **advance** (>30 m in places), indicating that coral reefs (healthy) provide sediments to the island system.
1. The rate of shoreline change remained high over the post-cyclone decade, compared to the values obtained for fair-weather periods that are not consecutive to TCs.

2. Over the post-cyclone decade, trends reverse:
   - The Stability Line advances
   - The Base of the Beach exhibits either stability, or retreat

   = reformation of beach ridges that were washed away by the cyclonic waves (sediment input to the inner part of islands = island upward growth)
1. Storm events make the living coral coverage on the reef outer slopes fall from 50-60% to 4-5%, indicating that sediment production occurs.

2. But, the predominance of steep (>45°) outer slopes makes around 75% of broken corals be lost to islands.

Despite “limited” sediments inputs to islands during TCs, islands were found to be resilient.
Human activities currently influence shoreline change on 63 islands representing 57.5% of the island sample: their influence on shoreline change is not limited to island capitals (6).

Among these 63 “disturbed islands”, 29 are highly-modified and have lost their resilience as a result of human disturbances (entirely fixed shoreline/reclaimed reef flats obstructing sediment deposition).
The fact that most “disturbed islands” were either stable (53%), or expanded (14%) over the study period does not mean that these islands are still healthy and would be resilient in the future if they were eroded by a TC:

- **Two arguments:**

  - Stability in island area is often due to the compensation of the retreat of the natural shoreline by an artificial advance of the modified shoreline.

  - Many islands have experienced accelerated shoreline destabilisation and beach loss over the last three decades: caused by human disturbances on some islands, but not on others – *decrease in sand supply*?
Human activities increasingly influence shoreline change and will probably remain a key driver of island resilience in the next decades. Highly-modified islands (26%) have lost the capacity to respond to TCs by upwards growth, which is concerning in the context of accelerated sea level rise.
WIDESPREAD INFLUENCE OF HUMAN DISTURBANCES ON TAKAROA ATOLL

42 “disturbed islands”

Intensity of human pressure and impacts on coastal dynamics and island resilience:
- **High human pressure (urbanisation and/or important shoreline modifications due to coastal developments, reclamation and mining, sediment transport disruption)**: 19
- **Localised human pressures (small villages/hamlets, localised mining and limited coastal developments)**: 23
- **No human pressure**: 34

**Atoll rim**
WIDESPREAD SAND MINING ON MATAIVA ATOLL... IMPACTING THE SEDIMENT BUDGET OF SOME BEACHES
Develop assessments of TCs impacts on other atolls (Takapoto and Takaroa, with similar conclusions)

Digitize the limit of fresh sediment deposits to determine which islands and areas are concerned by cyclone-driven upwards growth

Use remote sensing techniques to generate topographic profiles of the reef outer slopes to link sediment inputs to the island system and the reef outer slopes profile

DOCUMENT THE IMPACTS OF HUMAN ACTIVITIES...