

An underwater photograph of a coral reef. The water is clear and blue. In the center, there is a large, light-colored, somewhat flat coral structure. To its right, there is a more complex, branching coral structure. In the foreground, there are several smaller, rounded coral structures. The background shows more coral and the water surface.

REEF RESTORATION IN SINGAPORE'S URBANIZING ENVIRONMENT

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- An underwater photograph of a coral reef. In the foreground, there are large, brown, brain-like coral structures. In the background, a diver's head and snorkel are visible on the left, and a large, fan-like coral structure is in the center. Many small fish are swimming in the blue water.
- Restore degraded reefs.
 - Create new reef habitats.
 - Innovative techniques.

COASTAL URBANISATION IMPACTS ON CORAL REEFS

Compressed coral growth zone

Slope depth limit reduced -

Inshore, sheltered reefs (8-12m to 3-5m).

Offshore, exposed reefs (12-15m to 5-8m).

Unstable substrate

Reef substrate degraded with increased unconsolidated rubble and silt.

Reef area decline

Intertidal **61%**, subtidal **89%** lost since 1953.



ENHANCING REEF BIODIVERSITY OF URBAN COASTS

- Visibility reduced from 10m (1960s) to 2-3m now.
- Sedimentation load 45 mg/cm²/day in 1990s.

UNDER SUCH CONDITIONS,

1. *IS PROTECTION NECESSARY?*
2. *IS RESTORATION RELEVANT?*

YES, because despite urbanization impacts

- high biodiversity maintained (>180 hard coral spp, > 100 reef fish spp).
- reefs withstood 3 major mass bleaching events (1998, 2010, 2016).
- annual mass spawning occurs during April full moon.
- reefs are self-recruiting.

An underwater photograph of a coral reef, heavily overgrown with green algae or seaweed. The water is murky and green, suggesting high sedimentation. A white rectangular box with a thin border is centered in the upper half of the image, containing the title text. Below the box, the text 'Circumvent challenges of:' is followed by a bulleted list. The background image shows various coral structures and a sea urchin in the lower left corner.

REEF RESTORATION – WHAT WORKS?

Circumvent challenges of:

- high sedimentation
- substrate instability

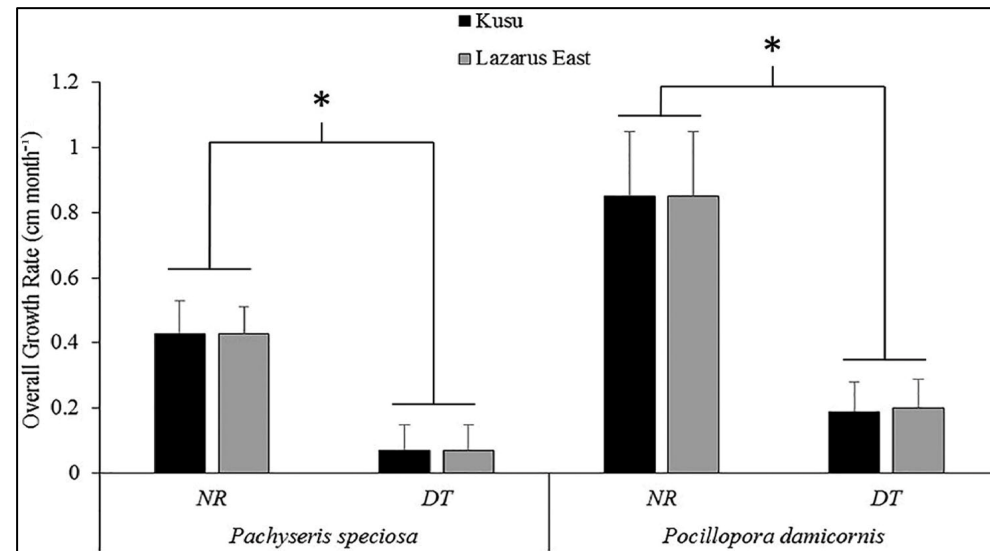
In-situ coral nurseries useful in high sediment conditions

- provide stability for coral growth
- reduce impacts of sedimentation

Mesh nets minimize sediment accumulation and provide secure platforms for coral attachment.



Improves post-transplantation survival and growth



(Afiq-Rosli *et al* 2017)

Addressing unstable substrate using Reef Enhancement Units (REUs)



An underwater photograph showing a sandy seabed with several large, light-brown, rounded coral structures. In the background, there is a larger, more complex coral formation. A small, striped fish is visible near the background coral. The water is clear and blue. A white text box with a thin black border is overlaid on the upper part of the image.

CREATING REEF COMMUNITIES IN NON-REEF AREAS



Acropora fragments (10cm)
on nursery table after 3.5 years



Nursery frames (1m x1m).
Echinopora lamellosa fragments
March 2015 - 5cm diameter,
March 2018 - 1m diameter.
20x size increase in 3 years.

A photograph of a rocky coastline during low tide. The foreground and middle ground are filled with dark, wet rocks of various sizes, many of which are covered in brown and green seaweed. Several shallow tide pools are scattered among the rocks, reflecting the sky. In the background, a steep, light-colored hill rises from the left side of the frame. The ocean is visible in the distance under a clear sky.

COASTAL DEFENCE AND REEF BIODIVERSITY ENHANCEMENT



More marine biodiversity settlement opportunities with terraced sea wall



Large intertidal pools provide better opportunity for coral and marine biodiversity development.

URBANISATION AND REEF BIODIVERSITY

- Human-modified coastal environment cannot adequately match ecosystem service levels of natural habitats
- However, they can be enhanced to support/sustain diverse biological communities.
- The urbanised coast can serve both, development and biodiversity functions.
- Restoration is necessary to enhance biodiversity of degraded habitats as well as create new habitats - helps mitigate urbanization and climate change impacts.