Identification of two-phase recovery in hard corals across the Great Barrier Reef

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Introduction

- The Great Barrier Reef (GBR) is in decline due to [1]
  - increased disturbance frequencies (e.g., storms, heat waves, crown-of-thorns outbreaks) from
  - anthropogenic causes such as climate change and poor water quality.
- Effective management requires recovery models:
  - to assess reef heath and performance [5];
  - and to quantify delays in recovery [4]
- Standard modelling is based on single-phase recovery,
  - e.g., Gompertz growth model ($C(t)$ is cover at time t and K is carrying capacity)

$$\frac{dC(t)}{dt} = -\alpha C(t)\ln\left(C(t)/K\right)$$

where the intrinsic growth rate, α, is assumed to be constant. [6]

  - Empirical evidence suggests possible multi-phase recovery. e.g., for two-phases

$$\frac{dC(t)}{dt} = \begin{cases} \alpha_d C(t) & \text{if } t < T_d \\ -\alpha C(t)\ln\left(C(t)/K\right) & \text{if } t \geq T_d \end{cases}$$

where $\alpha_d < \alpha$ is a reduced intrinsic growth rate and T_d is the duration of the slower phase.

  - The existence of multi-phase growth has implications for monitoring and management since performance assessments and forecasts may be inaccurate if a single-phase model is used.

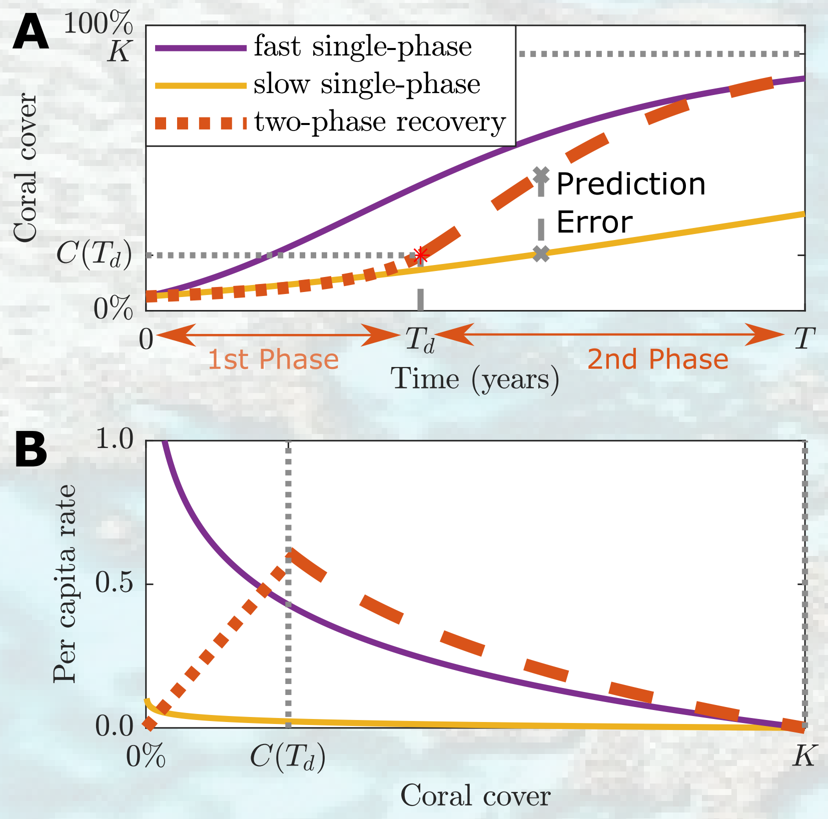

Figure: (A) Single-phase models cannot replicate two-phase recovery in both short and long timescales. (B) When per capita rates are compared with cover, single-phase models are monotonically decreasing functions.

Quantification of two-phase growth

- A substantial proportion of analysed recovery trajectories show two-phases.

Table: Breakdown of trajectory classifications

Classification	Count	Relative Frequency
Single-phase	19	31 %
Two-phase	29	48 %
Inconclusive	13	21 %

- The visit corresponding to the estimated change-point provides an estimate of the duration of the slower first phase.
- This phase often persists for ≥ 4 years (mean: 4.6; IQR: [4.1, 5.8]).

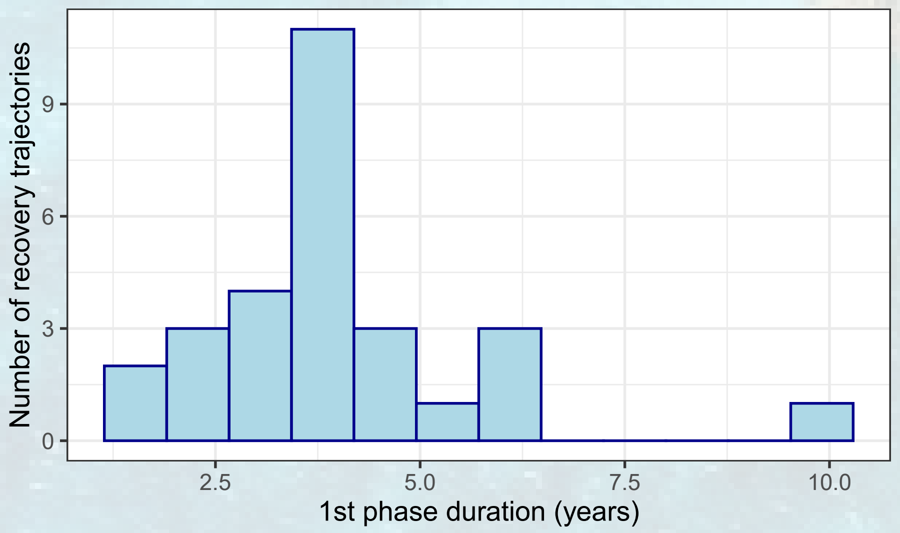

Figure: Distribution of estimated slow phase durations.

- Most examples of longer slow phases (≥ 5 years) occur in the northern GBR.

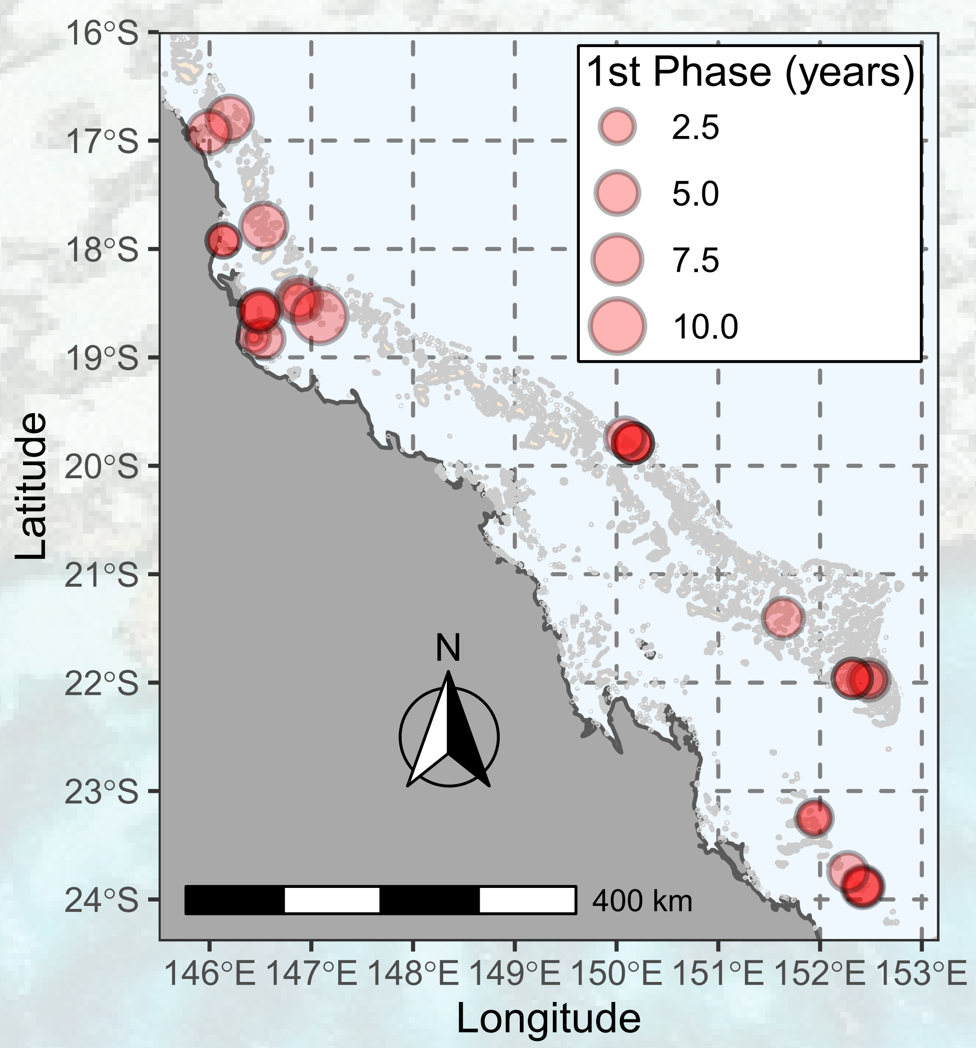

Figure: Location of reefs where two-phase recovery is identified.

Materials and Methods

- Data obtained from AIMS Long Term Monitoring Program (LTMP) [3].
- Recovery trajectory inclusion criteria:
  - post-disturbance cover $\leq 5\%$ and ≥ 5 observations;
  - 61 recoveries over 27 reefs for analysis.
- Analysed using methods from cell biology [2]:
  - compute per capita rate P_i as function of cover C_i at the ith visit

$$P_i = \frac{1}{X_i}\frac{X_{i+1} - X_{i-1}}{2h}, \quad X_i \sim \mathcal{N}(C_i, s_i^2)$$

where X_i are noisy observations with variance s_i^2, and h is the time between visits;

  - then apply two-segment regression with change-point detection.
- Simulation study indicates specificity of 86% and power of 48% for typical trajectories.

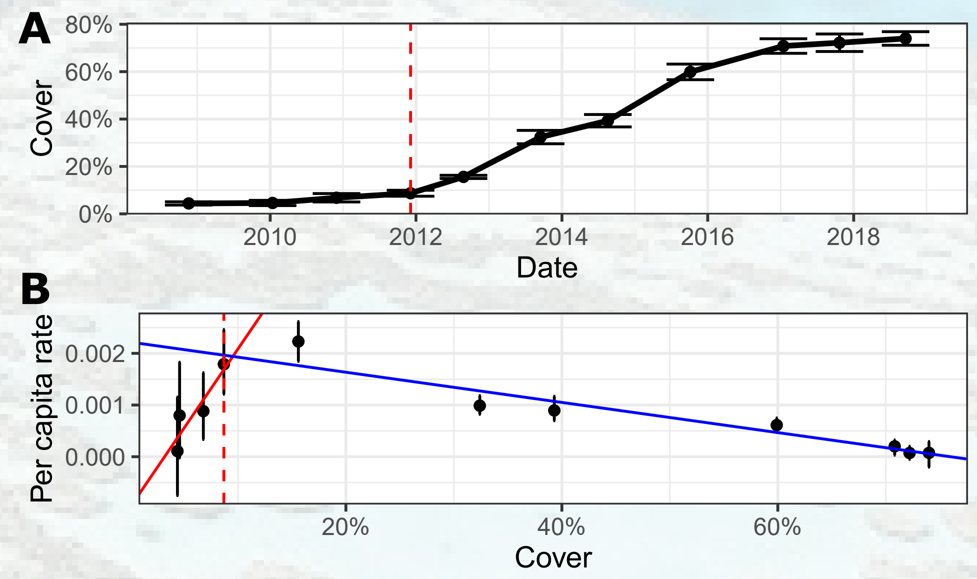

Figure: (A) Example LTMP recovery trajectory showing two-phase growth. (B) Change-point (red dashed) identified with two-segment regression showing increasing per capita (red solid) followed by decreasing per capita (blue solid).

Impact of two-phase recovery

- Using estimated slow first-phase durations we can simulate recovery without this phase. This enables a data-driven assessment of how this slow phase affects recovery under different future scenarios.
- Overall, two-phase recovery may cause a reduction in cover by up to 20% (absolute cover), and could lead to complete collapse should major disturbances occur every five years on average.

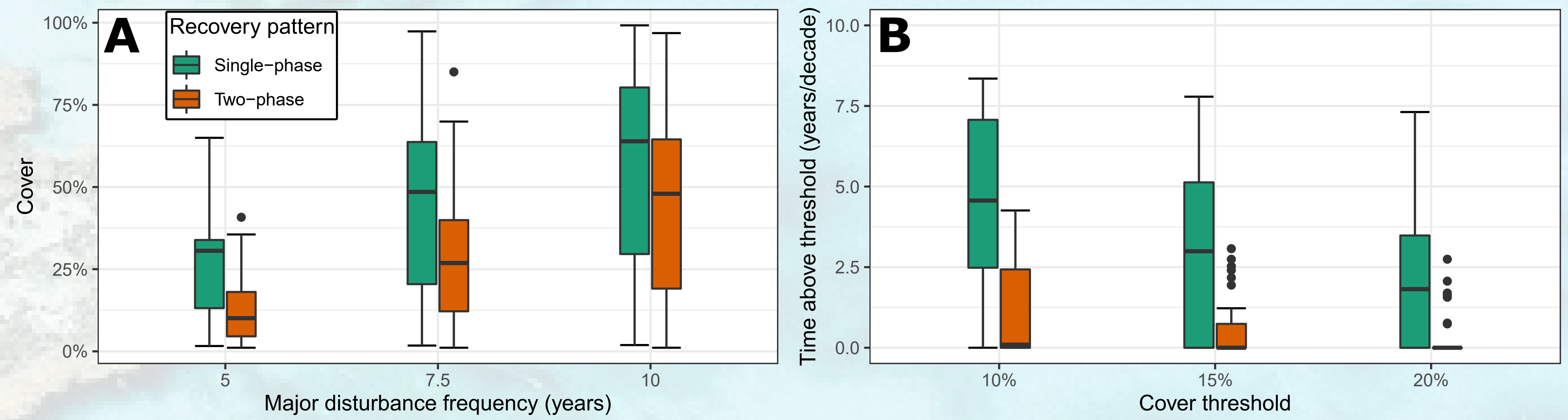

Figure: Estimated effect of two-phase growth on recovery under different major disturbance frequencies. (A) Final cover before next major disturbance. (B) The expected number of years per decade above different cover thresholds (a proxy for ecological services) assuming major disturbances every five years.

Conclusions

- Our analysis demonstrates the presence of two-phase recovery throughout the GBR.
- The impact of the slow recovery phase is substantial, therefore, more modelling is needed:
  - to elicit mechanisms that cause this behaviour;
  - and to improve targeted reef management and monitoring.
- Emissions must be reduced to prevent reef collapse.

References

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