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Disturbance-recovery dynamics inform seafloor management for recovery

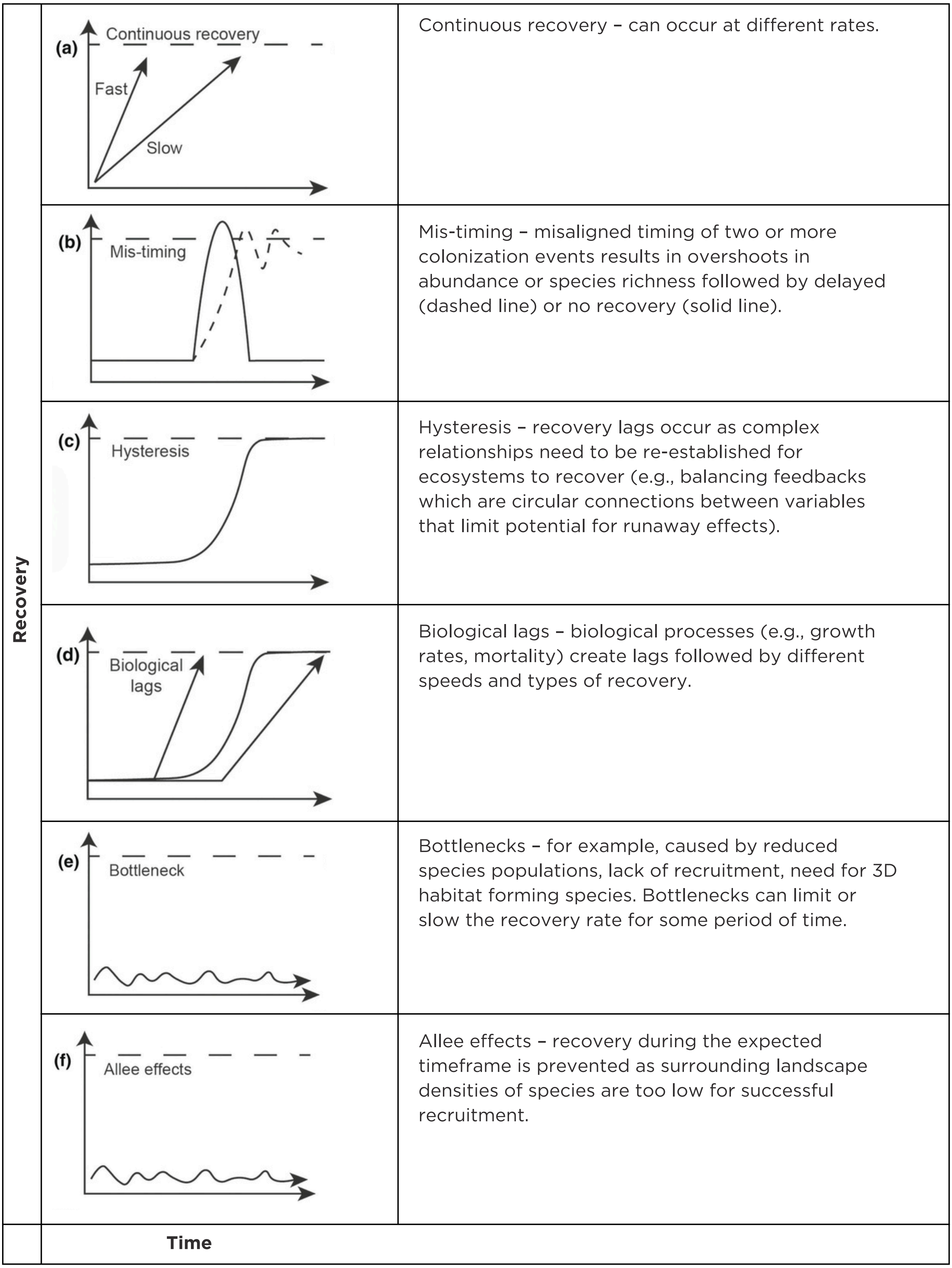
Summary

This document provides a discussion of ecological disturbance-recovery dynamics and how they can inform resource management and decision making to help the recovery of degraded seafloor communities and habitats. The document focuses on the drivers of marine seafloor recovery, in particular the role of key species, and the prioritisation of management actions and locations to optimise recovery success.

Marine habitat management and conservation needs to focus on advancing the recovery of degraded systems

Over most of the world's estuaries, coasts and continental shelves, key indicators of seafloor biodiversity, anthropogenic stress, and ecological sustainability emphasize the need to shift habitat management and conservation from prevention of ecosystem degradation to actions focused on ecological recovery. For long-term restoration success, it is now recognised that an ecosystem-based management approach is required that incorporates an understanding of disturbance-recovery dynamics and a focus extending beyond single species and onto how sets of communities and ecosystems interact and function.

Rather than a continuous rate of recovery, depending on the disturbance caused by human activities and the connectivity between systems, recovery can be delayed or suppressed due to bottlenecks, hysteresis, Allee effects, misaligned timing of events, and biological lags (see Figure 1 for definitions and how they may affect recovery pathways). In soft sediment systems, many species provide key functional roles that can facilitate ecosystem recovery (e.g., delivering 3D habitat structure or refuge from predation, or enhancing food resources). Apart from these functional roles, individual species which are culturally or commercially important may be key to management goals. Understanding the disturbance-recovery dynamics of a system is important to managers for determining what outcomes are possible, which management actions will achieve the desired result, and how long recovery will take - all of which are crucial for managing expectations of recovery.



Continuous recovery – can occur at different rates.

Mis-timing – misaligned timing of two or more colonization events results in overshoots in abundance or species richness followed by delayed (dashed line) or no recovery (solid line).

Hysteresis – recovery lags occur as complex relationships need to be re-established for ecosystems to recover (e.g., balancing feedbacks which are circular connections between variables that limit potential for runaway effects).

Biological lags – biological processes (e.g., growth rates, mortality) create lags followed by different speeds and types of recovery.

Bottlenecks – for example, caused by reduced species populations, lack of recruitment, need for 3D habitat forming species. Bottlenecks can limit or slow the recovery rate for some period of time.

Allee effects – recovery during the expected timeframe is prevented as surrounding landscape densities of species are too low for successful recruitment.

Figure 1*: Types of recovery trajectories; (a) continuous recovery, (b) mis-timing of colonisation events, (c) hysteresis, (d) biological lags, (e) bottlenecks, and (f) Allee effects. Solid lines indicate different recovery trajectories that can occur. Dashed horizontal lines indicate the desired recovery outcome.*

Disturbance-recovery dynamics can inform whether passive and/or active management interventions are needed

Managing for recovery requires an understanding of what successful restoration would look like, how long recovery would take, where restoration actions should be undertaken (i.e., ecological suitability in relation to management goals), and when management actions should be undertaken to enhance success. Managing for recovery of the seafloor can involve both passive (turning off the stressor tap) and active interventions, the success of which can be predicted by disturbance-recovery dynamics. Choosing the right management action is important as if an ecosystem passes an environmental threshold, due to postponed decision making or an ineffective management choice, the costs of active intervention are increased, and the likelihood of recovery is reduced.

Passive recovery

The success of passive intervention is often determined by how long managers and society are prepared to wait for recovery to occur, the presence of environmental legacies, the resilience of the present system, the connectivity of the area to sources of potential colonists, and the likelihood of hysteresis and/or recovery bottlenecks. Predicting recovery outcomes requires knowledge of:

- *The state of location* – Either the correct physico-chemical environmental state or the presence of species that can ameliorate adverse conditions is needed for successful passive recovery. Additionally, the area needs to be connected to sources of potential colonists. System connectivity and the likelihood of successful recruits being available is reduced with larger areas of degradation, habitat fragmentation (i.e., patches of degraded and non-degraded areas), hydrodynamic barriers (e.g., currents and frontal systems), and small species pool sizes available to provide colonists.
- *Species-specific factors* – Species-specific traits can inform how long recovery may take. Species with high adult mobility and/or high settlement and survivorship of larvae or juveniles will tend to recover more quickly, with recovery time dependent on the reproductive frequency of the species and the distance to the nearest area of adult recruits. Traits associated with low/delayed recovery include: low mobility, reproduction, and dispersal; slow growth; and inhibition of juvenile recruitment or growth by adults. The factors influencing the length of time to recover habitat-forming species and whether passive or active (brown boxes) recovery interventions are needed can be assessed using the flow diagram in Figure 2.
- Community and ecosystem connectivity and structure – The diversity of the location and surrounding landscape will influence passive recovery success. Diversity at the recovery location will increase slowly over time as species from the surrounding landscape are reintroduced. The presence of a dominant species which acts as a facilitator or provides multiple ecosystem functions can increase recovery rates. Conversely, if the location is strongly structured by competition (as in many rocky reefs), recovery will be slow or require active intervention. The factors that can influence recovery time and the need for passive or active intervention are illustrated in Figure 3.

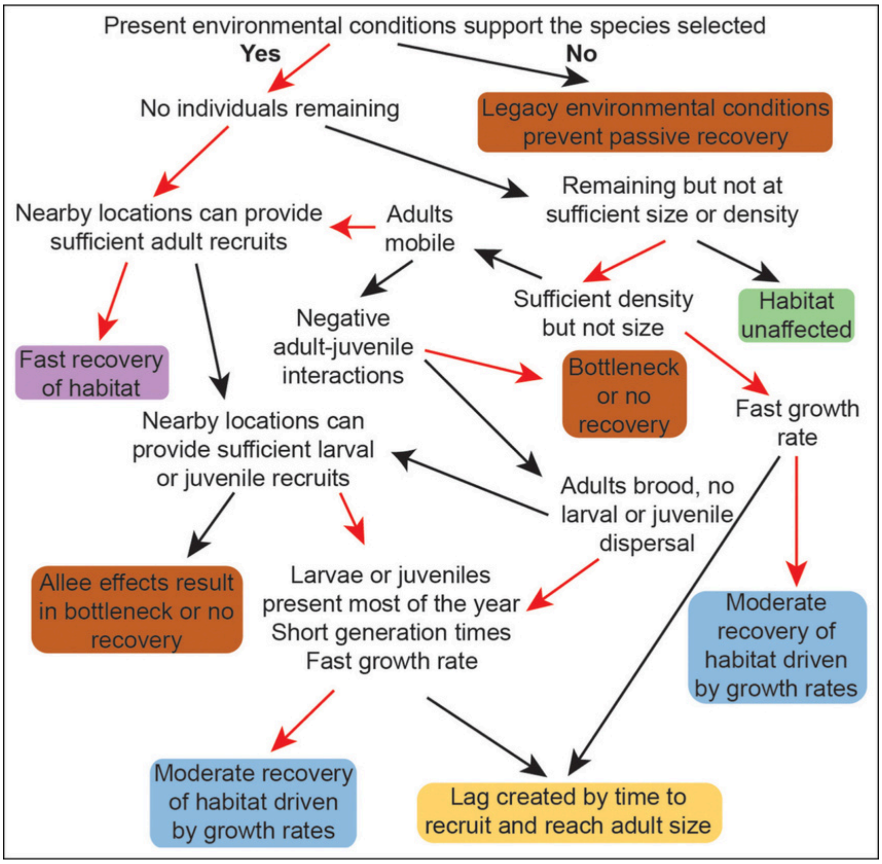


Figure 2: *Factors leading to lags and bottlenecks in habitat recovery driven by key species that are 3D habitat formers. In the decision tree, red and black arrows correspond to "yes" and "no" answers, respectively. The green box suggests passive management will allow recovery of habitat, although timescales will vary, whereas brown boxes suggest that active interventions are required. "Nearby locations" for adults are hydrodynamically connected within the monthly range of adult movement; for seed, larvae and juveniles they are hydrodynamically connected within the annual range of dispersal. High frequency reproduction = seed, larvae, and juveniles present for most of the year, due to either multiple events or extended duration.*

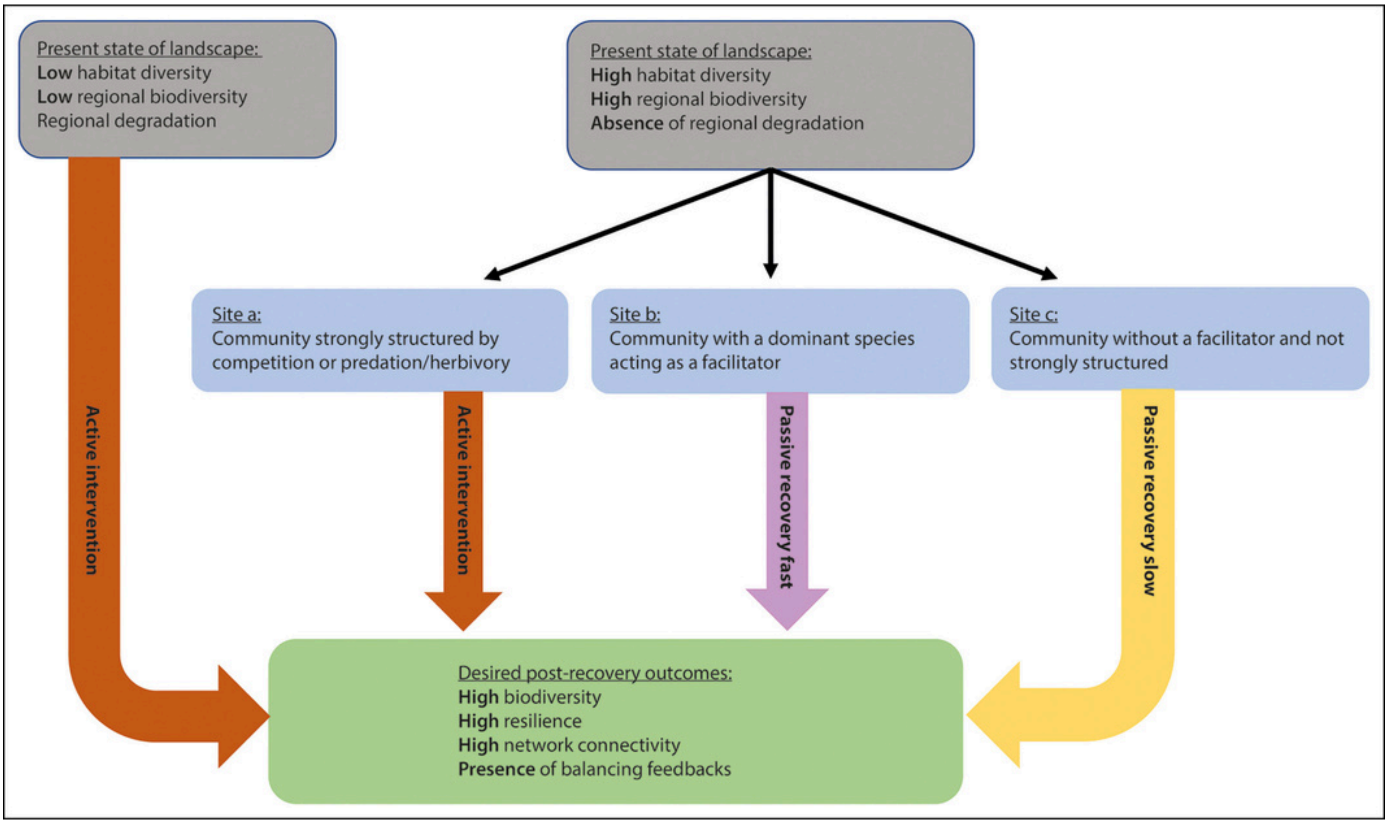


Figure 3: *Management types (coloured arrows) to achieve recovery of seafloor communities or ecosystems (green rectangle) depend on the present condition of sites and the surrounding landscapes (grey rectangles).*

Active intervention

Active interventions are direct actions that are undertaken to support ecosystem recovery. Some examples include:

- Transplantation of adults or juveniles to provide 3D habitat (e.g., seagrass, shellfish).
- Elimination of environmental legacies (e.g., removing or covering contaminated sediment).
- Provision of hard surfaces for colonists to attach to.
- Kina removal.

Once active interventions have been conducted, the aspects of the disturbance-recovery dynamics that control successful establishment of a functioning community/ecosystem are similar to those of passive recovery.

Locations for restoration action can be prioritised based on the likelihood of recovery success and how long it may take

Certain ecosystem aspects can be used to help prioritise recovery efforts when there are many potential locations requiring recovery, including:

- *The potential for stressors to be reduced* – Locations where the primary cause of degradation can be largely reduced or eliminated should receive the highest priority if environmental legacies have not created conditions beyond the sensitivity of species or adversely affected ecosystem functions associated with the desired outcomes.
- *State of community or ecosystem function* – Locations that have maintained high functionality (e.g., high biodiversity) should receive highest priority, while locations characterised by low biodiversity, an absence of the desired species, or the presence of altered functional networks should receive lowest priority.
- *Connectivity of an ecosystem to other less-degraded locations* – Locations that are hydrodynamically connected to areas that can provide recruits should receive the highest priority. For locations where sufficient recruits cannot be provided or species-specific traits may lead to lags and bottlenecks in recovery (Figure 2), locations should be prioritised based on recovery time.

Recovery of marine ecosystems requires co-development of adaptive learning-by-doing strategies

The necessary transformations in marine management needed to achieve sustainability, stewardship, and conservation goals require a focus on recovery, effective communication and bridging the science-policy divide to inform policy making, legislation and planning actions. This review highlights that in marine soft-sediment ecosystems, ecosystem networks, biodiversity landscapes, species-specific biological traits and location-specific context can provide managers with information for which likely temporal and spatial scales of recovery can be determined. Additionally, key species may also drive recovery or maintenance of biodiversity. As research into ecosystem recovery is ongoing, co-development of adaptive learning-by-doing management approaches will be important for linking ecological processes to societal expectations to improve ecosystem health.

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