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Seagrass population dynamics and water quality in the Great Barrier Reef region: A review and future research directions

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Abstract

Seagrasses in the Great Barrier Reef region, particularly in coastal habitats, act as a buffer between catchment inputs and reef communities and are important habitat for fisheries and a food source for dugong and green turtle. Within the Great Barrier Reef region there are four different seagrass habitat types now recognised. The spatial and temporal dynamics of the different types of seagrass habitat is poorly understood. In general seagrass growth is limited by light, disturbance and nutrient supply, and changes to any or all of these limiting factors may cause seagrass decline. The capacity of seagrasses to recover requires either recruitment via seeds or through vegetative growth. The ability of seagrass meadows to recover from large scale loss of seagrass cover observed during major events such as cyclones or due to anthropogenic disturbances such as dredging will usually require regeneration from seed bank. Limited research into the role of pollutants on seagrass survival suggests there may be ongoing impacts due to herbicides, pesticides and other chemical contaminants. Further research and monitoring of seagrass meadow dynamics and the influence of changing water quality on these is needed to enhance our ability to manage seagrasses on the Great Barrier Reef.

Keywords: Seagrass; Disturbance; Recruitment; Nutrients; Light limitation; Pollutant

1. Introduction

Global losses of seagrass meadows due to various human impacts have stimulated an active network of researchers attempting to understand the dynamic nature of seagrass communities (Short and Wyllie-Echeverria, 1996). This undertaking is considerable due to the global diversity of seagrass species and habitats. As Australia has the highest species diversity of seagrasses in the world and numerous different seagrass habitats, this region faces a significant challenge to gain the comprehensive understanding of seagrass dynamics required to facilitate the reversal of seagrass loss. Australia's high species diversity is due to overlap of both tropical and temperate seagrass floras, and its' biogeographic confluence with endemism in a number of regions (Walker and Prince, 1987). In particular, an extensive and diverse assemblage of seagrasses exists along tropical and subtropical coastlines of northeast Australia and the associated Great Barrier Reef (Birch and Birch, 1984; Lee Long et al., 1993; Carruthers et al., 2002). These seagrass meadows from tropical regions are known to provide critical habitat for various commercial fisheries (e.g. penaeid prawns) and maintain high biodiversity of various invertebrates and fish (Connolly et al., 1999). In addition seagrass meadows in the Great Barrier Reef region play a significant role as dugong and green turtle food resources enhancing the biodiversity values of the region. Our understanding of these important seagrass meadows remains far from extensive (Carruthers et al.,

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2002), in fact, new species (*Halophila tricostata*) and even new habitats such as deep water (>15 m depth) have only recently been described (Lee Long et al., 1996).

Tropical seagrasses are more dynamic than their temperate counterparts. They tend to be faster growing and have life histories that are well adapted to particular types of disturbance, some being annual. This is in contrast to many temperate seagrass species which are very long lived, for example the leaves of some species may survive for longer than 12 months. Generic concepts of seagrass ecology and habitat function from temperate regions (Duarte, 1999; Walker et al., 1999) are usually inappropriate to tropical seagrasses. For example, the extremes of tropical environments such as cyclonic events result in large scale changes in the dynamics of seagrass meadows and offer a contrast to the majority of temperate systems.

Globally, seagrass declines are often attributed to increased light stress induced by eutrophication in temperate environments and turbidity in tropical environments (Shepherd et al., 1989). The effect of eutrophication-related light stress (due to shading by epiphytes, macroalgae and phytoplankton) has been relatively well studied in temperate seagrasses (Cambridge et al., 1984; Ralph and Gademann, 1999). However, the effect of turbidity-related light stress, which has been identified as a major driver of seagrass habitat structuring in north eastern Australia (Carruthers et al., 2002), has received less research attention. The contrasting effects observed as a result of elevated nutrient inputs further exemplify the temperate–tropical dichotomy. Tropical seagrass ecosystems have been identified as nutrient limited and their response is to experience enhanced growth rather than any negative impacts associated with elevated nutrients as reported in temperate regions (Udy and Dennison, 1998; Schaffelke et al., in press; Mellors et al., 2005). Despite considerable scientific effort, predicting changes in tropical seagrass status and trend is difficult, at least in part due to significant deficiencies in the data available on the basic biology of seagrasses in this region.

2. Seagrasses in the Great Barrier Reef region

The Great Barrier Reef (GBR) region itself extends from latitude 10°40′55″ S to 24°29′54″ S covering an area of approximately 346,000 km^2. Inter-reef and lagoon areas of the GBR region represent a significant aerial proportion (up to 58%) of the Great Barrier Reef ecosystem (Wachenfeld et al., 1998). Seagrass meadows are a dominant vegetation type in these areas and occur across several environmental gradients within the GBR. Both catchment area and land use varies significantly within the region, with sections of the coast, at one extreme, exposed to run-off from large cattle dominated catchments, to very small, near-pristine catchments at the other. With seagrass meadows being a dominant vegetation type in the GBR region, and their occurrence across several environmental gradients it is intuitive that not all seagrass habitats are structured in the same way, particularly where there are numerous potential drivers of habitat stability.

The diverse and extensive array of seagrass habitats in northeast Queensland, including the GBR, have recently been classified as four distinct habitat types with different drivers affecting them (Carruthers et al., 2002). These habitat types provide a structure in which the processes that limit seagrass survival in the GBR region may be investigated. The four habitat types (Fig. 1); ‘River-Estuaries’, ‘Coastal’, ‘Deep water’ and ‘Reef’ may be further categorized by the level of exposure they receive with changing local environmental conditions such as tidal cycle and riverine inputs. Terrigenous run-off, physical disturbance, low light and low nutrients, respectively, are the main drivers of each of these seagrass habitat types and suggest key areas of concern for monitoring impacts on these seagrass meadows. Among these four seagrass habitat types in the GBR both estuarine and coastal seagrass habitats are of primary concern with respect to water quality due to their location immediately adjacent to catchment inputs. Due to the variable nature of land habitat type, climate and land use across the GBR region, the conditions in River-Estuary and Coastal seagrass habitats are highly variable. In drier locations estuaries literally dry up during the majority of the year and as a result there are limited occurrences of estuarine seagrasses in the dry tropics. In the wet tropics, north of Townsville to south of Cooktown, River-Estuary seagrass habitats are significantly influenced by the regular and sometimes massive freshwater inputs that occur during the summer wet season.

The status of seagrass in the GBR region has principally been assessed by a series of mapping studies (Lee Long et al., 2000). A number of broad-scale surveys, from the early 1980s to today, have provided a series of important distributional maps in the GBR, yet many areas still remain unmapped. Significant seagrass meadows exist in coastal habitats and given that the GBR region is dominated by agricultural land use adjacent to its waters (Brodie et al., 2001), the direct impacts of land use practices will be most prevalent in coastal marine plant communities. In addition a significant area of the GBR region is categorized as ‘dry tropical’ (Brodie et al., 2001). In this area, riverine inputs are restricted intra-annually and inter-annually to times when rainfall is significant but can be unusually intense. As a consequence, seagrass habitats in that area have to deal with pulsed events in sedimentation, increased nutrients and turbidity. Unfortunately, the magnitude of coastal inputs on seagrass meadows has not been directly assessed. Indirect evidence of nutrient and pollutant

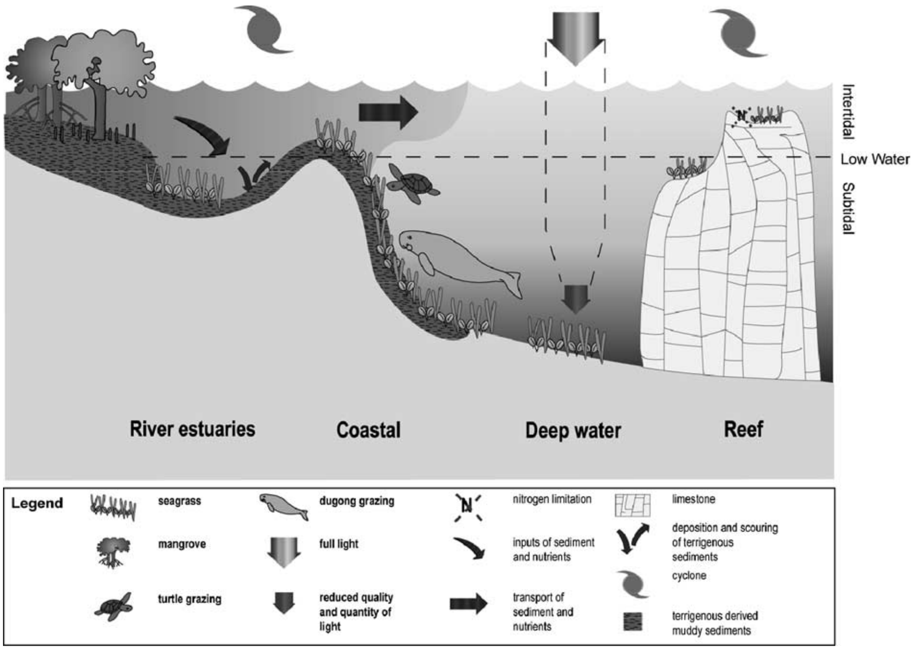

Fig. 1. Conceptual diagram of seagrass habitats in the Great Barrier Reef (GBR) region Queensland, Australia. The diagram depicts the identified key processes for each of the four habitat types in the GBR region (adapted from Carruthers et al., 2002).

loads (Haynes and Johnson, 2000; Haynes and Michalek-Wagner, 2000; Brodie, 2002; Mellors et al., 2005) indicate that there may be biologically significant loads in particular locations across the GBR waters.

The recently discovered extensive deep water seagrass habitat in the GBR lagoon (Coles et al., 2000) is expected to experience limited impacts from coastal land use. More than 40,000 km^2 of deep water seagrass habitat is likely to exist in the GBR lagoon. These deep water seagrasses are known to be low in biomass, however, the total area of deep water seagrass meadow represent a biological sink for nutrients in the region. The observed ephemeral nature of these deep water seagrass meadows (Coles et al., 2000), high seed production and the annual habit of *H. tricostata* (Greenway, 1979; Kuo et al., 1993) suggests that these meadows are a persistent but a changing feature of the GBR region. At present we know little about these areas although it has been inferred that they may be an important food resource for dugong and turtle (Coles et al., 2002). Although we expect these habitats to be under lower pressure from changing water quality, it may be that these habitats are more sensitive to changing water quality and effort should be made to understand the dynamics of these ecosystems.

In addition to ephemeral seagrass meadows there are many areas in the GBR which have persistent seagrass meadows (Lee Long et al., 1996). Many of the localities containing persistent seagrass meadows in coastal locations have been included in dugong protection areas (Coles et al., 2002) recognising their importance as dugong habitat. However, some of the dugong protection areas have little seagrass in them (e.g. Taylors Beach) but contain more ephemeral habitat and when seagrass biomass is low should be considered as 'potential' seagrass habitat (Coles et al., 2002). It is critical to recognise that the lack of seagrass in these potential seagrass habitats may not be due to 'impacts' but due to the dynamics of seagrass meadows in these regions.

3. Factors affecting seagrass population dynamics

Both intertidal and shallow subtidal seagrass meadows are known to have a seasonal growth cycle in the GBR region (Mellors et al., 1993; McKenzie, 1994; Rasheed, 1999; Inglis, 2000; Mellors, 2003). Significantly, quantification and understanding of these seasonal cycles is limited to a few sites namely around Cairns, Townsville and Hervey Bay. While the studies already undertaken provide useful baseline information, a greater understanding of the spatial and temporal variability across the region is needed. Many of the broadscale seagrass surveys have been done either twice per annum or only once. In such surveys, for example those included in the dugong protection area surveys (Coles et al., 2002), seagrass abundance, distribution, depth range and species richness has been observed to be greater in October than in May. This skewed sampling design has resulted in these surveys being biased against the detection of possibly important ephemeral beds such as *H. tricostata* (Coles et al., 2002).

In addition to seasonal growth, inter-annual differences in seagrass meadows have been described (Birch and Birch, 1984). Temporal variation in plant communities is not uncommon, however seagrass meadows of the GBR region appear particularly prone to short term changes in standing biomass. These changes are a part of the ongoing cycle of recruitment and disturbance, however, few studies other than that of Birch and Birch (1984) have quantified this variability and as such remains a key research need. This issue appears to be, at least in part, being addressed for coastal seagrasses throughout Queensland and the Western Pacific through the community based *Seagrass-Watch* program coordinated by the Queensland Department of Primary Industries and Fisheries (Campbell and McKenzie, 2001). A different measure of seagrass habitat value would have been achieved if samples had been taken in different months within the same year. The ongoing monitoring of seagrass species and cover, and more recently seed banks, by trained community groups will provide important data on longer term trends if their efforts are maintained. However, the success of this program requires the ongoing need for training, effective communication (including ongoing feedback), data management and support of community volunteers by experienced scientists and managers.

A general paradigm in the seagrass literature has been that seagrass beds recover poorly following large scale disturbances. This paradigm resulted from the over emphasis of research such as the seismic testing scars by West et al. (1989) in Jervis Bay near Sydney, Australia. These authors reported that a *Posidonia* meadow still bears the scars from seismic testing conducted in the late 1960s, some 20 years earlier. In contrast, research conducted by Birch and Birch (1984) before West's study, observed rapid recovery of seagrass at Cockle Bay, near Townsville, Australia, following cyclone disturbance and largely went ignored. An alternative view on seagrass recovery is emerging in the literature as a result of detailed studies (Kendrick et al., 1999; Cambridge et al., 2002; Plus et al., 2003; Campbell and McKenzie, 2004). Fast growing ephemeral seagrasses such as *H. ovalis* and *H. decipiens* are very dynamic and respond rapidly to changes in specific local conditions. In addition, ongoing observations (Campbell and McKenzie, 2004; Waycott and Mellors, unpublished data; *Seagrass-Watch* Program, Queensland Department of Primary Industries and Fisheries) indicate that some coastal seagrass meadows in the GBR region may recover quickly from disturbance.

Seagrass meadow recovery processes require the use of one of two main strategies, vegetative growth though rhizome extension or by seed. The predominance of either strategy will depend upon the species present and the nature of the disturbance, particularly the degree to which the seedbank and/or original established meadow is impacted and may differ between habitat types. Walker et al. (1999) propose a generic model that describes the relationship between differing seagrass species' capacity to persist through perturbations, vegetative growth rates and seed production. While this generic model provides a framework for investigating these important relationships, it lacks an understanding of seed bank processes such as seed resistance, survival and germination success. For example, some species such as *Halodule uninervis* have the capacity to build up a persistent seed bank in the sediment enabling them to recover from large scale vegetative loss (Inglis, 2000). In contrast, species such as *Thalassia hemprichii* do not form persistent seed banks and thus are more temporally limited in their recovery strategies. Seed bank production, like many other aspects of seagrass biology, is only known from a few localities and is known to be spatially heterogeneous. In addition, different species rely on different growth strategies to recover from disturbance (Inglis, 2000). This is an area of research that needs development and represents the key to a greatly improved adaptive management program with respect to seagrasses in the GBR region.

3.1. Light

Seagrass losses due to light reductions in tropical waters could be a major cause of fluctuations in various fisheries (e.g. prawns) and in reproduction and population structure of dugong and green turtles (Preen and Marsh, 1995). Brodie (2002) and others support the concept that one of the key threatening processes to nearshore seagrass growth in the GBR region is the reduction of available light. Tropical seagrasses must cope with seasonal turbidity to survive pulsed river flow events and wind driven resuspension of sediments (Carruthers et al., 2002). These provide strong selective pressures for adaptations that allow seagrasses to cope with low light, a process involving ecophysiological acclimation. The light quality and quantity is reduced due to water absorption and occasional pulsed runoff events from turbid rivers (Hamilton, 1994; Kirk, 1994). Seagrass losses of 1000 km^2 due to pulsed turbidity events and subsequent recovery have been observed in a variety of habitats in Hervey Bay (Preen et al., 1995). At present, the limited data available indicates the responses of seagrasses to complete shading differs between species (Longstaff and Dennison, 1999; Longstaff et al., 1999). *H. ovalis* grows rapidly and can tolerate occasional freshwater inputs and sediment deposition. Longstaff and Dennison (1999) demonstrate that under full shade this species can survive for more than 30 days. Thus *H. ovalis* is well adapted to the variable light environments it encounters. *Halodule* species were observed to survive significantly longer periods under extremely low light conditions (Longstaff and Dennison, 1999). These species specific responses should be considered in ongoing efforts to understand differential survivorship under light stress.

3.2. Nutrients

Additional stressors on seagrass survival is the presence of high or low, concentrations of nutrients in the environment. Seagrasses have the ability to act as a bio-sink for nutrients, sometimes containing high levels of tissue nitrogen and phosphorous (Mellors, 2003). Research to date in the GBR region has shown that nutrients do not have a negative effect on seagrass growth and distribution, as reported in temperate regions. This is not an unexpected observation as the region as a whole is in relatively healthy condition compared to many other regions globally (Furnas, 2003). However, Udy et al. (1999) observed an increase in seagrass cover at Green Island between 1936 and 1994 through aerial photographic analysis. The authors attribute this increase in seagrass to a net increase in the total nutrient pool available over 50 years of gradual build-up of nutrients in the Cairns region. This observation highlights the nature of gradual, diffuse sources of nutrients and sediments and the long term impact these may have. If, in fact, there has been such an increase in nutrients in the Cairns region, then short term sampling will not detect these differences. Recent data on seagrass tissue nutrient content (*H. ovalis*) collated by Mellors (2003) and Mellors et al. (2005) in Cleveland Bay shows an increase in tissue nutrients for a 25 year period which circumstantially reflects increases in fertiliser usage in the adjacent Burdekin catchment.

A broader spatial survey of nutrients by Mellors (2003) and Mellors et al. (2005) highlights another key factor in understanding nutrients in the GBR region. This survey, across eleven locations between Cairns and Bowen, revealed substantial heterogeneity in sediment nutrients and seagrass biomass even within species. The survey, conducted in 1994 during winter, demonstrates the value of sampling across a greater range of locations to encapsulate the variability present in the system. There would be particular value in returning to the sites of both Udy (1997) and Mellors (2003) to recollect data some 10+ years since they were collected and begin to describe an overall trend in nutrients across the region. The role of nutrients in seagrass survival in the GBR region has to date shown that seagrass growth is limited by nitrogen in the GBR region (Udy et al., 1999; Mellors, 2003). Both Udy and Mellors assessed the response of seagrass to enhanced nutrient levels and saw a response to both N and P but N was the primary limiting element. Thus at present seagrasses have the capacity to absorb additional nutrients enhancing their growth and it would appear that the current nutrient loadings in the GBR have not yet reached critical levels for seagrasses. We do not, however, know the limits of their ability to continue to absorb nutrients and we require additional experimentation that investigates the interaction between sediments, nutrients and the other limiters of plant growth light and temperature. In addition, nutrient analyses have been conducted primarily on the smaller more ephemeral species. Larger more persistent species may be more sensitive to additional nutrients in this region and this should be assessed.

3.3. Pollutants

The detection of chemical pollutants in the GBR such as that observed by Haynes et al. (2000) suggest an ongoing need to monitor and understand the impacts of such inputs. However, the interactions such pollutants may have with seagrass habitats and the future of meadows following inputs needs addressing. Schaffelke et al. (in press) provide a summary of these pollutants and their currently known effects on marine plants in the tropics and conclude that there is a poor understanding of their effects. Our current limited understanding of the impacts of pollutants does suggest that continued changing water quality in coastal seagrass habitats will negatively influence their health. In addition, pollutants may influence population recovery processes. At present our poor understanding of the dynamics of coastal seagrass habitats hampers interpretations of the health of coastal marine environments. This provides a framework for developing research priorities, in particular the links between seagrass decline and recovery.

4. Interpreting changes in seagrass habitats

It is intuitive that a continued decline in water quality will make plant growth increasingly difficult due to lack of light. However, we do not know the critical stress points for different seagrass species and their inherent adaptations to low light or variable light environments, the extreme example of which is the seagrass species *H. ovalis*s found intertidally, but also in deeper water habitats. This species occurs in high turbidity and clear water habitats, on reefs and in estuaries. How this same species survives in such a wide range of habitats is as yet unknown. For most other seagrass species that occur in coastal habitats of the GBR, we have no data available to aid in our interpretation of their ability to adapt to both baseline and changing water quality. In addition to dynamic light environments, pulses of turbidity, particularly where they are derived from catchments, bring associated nutrients and pollutants (Brodie, 2002). These inputs, as already discussed, are poorly understood with respect to seagrass meadow survival and require significant research effort to clarify effects before interpretation of change is possible.

To review and model predicted changes in seagrass meadows of the GBR region we present a diagram depicting a model of the response of seagrasses to stresses (Fig. 2). The model is based on that of Longstaff et al. (1999) and includes predicted changes in key plant parameters of ecophysiology, plant morphology and seagrass population structure. Initial plant response to an external stress such as limiting light would be an increased dependence on stored energy reserves (starches/sugars) or increased chlorophyll production to capture light energy more efficiently, which is the ecophysiological response. This would be followed by increasingly diminutive stature of plants, as they become resource limited (morphological response). The final stage of response is to limit population structure to individual plants with the greatest ability to survive in low light. In the model, some predicted interactions between the three classes of plant responses are made where an ecophysiological response is expected to be evident first, followed by a morphological response which then affects population structure.

The simple survivorship model presented (Fig. 2) does not quantify the amplitude and period of impacts that primary drivers have on seagrass health—light due to its essential role in photosynthesis and macronutrients due to their need in the production of new plant tissue—due to our lack of adequate empirical data across a diverse array of habitats and species. At present, in tropical systems, we have at best preliminary information on the variability, both natural and impacted, of these drivers. To better assess impacts additional baseline information is required urgently to put observed changes to seagrass meadows in context. In addition to research needs highlighted in previous sections of this article, future studies that would benefit these goals include

- Improving our understanding of the spatial and temporal dynamics of the different types of seagrass communities in the GBR (as per Carruthers et al., 2002) to better predict outcomes from changes in seagrass habitats.
- Assess the reproductive health of seagrass beds as an indicator of meadow resilience, i.e. establish if they are producing seeds or are relying on vegetative (clonal) growth.
- As seagrass meadow recovery from impacts will require returning the habitat to a more natural disturbance cycle where possible there is a need to track evidence of major causes of seagrass decline and the key indicators of that decline including a comparison of natural disturbances and known anthropogenic disturbances.
- Evaluate the biodiversity value of different seagrass community types and gain a better understanding of the different ecosystem services these seagrass meadows provide, in particular with reference to their role as food resource for grazers such as dugong and turtle, and as habitat for species of fisheries value.
- Improve our knowledge of the inter-connectivity of coastal marine habitats to better understand the consequences of habitat fragmentation or loss on the ecology of the GBR.

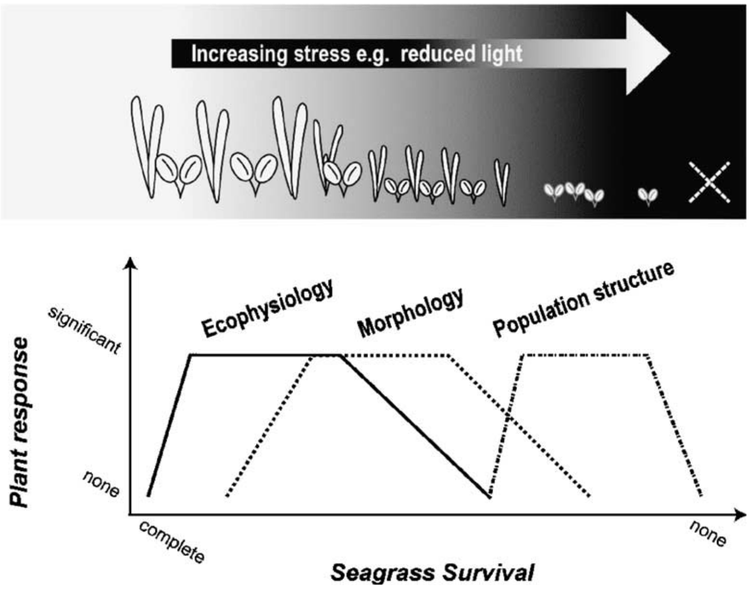

Fig. 2. Conceptual model of tropical seagrass response to increasing stress as typified by known and predicted seagrass population responses to decreased light. The graphical depiction of population survivorship has three elements: (1) the physiological response of plants to increasing stress where plant biochemical activities and growth alters to adapt to changing conditions; (2) morphological responses of plants to increasing stress; and (3) the changes to population structure, i.e. loss of ramets (independent shoots of a genetic individual) or genets (different genetic individuals) in populations.

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