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Stress in mangrove forests: Early detection and preemptive rehabilitation are essential for future successful worldwide mangrove forest management

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ABSTRACT

Mangrove forest rehabilitation should begin much sooner than at the point of catastrophic loss. We describe the need for "mangrove forest heart attack prevention", and how that might be accomplished in a general sense by embedding plot and remote sensing monitoring within coastal management plans. The major cause of mangrove stress at many sites globally is often linked to reduced tidal flows and exchanges. Blocked water flows can reduce flushing not only from the seaward side, but also result in higher salinity and reduced sediments when flows are blocked landward. Long-term degradation of function leads to acute mortality prompted by acute events, but created by a systematic propensity for long-term neglect of mangroves. Often, mangroves are lost within a few years; however, vulnerability is re-set decades earlier when seemingly innocuous hydrological modifications are made (e.g., road construction, blocked tidal channels), but which remain undetected without reasonable large-scale monitoring.

1. Introduction

Mangrove forests are often stressed beyond their limits of survival for a number of reasons (e.g., hydrological change, artificial in-filling of sediments, subsidence, climatic variability). Much of the scientific literature discusses acute stress events, which are readily recognized, researched, and assigned cause. Yet for mangrove forests stress often manifests over decades with little apparent incremental change signalling their future demise. Indeed, individual stress events may have occurred decades before mortality is formally detected; the classic case involves road construction disrupting critical tidal flows (Jiménez et al., 1985; Botero and Salzwedel, 1999; Rivera-Monroy et al., 2006) or damming of rivers reducing sediment supplies to deltaic mangroves (Syvitski et al., 2005; Lovelock et al., 2015). Early detection of stress and preemptive rehabilitation have the potential to alleviate much of this loss, at least in areas having adaptive, or even reactive, management plans in place.

It is not our intent to conduct an intensive review of the published literature on stress in mangrove forests, but rather to suggest what Swart et al. (2013) termed "…new transformative solutions" for responses to environmental stress, and apply that concept to preemptive management of mangrove mortality. Swart et al. emphasized climate stress testing and development of proposed solutions with "[a] focus on thresholds…" to "…foster a salient dialogue between decision makers and scientists about the magnitude of acceptable change, when unacceptable conditions could occur, how likely these conditions are and which adaptation pathways to consider." Stanturf et al. (2014) also referenced "transformative adaptations" to the challenge of forest restoration in general, noting adaptations "…may be responsive or anticipatory, reactive or proactive" and also termed "intervention ecology" after Hobbs et al. (2011).

Eslami-Andergol et al. (2015) in discussing "abrupt ecosystem regime shifts" in intertidal ecosystems note that "detecting an approaching tipping point may help management to adapt to or mitigate the effects of catastrophic change." We intend to propose a transformative approach to do just that through a recommended protocol for early detection and preemptive rehabilitation of mangrove forests before they degrade to nearly complete lack of cover (i.e. "deforestation" from Putz and Redford, 2010) and significantly reduce ecological function. We term this approach "mangrove forest heart attack prevention" in line with the major cause of mangrove stress being modified tidal water flows and exchange, much like blocked blood flows to a heart.

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The medical parallels are clear; long-term degradation of function leads to mortality prompted by acute events, but created by a systematic propensity for long-term neglect.

2. Brief summary of the mangrove forest stress literature

Lugo and Snedaker (1974) in the first modern review of the ecological structure and function of mangrove forests presented a simple model of the "…essential structural and functional attributes of mangrove ecosystems…", later modified by Lugo (1978) and Lugo et al. (1981) and reproduced here as Fig. 1 (from Lugo et al., 1981). Changes in a single individual stressor pathway (e.g., partial changes in hydroperiod; Fig. 1) may lead to eventual mortality of the entire mangrove ecosystem or of critical components (e.g., understory regeneration) for continued persistence. Managers need to be able to detect this gradual mortality and make adjustments while it is occurring. The model identifies five different types of stressors (Lugo, 1998), quoted as:

> "(1) those that change the main energy source (i.e., tides, runoff, etc.), (2) those that divert a fraction of the inflow of resources to the mangroves before these resources can be used within the mangroves, (3) those that remove photosynthate before [it is] stored or used by plants, (4) those that remove soil nutrients or mass from the system, and (5) those that affect metabolism… In general, the severity of the stress decreases from type 1 to type 5 stressors." (p. 427).

Lugo (1998) further notes that "this model depicts rehabilitation actions that reverse the conditions of the five types of stressors. For example, removing limiting factors or toxins, seeding or adding resources, restoring growth conditions, or restoring hydrological conditions or topography" might serve to rehabilitate the mangrove forest.

In general, the cost and difficulty of rehabilitation increases from actions that reverse type 5 stressors to those that reverse type 1 stressors (Fig. 1). For example, "it is more difficult to rehabilitate mangrove habitats (hydrology, topography) than it is to replace plants or overcome a limiting factor.". We have some differences of opinion on this latter statement, but the general concept is applicable. The title of the Lugo (1998) paper is "Mangrove Forests: a Tough System to Invade but an Easy one to Rehabilitate." Here we agree, but note that the state of the mangrove forest after stress impacts, and the time period to rehabilitate conditions of former forest structure and function, can vary considerably and need to be examined carefully to determine where financial and human resources are best invested in any mangrove forest rehabilitation project. Unfortunately, the justification for the rehabilitation process in terms of costs-to-benefits is more clear when the ecosystem is denuded. We suggest there should be priorities for rehabilitation based upon the stressors at play and the probable time to true rehabilitation, after rehabilitation actions are instituted. Such consideration is not now a routine part of mangrove management planning and rehabilitation processes. If mangroves look healthy from a distance, they are often assumed to be fine without conducting important verification either on-site or through remote sensing.

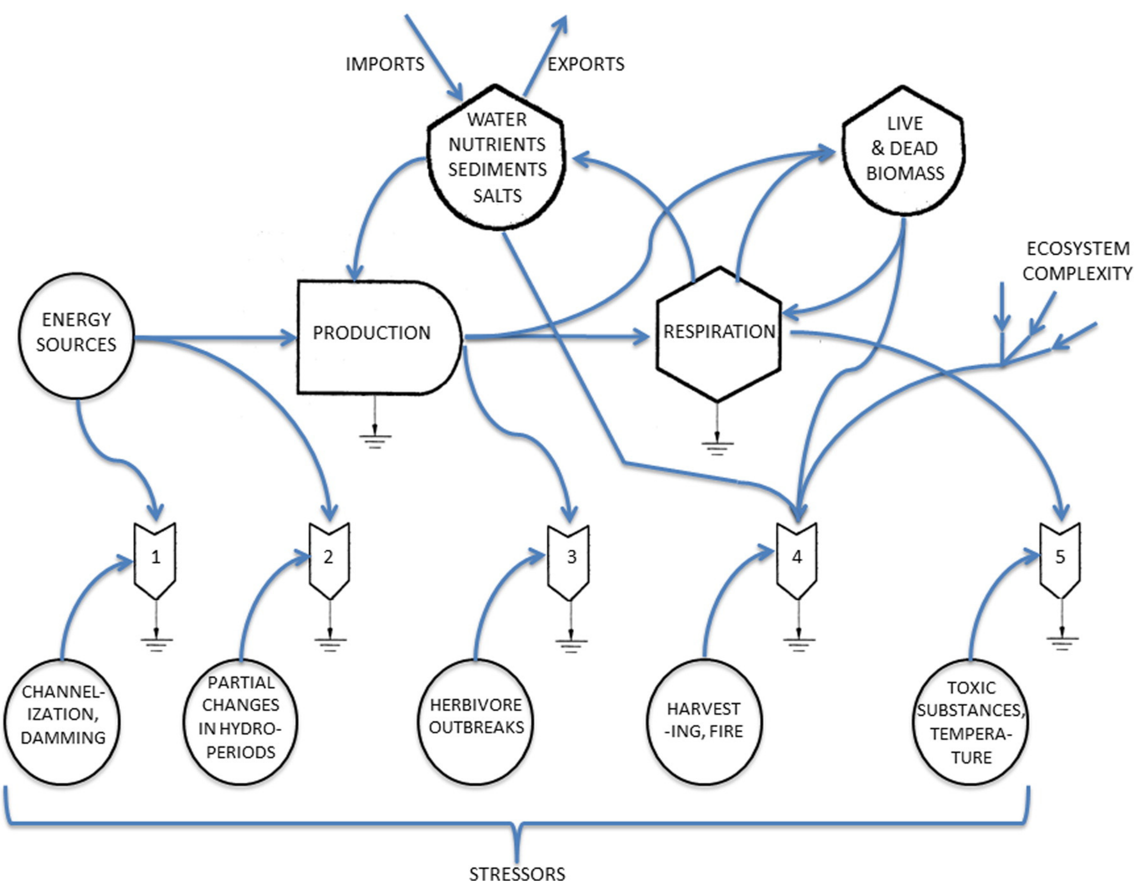

Fig. 1. Chronic stressors (types labelled 1–5) in mangrove ecosystems [redrawn from Lugo (1978) and Lugo et al. (1981), but with original wording, lettering, and connections]. Original caption: "Diagram illustrating the point of attack of stressors on wetland ecosystems, modified from Lugo (1978). An example is given for each type of stressor [see text]. Symbols are described in H.T. Odum (1967). Circles represent external forces acting on the ecosystem. Tanks represent storages of matter. Arrow-shaped symbols are used to illustrate the interaction of two flows, in this case the stressor and an ecosystem component. Plants are represented by the symbol labelled 'production' and all consumers are represented by the symbol labelled 'respiration'. Flows of energy and matter are unidirectional and represented by solid lines. Energy drains are shown wherever there are energy transformations in order to comply with the second law of thermodynamics" (p. 130, Lugo et al., 1981). From the original document, "ecosystem complexity" appears to relate to structural complexity, such as the distribution of trees, species, aerial roots, seedlings, leaves and buds, etc. that define a mangrove forest when relatively free of environmental stressors.

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