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Remote sensing of unhelpful resilience to sea level rise caused by mangrove expansion: A case study of islands in Florida Bay, USA

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ABSTRACT

Previous studies have found that vegetated coastal areas can increase their elevation indicating resilience to inundation by sea level rise (SLR), but the potential resilience were ignored or showed controversial results (i.e., soil accretion of vegetated areas *vs*. SLR). To estimate the resilience influences on 15 islands in Florida Bay (Florida, U.S.), our study used indicators (areas of the 15 islands and their mangrove forests) by analyzing 61-yr high-resolution historical aerial photographs and a 27-yr time-series of Landsat images. In these islands, coastal fringes are dominated by mangroves, and inland parts are dominated by brackish or freshwater species. Our results showed that: (1) despite rising sea levels, these low-lying islands significantly increased in area; (2) all of these islands had significant mangrove expansion, and the landward part of expansion led to the replacement of inland non-mangrove habitats; (3) there was a positive relationship between the increase of island area and mangrove expansion in these islands; (4) without the mangrove expansion, simulations showed that all of the islands had decreased areas by 2014 compared with that in 1953. On the basis of our spatial analyses and previous field studies in our study areas, these islands showed resilience to inundation and the mangrove expansion contributed to processes stabilizing these islands under SLR. Meanwhile, the mangrove expansion were partly at the expense of the habitats previously covered by non-mangrove species, thus potentially leading to a loss of plant diversity. Therefore, the mangrove expansion increased unhelpful resilience to maintain islands in a degraded state losing biodiversity, which should be considered in conservation accounting for future SLR. Moreover, the unhelpful resilience can be monitored by remote sensing based indicators, such as island area.

1. Introduction

Inundation of island or coastal ecosystems under sea level rise (SLR) remain controversial, and potential resilience of these ecosystems to the inundation are ignored in many long-term assessments of ecosystem stability or biodiversity. For example, Bellard et al. (2014) simulated decline of coastal areas in different SLR scenarios and their corresponding biodiversity loss, but they didn't consider the resilience effects. However, global measurements of elevation changes in coastal marshes indicate that the marshes are increasing in elevation at rates similar to or exceeding historical SLR, and simulations predict survival of the coastal marsh under different future sea level scenarios (Kirwan et al., 2016). The potential resilience of coastal vegetated areas are contributed from two processes, including: (1) Surface physical sedimentation processes: it can increase the elevation by sediment trapping and accretion, and the sediment sources may be organic or mineral materials from local plant community (e.g., litterfall) or outside transport; (2) Subsurface biophysical process: it can increase the elevation by subsurface organic matter accumulation (e.g., peat formation), and root expansion (Kirwan and Megonigal, 2013; Lovelock et al., 2015a; McKee, 2011).

Both of the above processes can be enhanced in coastal mangrove ecosystems (Krauss et al., 2014), because mangroves can produce organic carbon in excess of respiration, principally in the form of litterfall for surface sediments or deposited as peats (Duarte et al., 2005). The sediment accumulation can be enhanced in robust aerial root structures of some mangrove species by effectively slowing water velocities and settling sediment onto coastal soils (Gedan et al., 2011; Krauss et al., 2003). In addition, fast generating roots of mangroves can grow into newly accumulated sediment, and further promote the elevation

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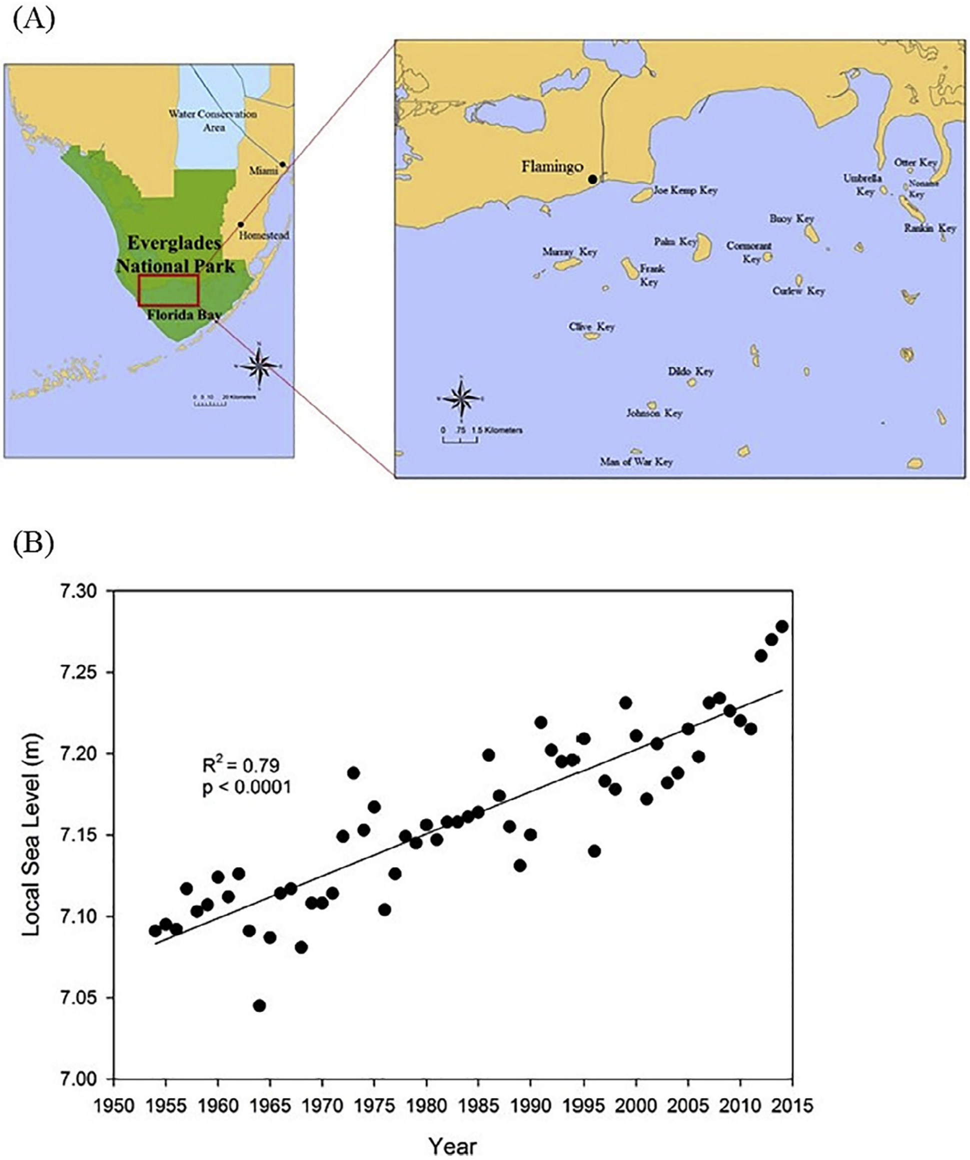

Fig. 1. (A) Location of the 15 islands in Florida Bay. (B) The local sea level data from a monitoring station of National Oceanic and Atmospheric Administration (NOAA) in Key West, FL (http://www.psmsl.org/), which is located in the south end of Florida Bay.

increase (Lovelock et al., 2011).

As a globally important community covering more than $1.3 \times 10^5\,km^2$ coastal areas (Giri et al., 2011), mangrove forests showed a various comparison between their elevation increase and local SLR. For example, in Tampa Bay (Florida, U.S.), increases of surface elevation in mangroves were 4.2–11.0 mm/yr, which exceeded current local SLR rates (2.6 mm/yr) (Krauss et al., 2017). However, in the Pacific islands of Micronesia, coastal mangrove zone had elevation deficit (-3.2 mm/yr) under local SLR (0.8–1.8 mm/yr) (Krauss et al., 2010). In some Indo-Pacific mangrove forests, their elevation increases were also less than the long-term SLR, and the low elevation increases may have been caused by human activities, such as compaction of surface sediments, deforestation, groundwater extraction (Laura et al., 2014; Lovelock et al., 2015b). Therefore, to validate the long-term resilience of island ecosystems to SLR, studies need to focus on sites where human disturbances are minimal or absent, such as islands in Florida Bay, USA (see more details in Methods).

In addition to the resilience to inundation, mangrove growth potentially lead to plant biodiversity loss through zonal shifts in plant communities with SLR. In coastal areas, freshwater communities are exposing to growth stress caused by SLR (Zhai et al., 2018), and their habitats can be invaded and finally replaced by species being more adaptive to saltwater intrusion (e.g., mangroves) (Fuller and Wang, 2014; Jiang et al., 2015). Consequently, mangrove species have shown landward invasion into habitats covered by other species with SLR, such as in southern Florida, USA (Yao and Liu, 2017), at the mouth of Amazon River, Brazil (Nascimento Jr. et al., 2013), at the border of New South Wales and Queensland, Australia (Rogers et al., 2014), and in Pacific island atolls (Ellison et al., 2017). In southern Florida, there are only three mangrove species, but many more species in the freshwater habitats (Ross et al., 1992). Therefore, mangrove expansion at the expense of freshwater species habitats indicate potential biodiversity loss in coastal ecosystems. Meanwhile, mangrove expansion can contribute to stabilizing islands under SLR. As a result, the resilience caused by mangrove expansion could maintain islands in a degraded state losing biodiversity, and the resilience thus fall within the category of “unhelpful resilience” as defined by Standish et al. (2014). However, the unhelpful resilience have received very little attention from both research and management of coastal conservation.

The unhelpful resilience may be detected by remotely sensed