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Processes affecting the spatial distribution of seagrass meadow sedimentary material on Yao Yai Island, Thailand

Michelle S.Y. Quak [a], Alan D. Ziegler [a, *], Shawn G. Benner [b], Sam Evans [b], Peter A. Todd [c], Lucy G. Gillis [d], Sukanya Vongtanaboon [e], Nick Jachowski [a], Tjeerd J. Bouma [f]

[a] Geography Department, National University of Singapore, Singapore
[b] Department of Geosciences, Boise State University, Boise, United States
[c] Department of Biological Sciences, National University of Singapore, Singapore
[d] Mangrove Ecology, Leibniz Center for Tropical Marine Ecology GmbH, Bremen, Germany
[e] Phuket Rajabhat University, Phuket, Thailand
[f] Deltares, Delft, The Netherlands & Spatial Ecology Department, Royal Netherlands Institute for Sea Research (NIOZ), The Netherlands

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ABSTRACT

Many islands throughout SE Asia are experiencing rapid development and land-cover conversion that potentially threaten sensitive coastal ecosystems, such as seagrasses, through increased loading of sediment and nutrients originating from disturbed catchments draining to the sea. To evaluate this threat for one such island in Southern Thailand (Yao Yai), we perform sediment source tracing via end-member mixing analysis using stable isotopes $\delta^{13}C$ and $\delta^{15}N$ in organic matter to explore sediment loading in a seagrass meadow. The analysis indicates that sedimentary material in the meadow originates mostly from ocean-associated sources (~62% from seagrass detritus, seston, and ocean sediments). Terrestrial material comprises ~19% of the organic material found in the seagrass meadow, with another 20% originating from an adjacent mangrove forest. Approximately one-fourth of the seagrass meadow material (24%) is detritus that has been (re)deposited internally. The high contribution of terrestrial-derived organic matter deposited near the river mouth demonstrates that substantial quantities of sediment are being transferred from upslope erosion sources into the seagrass meadow. However, only a small amount of this material is deposited throughout the entire bay because much of the terrestrial- and mangrove-derived sediment is transferred to the open ocean via channels that are periodically dredged to allow boat access to two small inland harbours. This positive affect of dredging has not received very much attention in existing literature. River water flowing to the channels during falling tide delivers sediment to these efficient pathways, where much of it bypasses the seagrass meadow at periods of time when sediment deposition would normally be the greatest. There is growing concern that ongoing land-cover changes and planned urbanization related to tourism and agriculture on the island may boost sediment/nutrients above a critical threshold, beyond that revealed in our baseline survey. Our tracer-based sediment source approach did not corroborate our observations of substantial erosion and land degradation in the upper catchment—but this could be a result of sediment flushing through the dredged channels. We encourage others to combine such methods with sediment budgeting approaches to triangulate results for consistency. Finally, from an ecological perspective, the high presence of seagrass detritus we found in bay sediments suggests seagrass is potentially a key source of nutrients for the meadow itself, as well as other connected ecosystems.

1. Introduction

Seagrasses are aquatic flowering plants that are widely distributed along temperate and tropical coastlines of the world (Orth et al., 2006; Gattuso et al., 2006). Globally, seagrass meadows are increasingly facing rapid degradation and destruction (Waycott

* Corresponding author. Geography Department, AS02-04-21, 1 Arts Link, Kent Ridge, National University of Singapore, 117570, Singapore.
E-mail address: geoadz@nus.edu.sg (A.D. Ziegler).
URL: http://www.adziegler.com/peeps/alan-d-ziegler/

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et al., 2009; Orth et al., 2006) and several species are in danger of extinction (Short et al., 2011). The mean annual decline in seagrass area has been 7% yr^{-1} since 1990, reflecting the devastating effect of a broad spectrum of anthropogenic and natural stressors concentrated at the coasts (Short and Wyllie-Echeverria, 1996; Duarte, 2002; Salomons et al., 2005; Waycott et al., 2009; Elliott and Whitfield, 2011).

Human-induced disturbances in particular can cause long-lasting changes in the sedimentary environment, often resulting in seagrass loss (Lee et al., 2006; Erftemeijer and Lewis III, 2006; Cabaco et al., 2008; Yaakub et al., 2014b). Prolonged reduction of underwater irradiance from increased turbidity from the loading of fine sediments inhibits photosynthesis and seagrass growth, leading to large-scale seagrass die-offs (Burkholder et al., 2007; Lee et al., 2007; Yaakub et al., 2014a). Short et al. (2014) found that seagrass meadow cover was in decline for seven of ten study sites in the Western Pacific. Three of the sites of decline experienced degradation related to sedimentation; the other four, nutrient loading. One site in Palau showed low-level seagrass decline from increased sediment loading due to road construction. Two sites in Sabah, Malaysia, were affected by forest cover change in headwater catchments that produced massive sediment loading. One site on Komodo Island, Indonesia, was affected by nutrient loading from beachside tourist cabins. The commonality (and relevance to the present study) among all sites experiencing seagrass loss is the direct linkage between the coast and sources of terrestrial pollution (e.g. sediment and/or nutrients).

Here, we investigate sediment loading using carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) stable isotope signatures of seagrass meadow sediments to identify the sources of organic material accumulating in a sheltered bay on Yao Yai Island, southern Thailand. The overarching framework of the study is the catchment-coast continuum, which supports the notion that rivers link coastal systems with potential degradation sources through the transfer of water, mineral sediment, organic matter, and inorganic nutrients (Owens, 2007; Salomons et al., 2005). Thus, the extent that pollution-causing activities contribute to degradation in downstream ecosystems is in part related to hydrological connectivity, as well as the level of disturbance upslope (Bracken and Croke, 2007). While we do not examine habitat degradation per se, we are motivated by observations of impacted coral reefs, islander reports of fish decline, and reductions in dugong sightings (perhaps related to seagrass meadow deterioration). Yao Yai Island is typical of many islands in Thailand where modification of watersheds and coastlines is associated with economic development, hence we anticipate that our finding will be relevant to other sites beyond the one studied in detail here.

We are also guided by fundamental ecological questions related to the role of mangroves in outwelling nutrients to the coastal zone (Odum, 1980). In a prior investigation, Gillis et al. (2014a) used sediment traps to identify sources of particulate organic matter samples along transects extending from the mangroves to the open ocean. They determined that organic matter in the traps was divided unevenly between oceanic (34–50%), mangrove (24–38%), seagrass (16–19%), and terrestrial (6–17%) sources. Based on habitat area, however, the contribution of particulate organic matter derived from seagrass meadows was disproportionally high relative to land-based sources, demonstrating the potential of seagrass meadows to provide nutrients to surrounding ecosystems. Our rationale for revisiting the site is to examine the connectivity between inland erosion sources and the coastal zone, as well spatial distribution of organic material in the bay.

2. Study area

The bay is located at the southern end of Yao Yai Island (98°35′E, 7°55′N), which is situated in Pang Nga Bay, Thailand (Fig. 1). The bay is approximately 1.2 km wide and 3 km long, and receives runoff water, sediment, and other materials from nine small catchments draining to the coast (Fig. 1). The dry season extends from November to April; the wet season extends from May to October (Southwest monsoon). Mean annual precipitation is approximately 2200 mm (Chansang, 1984). The main stream draining to the bay is perennial and flow is affected by the tides. Streams draining into the main stream from mountain headwater catchments are ephemeral, producing flow only during the wet monsoon season or immediately following storms. The study area is subjected to semidiurnal tides with a tidal range of ~2.5 m during spring tide (Chansang, 1984). Water depth of the bay where the seagrass meadow is located has less than a 5 m range during the highest observed tide (Fig. 2). The sheltered bay likely protects the seagrass and coral reef ecosystems from strong open sea waves, thereby limiting mixing (Fig. 3A).

The livelihoods of islanders was once predominantly fishing, but now plantation agriculture is an important source of income, as is a growing tourism industry. The extent of natural forest has been in decline for a number of years—much of the forest on the inward slopes and flat areas of the island has been converted to plantations

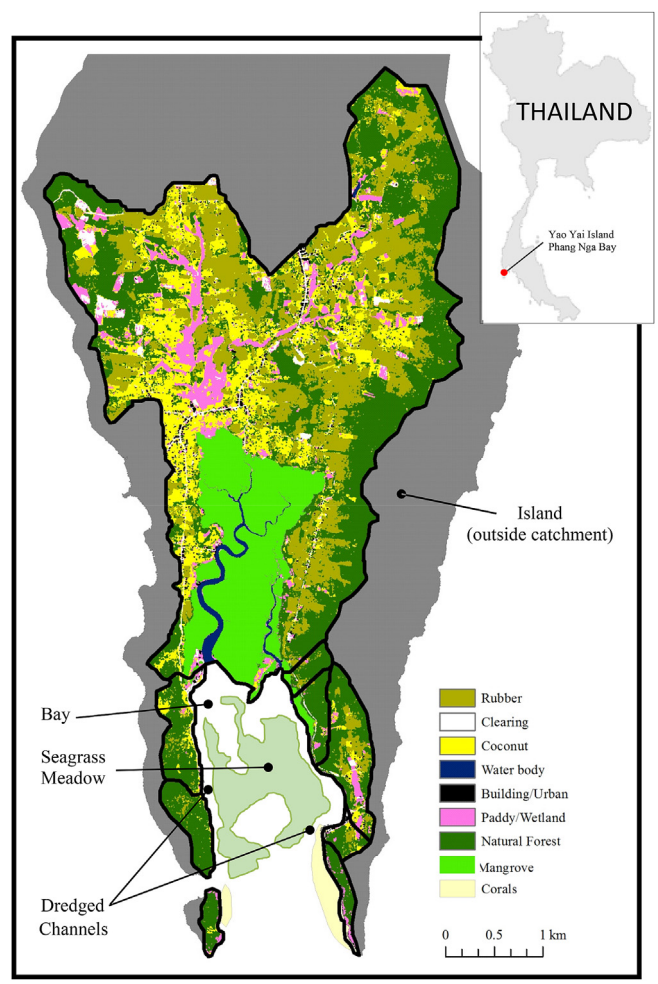

Fig. 1. Land-cover map of Yao Yai Island (2012). Rubber and coconut plantations are the dominant land covers. The 1.2 km by 3 km bay is fed by nine sub-watersheds (delineated with the black solid line). Land-cover analysis was carried out with a 2-m resolution DigitalGlobe satellite image (Date of image: July 2012), using a supervised classification technique in ArcGIS v10.1. Groundtruthing was performed during the two visits to the study site.