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Sources and dispersal of land-based runoff from small Hawaiian drainages to a coral reef: Insights from geochemical signatures

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ABSTRACT

Land-based sediment and contaminant runoff is a major threat to coral reefs, and runoff reduction efforts would benefit from knowledge of specific runoff sources. Geochemical signatures of small drainage basins were determined in the fine fraction of soil and sediment, then used in the nearshore region of a coral reef-fringed urban embayment on southeast Oahu, Hawaii, to describe sources and dispersal of land-based runoff. The sedimentary rare earth element ratio $(La/Yb)_N$ showed a clear distinction between the two main rock types in the overall contributing area, tholeiitic and alkalic olivine basalt. Based on this geochemical signature it was apparent that the majority of terrigenous sediment on the reef flat originated from geologically old tholeiitic drainages. Sediment from one of five tholeiitic drainages had a distinct geochemical signature, and sediment with this signature was dispersed on the reef flat 2 km west and 150 m offshore of the contributing basin. Sediment and the anthropogenic metals Cd, Pb, and Zn were entrained in runoff from the most heavily urbanized region of the watershed. Although anthropogenic Cd and Zn had localized distributions close to shore, anthropogenic Pb was found associated with fine sediment on the westernmost part of the reef flat and 400 m offshore, illustrating how trade-wind-driven sediment transport can increase the scale of runoff impacts to nearshore communities. Our findings show that sediment geochemical signatures can provide insights about the source and dispersal of land-based runoff in shallow coastal environments. The application of such knowledge to watershed management and habitat remediation efforts can aid in the protection and restoration of runoff-impacted coastal ecosystems worldwide.

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1. Introduction

Coastal areas have long been desirable locations for human settlement and economic activity (Mee, 2012). Human use of coastal areas and watersheds can, however, exert a heavy toll on ecosystems by altering natural processes and habitats and overusing resources (Jackson, 2008; Lotze et al., 2006). For example, increased erosion and runoff of sediment, nutrients, and contaminants can degrade coastal water quality and lead to the loss of vital ecosystems including coral reefs (Fabricius, 2005; Pandolfi et al., 2005), seagrasses (Short and Wyllie-Echeverria, 1996; Waycott et al., 2009), and kelp forests (Jackson et al., 2001). Land-based sediment and contaminant runoff is harmful to coral reefs in many ways: it inhibits photosynthesis and larval recruitment, it smothers live corals and exposes them to contaminants, and it is associated with lower live coral cover, lower species diversity, and degraded fisheries (e.g., Fabricius, 2005; Knowlton, 2001; Rogers, 1990). Runoff prevention and control measures in watersheds upstream of coral reefs are recognized globally as means to prevent further degradation and facilitate recovery of runoff-impacted coral reefs (e.g., Bartley et al., 2014; Hughes et al., 2010; Richmond et al., 2007). In addition, the coupling of land-based runoff management with an understanding of local hydrodynamic controls on nearshore sediment and contaminant transport is an important component of comprehensive and effective remediation strategies for runoff-impacted reefs (Done, 1995; Hunter and Evans, 1995; Restrepo et al., 2016). Recent studies have demonstrated the use of sediment-geochemical tracers in identifying sources of land-derived sediment to the coastal zone (Araújo et al., 2002; Prego et al., 2009, 2012; Roussiez et al., 2013; Smith et al., 2008). The goals of this study were to identify geochemical signatures of terrigenous sediment and trace metal runoff to a coral reef-fringed

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urbanized embayment from several short, steep drainages; to use these signatures to identify sediment sources and infer nearshore transport; and to describe the distribution of anthropogenic metals in urbanized basins and the reef flat. The trace metals cadmium (Cd), copper (Cu), lead (Pb), and zinc (Zn) are enriched by anthropogenic activities, particularly the operation of motor vehicles (Alloway, 1995). Insights from geochemical signatures about sources of land-based sediment and contaminants and their nearshore dispersal can help runoff management efforts target priority contributing areas and guide nearshore habitat remediation of sediment-impacted coastal ecosystems.

2. Site description

2.1. Environmental setting

Maunalua Bay is an urbanized embayment on the southeast shore of the Island of Oahu, Hawaii, U.S.A. (Fig. 1). Hawaiian watersheds are generally composed of several small, steep valleys with streams that enter a larger body of water. Maunalua Bay is one such body, receiving runoff from 10 small drainage basins with a total contributing area of 57 km^2. A major highway parallels about half of the shoreline (Fig. 1) and dense residential development occupies the coastal plain, valley floors, and some ridges. Kuapa Pond, a 2 km^2 shallow lagoon in the east part of the watershed, was breached permanently, its marshland filled, and developed into the Hawaii Kai Marina complex (Coles et al., 2002). Urban stream sediment and roadside soil in southeast Oahu have been found to contain elevated anthropogenic trace metals (De Carlo et al., 2005; Sutherland and Tolosa, 2000).

Maunalua Bay lies in the lee of Koolau Ridge relative to the direction of the northeast trade winds. Rainfall in the watershed is higher in winter than in summer due to a higher frequency of southerly (Kona) storms and other low pressure disturbances (Giambelluca et al., 2013; Oki and Brasher, 2003). At high elevations on Koolau Ridge where many streams have their headwaters, mean annual rainfall is approximately 1500–2000 mm, whereas rainfall on the urbanized coastal plain is about half that amount (Giambelluca et al., 2013; Oki and Brasher, 2003). Sediment retention structures were built in valleys above residential areas to control runoff and stream channels have been straightened and hardened to varying extents. Storm runoff is flashy in nature (Tomlinson and De Carlo, 2003) and exacerbated by the high degree of impervious surface in urban areas (Wolanski et al., 2009).

The Maunalua Bay reef flat ranges from 0.2 to 1.0 km wide and is approximately 1 m deep and 10 km long. It is subject to water quality impairments due to elevated nutrients and chlorophyll, non-native algae, low live coral cover, and diminished fish and seagrass communities (Coles et al., 2002).

Currents in Maunalua Bay are driven by winds and tides (Presto et al., 2012; Storlazzi et al., 2010). At the surface to a depth of 1 m, the prevailing trade winds drive westward transport (Presto et al.,

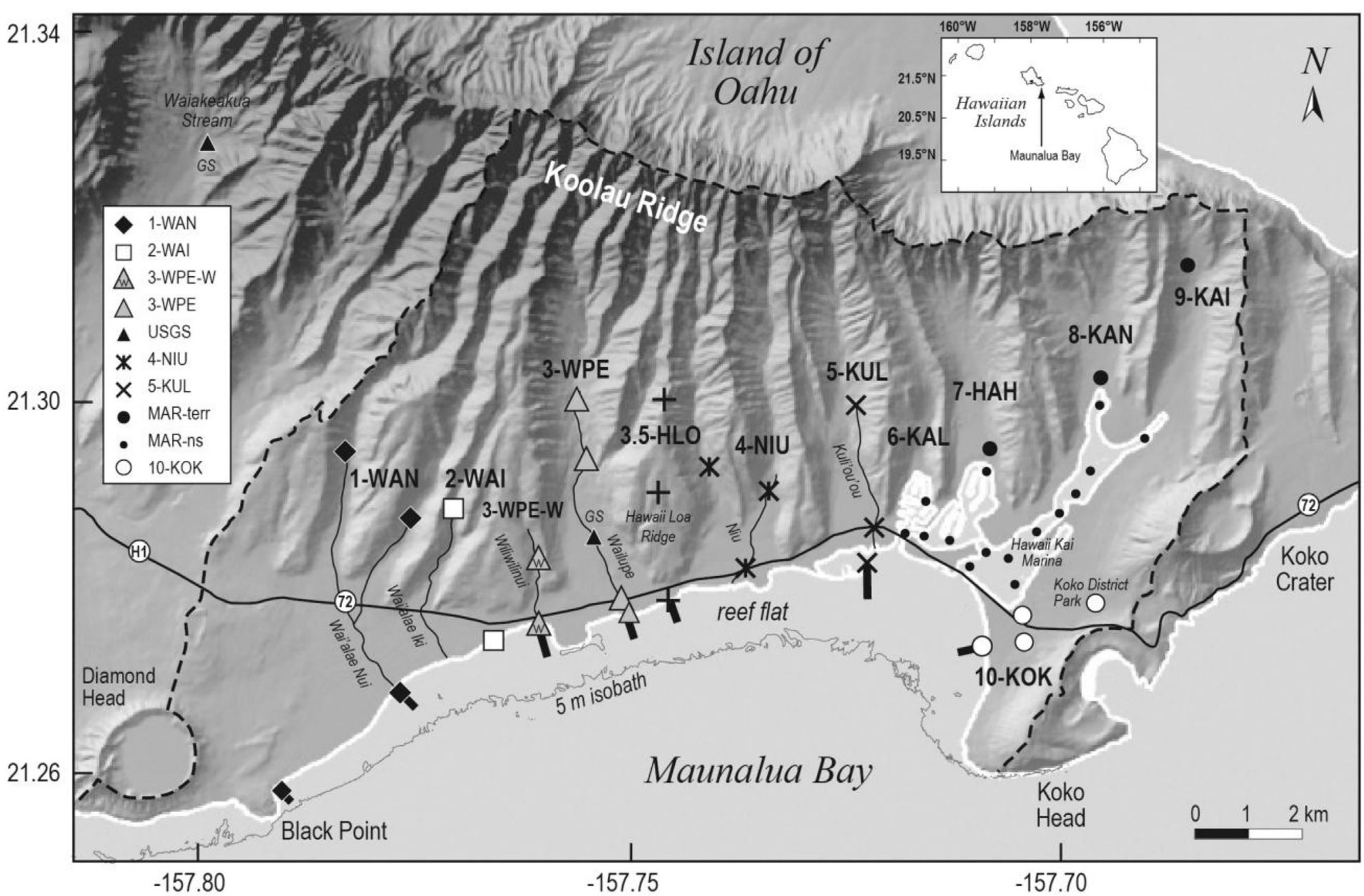

Fig. 1. Shaded relief map of southeast Oahu showing Maunalua Bay (white line marks the shoreline) and its watershed (dashed line). Drainage basins are identified with numbers and abbreviations described in Section 3.1. Streams in basins 1–5 are shown by name. The sub-basin 3-WPE-W (Wiliwilinui) is denoted by a 'w' inside a gray triangle. Black triangles show USGS gaging stations (GS) on Wailupe and Waiakeakua Streams. 'terr', terrestrial; 'ns', nearshore. Black lines on the reef flat show reef transects. The 5 m isobath is shown for reference. Inset shows the location of Maunalua Bay in the Main Hawaiian Islands.