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Quantifying the impact of watershed urbanization on a coral reef: Maunalua Bay, Hawaii

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ABSTRACT

Human activities in the watersheds surrounding Maunalua Bay, Oahu, Hawaii, have lead to the degradation of coastal coral reefs affecting populations of marine organisms of ecological, economic and cultural value. Urbanization, stream channelization, breaching of a peninsula, seawalls, and dredging on the east side of the bay have resulted in increased volumes and residence time of polluted runoff waters, eutrophication, trapping of terrigenous sediments, and the formation of a permanent nepheloid layer. The ecosystem collapse on the east side of the bay and the prevailing westward longshore current have resulted in the collapse of the coral and coralline algae population on the west side of the bay. In turn this has lead to a decrease in carbonate sediment production through bio-erosion as well as a disintegration of the dead coral and coralline algae, leading to sediment starvation and increased wave breaking on the coast and thus increased coastal erosion. The field data and resulting coral reef ecohydrology model presented in this paper demonstrate and quantify the importance of biophysical processes leading to coral reef degradation as the result of urbanization. Coral restoration in Maunalua Bay will require an integrated ecosystem approach.

1. Introduction

Increasing human population in most coral fringed oceanic islands has lead to the degradation of shallow water coral reefs as a result of modification of coastal watersheds by human activities (Cote and Reynolds, 2006). Data are lacking to quantify the apparent link between watershed development and coral reef degradation, but it is generally recognized that both physical and biological processes may contribute simultaneously to this degradation (Zann, 1994; Hunter and Evans, 1995; Costa et al., 2000; Fabricius, 2005; Riegl and Dodge, 2008). Because of the complexities of the biophysical links in coral reef ecosystems, it is often difficult to quantify the relative contribution of each land-based human activity to coral reef degradation, and to develop policies that integrate across the land–sea boundary. The field data and resulting coral reef ecohydrology model presented in this paper demonstrate and quantify the importance of biophysical processes leading to coral reef degradation as the result of urbanization, and quantify the relative contribution of various human activities.

The study site was Maunalua Bay (157° 45′ W, 21° 15′ N), Oahu, Hawaii (Fig. 1). The bay is 8 km long and has a fringing reef flat. The bay receives discharges from nine small watersheds, each typically 10 km^2 in size (e.g. the Wailupe watershed is 8.8 km^2, the Kamilo Iki watershed is 12.4 km^2, and the Kamilo Nui watershed is 10.8 km^2). Each stream drains across the reef flat through a small, often ill-defined, channel and a well-defined passage through the reef crest (Fig. 2).

When first mapped in 1855, the human settlements were few, the reef crest was observed to be near the ocean's surface where waves broke permanently, and there was a large lagoon ('Lake Maunalua' commonly known as Kuapa Pond, now a marina) on the east side of the bay (Fig. 3a). This same map shows that most of the peninsula separating the lagoon from the reef flat was too narrow for human settlement but it was continuous, i.e. Kuapa Lagoon was closed except during the highest spring tides when it overtopped, and during river floods when the peninsula would have been breached. Fishermen created permanent openings bridged by rock walls; by 1921 these rock walls, made visible as thin straight lines in Fig. 3b, closed most of the lagoon and only

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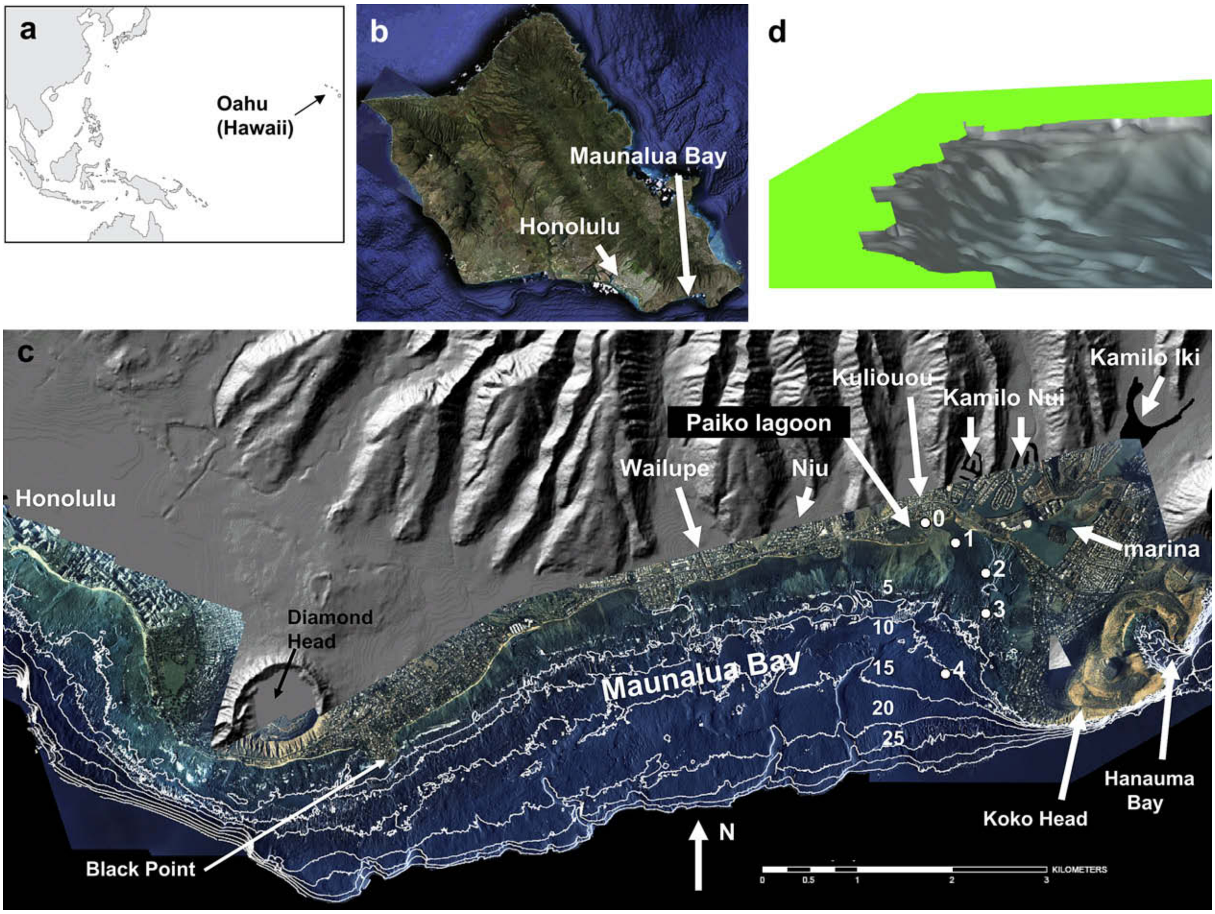

Fig. 1. (a–b) General location maps. (c) Bathymetry (depth in m) of Maunalua Bay and the location of the oceanographic mooring sites 0–3 and the streams mentioned in the text, together with key sites and a visualization of the coastal urbanization and the topography. (d) A 3-D rendering of the bathymetry of Maunalua Bay.

a small opening existed on the west side of the peninsula. In 1855 a large fish pond existed near the mouth of the Wailupe stream (Fig. 3a); this pond was created by constructing rock walls (Fig. 3c). This fish pond was later filled for a housing development. In 1900 mangroves and halophytes were fringing Kuapa Pond and man-made fish ponds in coastal waters (Fig. 3b and c). In 1890 the reef flat on the east side of the bay was sandy and extremely shallow at low tide (Fig. 3d). In 1927, Kuapa Pond was fringed by seasonal wetlands used as pastures (Fig. 3e), and urbanization was still minimal. In 1930 the coast was sandy on the west side of Maunalua Bay (Fig. 3f). Large-scale urbanization occurred since the 1960s when two navigation channels were dredged that traverse Maunalua Bay, one on the east side of Maunalua Bay and another, smaller, channel in the central region near the Wailupe stream mouth. The Kuliouou stream that historically discharged into Paiko Lagoon was diverted to flow directly into Maunalua Bay. All of the coastal plains and much of the surrounding hills have been urbanized (Fig. 3h), the surface area of Kuapa Pond was decreased by 30% when it was urbanized into a marina, the streams were channelized and lined with concrete (Fig. 3i), and new houses were constructed, and are still being constructed, on steep, highly erodible slopes with flimsy sediment curtains being used for mitigation; these curtains readily fold and fail to trap sediment during runoff events (Fig. 3j). The degree of urbanization in 2008 varied between catchments, examples being 33% in the Kamilo Nui catchment, 34% in the Wailupe catchment, and 56% in the Kamilo Iki catchment, with similar high values in all of the other catchments. Runoff from these hard surfaces is largely directed by pipes to the channelized streams, thus reducing groundwater recharge. The remaining parts of the catchment are designated as conservation areas and are degraded by invasive alien species of plants and by a large population of feral pigs and goats. As a result, erosion is prevalent within the upper regions of the catchment as well as along stream banks.

2. Methods

Four oceanographic moorings were deployed at sites 1–4 (see location map in Fig. 1) from August to December 2008. These sites formed a transect along the east side of the bay. Tidal height, salinity, temperature, dissolved oxygen concentration, pH, and suspended solid concentration (SSC) were measured at sites 1–3 using self-logging YSI (Yellow Springs Instruments) self-logging CTD-cum nephelometers moored nominally 1 m below the surface at low tide. The YSI instruments were equipped with wipers that cleaned the sensor every 5 min. The instruments logged data at 5 min intervals. At site 3, the vertical profiles of horizontal currents were measured at 10 min intervals using a bottom-mounted Workhorse ADCP from September to December 2008. In addition, the vertical profile of salinity, temperature, dissolved oxygen and SSC was measured at sites 0–3 at intervals of 1–4 weeks from a ship-born YSI CTD profiler-cum nephelometer. The nephelometers were calibrated at the Kewalo Marine Laboratory using sediment from site 1.

Other data sets were collected from a number of sources. The Wailupe stream discharge time-series data for October–December