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Synthesis of Water Quality & Coral Reefs In Relation to Sewage Contamination: Importance to the Puakō Region

Introduction

Sewage contamination is impacting coastal waters worldwide. Sewage can enter coastal waters from accidental spills (Dingeman 2006; Zimmerman 2010; Star-Advertiser Staff 2013; DOH 2014), injection wells (Peterson & Oberdorfer 1985; Hunt 2006; Knee et al. 2008), and leaks from cesspools and septic tanks (Hunt 2006; DOH 2014). The United States Environmental Protection Agency (EPA) estimates that nationwide 61% of small communities (<10,000 people) use cesspools or septic tanks for wastewater disposal (EPA 2012). According to AECOS Inc., an environmental consulting firm, "*Any method of treatment and disposal of domestic sewage can increase nutrient levels in groundwater percolating seaward*" (AECOS 1980). A common septic system consists of a septic tank to collect wastewater and a leach field where effluent flows through leaching chambers within the ground, before percolating into the soil. Depending upon the system and household occupancy, a septic tank should be inspected and/or pumped every five years (EPA 2000; Ogata & Babcock 2009). Cesspools are unlined underground holding areas that receive untreated wastewater allowing the liquid to percolate directly into the soil and may contaminate groundwater, rivers, and nearshore environments (EPA 2004). Studies have concluded that if cesspools are not pumped annually they may become a non-point source of nutrients, bacterial pathogens, and water contamination to surface and/or groundwater (Ogata & Babcock 2009; Boehm et al. 2010). This contamination is considered a hazard to humans, jeopardizing the health of recreational swimmers nearshore. Exposure to wastewater, either from ingestion, inhalation, digestion, or direct contact, may result in infections such as skin infections, hepatitis, and gastroenteritis (Pinto 1999; EPA 2011).

Wastewater contamination of groundwater is also harmful to shoreline environments (Friedlander et al. 2005) causing elevated nutrient levels (AECOS Inc. 1980; Bruno et al. 2003; Payton et al. 2006; Knee et al. 2008) that alter coral reef growth rates, species distribution, diversity, and abundance, and increase the incidence of coral disease (Pastorok & Bilyard 1985; Dollar & Grigg 2004; Parsons et al. 2008; Vega et al. 2013). The following paragraphs discuss what is known about the impacts of sewage on coastal ecosystems and how these impacts are measured, focusing on South Kohala and Puakō, Hawai'i.

Puakō Bay, Hawai'i

Puakō Bay, located on the Northwestern side of Hawai'i Island, has a small but growing community of about 500 people. The Puakō community consists of 163 homes along a 3.5km stretch of coastline (Minton et al. 2012) and contains 58 known cesspools. The community heavily relies on cesspools and septic tanks for sewage disposal and there is a concern that wastewater is impacting the health of nearby coral reefs. In 2012, NOAA's Coral Reef Working Group (CRWG) declared Puakō Bay a priority site (NOAA 2012). A priority site is defined as an area with a highly diverse coral reef ecosystem that is currently threatened and that has a potential for improvement. Puakō Bay has also been recently named as a habitat focus area under NOAA's Habitat Blueprint to improve habitats for fisheries marine life, and coastal communities. In addition, the Hawai'i Coastal Zone Management

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(CZM) program chose Puakō as Special Management Area (SMA), which protects coastal resources from certain levels of runoff. Since this designation, erosion control measures and runoff mitigation actions have been used to prevent pollutants and nutrients from entering nearshore waters.

Nutrients

In the marine environment, wastewater can lead to elevated nutrient levels that are measured by high levels of orthophosphate (AECOS Inc. 1980; Knee et al. 2010), nitrogen (nitrate + nitrite (N+N), total dissolved nitrogen (TDN), and total inorganic nitrogen (TIN)) (AECOS Inc. 1980; DOH 1984; Savage & Elmgreen 2004; Lapointe et al. 2005; Payton et al. 2006; Knee et al. 2010), and nitrogen and phosphorous ratios. These nutrients stimulate growth of phytoplankton and benthic algal, which can result in algal blooms (high algal abundances) that can negatively impact corals, humans, and other organisms (Lapointe et al. 2005).

According to Payton et al. (2006), sewage could explain eutrophication (an overabundance of nutrients) within coastal reef ecosystems and cause a significant shift in the biological structure of these systems, from dominance by corals to overgrowth of algae. This biological shift was seen in Kaneohe Bay after a sewage spill event. Hunters & Evan (1995) also observed increases in algae that were thought to indicate eutrophic conditions. Nutrient pollution has also been shown to increase coral disease and bleaching (Vega 2013). Following wastewater exposure, one study found that within a single year of cessation of nutrient enrichment, coral diseases returned to typical levels (Vega 2013), whereas another study found that corals take decades to recover (Dollar & Grigg 2003).

Elevated nutrient levels have been found in Puakō and surrounding areas. Knee et al. (2010) found high concentrations of N+N (160 µmol/L), which exceeds the Hawaiʻi Department of Health (HDOH) water quality standards of 70 µmol/L, and phosphate compared to ten other sites along the Kona Coast. Parsons & Preskitt (2007) also observed this area to have higher concentrations of N+N (2.5 µmol/L) and chlorophyll α (a proxy for algal abundance; 0.5 µmol/L), as compared to six other sites on Hawaiʻi Island. Elevated condensed dissolved nutrients were also found by The Nature Conservancy (TNC unpublished data) in surface waters. In addition, Payton et al. (2006) found Puakō Bay to have the highest TIN (126 µmol/L) and the second highest TIN flux (344 mmol/m/h) in groundwater compared to six other sites (Gulf of Aqaba, Kaloko Hawaiʻi, Kahana West Maui, Key Largo Florida, and West Coast Manutius). Kay et al. (1977) also observed groundwater flux in this area and concluded a nutrient flux for total nitrogen (0.948 mg/l), nitrate + nitrite (0.840 mg/l), total phosphorus (0.108 mg/l), and soluble phosphorus (0.060 mg/l). In summary, studies agree that anthropogenic nutrient loading from groundwater plays a role in nutrient enrichment (Payton et al. 2006; Knee et al. 2010).

Coral reefs

Wastewater pollution greatly impacts coral communities (Dollar & Grigg 2003). The most common effect is the overgrowth of reefs by algae as a result of nutrient enrichment (Smith 2003; Parsons et al. 2008). This effect has been reported for shallow, mid, and deep reefs (Lapointe et al. 2005) with wastewater rising to surface waters (AECOS Inc. 1980; Dailer et al. 2012a). Parsons et al. (2008) found a positive relationship between algae and the amount of dead coral, and that a higher percentage of corals were stressed under elevated TDN concentrations. Additional studies have linked nutrient enrichment to coral mortality (Smith et al. 2001; Parsons et al. 2008). This indicates that nutrient loading to coastal waters can negatively impact coral reef health.

A recent study examining data from 1970-2010 found that overall coral coverage decreased by 50% at various sites around Puakō, plummeting from 80% coral cover in 1975 to 32.6% coral cover in 2010 (Minton et al. 2012). Studies have also recorded overall decreases in fish abundances. In 1979 the University of Hawai‘i's Cooperative Fisheries Research Unit surveyed six transects within Puakō and during a resurvey by the Hawai‘i Division of Aquatic Resources in 2007-2008, found fish abundances to have declined by 43% - 69% across all transects.

Fecal Indicating Bacteria (FIB)

In addition to nutrients, wastewater also transports pathogens into the marine environment. Measurements of fecal indicator bacteria (FIB) are used to evaluate the risk to human health from sewage contamination in recreational waters. In most places, the FIB used in coastal waters is *Enterococcus* (EPA 2012). In Kaua‘i, Knee et al. (2008) found that *Enterococcus* may be derived from freshwater sources in nearshore coastal waters. Using an additional enterococcal surface protein gene method, Knee et al. (2008) also determined *Enterococcus* originated from human waste. This was shown by Boehm et al. (2010), who used fecal source tracking to identify human sources of microbial pollutants, finding that human population growth and densities contributed increasing microbial pollutants to coastal waters.

In tropical areas, like Hawai'i, *Enterococcus* naturally occurs in soils, and high levels of *Enterococcus* may reflect high runoff events and not sewage pollution. Therefore, the HDOH has adopted an additional FIB: *Clostridium perfringens*. Fung et al. (2007) found *C. perfringens* to be the best indicator of sewage pollution and developed a source scale to indicate when C. perfringens levels indicate contamination.

Bacteroides has also been shown to be a reliable indicator for fecal contamination in Hawai'i (Boehm 2010; Vijayavel et al. 2010). *Bacteroides* is an anaerobic bacterium found in the gut of warm-blooded animals. This type of host- specific molecular detection has allowed identification of specific fecal sources such as cesspool, swine, horse, cow, and chicken (Betancourt & Fujikoa 2006; Boehm et al. 2010). Using tracking source markers of swine (PF), ruminant I (CF128), ruminant II (CF193), human (HV), and Enterovirus (EV), in Hanalei Bay, Boehm et al. (2010) found traces of human-derived *Bacteroides* present with the potential source being wastewater management systems (cesspools and septic tanks). Alongside *Bacteroides,* male specific RNA (F+) coliphages have also shown to be useful as an indicator of fecal contamination in Hawaiian waters (Betancourt & Fujioka 2006; Vijayavel et al. 2010) and also for the identification of specific fecal sources.

In the Puakō area, in addition to high nutrient levels and declining coral cover, FIB levels are high. TNC (unpublished data) found *Enterococcus* levels in excess of HDOH standards at six of fourteen sites within Puakō and found the mean elevated levels to be highest nearshore. Kim et al. (2014) also found after a heavy rain event, seven of eight sites exceeded HDOH limits and concluded that elevated *Enterococcus* levels could be from sewage contamination.

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$\delta^{15}N$

Nitrogen sources have distinct isotopic signatures and macroalgal tissues reflect the nitrogen they consume (Savage 2005). Based on this, another method used to determine if human sewage pollution is present in coastal waters is to measure the $\delta^{15}N$ signatures in macroalgal tissue. This method has proven to be an efficient way to monitor sewage contamination in many coastal areas globally (Lapointe et al. 2005; Savage 2005; Hsing-Juh Lin et al. 2007; Dailer et al. 2012a) and has proven useful in distinguishing among various nitrogen sources (Savage 2005; Umezawa et al. 2002; Dailer et al. 2012; Mokiao-Lee 2012). For example, in Maui and Kauaʻi, studies have found treated sewage $\delta^{15}N$ values ranging from 10% per hundred – 20% per hundred which differs from fertilizers (0‰-3‰), soil nitrogen (2‰-5‰), seawater nitrogen (7‰), and atmospheric nitrogen (0‰) (Hunt 2006; Derse et al. 2007). An increase in the amount of $\delta^{15}N$ was observed near sewage affected areas, cesspools (Hsing-Juh Lin et al. 2007; Dailer et al. 2012b), and discharge points near secondary wastewater treatment facilities (Lapointe et al. 2005). Parsons et al. (2008) found a significant positive relationship between $\delta^{15}N$ quantities and the amount of dead coral. Rainfall conditions can also have a significant impact on $\delta^{15}N$ signatures, with values increasing during higher rain events (Hsing-Juh Lee et al. 2007), indicating that it may be a localized point in which rainfall and types of substrate are influencing these levels. Yet others have seen increased $\delta^{15}N$ signatures near warm freshwater seeps (dialer et al. 2012) and some have found $\delta^{15}N$ signatures did not vary between wet and dry conditions (Lapointe et al. 2005).

$\delta^{15}N$ signatures are a favorable method for monitoring anthropogenic nitrogen sources in coastal regions and have been shown to be very effective in Hawaiʻi region (Laws et al. 1999; Derse et al. 2007; Parson et al. 2008; Dailer et al. 2010; Dailer et al. 2012). South Kona specifically Kawaihae Harbor, Puakō, Waikoloa Beach Marriot, Honokohau harbor (below Kealekehe Wastewater Treatment Facility) were shown to have the highest $\delta^{15}N$ signatures along the West Hawaiʻi coastline (Dialer 2010). A positive relationship between elevated $\delta^{15}N$ signatures and dead coral abundance was also found along south Kona's coast (Parsons et al. 2008). Data from the Puakō Middle lot station, using the Fung et al. (2007) sewage pollution scale, also suggests a possible non-point source sewage problem in the area.

Summary

The coral reefs in the Puakō region of South Kohala, Hawaiʻi are some of the best remaining reefs in the Main Hawaiian Islands. They are recognized by the federal government and the State as a priority area for conservation due to their biodiversity value and alarming observed decline. As described above, nutrient pollution and wastewater in particular, is a proven threat to coral reefs. Recent and ongoing studies show nutrient pollution is a contributing factor to reef decline in Puakō. Nutrient pollution from sewage is a concern for human and coral reef health and ongoing studies have revealed that non-point source sewage pollution is a problem in the Puakō region. The source of the sewage pollution is suspected to come from household wastewater treatment, including cesspools and leaky septic tank systems. Addressing the source of this pollution will be critical to relieving this stress on the nearshore coral reefs of Puakō and for preserving the health of the coastal water quality in the region.

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