FINAL REPORT

Managing for Multiple Ecosystem Services with Changing Land Use in West Maui

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Introduction

Coastal water quality is an integral part of the Hawaiian landscape and economy, affecting both coral ecosystem health and visitor satisfaction. Hawaii's coastal water supports an abundance of marine life while drawing visitors from around the world. However, it is threatened by changing land use practices and increased land-based pollutants such as nutrients and other contaminants. In particular, the land use of West Maui Watershed is in transition from agricultural to suburban. Many hectares of former sugarcane and pineapple land are currently fallow, and previous management practices for irrigation and erosion control have been abandoned. An additional 7,000 homes scheduled to be built in the watershed within the next 15 years will further burden scarce freshwater supplies and impact the environment.

Managers in West Maui recognize the need to balance development and conservation goals. Past and future development tax scarce water resources and threaten the freshwater quality, affecting important ecological functions that in turn benefit local communities. To preserve biodiversity and water-related ecosystem services such as groundwater recharge, the West Maui Mountain Watershed Alliance preserves and manages the upper forests. To mitigate the loss of fisheries, recreation, coastal protection, and biodiversity (i.e., ecosystem goods and services from coastal systems), NOAA prioritized the coral ecosystem at the base of the Wahikuli and Honokowai Watersheds and is funding an initiative that actively seeks ridge-to-reef solutions to control land-based sources of pollution affecting the reef. The objective is to study the significant hydrological links between the reef and land-based activities—namely groundwater recharge, surface water flow, sediment loads, and nutrient loads.

Despite ongoing management actions, there is a critical need to evaluate the potential trade-offs posed by alternative resource management strategies across a broad suite of ecosystem threats, resource uses, and stakeholder groups. Because of their critical importance in this watershed, and because they are the links between land management and reef health, our initial focus is estimating land-based source pollutants (i.e., sediments and nutrients) and including these results in a decision support tool. This decision-support tool needs to be designed to reveal biophysical impacts (i.e., erosion, runoff, and infiltration) that result from specific land management actions (e.g., land use, adoption of best management practices, and restoration).

In addition, the economic data that links the hydrologic models to the economic value of the service is unavailable for many of the hydrologic ecosystem services in Hawaii, including water quality. Nearly eight million visitors stayed in Hawaii in 2012, for a combined 74 million visitor-days (HTA 2012). Out-of-state Americans spend on average $167 a day, and Japanese on average $310 a day (State of Hawaii 2011). Across the state, an astounding 302 closures occurred in 2009 (EPA 2010). If visitors decided not to visit Hawaii as a result of frequent coastal water contamination events, the economic impact would be negative for the state economy where tourism comprised 29% ($15 billion) of the economic output in 2012 (State of Hawaii 2011). A 2011 study found that more than 80% of American visitors participate in beach-related recreational activities, more than 25% surf, over 50% snorkel and dive, and 5% jet-ski and/or windsurf (HTA 2011), yet did not indicate the effect of water quality on participation in these activities.

Problem and Research Objectives

In order to predict the effect of land use change on water quality, and to estimate the impact that water quality has on the tourism economy, we conducted two field studies to support efforts to quantify and map water quality-related ecosystem services in West Maui.

Common hydrological models used to predict sediment export and water quality at the coast are difficult to adapt because of Hawaii's small watersheds and resulting flashy streams. This potentially adds large uncertainty to the ecosystem service tools in consideration. It remains unclear which erosion process (sheet erosion, channel erosion or gully erosion) contributes the most to the overall sediment budget. Previous work (Hill 1996, Stock et al. 2010) estimated contributions from different sediment processes in Hanalei, Kauai and Kawela, Molokai using comprehensive field studies and modeling efforts. West Maui, however, is data poor, and lacks rain gauges, flow measurements, and total suspended solids data to calibrate and validate daily, event-driven models like the Soil and Water Assessment Tool (SWAT) and the Gridded Surface Subsurface Hydrologic Analysis (GSSHA). There have been no field studies that assess the geomorphological characteristics of the five priority watersheds. The objective of this research was to conduct initial rapid geomorphological surveys, and to estimate contributions from channel erosion. A simple model based on the Universal Soil Loss Equation (USLE) and Borselli's sediment delivery ratio model (InVEST) was chosen to model sediment export. The field surveys will be used to spatially calibrate the output of the model.

Estimates that capture the lost economic value of water quality problems can inform management and help draw attention to the broader implications of land-based source pollution. Various valuation methods could be used to explore the economic losses (or gains) from the environmental attributes of the nearshore system. In environmental economics, non-market valuation is used to estimate values for environmental goods and services that are not readily apparent in the market. Stated or revealed preference models are commonly applied to elicit willingness to pay. This project identifies candidate valuation approaches and demonstrates the methodology in a pilot study on Oahu.

Methodology

Improving Sediment and Nutrient Models with Field Validation

During the summer of 2014, we traveled to West Maui with U.S. Geological Survey (USGS) geomorphologist Johnathan Stock and Sustainable Resources Group International, Inc. (SRGII) hydrologist Andrew Hood. The purpose of the field visit was to identify sources of sediment and to better understand the hydrologic connectivity between sediment sources and the intermittent stream system. About four miles of the two stream systems (Wahikuli and Honokowai Streams) were surveyed, in addition to neighboring fields, urban drainage systems, reservoirs, and outfalls. We identified features on the landscape to correspond to the remote imagery and sediment export modeling efforts.

In August 2014, four sites in the Wahikuli Stream were chosen to install erosion pins to measure the erosion rates of the stream channel walls. At each site, ten 8-cm pins were gently hammered into the sidewall. The sites were chosen to represent reaches of the stream where the bank was exposed. The sites were evaluated for changes in early April 2015 using calipers. An additional field survey will be conducted to estimate what percentage of the reaches are exposed bank.

Figure 1. Installation of erosion pins at Site 3 on Wahikuli Stream, Maui.

Sediment Export Modeling Efforts

We collaborated with Natural Capital Project programmers and scientists to beta test new sediment delivery algorithms for the InVEST sediment delivery model. In the summer of 2014 we set out to determine the appropriate models for other types of erosion processes not included in InVEST's sediment retention module, and to compare what method might be most appropriate for Hawaii to model sediment transport processes. We collected data from collaborators and public datasets (USGS, Natural Resources Conservation Service [NRCS]) to evaluate previous studies in Hawaii that can estimate the importance of those processes. We conducted an extensive literature review of sediment retention, Soil Conservation Service (SCS) Curve Numbers, C-factor, and K-factor variables in Hawaii and other tropical mountainous locations, and incorporated those new parameterizations in the sediment delivery model.

In order to run the InVEST model, significant effort was made to improve input data to capture important processes that affect sediment and nutrients. The input data for the InVEST model included soil data from the Soil Survey Geographic Database (SSURGO), and the Costal Change Analysis Program (C-CAP) high resolution (2.4 m) 2005 land use data. We improved the input data for the InVEST model, rainfall factor information from the U.S. Department of Agriculture (USDA), and a digital elevation model (10 m) from the USGS. We compared sub-watershed designations to estimate an appropriate stream accumulation area. We added new land use classes to separate sugarcane, pineapple, grazing, and fallow agriculture based on the expert opinion of W. Nohara (Maui Land and Pineapple; personal communication, 2014). We also modified the land use designation in C-CAP for golf courses derived from LandFire.

We compared the static InVEST model to daily time-step models that are also based on the USLE input data, including SWAT, Nonpoint-Source Pollution and Erosion Comparison Tool (N-SPECT), and GSSHA. The input data was the same for each model, and calibrated first using Kawela, Molokai data available from the USGS. The model was run for the Honokowai Watershed. We collected rainfall data from a diverse array of partners, including community members, private landowners, and USGS monitoring sites.

Valuation Study

First, we evaluated alternative possible valuation methods via a thorough literature review. We considered choice modeling, contingent valuation, and travel cost method—all stated choice methods that are commonly used to value (coastal) water quality and recreation elsewhere (Arrow et al. 1993, Moncur 1975, Ofiara and Brown 1999, Krosnick et al. 1996). Choice modeling was determined to be the most suitable method. It allows several environmental attributes to be valued at the same time using believable scenarios realistic to the participants (Bishop et al. 2011, Loomis and Santiago 2013). This study closely follows Loomis and Santiago (2013), who conducted both choice modeling and contingent valuation to estimate the non-market value of beaches in Puerto Rico.

Next, having chosen the appropriate method, we identified the beneficiary group (coastal recreationalists) whose consumer surplus or loss (economic jargon for benefit or cost) we wanted to estimate. We designed a choice experiment. The experiment reflects environmental attributes of concern to recreationalists and associated levels, which we set via literature and discussions with experts. Specifically, the attributes considered were (1) water quality, (2) water clarity, (3) coral reef cover, and (4) fish diversity set at levels: high, medium, and low (quantitative metrics for these qualitative levels were specified, based on ecological and water quality experts' advice). We also included numerous additional questions to capture respondent demographics, beach/coastal uses, as well as attitudes and perceptions. We received approval from the International Review Board (IRB). In fielding the survey, we used lifeguard statistics (EPA 2007, 2010, 2011, 2012a, 2012b, 2013a, 2013b; HTA 2011, 2012) to estimate beach attendance and divided surveys proportionately across Oahu beaches. A total of 263 successful in-person interviews were conducted between June and November 2014. The majority of the interviews were conducted in Waikiki (47% of the total), followed by the remaining south shore beaches (23%), Oahu's north shore (13%), Waianae coast (11%), and Windward Oahu (6%). The refusal rate was 11%.

The results were analyzed by logistical regression using the statistical package STATA.

Principal Findings and Significance

Field Observations and Interpretations in West Maui

The former sugarcane fields in West Maui did not show evidence of being connected to the stream. A well-developed grass and haole koa stream buffer would likely prevent any connectivity during a rain event. Shallow landslides in Honolua watersheds may have been contributors to overall sediment export to Honolua Bay. Gullying along the makai ridges, past former agricultural land, may have been initiated due to excessive trail erosion or when the road was created many years ago. Field 52 did not show evidence of connectivity to Honolua stream, but legacy deposits from push piles may still exist on the hillslope.

Bank erosion was visible and common throughout the stream bed. Roughly, more than 25% of the banks had areas that exposed silt to stream water. Marks on the trees, leaf litter deposition, and the red coatings on the rocks shows where the water level has reached in the last decades. The water level seems to rise approximately 2 to 3 feet (at its highest). Grass root exposure and emergent seedlings visible in April indicate that the events might take place on a sub-year time scale in the Wahikuli Stream.

Pig activity was clearly evident in many of the upper watersheds in forested areas (i.e., Napili, Honokowai, and Wahikuli Gulch). Pigs specifically were observed rutting in dry stream beds, which often were under large fruit-bearing trees, suggesting that pigs are able to remove the natural armoring of the stream and expose the sediments below. Feral pigs are likely to dig rather deep as they eat roots and fruits from the wild lilikoi, mango, coffee, and avocado trees. The red marks on the rocks, especially surrounding the pools, may indicate that pigs are responsible for significant disturbance that accelerates how fast the stream is cutting into the soil layer.

There were very few, if at all, places where the bedrock was visible in this stream. We observed that the trails and roads directly connect to the stream. Usually the connection to the stream was limited to intersecting trails; however, in some watersheds to the north on the former pineapple land, the roads were so close to the stream that the kickouts drain directly into the stream. The roads that were adjacent to the streams have water bars that may contribute to the sediment loads. In contrast, the roads that were disconnected and/or run parallel further away from the streams are relatively distant sources.

We viewed examples of two different types of streams that accessed fine sediments. At one end of the spectrum, the main branch of the Honokowai Stream and Wahikuli Stream showed evidence of bank erosion into silty deposits, but was dominated by larger boulders and cobbles that likely originated from rockfall in the upstream reaches. Exposed bedrock was common and evidence of a stage height of more than a meter was seen. The second type of stream was observed in the lower reaches of the southern branch of the Honokowai and Mahinahina Streams. The low gradient stream cut through the fine sediment deposited throughout the valley floor. Multiple pathways for stream flow were seen. These deposits were located just before the reservoirs.

The above facts suggest that the West Maui Watershed is not source limited for sediments, but instead transport limited. In this case, sediment transport is the limiting factor for sediment export.

Using a field infiltrometer, we were able to assess the hydraulic conductivity data found in the SSURGO database. Six points were measured in the Wahikuli watershed on former corn fields. Estimates of the hydraulic conductivity on these fallow agriculture fields were approximately 10 to 30 mm/hr, similar to the value of the 30 found for these fields in SSURGO. An analysis of rainfall events recorded in the seaward, lower parts of the Wahikuli watershed, indicate that storm events that mobilize surface runoff for these fields are few (one per decade), which indicates the fields are not consistent new sources of deposits into the channels.

Initial bank erosion estimates between August and April 2015 showed an average of 5 mm lateral wall erosion during this period. Subsequent readings will help determine an annual rate of erosion of the bank walls, and future studies will be able to more accurately assess the percentage of the reaches that are exposed.

The implications for modelling are (1) channel erosion models that are developed using flow estimates are needed for accurate assessments of total sediment load to the coast, and (2) parameterizing the forest as having a higher export than traditionally estimated for non-disturbed forests in non-tropical conditions is appropriate given the presence of pigs and trails. Pig activity, in particular, can severely change the erodibility of a soil profile. This follows the work of Cheng (2007) in Hanalei.

Sediment Export Modeling

Figure 2 shows the output of the model calibrated with the new parameterizations, including increased sediment export due to forest and grassland disturbance. Sediment export at the coast ranged from 27 to 4,470 tons. Notably, the Kaopala watershed export was significantly higher than the surrounding subwatersheds. This result was identified by field observations in the USGS Open-File Report (Stock 2015).

Initial results suggest that InVEST and N-SPECT have comparable results, but that GSSHA, which estimates sediment delivery per rain event, predict values that are several orders of magnitude greater than the previous two models.

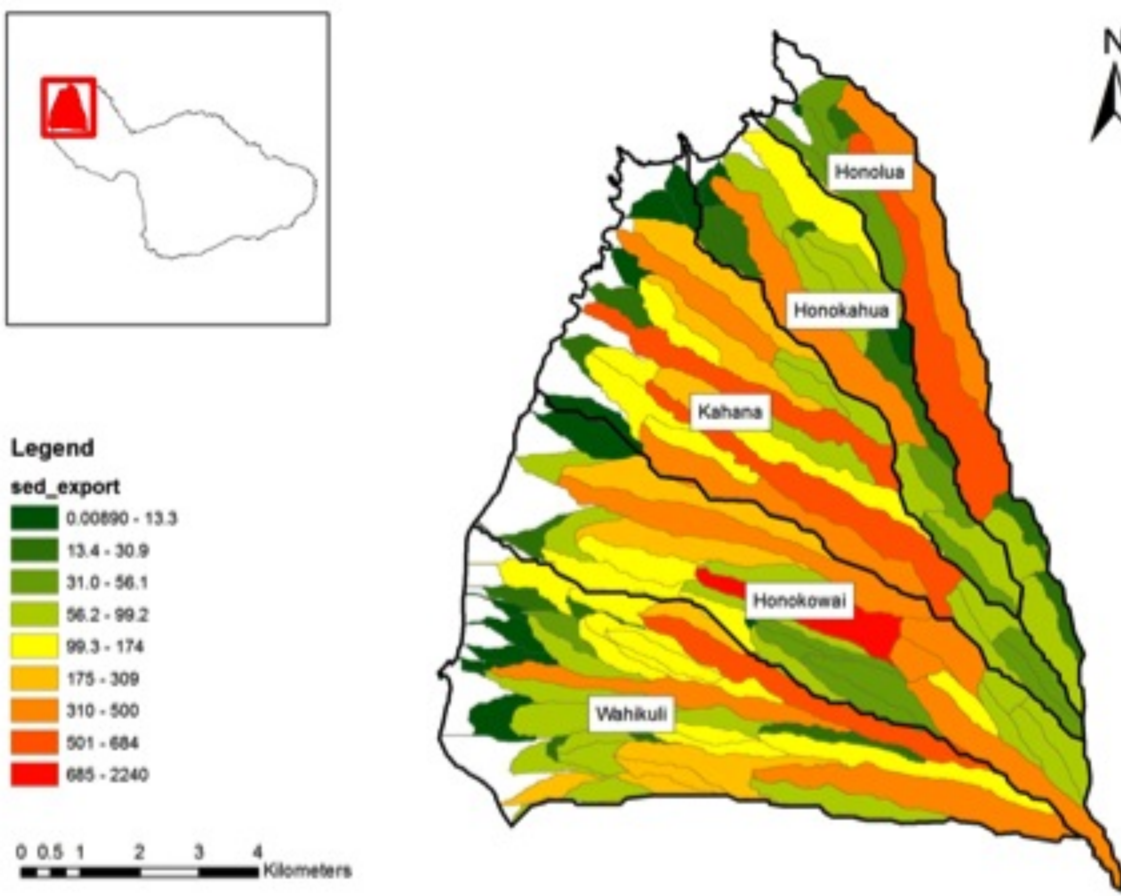

Figure 2. InVEST Sediment Delivery Model results in tons per year for West Maui.

Valuation Field Study

The results of the multi-nominal logit (MNL) regression revealed recreationalist are willing to pay for improved environmental conditions across all attributes in the study (Figure 3). We found that water clarity was the most important factor, followed by water quality. In particular, respondents were especially interested in the "high" levels of water clarity and quality. The diverse responses demonstrated a significant preference for water clarity and high levels of coral reef cover. In a latent class analysis, the respondent population was largely uniform, with greater than 75% belonging to the same class.

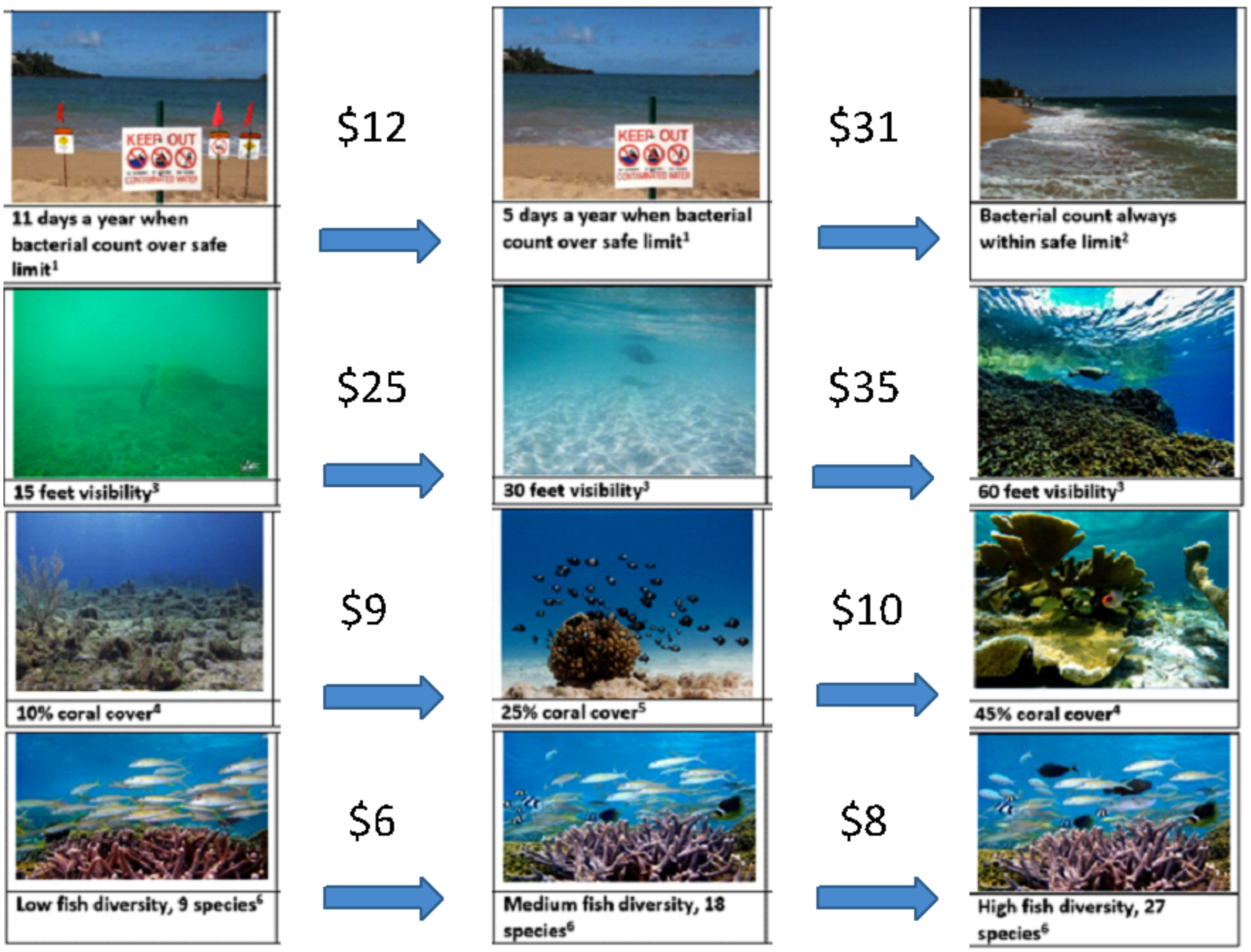

Figure 3. Willingness to pay for varying qualities of environmental conditions of the Oahu coastline (on a per person per trip basis).

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