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A watershed decision support tool for managing invasive species on Hawai‘i Island, USA

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ABSTRACT

Non-native species invasions, growing human populations, and climate change are central ecological concerns in tropical island communities. The combination of these threats have led to losses of native biota, altered hydrological and ecosystem processes, and reduced ecosystem services. These threats pose complex problems to often underfunded management entities. We developed a watershed decision support tool (WDST) for the windward coast of Hawai‘i Island aimed at prioritizing catchments for invasive species removal and native forest protection from non-native species invasions. Using the Ecosystem Management Decision Support (EMDS) system, we integrated spatial data from four sources: (*i*) native and invasive species coverage; (*ii*) modeled water yield; (*iii*) treatment cost and efficacy; and (*iv*) native species conservation value. We used a distributed hydrology model (DHSVM) to estimate catchment-level (~90 ha) water yield under six climate and non-native species invasion scenarios to identify where (1) invasive species removal and (2) protection from invasion would have the greatest benefit to increasing or maintaining native biodiversity and hydrologic functioning. The hydrology model predicted a 30% decline (386 Gl yr^{-1}) in total water yield under a drier future climate (20% reduction in rainfall), with an additional 2% reduction when catchments were fully invaded by non-native species. Increased temperatures had a small compensatory effect on water yield. The WDST identified 6.3% of the study area as high priority for invasive species removal, based on characteristics of large hydrological response to the removal treatment (concentrated in high rainfall areas), high quality road or trail access, and high conservation value. High protection priority from invasive species (5.9% by area) occurred in higher elevation catchments, near the upper range of strawberry guava (the main invasive species), where water yield was most sensitive to invasion. Climate change scenarios had little influence on the spatial distribution of priority scores despite large changes in overall water yield. In contrast, priority scores were sensitive to very high variation in treatment costs, which were influenced largely by travel times to catchments via road and trail networks. This last finding suggests that future management feasibility will hinge on improvements to road and trail networks, or development of alternative management strategies that reduce travel costs and time.

1. Introduction

Ecological service-based decision support systems have been developed to facilitate ecosystem management across a wide variety of natural resource applications (e.g., Rauscher, 1999; Reynolds and Hessburg, 2005; Daily et al., 2009; Staus et al., 2010; Reynolds et al., 2012, 2014; Bremer et al., 2015). Such tools permit fully integrated analysis of multiple spatial datasets, and facilitate analytical processes that enhance one or more socio-ecological benefits, while simultaneously incorporating logistical and operational considerations (Reynolds et al., 2014). Decision support tools can provide: (1) a formalized process for engaging, negotiating, and mediating multi-objective decision-making; (2) a quantitative framework for selecting among management alternatives in a

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spatial planning environment; and (3) an integrated strategy for justifying implementing specific management decisions (Reynolds et al., 2014).

While common in temperate regions, few documented applications of landscape-level decision support systems exist in tropical ecosystems (Westmacott, 2001; Bremer et al., 2015). However, the value of decision support in the tropics may be high because these tools assist managers in allocating limited resources to maximize treatment benefits. The advantages of such tools will increase in value as global changes progress and population-driven demands on watersheds increase.

A convergence of anthropogenic, climatic, and ecological stressors has created much uncertainty for tropical island forests. Particularly, their ability to sustain adequate freshwater to support local human populations, an expanding agricultural footprint, and other essential services (e.g., biodiversity protection, flood abatement, erosion control, carbon sequestration, recreation and tourism opportunities) into the future is unclear (Burns, 2002; Thaman, 2002; Parry, 2007; Duffy, 2011; White and Falkland, 2012). Successful mitigation of these impacts requires a strategic landscape-level approach in which managers and stakeholders effectively communicate and collaborate across ownerships, develop a shared understanding of cultural values and needs, and concentrate efforts to maximize management benefits. While access to decision support technology is currently limited, such approaches to managing landscapes are particularly relevant, and perhaps critical to watershed-based collaborations that seek to: (*i*) characterize land management needs; (*ii*) increase local resilience to climate and land use/land cover change; and (*iii*) efficiently use limited state and federal funding for management (White and Falkland, 2012). In the context of tropical landscapes, effective decision making must also emphasize cost-effectiveness, be relatively insensitive to limited data, and incorporate the diverse needs of complex ownerships that may include only a small proportion of shared public lands.

We piloted our tropical decision support tool effort in watersheds of windward Hawai‘i Island. The objectives of the tool were to: *(i)* provide local land management cooperatives with a quantitative method to identify key areas for invasive species management; and *(ii)* demonstrate an application of state-of-the science ecological processing modeling within a decision support framework for a tropical island ecosystem. Together, our goal was to highlight how decision support applications can be tailored to specific management concerns and locally relevant ecosystem services.

We conducted our work across a highly constrained, hydrologic study system that encompasses a steep ridge-to-reef elevational gradient and varies widely in mean annual rainfall, temperature, and ownership patterns (Strauch et al., 2014, 2016a, 2016b, 2016c). This study area has undergone both significant agricultural land-use changes at low elevations as well as invasion by non-native plants in mid-elevation forests (~600–1200 m), with anticipated impacts to watershed hydrology. Hawai‘i’s climate and impacts to forests are also anticipated to change in the coming decades (Giardina, 2012; Timm et al., 2015). In Hawai‘i, mid-elevation forests have already experienced a 0.163 °C decade^{-1} increase in surface temperature from 1975 to 2006, exceeding the global average (Giambelluca et al., 2008). Observed reductions in wet-season precipitation (October – March) and increased surface temperature have led to downward trends in stream base flow levels (Oki and County, 2004). Furthermore, climate projections point to continued warming, and for leeward areas of Hawai‘i, a pattern of reduced rainfall, and altered precipitation distribution (Timm and Diaz, 2009; Timm et al., 2015). Yet, demand on water supply will likely increase as human population growth increases the number of water-users in the region. These factors, along with limited and aging water production systems, increased levels of freshwater contamination by saltwater, and high natural variability in the water supply due to ENSO events (Chu and Chen, 2005) leave many island nations facing a critical need for improved freshwater security.

As with much of the tropics, forests across Hawai‘i have undergone significant change due to the combined influences of urban encroachment, intensive agriculture and forestry practices (Cuddihy and Stone, 1990), invasion by non-native plants and animals (Smith, 1985; Giardina, 2012), and climate change (Keener et al., 2012). Since European settlement in the mid-19th century, native forest area declined by nearly half (DLNR, 2011), and the introduction of non-native ungulates (e.g., feral pigs *Sus scrofa*), and invasive plant species (e.g., *Psidium cattleianum* or strawberry guava – the focus of the current study), have altered the structure, functioning, and connectivity of remnant forested patches (Nogueira-Filho et al., 2009; Strauch et al., 2016a, 2016b) . Forested watersheds in Hawai‘i are particularly vulnerable to non-native species invasions due to the influence of the islands’ remoteness of native flora and fauna, volcanic geology, complex topography, and steep climatic gradients (Loope and Mueller-Dombois, 1989; Loope, 1992; Gagne and Cuddihy, 1999; Leigh et al., 2007). Non-native invasive plants typically exhibit higher evapotranspiration rates compared to the native species they replace (Funk and Vitousek, 2007; Cavaleri and Sack, 2010), as well as lower canopy water storage capacity and cloud water capture (Takahashi et al., 2011), which leads to reduced freshwater retention in invaded ecosystems. For example, Giambelluca et al. (2009) found 27–53% higher evapotranspiration rates in a strawberry guava infested stand compared to a stand dominated by native ‘ōhi‘a (*Metrosideros polymorpha*) forest, with larger differences occurring during especially warm and dry periods (Giambelluca, 2009). As such, major foci of restoration activities in Hawai‘i are the maintenance of native species assemblages, and the reduction in extent and level of invasion by non-native species (Conry and Cannarella, 2010).

In the current assessment, we first used a distributed hydrology model to quantify catchment-level water yield under various non-native species invasion and climate change scenarios, using standard modeling methods (Wigmosta et al., 1994). We then used the Ecosystem Management Decision Support (EMDS) software to build a watershed decision support tool (WDST) that prioritized treatments across the North Hilo-Hamakua districts of Hawai‘i Island (Fig. 1). We chose this area because it: *(i)* includes a highly constrained gradient in mean annual rainfall (MAR), spanning 2000–6000 mm, where the elevational distribution of overstory species, soils, land use and non-native species invasion patterns is relatively constant across MAR; *(ii)* encompasses diverse ownerships aligned in the goal of managing for fresh water and controlling invasive species; *(iii)* is managed by a watershed management partnership (Mauna Kea Watershed Alliance) through which the WDST could be developed and implemented; and *(iv)* was identified by the *Rain Follows the Forest Initiative*, now the *Healthy Forests Initiative* (HFI), as a Priority I management area due to high rainfall, native wet forest extent, and concern about non-native species invasions (DLNR, 2011).

We used the following workflow to develop the WDST (Fig. 2):

Stakeholder input and data gathering: We collected stakeholder input on potential decision criteria to be used in the Decision Model, and gathered representative GIS layers. The intended users of the WDST were the diverse collection of land ownership partners in the area including federal, state, county, and private entities. Management priorities for each partner varied widely, which necessitated a flexible decision tool to incorporate the level of complexity in the overlapping and independent goals of the local land managers. The data for our WDST included information on