Benefit-cost analysis of watershed conservation on Hawai'i Island

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ARTICLE INFO

Article history:
Received 16 October 2015
Received in revised form 13 September 2016
Accepted 15 September 2016
Available online xxx

Keywords:
Freshwater
Watershed conservation
Evapotranspiration
Non-native species
Benefit-cost analysis

ABSTRACT

In landscapes around the world, growing attention is being paid to the link between forest structure and water resources. More clarity is vital for informed decision making, especially as water scarcity continues to increase in many regions across the globe. The objective of this study is to estimate the volume of freshwater yield saved per dollar invested in forest restoration at several sites on Hawaii Island. Using budget information and publicly available land cover and evapotranspiration data, we find that under baseline conditions—a 3% discount rate and 10% rate of spread for existing non-native plant species—1487 l are saved on average across management sites per dollar invested. In other words, $0.67 in present value terms is required to protect every 1000 l of freshwater over a 50-year time horizon. Annual benefits increase continuously as the avoided loss of freshwater yield rises over time, while conservation costs tend to be front-loaded, as a result of high fence installation and ungulate removal costs. Thus, it is important to consider the long run when comparing the benefits and costs of conservation activities.

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1. Introduction

Worldwide, growing attention is being paid to the link between forest composition and freshwater resources. Understanding this relationship is key for informed decision making (Le Maitre et al., 2015; Richardson et al., 2000; Pyšek and Richardson, 2008), especially as water scarcity continues to increase in many regions across the globe. Existing studies (Cavaleri and Sack, 2010) have shown evidence of greater water use by native versus non-native plant species, but demonstrating that these site-specific results scale up to the watershed level remains a challenge. Linking larger scale land use to hydrology requires complex spatial models, as well as spatially-extensive data inputs required to run those models.

Hawaii is an ideal location to study the connection between forest structure and water resources for a variety of reasons. Intact native forests with significant potential for capturing freshwater are increasingly being converted to non-native-dominant forests with noticeably diminished ability to retain freshwater resources. The ability to retain freshwater is particularly important in Hawaii because nearly all of the domestic water consumption in the state is supplied by groundwater aquifers. Moreover, linking the impact of watershed conservation to investment costs to inform decision making is greatly assisted by the fact that Hawaii has a rich network of conservation agencies collecting detailed management information on restoration activities and their associated costs.

Several site-scale studies in Hawaii have examined differences between native and non-native plant species in terms of various water balance components (Table 1). We can generally conclude that when compared to native plant species, non-native plant species in Hawaii tend to have higher evapotranspiration (ET) rates, generate larger throughfall rain drops, have higher sap flux density, reduce the velocity of water to depths of 1-meter, have lower canopy storage capacity and cloud water interception capability, and generate lower net precipitation. In aggregate, these studies suggest that native plants tend to use less water than their non-native counterparts, thus allowing more freshwater to recharge underlying aquifers. However, some of the observed differences may have more to do with the characteristics of the vegetation rather than whether the plant is native or non-native (Le Maitre et al., 2015). It is also important to note that most of the reviewed studies focused on Metrosideros polymorpha, which, while an important species in Hawaiian forests, is not the only type of native plant species in the region.

The logical next step is to transition from site-scale to watershed-scale studies, which as previously mentioned, requires spatial modeling and data. In 2011, the U.S. Geological Survey developed a water budget model for the island of Hawaii (Engott, 2011). Results from the model showed an increase in recharge of approximately 10% for several hydrological units when moving from the current land cover (mixed native and non-native forest) to a hypothetical scenario wherein all non-native forest was replaced by native forest. This would be a natural starting point, but their approach is not replicable due to data sharing.
restrictions. Moreover, spatially-extensive ET datasets, which did not exist at the time of the USGS publication, are now publicly accessible (Giambelluca et al., 2014). In our study, we use spatial ET data to get a clearer picture of how water use varies by forest type at the watershed scale.

More specifically, we obtain average values for ET by forest type (native or non-native), which allows for watershed-scale predictions of changes in ET—changes that are expected to occur if watershed conservation activities are reduced. Although we are ultimately interested in implications for groundwater recharge, we cannot estimate that component directly. Instead, we view reductions in ET as a net benefit for freshwater yield, where water yield is simply the difference between precipitation and ET. Ultimately, our objective is to use publicly available spatial land cover and actual evapotranspiration

Table 1
List of studies reviewed.

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Year</th>
<th>Location</th>
<th>Species</th>
<th>What was measured</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cavaleri et al.,</td>
<td>2014</td>
<td>Hilo</td>
<td>Metrosideros polymorpha, Cecropia obtusifolia, Macaranga mappa, and Melastoma septemnervium</td>
<td>Sap-flow rate, transpiration</td>
<td>M. polymorpha had the lowest sap-flow rate per unit sapwood but the highest rate per tree; a 54% decrease in plot-level transpiration (400 mm/yr) was observed in plots where non-native trees were removed.</td>
</tr>
<tr>
<td>Giambelluca et al.,</td>
<td>2008</td>
<td>Hawai’i Island</td>
<td>Psidium cattleianum, Metrosideros polymorpha</td>
<td>Evapotranspiration</td>
<td>A site heavily invaded by P. cattleianum had 27% higher ET than a site within a M. polymorpha forest, with the difference rising to 53% during dry-canopy periods.</td>
</tr>
<tr>
<td>Giambelluca et al.,</td>
<td>2009</td>
<td>Hilo</td>
<td>Miconia calvescens, Metrosideros polymorpha</td>
<td>Throughfall rain drops</td>
<td>Throughfall raindrops under M. calvescens had a median diameter of 3.8 mm and a max of 7 mm vs. 1-3.5 mm out in the open. Drop diameter in a spray experiment was 5.33 mm for M. calvescens versus 3.66 mm for M. polymorpha.</td>
</tr>
<tr>
<td>Kagawa et al.,</td>
<td>2009</td>
<td>Honaunau Forest Reserve</td>
<td>Metroxideros polymorpha, Eucalyptus saligna, Fraxinus uhdei</td>
<td>Sap flux density, water use</td>
<td></td>
</tr>
<tr>
<td>Perkins et al.,</td>
<td>2014</td>
<td>Auwahi</td>
<td>Nestegis sandwicensis, Dodonaea viscosa, Pennisetum clandestinum</td>
<td>Water velocity</td>
<td></td>
</tr>
<tr>
<td>Takahashi et al.,</td>
<td>2011</td>
<td>Hawai’i Volcanoes National Park</td>
<td>Psidium cattleianum, Metroxideros polymorpha</td>
<td>Canopy water storage capacity, cloud water interception, net rainfall (throughfall + stemflow)</td>
<td>Canopy water storage capacity was 1.86 mm at the native site and 0.85 mm at the invaded site; Annual CWI was 1188 mm at the native site compared to 734 mm at the invaded site; net rainfall was 123% of rainfall at the native site versus 110% at the invaded site.</td>
</tr>
</tbody>
</table>

Fig. 1. Locations of conservation sites.
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