Integrating ecosystem-service tradeoffs into land-use decisions

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Recent high-profile efforts have called for integrating ecosystem-service values into important societal decisions, but there are few demonstrations of this approach in practice. We quantified ecosystem-service values to help the largest private landowner in Hawaii, Kamehameha Schools, design a land-use development plan that balances multiple private and public values on its North Shore land holdings (Island of O'ahu) of ∼10,600 ha. We used the InVEST software tool to evaluate the environmental and financial implications of seven planning scenarios encompassing contrasting land-use combinations including biofuel feedstocks, food crops, forestry, livestock, and residential development. All scenarios had positive financial return relative to the status quo of negative return. However, tradeoffs existed between carbon storage and water quality as well as between environmental improvement and financial return. Based on this analysis and community input, Kamehameha Schools is implementing a plan to support diversified agriculture and forestry. This plan generates a positive financial return ($10.9 million) and improved carbon storage (0.5% increase relative to status quo) with negative relative effects on water quality (15.4% increase in potential nitrogen export relative to status quo). The effects on water quality could be mitigated partially (reduced to a 4.9% increase in potential nitrogen export) by establishing vegetation buffers on agricultural fields. This plan contributes to policy goals for climate change mitigation, food security, and diversifying rural economic opportunities. More broadly, our approach illustrates how information can help guide local land-use decisions that involve tradeoffs between private and public interests.

conservation | mapping | private lands

Recent high-profile studies (1–4) have emphasized the importance of ecosystems in providing valuable services to humanity, and recent events have provided strong evidence of the value of flood-risk mitigation (5, 6), coastal protection (7, 8), and pollination (9). Global changes in land use and climate also have highlighted the role of ecosystems in food, water, and energy security and in climate change mitigation and adaption (10–13). New policy and finance mechanisms are being deployed worldwide to protect the natural capital embodied in Earth's lands, waters, and biodiversity (14). China, for instance, has pursued multiple national policies on payments for ecosystem services aiming to harmonize human development goals with watershed protection, carbon sequestration, biodiversity conservation, and other environmental objectives, with planned investment on the order of $100 billion (15).

However, current efforts to protect natural capital that provides valuable ecosystem services are in their infancy. The urgent challenge is to move from ideas to action to change societal decision making (16, 17). A necessary step forward to mainstream ecosystem services is the ability to factor multiple ecosystem services into local and regional land-use planning (18, 19). We conducted an ecosystem-services analysis of land-use planning in Hawaii that informed actual decisions by the state's largest private landowner, the educational trust Kamehameha Schools (owning ∼147,710 ha or ∼8% of the total land base). Hawaii is a microcosm of the forces at play globally that are intensifying pressure on land for competing uses. In response, recent policy initiatives in Hawaii have focused attention on ecosystem services, mitigation of and adaptation to climate change, and food and energy security (e.g., House Concurrent Resolution 200 House Draft 1, Regular Session of 2006; House Bill 226, Regular Session of 2007; Hawaii Clean Energy Initiative).

Our analysis quantified ecosystem service and economic implications of alternative futures for Kamehameha Schools' land holdings on the North Shore of O`ahu (Fig. 1). From 2006 to 2008, Kamehameha Schools undertook an extensive land-use planning process with the local community. During that process, we used a spatially explicit modeling tool, Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) (20, 21) to address a pair of linked planning questions: (*i*) What is the best use of the largely abandoned agricultural lands to meet the needs of the local community and those of the broader public (related particularly to policy initiatives for climate, food, and energy security) while also generating positive financial return for Kamehameha Schools? (*ii*) Do alternative land uses result in win-win outcomes or tradeoffs for ecosystem services and financial return relative to a business-as-usual scenario? These questions are relevant far beyond Hawaii to the many regions globally that are undergoing extensive land-use change precipitated by shifting economic and political forces (22).

Kamehameha Schools' lands in the North Shore region (∼10,600 ha) have an historical legacy of use for agriculture, aquaculture, and human habitation. Until recently, about 2,200 ha of arable land had been in continuous sugarcane production for more than 100 y. This situation ended in 1996 when the Waialua Sugar Company surrendered its lease and ceased production. Since then, agricultural production has been restored on only one-third of the former plantation lands. The remainder is no longer in use and is largely being overtaken by invasive plants (e.g., *Megathyrsus maximus*, *Falcataria moluccana*, and *Leucaena leucocephala*).

Beginning in 2000, Kamehameha Schools adopted a new strategic planning framework that seeks to balance economic, environmental, educational, cultural, and community returns rather than focusing strictly on economic return (23). As a strategic test of its new planning approach, Kamehameha Schools faced a critical decision about what to do with its lands in the North Shore

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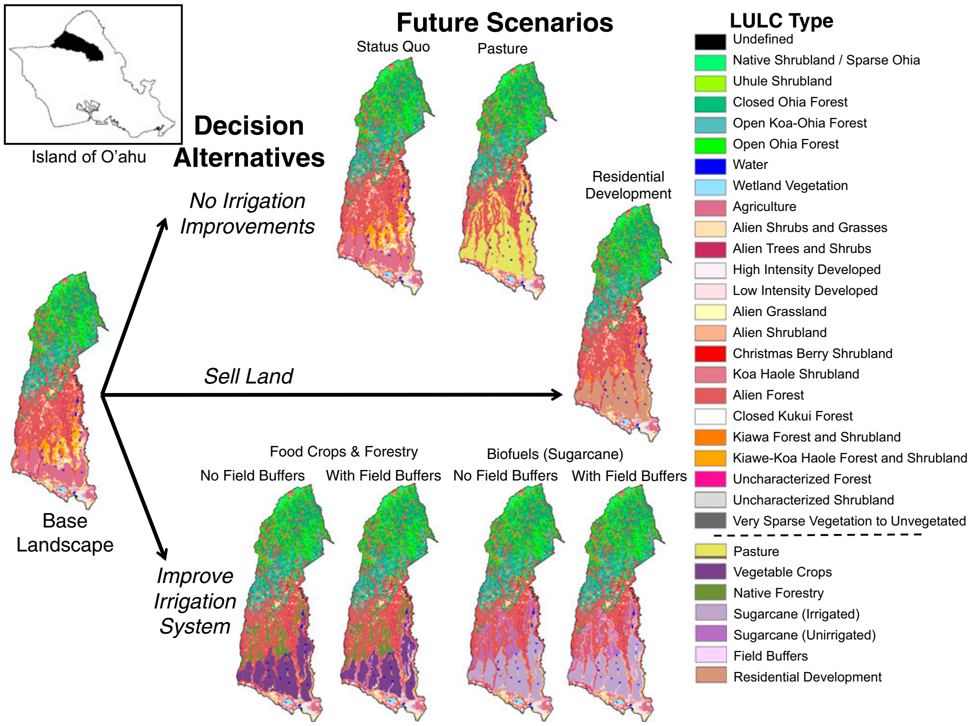

Fig. 1. Study region on the North Shore of O`ahu, Hawaii. The area depicted includes all of Kamehameha Schools' land holdings as well as small interior parcels that make for a continuous region. The base map shows LULC from the Hawaii Gap Analysis Program published in 2006. Seven land-use planning scenarios are shown in the context of the three decision alternatives considered in the analysis. LULC types above the dashed line were from the Hawaii Gap Analysis Program classification, and LULC types below the dashed line were created for planning scenarios.

region. Specifically, Kamehameha Schools needed to decide whether to invest an estimated $7.0 million to improve the region's aging irrigation system to sustain and enhance agricultural production or to pursue other options instead. In this context, Kamehameha Schools had three overarching decision alternatives for which we developed a total of seven land-use planning scenarios (Fig. 1, Figs. S1 and S2, and Table S1). Choices that involved no improvements to the irrigation system were scenario 1, Status Quo (maintaining current land uses into the future) and scenario 2, Pasture (converting all fields to cattle-grazing pasture). Choices that involved improvements to the irrigation system were scenarios 3, Food Crops and Forestry (using the lower irrigated fields for diversified food crops with forestry plantings on the upper fields); 4, Biofuels (returning the agricultural lands to sugarcane to produce an energy feedstock); 5, Food Crops and Forestry with Field Buffers; and 6, Biofuels with Field Buffers; in scenarios 5 and 6, vegetation buffers would be added on fields adjacent to streams in scenarios 3 and 4 to reduce nutrient and sediment runoff. The third choice was to sell land; in scenario 7, Residential Development, the agricultural lands would be sold for a housing development. Although neither Kamehameha Schools nor the community was disposed to pursue this last option, it represents a development pattern that has occurred repeatedly on former agricultural lands across the state.

We evaluated each scenario based upon three metrics with contrasting primary beneficiary groups spanning multiple scales: (*i*) carbon storage (a global benefit related to climate change mitigation), calculated as the carbon fraction in above- and belowground biomass (Table S2); (*ii*) water-quality improvement (affecting communities living in the study region), focused on the relative export of total dissolved nitrogen as our proxy for pollution, given the proximity of the agricultural lands to the ocean and nitrogen generally being considered a limiting nutrient in marine systems (Table S3) (24, 25); and (*iii*) financial return (to support mission-related activities for the private landowner, Kamehameha Schools), calculated using projected real property taxes, agricultural land rental rates, and real estate prices for bulk sale of irrigated and nonirrigated agricultural lands. Net present value calculations used a 6% real discount rate (a financial value used to convert future values into present values), with sensitivity analysis from 3 to 12% (Table S4). We present results showing net ecosystem service and financial changes over a 50-y time horizon.

Results and Discussion

We quantified our three metrics for the current landscape to provide a reference point from which to measure future scenario changes (Fig. 2). The greatest carbon stocks currently are found in the upper-elevation forested region with substantially lower stocks in the agricultural and developed regions. Agricultural fields are the predominant source of nitrogen, with developed areas below the fields also of concern. Financially, less than one-third of the agricultural area currently is being rented and generating income for Kamehameha Schools, but property taxes are levied on all fields. As such, a financial loss estimated at $530,000 per year currently is being incurred by Kamehameha Schools. Indeed, reversing this loss was a motivating factor to explore new land-use strategies.

We projected all land-use planning scenarios considered in the analysis to generate positive net present values and to exceed greatly the negative return of –$8.9 million projected for the Status Quo scenario (Figs. 3 and 4 and Fig. S3). The Residential Development scenario generated the highest net present value of $62.4 million. The Food Crops and Forestry scenario generated a net present value of $10.9 million, and the Biofuels scenario generated a net present value of $10.3 million, both after accounting for the cost of improving the irrigation system. Net present value rankings are robust across changes in the discount rate (Fig. S3).

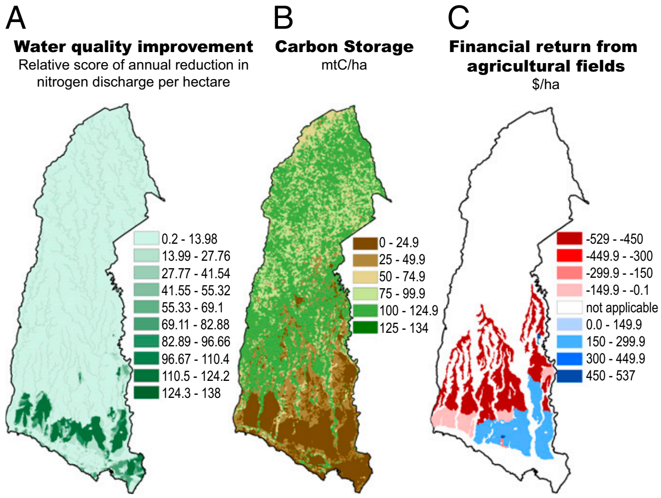

Fig. 2. Maps of study region showing provision for the base landscape of (*A*) water-quality improvement (nitrogen export reduction), (*B*) carbon storage (in above- and belowground pools), and (*C*) annual financial return from the agricultural fields.

Stakeholders identified tensions between pursuing a strict financial profit-maximizing strategy and nonfinancial cultural values. Although profits from the land sale would flow into Kamehameha Schools' endowment to support its educational mission, selling and developing these lands (e.g., Residential Development) could raise concerns about potentially irreversible losses of on-site educational and cultural assets, affecting current and future trust beneficiaries. Although we were not able to capture such intergenerational tradeoffs explicitly in our analysis, they are an additional consideration informing land-use decisions by Kamehameha Schools.

For water quality and carbon storage, no scenarios presented lose-lose or win-win outcomes relative to the Status Quo scenario (Figs. 3 and 4*C*). Water quality declined with Food Crops and Forestry (15.4% increase in nitrogen export), Food Crops and Forestry with Field Buffers (4.9%), and Residential Development (11.8%). For these scenarios, however, carbon storage increased by 0.5% [3,458 tons Carbon (tC)], 1.6% (12,670 tC), and 0.4% (2,881 tC), respectively. The pattern was reversed for the remaining three scenarios. Water quality improved with Pasture (23.4% reduction in nitrogen export), Biofuels (29.2%), and Biofuels with Field Buffers (32.4%). For these scenarios, however, carbon storage declined by 9.9% (82,581 tC), 9.9% (82,581 tC), and 8.0% (66,556 tC), respectively. These reductions in carbon storage are driven by the need to clear invasive woody plants to establish pasture or sugarcane cropping on currently abandoned fields. For the two biofuels scenarios, on-site carbon reductions could be repaid off site by using sugarcane ethanol to offset more carbon-intensive energy sources. Following the biofuel carbon debt methodology of Fargione et al. (26), the estimated payback period to return to baseline conditions is ~10 y for the Biofuels scenario and 8 y for the Biofuels with Field Buffers scenario.

Creating vegetation buffers to reduce runoff is a well-established agricultural best-management practice (27). In this analysis, vegetation buffers could provide a double benefit in terms of modest increases in carbon storage [relative enhancements of 1.1% (9,212 tC) and 1.9% (16,025 tC) for the Food Crops and Forestry with Field Buffers and Biofuels with Field Buffers scenarios, respectively, compared with the same scenarios without field buffers] and improved water quality (relative enhancements

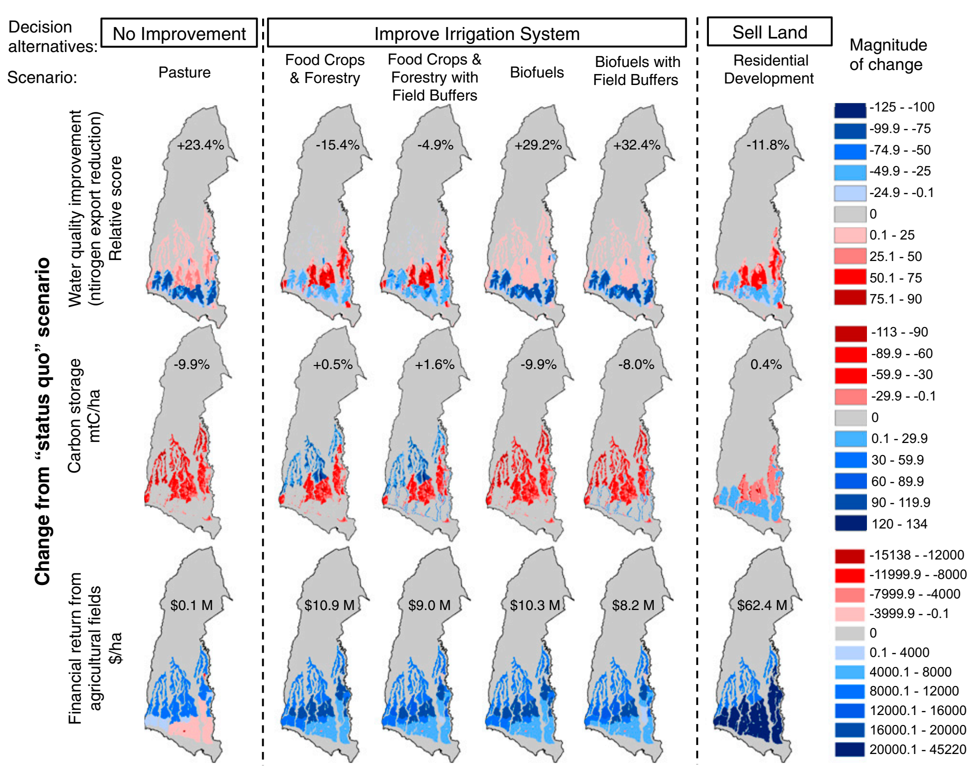

Fig. 3. Maps showing field-level changes between the land-use planning scenarios and the base landscape for water-quality improvement (nitrogen export reduction), carbon storage, and financial return from the agricultural fields. Blue indicates areas with enhanced ecosystem services and financial return; red indicates areas with reductions; gray indicates no change. The number associated with each map shows the net scenario change. The cost of improving the irrigation system is not factored into relevant scenarios at the field-level for display on the financial return maps, although it is factored into the overall net return numbers reported in the text.

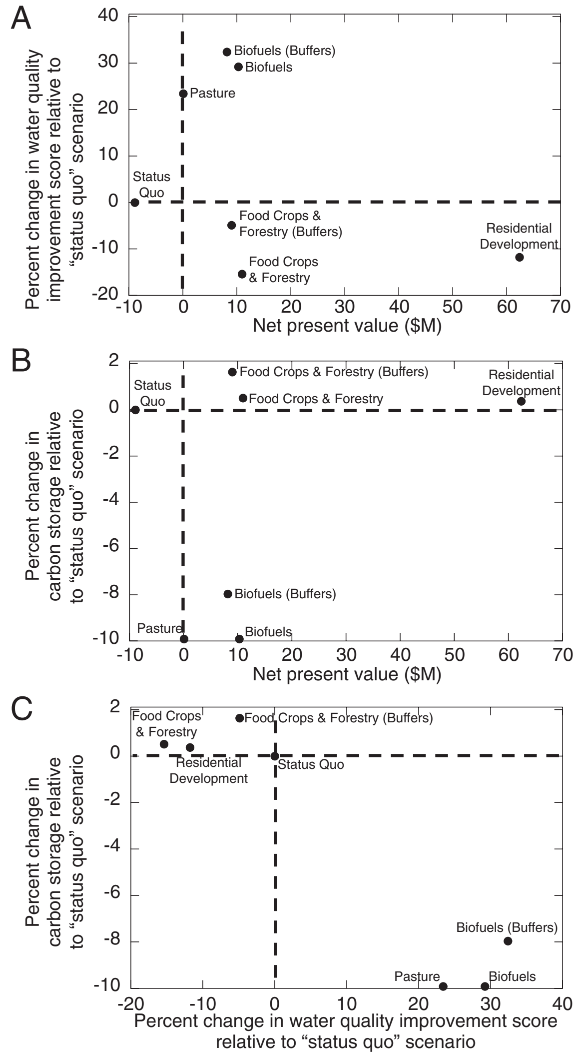

Fig. 4. Tradeoffs comparison of the enhancement or reduction in ecosystem-service and financial metrics relative to the Status Quo scenario for the entire planning region. (*A*) Water-quality improvement and financial return. (*B*) Carbon storage and financial return. (*C*) Carbon storage and water-quality improvement.

of 10.5% and 3.2% for Food Crops and Forestry with Field Buffers and Biofuels with Field Buffers, respectively). These ecosystem-service improvements, however, come with a tradeoff of land taken out of agricultural production, resulting in reduced financial return (reductions of $1.9 million for both Food Crops and Forestry with Field Buffers and Biofuels with Field Buffers), although overall net present values remain positive. Currently neither carbon storage nor water quality has a direct price in the study region, meaning that decisions about whether to establish vegetation buffers hinge on the value assigned by decision-makers to the carbon-storage and water-quality improvements relative to the financial penalty. The Hawaii State Legislature has passed legislation mandating a reduction in greenhouse gas emissions to 1990 levels by 2020, and efforts to achieve these reductions could involve creating a market or other mechanism that establishes a state-wide carbon price. Furthermore, novel markets to incentivize water quality and quantity improvements are being trialed globally (although not yet in Hawaii) and provide models for how first approximation prices can be established for water-related ecosystem services (28).

Our analysis linked to the land-use planning process did not consider a full native vegetation-restoration scenario, given the ecological and financial challenges of doing so and the perception that such a scenario would not best achieve the balance of goals targeted by Kamehameha Schools and the community. Still, a full-restoration scenario provides a useful upper baseline from a conservation perspective and provides decision-makers an additional reference point informing the planning process. We found that a full-restoration scenario would deliver the greatest carbon storage enhancement, with a 30.4% (254,035 tC) improvement over the Status Quo scenario and a 28.4% (241,365 tC) improvement over the next-highest scenario, Food Crops and Forestry with Field Buffers. For water quality, we found that the full-restoration scenario also would deliver the greatest enhancement, with a 46.0% improvement over the Status Quo scenario and a 13.6% improvement over the next-highest scenario, Biofuels with Field Buffers. These results illustrate that additional ecosystem-service improvements could be realized if restoration were pursued as the overarching planning goal.

Our ecosystem-services modeling focused on carbon storage and water quality, but our planning scenarios also would be expected to affect differentially other ecosystem services that we did not quantify. For example, crop pollination services would be enhanced by scenarios that incorporate crops benefiting from pollination (e.g., some vegetable and fruit crops) and that add land uses/covers providing pollinator habitat (e.g., agricultural field buffers or adjacent forest cover). Alternatively, this crop-pollination service would decrease for the Residential Development scenario, in which there are no crops to pollinate. Using additional models to quantify pollination and other ecosystem services would further strengthen information supporting planning processes.

Integrating ecosystem services into local land-use planning, as our analysis does, provides a quantitative way for stakeholders to consider the environmental and economic implications of alternative land-use scenarios. Informed by the positive and negative outcomes of each scenario, Kamehameha Schools is working with the community to implement a land-use plan that prioritizes diversified agriculture and forestry while also considering additional compatible land uses on a smaller scale. The approach is designed to enhance on-site benefits, contribute to state-wide policy initiatives, and also inform the mitigation of negative impacts where necessary. Kamehameha Schools' plan was the recipient of the American Planning Association's 2011 National Planning Excellence Award for Innovation in Sustaining Places. This award recognized Kamehameha Schools for its community-engagement process and its final plan, which advances the organization's strategic goal of incorporating economic, environmental, educational, cultural, and community values in all its land-use planning across the state.

Our results highlight that ecosystem-service and economic tradeoffs are a key challenge that decision-makers will need to confront. A notable gap remains between recognition of the economic value of ecosystem services to society (e.g., carbon storage, water-quality improvements, and others) and the financial value to landowners, because the value of ecosystem services remains largely external to existing markets (17, 29–31). Addressing this situation through economic, legal, and cultural approaches remains a key challenge for mainstreaming ecosystem services in land-use planning. Making ecosystem-service tradeoffs explicit in decision making provides a window of opportunity to inform the adoption of strategies in which local and regional-scale land-use planning decisions contribute meaningfully to addressing sustainability challenges.

Innovative projects advancing conservation to support human well-being are being documented increasingly, but turning scientific knowledge into action remains a fundamental challenge at local to global scales (16, 17). Examples of strategies found to enhance the knowledge-to-action transition include addressing decision-relevant questions and using boundary institutions to facilitate bidirectional information flow between researchers and decision makers (32); enabling policy makers and communities to work collaboratively with researchers through a continual engagement model (33); and developing effective resource-management institutions to facilitate participatory processes and manage associated costs and complexities (34). Finding workable models and scaling them up will require continued advances in theory and practice and the recognition that these aspects inform and improve each other in motivating real-world change (35).

Materials and Methods

Study Context. Kamehameha Schools' land holdings of ~10,600 ha on the North Shore of O`ahu, Hawaii include ~890 ha of rural residential and commercial lands along the coast, ~3,640 ha of agricultural lands in the middle section (of which ~2,200 ha, or 60%, are usable; the remainder is gulches), and ~6,070 ha of rugged forest lands in the upper elevations. Our modeling analysis occurred in the background of Kamehameha Schools' planning process with North Shore communities to evaluate the potential of ecosystem-service mapping to provide information to support the planning process and to be integrated routinely going forward into Kamehameha Schools' strategic planning activities with communities across the State of Hawaii.

Planning Scenarios. We created seven spatially explicit land-use–planning scenarios in a Geographic Information System that were directly relevant to the planning process and which represented contrasting directions that could be taken with the agricultural lands (Fig. 1 and Table S1). To expand upon the decision context described briefly earlier in this paper, we focused the scenarios on a key planning decision: Should Kamehameha Schools spend approximately $7.0 million to improve the region's aging irrigation infrastructure? This improvement would involve a substantial up front cost, but it would make possible the return of agricultural production to fallow fields currently lacking reliable irrigation water. This outcome would have the associated financial benefits of effectively lowering property taxes (because the land would be in production) and delivering higher field rental rates because of the ability to grow higher-value crops, including food crops (e.g., vegetables) and sugarcane as a biofuel feedstock. Alternatively, if the irrigation system improvement was not made, agriculture would be limited to the approximately one-third of fields currently in production (assuming no future failure of the remaining irrigation system, which was a concern); this situation would have the associated financial impacts of land uses with lower field-rental rates and continued high property taxes on fallow lands.

To construct the planning scenarios, we considered seven land uses for the agricultural fields. Two land uses—producing vegetable crops (for local markets) and sugarcane (as a biofuel feedstock)—were dependent upon improving the irrigation system; the remaining uses—leaving fields fallow [meaning that current land use/land cover (LULC) remained], producing nonhuman food crops (e.g., seed corn, as was currently being grown), pasture, native forestry plantings, and a residential development—were not irrigation-dependent. To code the scenarios, the agricultural fields were divided into three groups with each group being assigned one of these land uses: (*i*) low-elevation fields currently receiving irrigation water; (*ii*) mid-elevation fields that could receive irrigation water if the improvement was made; and (*iii*) upper-elevation fields that would remain dependent upon precipitation (Fig. S1). The resulting scenarios are described in the Introduction.

Beneficiary Groups. Applying an ecosystem-services framework to land-use planning requires identifying the actors who supply ecosystem services (e.g., landowners and land managers through their choices of land-use and management practices) and those actors who benefit from ecosystem-service provision (36, 37). In our study region, we identified three beneficiary groups operating at different scales, all of whom have a direct stake in the current and future provision of ecosystem services and associated financial benefits from the landscape: (*i*) local communities, i.e., the residents of the towns and rural residential areas along the North Shore coast; (*ii*) the private landowner, Kamehameha Schools; and (*iii*) the broader public, which benefits from the provision of public goods (e.g., carbon sequestration and storage contributing to climate stabilization). Although these groups are distinct, we note that there is partial overlap; for example, Kamehameha Schools is both the landowner and part of the local community, and public goods accruing to the broader public also benefit Kamehameha Schools and the local community.

Modeling of Ecosystem Services and Financial Return. We evaluated each planning scenario based upon three metrics: (*i*) carbon storage related to global climate change mitigation; (*ii*) water-quality improvements affecting communities living in the study region; and (*iii*) financial return to support mission-related activities for Kamehameha Schools as an educational trust. Below, we provide details on each of these calculations. Although the land-use planning scenarios included only changes to the agricultural lands, we modeled ecosystem-service flows across the entire planning region to ensure connectivity of the analysis for hydrologic flows. Input values for each of these models are provided in Tables S2–S4. Ecosystem services and financial return were computed as a function of land characteristics and LULC type. The baseline LULC map was obtained from a spatial layer for O`ahu based upon imagery from the Hawaii Gap Analysis Program published in 2006. This layer has a 30-m pixel size, and all models were run at this resolution. Projected changes in ecosystem-service flows and financial return were computed by subtracting the model output for the Status Quo scenario from alternative planning scenarios.

Carbon storage. We used the InVEST Tier 1 carbon sequestration and storage model to calculate the carbon fraction in above- and belowground biomass according to LULC type. We assumed that carbon was 50% of total biomass and used root-to-shoot ratios to estimate belowground biomass based upon specified values for aboveground biomass. We estimated biomass values to reflect full storage capacity for each LULC type based upon Hawaii studies, when available, and otherwise from the Intergovernmental Panel on Climate Change's Guidelines for National Greenhouse Gas Inventories Tier 1 protocol (Table S2) (38). In many situations, as with our study, data obtained directly from the study region are limited, meaning that in practice local land-use planning efforts must use more general information sources (e.g., Intergovernmental Panel on Climate Change guidelines) as inputs. We assumed that woody biomass cleared from fallow fields would decay fully over our model time horizon of 50 y.

Water-quality improvement. We used the discharge of dissolved nitrogen as our proxy for pollution (recognizing that there are other important pollutants), because the agricultural lands are in close proximity to the ocean, and nitrogen generally is considered a limiting nutrient in marine systems (24). We used the InVEST Tier 1 water-quality model (run during November 2008; this model has been modified since then), which projects relative improvements (or impairments) to water quality based upon slope, soil characteristics, and pollution export coefficients linked to LULC types (Table S3). For the two scenarios that incorporated vegetative field buffers, we assigned a filtering efficiency of 75%. Numerical results should be interpreted in a relative rather than absolute manner. As such, we present results as percent change from the Status Quo scenario. Positive changes project relative improvements in water quality for dissolved nitrogen; negative changes project relative impairments.

Financial return. We projected the net present value of each land-use type using a discounted cash flow model over a 50-y time horizon with a 6% real discount rate and sensitivity analysis to 3–12% (Fig. S3). Kamehameha Schools provided information on expected agricultural land-rental rates and real property taxes, which were subtracted from rental rates to compute annual net return (Table S4). Kamehameha Schools also provided estimates of real estate prices for bulk sale of irrigated and nonirrigated agricultural lands for the Residential Development scenario. We assumed that this scenario involved financial returns for the current landscape in model year 0 with the full land sale occurring in year 1; this assumption is reasonable, given the land area considered in this analysis. Improvements to the irrigation system were assumed to cost $7.0 million, with costs spread evenly over the first 4 y. These costs were incorporated into all scenarios involving irrigation system improvements.

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