Business strategies for conservation on private lands: Koa forestry as a case study

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Innovative financial instruments are being created to reward conservation on private, working lands. Major design challenges remain, however, to make investments in biodiversity and ecosystem services economically attractive and commonplace. From a business perspective, three key financial barriers for advancing conservation land uses must frequently be addressed: high up-front costs, long time periods with no revenue, and high project risk due to long time horizons and uncertainty. We explored ways of overcoming these barriers on grazing lands in Hawaii by realizing a suite of timber and conservation revenue streams associated with their (partial) reforestation. We calculated the financial implications of alternative strategies, focusing on *Acacia koa* ("koa") forestry because of its high conservation and economic potential. Koa's timber value alone creates a viable investment (mean net present value = $453/acre), but its long time horizon and poor initial cash flow pose formidable challenges for landowners. At present, subsidy payments from a government conservation program targeting benefits for biodiversity, water quality, and soil erosion have the greatest potential to move landowners beyond the tipping point in favor of investments in koa forestry, particularly when combined with future timber harvest (mean net present value = $1,661/acre). Creating financial mechanisms to capture diverse ecosystem service values through time will broaden opportunities for conservation land uses. Governments, nongovernmental organizations, and private investors have roles to play in catalyzing this transition by developing new revenue streams that can reach a broad spectrum of landowners.

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Expanding efforts to conserve biodiversity and to supply ecosystem services from private, working lands has become an increasingly important focus of conservation projects throughout the world (1). Innovate financial instruments are emerging that link revenue streams to ecosystem service benefits to encourage private landowners to adopt conservation land uses. Costa Rica, for example, began a Payment for Environmental Services Program in 1997, which pays private landowners for the provision of four ecosystem services: carbon sequestration, biodiversity conservation, hydrological services, and provision of scenic beauty for recreation and ecotourism (2). Australia has launched numerous conservation programs using market-based instruments to enlist private landowners in managing for water quality, salinity, and biodiversity targets (National Market-based Instruments Pilot Program, www.napswq.gov.au/mbi). These newer approaches complement existing mechanisms, such as government land retirement and conservation subsidy programs, conservation easements, tax incentives, and others.

Developing business strategies for private land management that draw on revenue streams aligning conservation and economic incentives provides an opportunity for conservation land uses to compete with alternative uses. These revenue streams could come from several sources, such as payments for ecosystem service provision, government conservation payments, partnerships with nongovernmental organizations, and sustainable production and natural resource extraction. Here we explore how private landowners can tap into revenue streams connected to forest conservation benefits to enhance the financial attractiveness of nonindustrial private forestry operations. We focus on opportunities to reforest existing montane pastureland in the Kona region of Hawaii by developing forestry ventures based on the high-value, native tropical hardwood *Acacia koa*, commonly referred to as koa, which takes 30–50 years to reach merchantable timber size (3). Historically, koa forests were a key feature of this landscape, although only ≈10% of original forest cover remains (4). We perform financial analysis using discounted cash-flow models, Monte Carlo simulation, and stochastic dominance (SD) analysis with the aim of identifying opportunities to make koa forestry in Hawaii and, more generally, sustainable forestry throughout the tropics economically attractive for private landowners.

We use koa as the point of entry here for four reasons. First, from a biodiversity perspective, a large fraction of native Hawaiian biota is associated with koa forests, including endangered birds, the one native land mammal, understory plants, and other groups (5). Second, from an ecosystem services perspective, koa forests provide carbon sequestration (6) and hydrological and cultural benefits (3). Third, from an economic perspective, koa is Hawaii's premier timber, and its high market value creates a potentially lucrative investment (3). Fourth, finding economically viable means of reforesting degraded pastureland is relevant far beyond Hawaii, particularly in the tropics (7, 8).

Land-Use Business Strategies. For forestry ventures such as koa that have a multiple-decade time horizon, three financial barriers to entry stand out from a private landowner's perspective: high up-front establishment costs, a long time period until revenue is realized from timber harvest, and high project risk due to the long time horizon and uncertainty about how future biophysical, economic, and institutional factors will affect the investment. Amplifying these barriers is the risk aversion typical of many landowners (9, 10).

We designed a set of koa forestry business strategies that address these barriers to explore profitable, risk-efficient conservation investments for private landowners. These strategies draw on income from timber harvest, two existing government

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Abbreviations: CCX, Chicago Climate Exchange; CREP, Conservation Reserve Enhancement Program; FSP, Forest Stewardship Program; mt CO_2e, metric ton of carbon dioxide equivalent; NPV, net present value; SD, stochastic dominance.

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conservation programs, integrated cattle grazing, and selling carbon offset credits.

Timber. This strategy represents a koa forestry venture based on managing a parcel of land in a plantation-like fashion for its timber value on harvest.

Timber + Subsidy1. In this strategy, the landowner manages for timber harvest while also enrolling in the State of Hawaii's Forest Stewardship Program (FSP), which is a government cost-share program akin to various conservation subsidy programs found in the United States, Europe, and elsewhere that are designed to encourage better land stewardship by offsetting a portion of land management costs. The FSP specifically targets private forest owners who are "committed to stewardship, conservation, and enhancement of their forest resources" (Forest Stewardship Handbook, 2002, Hawaii Department of Land and Natural Resources, www.state.hi.us/dlnr/dofaw/hfsp/hfsp_handbook/index.html).

Timber + Cattle. This strategy integrates cattle grazing with koa timber production in a silvopastoral system. The financial benefits are that cattle provide an additional and earlier revenue stream than timber.

Timber + Subsidy1 + Cattle. This strategy combines cost-share assistance through the FSP with an integrated koa–cattle silvopastoral system. The financial benefits are reduction of management costs and added revenue from cattle.

Timber + Subsidy2. Government-supported retirement of environmentally sensitive agricultural lands is another important type of subsidy in the United States, Europe, and elsewhere. In this strategy, the landowner participates in the Conservation Reserve Enhancement Program (CREP), which is in the process of being launched in Hawaii through the United States Department of Agriculture Farm Service Agency. CREP targets the provision of significant conservation benefits related to water quality, soil erosion, and threatened and endangered species recovery. If enrolled, the landowner would receive rental payments and cost-share assistance covering initial forest establishment and ongoing major maintenance costs. We assume that the landowner manages the parcel for timber harvest and conservation benefits.

Carbon Credits. The emergence of carbon markets in recent years to mitigate greenhouse gas emissions has created a new financial opportunity for landowners. In this strategy, the landowner sells carbon offset credits from the regenerating koa forest by enrolling as a "forestry offset provider" in the Chicago Climate Exchange (CCX), which is a voluntary, legally binding greenhouse gas emissions reduction market (www.chicagoclimatex.com).

Carbon Credits + Subsidy2. This strategy combines the value layers of selling carbon credits in the CCX with participation in CREP, which provides rental payments and cost-share assistance. Although a carbon-sequestration forestry project would qualify under CREP, we do not consider a strategy involving FSP, because this program focuses on timber harvest and probably would not support a project whose sole goal is carbon sequestration.

We also consider a scenario in which the landowner undertakes no koa reforestation project and continues in cattle ranching ("Cattle" strategy). We thus have a means to compare the financial viability of the koa strategies with the existing land use.

We focus on a hypothetical 202-hectare (500-acre) parcel, which is a plausible size for a reforestation project. Because many landowners own on the order of several thousand acres, this koa reforestation project would involve only a portion of their total land holdings. We assume that the parcel is currently used for cattle grazing and located at ≈1,525-m (5,000-feet) elevation, where koa grows well (11). We consider a hypothetical landowner who is the primary agent responsible for making land-use decisions and who factors profit and risk into these decisions. Although real landowner decisions are driven by personal values beyond economics, the financial viability of alternative land uses is a key input, particularly with regard to maintaining the capacity to retain ownership over their land and to pass it on to future generations (12).

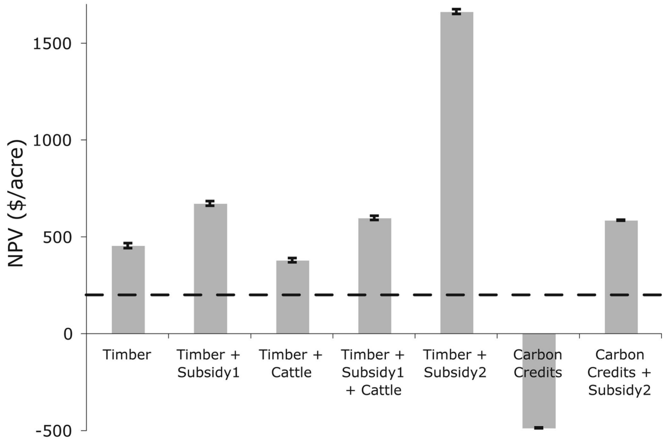

Fig. 1. Mean NPV ($/acre) ± SE for each koa forestry business strategy from the Monte Carlo simulation. Dashed line shows the NPV for the "Cattle" strategy opportunity cost ($194/acre).

We do not consider nonnative species plantations in our analysis. Although many nonnative species grow well at the higher elevations considered here, these have far lower stumpage values than koa (e.g., *Eucalyptus* species), tend to become invasive weeds (e.g., *Grevillea robusta* and *Fraxinus uhdei*), or are less well understood silviculturally than koa (e.g., *Toona ciliata* and *Flindersia brayleyana*). Local, low-volume markets that nonindustrial landowners would be able to enter are uncertain for nonnative species. Koa has an ecological and economic comparative advantage over these species in montane areas and is the most suitable tree species for landowners considering forestry investments (3, 11, 13).

Results and Discussion

Our economic analysis demonstrates that reforesting pastureland in Hawaii to launch forestry ventures based on the high-value, native hardwood koa is a financially viable investment with strong potential to be a "win–win" land use for private landowners and for conservation. This potential could be realized in any of several ways, tailored to the particular needs and desires of different landowners.

Comparing strategies on the basis of mean net present value (NPV), the five koa strategies that include timber and the "Carbon Credits + Subsidy2" strategy have mean NPV that are significantly higher than the land's opportunity cost in cattle ranching, which has a mean NPV of $194/acre (Fig. 1). When only future sales of koa timber are considered ("Timber" strategy), the mean NPV is $453/acre. The dominant strategy by far is "Timber + Subsidy2," which realizes a mean NPV of $1,661/acre (Fig. 1). This result arises from CREP's substantial cost-share and rental payments to the landowner in combination with timber revenue. In this context, CREP provides landowners with a strong economic incentive to invest in koa reforestation.

The "Carbon Credits" strategy has a strongly negative mean NPV of −$488/acre and is not a viable strategy given our assumptions and current market conditions. Carbon can be part of a profitable strategy, however, if the landowner participates in CREP ("Carbon Credits + Subsidy2" strategy; mean NPV = $584/acre; Fig. 1).

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Addressing Cash-Flow Barriers to Conservation Land Uses. To undertake koa reforestation, the landowner incurs substantial forest establishment costs in year 0, as well as ongoing management costs, particularly for forest thinnings in years 5 and 20 for timber-related strategies (see *Methods*). The timing of these costs, 35–45 years before timber harvest, is financially problematic. Notably, recent interviews with landowners and other key stakeholders in Hawaii show that koa forestry's projected cash flow, particularly the large initial investment, is perceived to be a real barrier to entry (14). Realizing koa forestry's win–win potential requires building business strategies that decrease up-front costs and add and diversify revenue streams to generate attractive year-to-year cash flows for the landowner.

Although the "Timber" strategy has an attractive NPV, it may not be attractive to a landowner, because its cash flow is negative in all years before timber harvest. The project's average total cost is \$1.04 million, with \$0.38 million of this total ($\approx$37%) coming with forest establishment in year 0. Average total timber revenue is \$26.3 million, which corresponds to an $\approx$25:1 total revenue to total cost ratio. Although this ratio is quite attractive in isolation, it is problematic that the timber revenue occurs at least 35 years out in the investment's time horizon.

The significant levels of cost-share and rental payments from CREP greatly improve the cash flow for the "Timber + Subsidy2" and "Carbon Credits + Subsidy2" strategies relative to the single revenue stream "Timber" and "Carbon Credits" strategies. CREP payments decrease the large year 0 costs by 56% for both "Timber + Subsidy2" (relative to "Timber") and for "Carbon Credits + Subsidy2" (relative to "Carbon Credits"). Although the remaining costs still average \$0.17 million, CREP payments provide the most assistance to the landowner across the set of revenue streams considered in our analysis. Over the full time horizon, CREP payments decrease total costs by 42% for "Timber + Subsidy2" and 37% for "Carbon Credits + Subsidy2."

Taken as a whole, CREP provides a highly valuable revenue stream to a landowner interested in koa forestry, because its substantial cost-share and rental payments stabilize the cash-flow stream while also generating an attractive NPV in combination with timber or carbon credits. Other revenue streams also improve the cash flow for koa forestry, although to lesser degrees than does CREP. Integrating cattle into a koa forestry operation ("Timber + Cattle" strategy) provides a small amount of revenue beginning in year 5, which leads to a nearly zero net income from year 6 until harvest starts, with the exception of year 20, when the second precommercial thinning occurs. There are still, however, two main financial concerns. The landowner continues to face all management costs, and tree damage from cattle grazing likely reduces the value of the timber harvest (ref. 15; see *Methods*). That said, integrating cattle might be attractive to landowners wishing to maintain the lifestyle and other cultural values associated with ranching.

Participating in the FSP cost-share program with timber harvest ("Timber + Subsidy1" strategy) decreases the major costs incurred in year 0 by 20% relative to the "Timber" strategy. The landowner still faces several decades of negative income before timber harvest, however, because the FSP has no rental payments and lower cost-share levels than CREP. FSP payments are valuable to a landowner undertaking koa reforestation, but additional complementary revenue streams are needed to create a more attractive cash flow.

The "Timber + Subsidy1 + Cattle" strategy combines participation in the FSP with cattle grazing to get the financial benefits of both for decreasing upfront costs and adding a nontimber revenue stream, which generates a mean NPV of \$596/acre. Whereas the "Timber + Subsidy1" strategy has a higher NPV at \$671/acre (no lost timber revenue from cattle damage), the "Timber + Subsidy1 + Cattle" strategy has a better cash flow and may be more attractive to a landowner. In addition, the "Timber + Subsidy1 + Cattle" strategy could be attractive if participating in CREP is not possible. If many landowners become interested in CREP, it is likely that only some will receive contracts given the program's limited budget and eligibility requirements. For those who can participate, entering into a contract would be lucrative. For those who cannot, alternative koa strategies are still viable.

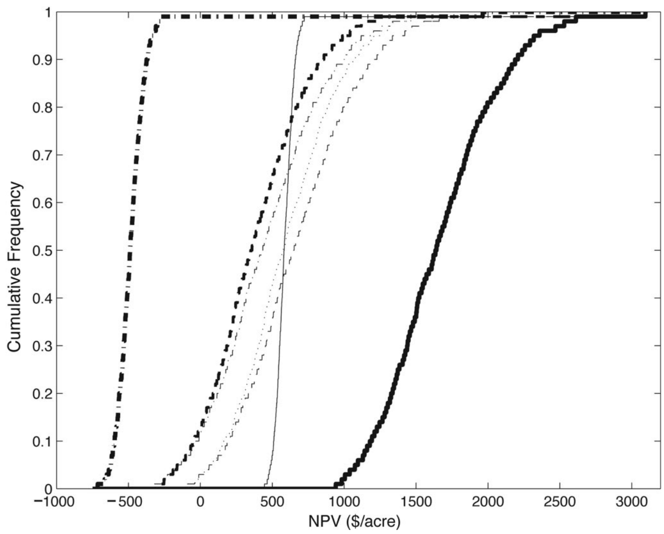

Fig. 2. Cumulative distribution of NPV for each koa forestry business strategy from the Monte Carlo simulation used in the SD analysis. The "Timber + Subsidy2" strategy has first-degree SD over all other strategies. Each line represents a single strategy: "Timber," thin dot-dash; "Timber + Cattle," thick dashed; "Timber + Subsidy1," thin dashed; "Timber + Subsidy1 + Cattle," dotted; "Timber + Subsidy2," thick solid; "Carbon Credits," thick dot-dash; and "Carbon Credits + Subsidy2," thin solid.

Identifying Risk-Efficient Land-Use Strategies. Risk aversion is a key factor driving land-use decisions and must be accounted for in comparing the benefits and drawbacks of alternative strategies from the landowner's perspective (9, 10). We use SD analysis to identify the specific koa forestry business strategies that represent risk-efficient land-use options (see *Methods*). Results from this analysis, based on the cumulative distribution functions of NPV generated from the Monte Carlo simulation, support and enhance the conclusions reported above (Fig. 2). Most striking is that the "Timber + Subsidy2" strategy exhibits first-degree SD over all other strategies. First-degree SD means that this strategy always has a higher probability of realizing a higher NPV than any other strategy, and it requires only the reasonable assumption that landowners have monotonic preferences (16). Combining this result with the earlier discussion of its improved cash flow, "Timber + Subsidy2" is the dominant strategy based on economic criteria for any landowner interested in koa forestry. Because eligibility and budget constraints will limit the number of landowners that can participate in CREP, as noted above, it is also relevant that the "Timber + Subsidy1" and "Timber + Subsidy1 + Cattle" strategies first-degree stochastically dominate both the "Timber" and "Timber + Cattle" strategies. Last, "Carbon Credits" is not a desirable strategy, because it is first-degree stochastically dominated by all other strategies.

Second-degree SD requires the additional assumption that landowners are risk-averse. Because first-degree SD implies second-degree, the "Timber + Subsidy2" strategy dominates again. We find, however, the additional result that "Carbon Credits + Subsidy2" dominates "Timber" and "Timber + Cattle" for risk-averse landowners. Clearly, CREP stands out as the most beneficial revenue layer in terms of reducing landowners' risk-related concerns. Yet, even in its absence, other revenue streams create viable business strategies for risk-averse Hawaiian landowners.

Sensitivity Analysis of Financial Projections. Koa forestry investments have a multidecade time horizon, and like all long-term investments, financial projections are highly sensitive to the discount rate. We used an 8% real discount rate, which results in the four timber-related strategies and the "Carbon Credits + Subsidy2" strategy all being financially viable. Considering a range from 4% to 12% to simulate relatively longer versus shorter time preferences, respectively, the "Timber + Subsidy2" strategy has the highest mean NPV, up to 11%, with "Carbon Credits + Subsidy2" most attractive at 12% (Fig. 3, which is published as supporting information on the PNAS web site). This switch occurs because, as the discount rate increases, the early revenue from carbon credits becomes relatively more important in its contribution to NPV than the farther-off timber revenue, which gets heavily discounted.

Studies examining individual discount rates suggest that values may actually be ≥15% (17, 18). Clearly, win–win opportunities for koa forestry shrink as landowners apply increasing discount rates. The most robust strategy to higher rates is "Carbon Credits + Subsidy2," which maintains a positive NPV until ≈28%. The "Timber + Subsidy2" strategy, which strongly dominates at 8%, remains positive until ≈15%. In the context of Hawaii, however, interview results suggest that landowner interest in koa forestry is driven, at least in part, by desires to retain ownership over their land and pass it on to future generations (14). Accordingly, this argues for these landowners having relatively lower opportunity costs of time for economic return from land devoted to koa forestry.

The "Carbon Credits" strategy was the only one in our analysis to have a negative mean NPV (−$488/acre). The costs of participating in the CCX, however, do not drive this result, as this strategy's NPV increases by only 3% and remains negative even if CCX-related costs are set to zero. We assumed a carbon price of $15 per metric ton of carbon dioxide equivalent (mt CO_2e) in our calculations. To generate even a $0/acre NPV, a carbon price of ≈$31/mt CO_2e is needed. Interestingly, this price is at the upper end of current market prices, which range from $2.15/mt CO_2e on the CCX to $31.85/mt CO_2e in the European Union Emissions Trading Scheme (midprice reported on Ecosystem Marketplace, March 29, 2006, http://ecosystemmarketplace.com/pages/static/marketwatch.php).

For the five timber-related strategies, the "one-at-a-time" sensitivity analysis (see *Methods*) showed that the model inputs related to timber revenue are the key drivers of uncertainty in projected NPV, because they account for ≥94% of the variance. In particular, the input for the percent annual real growth in koa stumpage price accounts for 58–60% of the variance, depending on the particular strategy. Although landowners cannot control the future of the koa timber market, they can reduce their vulnerability to price changes by incorporating other desirable revenue streams into their business plan, as we have explored here. The cost input components for koa reforestation are relatively unimportant in their contribution to uncertainty in projected NPV, accounting for no more than 5% of the variance. However, because the major costs come in the early years of the investment, project costs remain critical from a cash-flow perspective.

We have explored the relative merits of using a land parcel in a single, uniform way. A crucial direction for future work is to examine opportunities for mixed strategies applied to a land parcel with heterogeneity in biophysical capital and expected economic return. Accordingly, the opportunity cost of any land use will vary across the parcel and across the broader landscape. If areas that are especially productive for koa forestry are poor for cattle, then there will be considerably more opportunities to realize win–win land-use outcomes. If the reverse holds, as is likely, because productivity of both pastures and koa forests depends on rainfall and soil fertility (13), then there is scope for conflict and potentially a need for larger incentives to shift to koa. This result will be especially true if there are intangible cultural values associated with existing land uses such as cattle, as well as cash flow and risk factors connected with conservation land uses such as koa forestry.

Making conservation pay is a critical step toward encouraging conservation land uses on private, working lands. Our results, in the context of koa forestry in Hawaii, highlight the important role that government conservation programs such as CREP can have, in the near-term, in aligning conservation and economic incentives and encouraging landowners to adopt conservation practices. Because these programs transfer public funds to private landowners, it will be important to examine whether the size of payments to landowners is justified given the level of social benefits generated by conservation land uses such as koa forestry. This analysis will be particularly necessary if these programs are to be sustained over time and remain palatable to landowners and taxpayers. More broadly, nongovernmental organizations and private investors, in addition to governments, can play a catalytic role by subsidizing conservation practices today while developing concurrently new and more efficient financial instruments to expand opportunities for conservation on private lands.

Methods

Site Description. The Kona region, composed of the North Kona and South Kona Districts, is located on the leeward side of the island of Hawaii in the United States (Fig. 4, which is published as supporting information on the PNAS web site). The uplands in Kona are a mosaic of pasture and forested lands of which 90% is privately owned and 70% is zoned for agriculture at 3,500- to 5,500-feet (1,067- to 1,676-m) elevation (L. Nelson, The Nature Conservancy, Hawaii, personal communication). This high percentage of agricultural rather than conservation zoning in upland Kona is unusual for Hawaii, and significant portions of koa forest were cleared to create pasture for cattle grazing, which remains a major economic use.

Discounted Cash-Flow Models. We built discounted cash-flow models in Microsoft EXCEL 2004 to quantify financial projections for each strategy. The models project cost and revenue streams in real terms. We used an 8% real discount rate, which is based on two sources. First, discount rates of 8–10% real are commonly used in valuing forestry asset projects (19). Second, the Farm Credit System Bank computes the average annual effective interest rate charged on new loans, and the 5-year average from 2001 through 2005 for the region that includes Hawaii is 7.09% (National Timber Tax Website, www.timbertax.org).

Model Inputs and Assumptions. To define the cost and revenue components for the models, we synthesized information from the literature and from fieldwork in Hawaii during January, February, and July 2005 involving discussions with people knowledgeable about koa forestry and the Kona region, including academics, forestry professionals, landowners, and government employees. Our input values are tailored to our study site in Kona. We provide a discussion here of our inputs along with additional *Supporting Methods*, including Tables 1–4, which are published as supporting information on the PNAS web site.

For the "Cattle" strategy, we simulate expected financial return from continuing in cattle ranching by using the rental rate of $16.50/acre per year for Hawaii in 2005 for the Grassland

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Reserve Program administered by the United States Department of Agriculture Natural Resources Conservation Service. This rate is constant across Hawaii and is based on estimated forage production by soil type and information on local rental rates. Annual real property taxes of approximately \$0.59/acre (10-year dedicated use for agriculturally zoned "average" pasture for Hawaii County in 2005) are subtracted from the rental payment to compute annual profit. Capital investments and depreciation are not explicitly modeled. Rental rates and property taxes are assumed to stay constant in real terms over the model's 50-year time horizon beginning in 2005.

For all of the koa forestry strategies, the process of restoring koa forest cover begins in year 0 with site preparation, fencing to keep out large ungulates, and regenerating koa seeds in the ground through the well established practice of scarification, which involves running a bulldozer blade over the land to break up the surface grass mat (20). We assume that the land has a viable seed bank, which is reasonable given that koa seeds are known to remain viable up to 25 years in the ground (11). For lands with no viable seed bank, landowners would need to investigate options for planting seedlings, which we do not address here. Forest management also involves precommercial thinnings in years 5 and 20 to promote stand development for timber harvest. Thinnings are not performed, however, for strategies involving carbon credits (see below). The landowner incurs all management costs net of any government cost-share payments. For strategies involving timber harvest, the landowner receives revenue from selling stumpage to an outside harvester who incurs all harvest costs.

Timber harvest begins in year 40 for our base case with a range of 35–45 years for sensitivity analysis (15). Independent of the starting year, 50 acres are harvested each year over 10 years. Such small annual harvests are typical of the capability of the local logging industry. Harvest volume is determined by a merchantable timber volume curve, which we specified using plausible values representative of our study site. For our base case, ≈8,500 board feet/acre (120.0 m^3/hectare) are harvested in year 40 and 10,100 board feet/acre (142.6 m^3/hectare) in year 49 (refs. 3, 13, and 15; Table 2). To quantify how uncertainty in merchantable volume affects our financial projections, we compute sensitivity to ±25% of the base case.

The initial stumpage price is \$3.50/board foot (\$612.5/m^3), which reflects current market conditions (D. Matsuura, land manager, personal communication). This price grows annually in the model by a real rate of 1%, with a range of 0–2% used for sensitivity analysis. Koa stumpage prices rose sharply in the late 1980s and early 1990s, from \$0.10 to \$3.00 per board foot (\$17.5–\$525/m^3) from 1980 to 1996 (21). Although this growth has tapered off since then, demand remains high relative to the current limited supply, suggesting future price growth.

For the "Timber + Subsidy1" strategy, cost-share assistance through the FSP ("Subsidy1") is at 50% for most practices with practice-specific payment caps and a \$75,000/year total cap. Payments are available for up to 10 years after site preparation. For commercial harvest of high-value trees such as koa, the landowner is required at harvest to repay 10% of the funds received (S. Mann, Hawaii Division of Forestry and Wildlife, personal communication) (Table 3).

For the "Timber + Cattle" strategy, cattle are first introduced in year 5, which provides the koa seedlings with time to grow sufficiently large to lessen damage from grazing, because cattle move freely through the stand (15). Only young cattle are used in the initial years to further reduce potential damage. Cattle are removed gradually from the stand as harvest occurs in a particular area. We model cattle revenue as a rental payment of \$12.50/acre, under our base case, with a range of \$10–15/acre for sensitivity analysis (D. Matsuura, personal communication). This payment is lower than in the "Cattle" strategy, because we assume that the landowner will have a lower stocking density to manage for the land's more valuable timber resource.

Grace (15) examined the impacts of grazing practices on koa forest growth and merchantable timber volume by using a simulation model based on field data. He found that grazing reduces leaf area on trees, which in turn decreases growth rates. Meanwhile, the negative effects from soil trampling and the positive effects from removing grass competition offset each other. For cattle that are pulsed in at year 2, the model indicated that timber volume (relative to ungrazed stands) would be 30% lower at year 35 and 20% lower at year 50. We assume that cattle are not integrated until year 5, when the larger trees would be less susceptible to damage from browsing and tree growth should be less affected. Our base assumption is that cattle grazing reduces timber volume by 15% at year 35 and 10% at year 50, with a linear extrapolation in between. Our sensitivity analysis explores a range of ±5% points on each value.

The "Timber + Subsidy1 + Cattle" strategy uses the same inputs and assumptions as described above for participating in the FSP ("Subsidy1") and integrating cattle with koa in a silvopastoral system.

For the "Timber + Subsidy2" strategy involving participation in CREP ("Subsidy2"), landowners undertaking reforestation projects receive CREP rental payments totaling \$48.40/acre per year composed of three parts: a \$32/acre per year soil rental rate, a 20% incentive payment bonus, and a \$10/acre per year sign-up incentive. Initial establishment costs qualify for 40% cost-share payments, which, along with the rental payments, are subject to a \$50,000/year per landowner cap. Landowners also receive unlimited cost-share assistance for 50% of initial establishment costs and 50% of ongoing major management costs (T. Male, Environmental Defense, personal communication) (Table 4). We assume that the landowner enrolls in two consecutive 15-year contracts during the first 30 years of the koa forestry investment and then removes the land from the program in anticipation of timber harvest beginning in years 35–45.

For the "Carbon Credits" strategy, the landowner enrolls as a "forestry offset provider" in the CCX, which is a practical choice, because koa reforestation projects are eligible for participation there but not in other major markets. Currently, no Hawaiian lands are registered with the CCX (M. Kanakasabai, CCX, personal communication). Because the CCX requires that the carbon stock be maintained over time, the landowner does not undertake timber harvest in any strategy incorporating carbon credits. Thinnings are also not performed, because thinning forest stands reallocates production within stands but usually does not increase overall biomass production or carbon sequestration (22).

We assume that the landowner participates in a cooperative of 10 members who all contribute equally to a carbon pool. This scenario is representative of what small- to medium-sized nonindustrial private landowners would do to spread out the costs of enrolling in the carbon market. Each landowner's startup and annual costs, which represent 10% of total costs to the cooperative, are a \$100 initiation fee and \$100 annual registration fee to participate in the CCX, \$600 for initial third-party verification, and \$300 for annual monitoring and verification (B. Reynolds, SGS Inc., personal communication). The landowner also pays \$0.14 for each mt CO_2e sold in the market. This cost includes a \$0.05 per mt CO_2e audit fee proposed for phase II of the CCX beginning in year 2007 (M. Kanakasabai, personal communication; ref. 23) (Table 1).**

The CCX issues carbon credits (equal to 1 mt CO_2e) on the

**As of publication, the proposed audit fee is no longer included in phase II (M. Kanakasabai, personal communication). Removal of this fee does not change the main results.

basis of increases in carbon in aboveground living biomass. Drawing on previous work with koa, we assume that the growing koa forest sequesters 1 metric ton of aboveground carbon per acre per year (6, 13, 24). We further reduce this value by 30% to be consistent with the CCX's general approach for similar forestry offset projects. We convert to carbon credits by using the conversion factor of 1 metric ton carbon equals 3.667 metric tons CO_2. We assume a central estimate of \$15 per mt CO_2e, and also compute the break-even price to obtain \$0/acre mean NPV, because carbon prices vary across different markets.

The "Carbon Credits + Subsidy2" strategy uses the same inputs and assumptions as described above for the carbon credits and CREP ("Subsidy2") value layers.

Sensitivity Analysis, Monte Carlo Simulation, and SD Analysis. Koa forestry has a time horizon of multiple decades, making it critical to use sensitivity analysis to quantify how uncertainty in model inputs affects financial projections. We used "one-at-a-time" sensitivity analysis to identify the inputs that contribute the greatest fraction of total variance in projected NPV (25). To perform this analysis, we defined "low," "base," and "high" values for each input related to koa forest management, cattle integration, and carbon sequestration (Table 1). For the inputs associated with participating in the FSP, CREP, and CCX (except monitoring and verification costs), we defined base values only, because these are fixed through contracts.

We performed the analysis using the "Tornado" macro in the EXCEL add-in SENSIT.XLA 1.13 (Decision Support Services, San Francisco). For cost components, with the exception of those whose base value is 0, high and low values were defined as the base ±25%, respectively. Cost levels are uncertain, and this provides a reasonably broad range for examining the importance of each cost component on the overall cash flow for each strategy. Furthermore, this approach provides a method for standardizing that the low values are equally low and the high values are equally high, which is important for screening sensitivity analysis. For revenue components, ±25% was again the default if no additional information was available. For the discount rate, we examined a range from 4% to 12%.

To incorporate uncertainty into the NPV projections, we performed a Monte Carlo simulation using the EXCEL add-in INSIGHT.XLA 2.0 suite (26). The projections for the "Cattle" strategy are the only exception, because we assumed, for simplicity, a certain and fixed rental rate over time. For all other strategies, we defined triangular probability density functions for each input by using the low, base, and high values described above. We assume statistical independence between inputs in our Monte Carlo simulation. Although admittedly a simplification, we believe this to be a reasonable assumption given economic and biophysical conditions related to Hawaiian montane pasturelands and given that this assumption does not meaningfully influence our analyses. Simulation outputs for NPV were compiled from 1,000 model runs.

We used SD analysis to identify risk-efficient land-use options from the set of business strategies (16). The analysis involves pair-wise comparison of cumulative distribution functions of NPV across the set of feasible strategies. The main advantage of this analysis is that it allows for relatively general assumptions about probability distributions of net return and landowner utility functions and therefore of risk preferences. A potential drawback to SD analysis is that no algorithm exists to identify the set of SD-efficient diversification strategies. Because we define the strategies as being mutually exclusive, however, performing all pair-wise comparisons is a sensible basis for assessment.

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