Conserving tropical biodiversity via market forces and spatial targeting

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The recent report from the Secretariat of the Convention on Biological Diversity [(2010) *Global Biodiversity Outlook 3*] acknowledges that ongoing biodiversity loss necessitates swift, radical action. Protecting undisturbed lands, although vital, is clearly insufficient, and the key role of unprotected, private land owned is being increasingly recognized. Seeking to avoid common assumptions of a social planner backed by government interventions, the present work focuses on the incentives of the individual landowner. We use detailed data to show that successful conservation on private land depends on three factors: conservation effectiveness (impact on target species), private costs (especially reductions in production), and private benefits (the extent to which conservation activities provide compensation, for example, by enhancing the value of remaining production). By examining the high-profile issue of palm-oil production in a major tropical biodiversity hotspot, we show that the levels of both conservation effectiveness and private costs are inherently spatial; varying the location of conservation activities can radically change both their effectiveness and private cost implications. We also use an economic choice experiment to show that consumers' willingness to pay for conservation-grade palm-oil products has the potential to incentivize private producers sufficiently to engage in conservation activities, supporting vulnerable International Union for Conservation of Nature Red Listed species. However, these incentives vary according to the scale and efficiency of production and the extent to which conservation is targeted to optimize its cost-effectiveness. Our integrated, interdisciplinary approach shows how strategies to harness the power of the market can usefully complement existing—and to-date insufficient—approaches to conservation.

conservation | economics | Sumatra | oil-palm | biodiversity

The urgency of the global biodiversity crisis has been well documented, with one-fifth of the world's assessed vertebrates being at imminent risk of extinction (1) and many more less-understood species thought to be under similar threat (2). The overwhelming cause of this biodiversity loss is land-use change (3, 4), driven in major part by the expansion and intensification of agriculture and plantations (5, 6). Some of the most dramatic changes have occurred within forests (7), which are being lost at an estimated rate of ∼13 million hectares (ha) annually (8). Such loss is particularly prevalent in the tropics of southeast Asia, where the overall rate of deforestation between 2000 and 2010 was 1% per annum (9), with annual peaks >5% in areas such as the naturally biodiverse lowlands of Sumatra, where much of this loss has been due to the growth of oil palm plantations (10).

Despite the tremendous loss of primary forests, recent findings from southeast Asia suggest that much of the region's fauna can persist in logged "secondary" forests and that it is the subsequent clearance of such areas and conversion to plantations of crops such as oil palm that causes major losses of biodiversity (11, 12). However, even in lowland areas where logging of primary forests has been substantial, subsequent clearance of secondary forests has not been complete. The region is thus a mosaic of land-use types, primarily composed of secondary forests, cleared land, and palm-oil plantations (13), rather than uniform crop monocultures. From a conservation perspective, it is therefore imperative to incentivize landowners to conserve as much of the remaining secondary (and of course primary) forests as possible (14).

The international community has recognized the problem of global biodiversity loss and, through the Convention on Biological Diversity (CBD), has committed to achieving a significant reduction in the rate of loss by 2010 (11). Unfortunately, not only was the CBD target missed, but recent assessments have shown that the overall rate of biodiversity loss is not even slowing (15, 16). Reasons for this policy failure are varied, but in southeast Asia, it appears that inadequate international public sector funding (17), and a focus on conserving extensive tracts of primary forest that now no longer exist (7), have been major contributors. To effectively halt biodiversity decline in the tropical forest regions of southeast Asia, conservation strategies must recognize the importance of large private landowners and that, at present, there is little incentive for such landowners to conserve biodiversity. Indeed, conservation incurs significant costs in terms of foregone income (18, 19), which, given the lack of sufficient national and international public-sector funding, needs to be addressed if biodiversity on that majority of land that resides in the private sector is to be conserved.

Here, to our knowledge, we provide the first interdisciplinary, scientific assessment of a private-sector, market-based approach to large-scale conservation in the tropical forest regions of southeast

Significance

Protected public lands are insufficient to halt the loss of global biodiversity. However, most commercial landowners need incentives to engage in conservation. Through an interdisciplinary study examining palm-oil plantations in Sumatra, we demonstrate that (*i*) joint consideration of both biodiversity and economic relationships permits the spatial targeting of areas that enhance conservation of International Union for Conservation of Nature Red Listed species at relatively low cost to the landowner and (*ii*) the potential exists for funding such private costs of conservation through a price premium on a conservation-certified good. Such an approach avoids the need to assume intervention from an international social planner, while establishing the potential for profitable conservation on private lands, providing an important additional route for sustaining endangered species.

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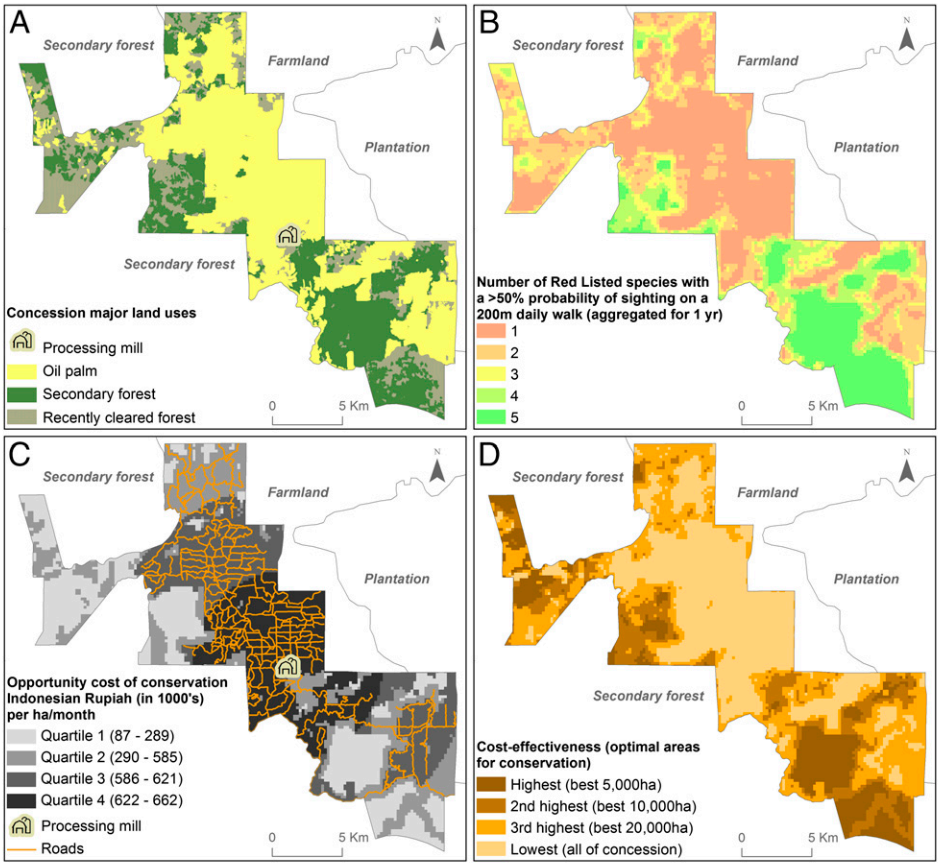

Fig. 1. Study area and analysis results. (*A*) Distribution of predominant habitat types across the concession [areas shown as oil palm are principally plantation; secondary forest is typified by areas where large trees had been logged but were otherwise relatively undisturbed; recently cleared areas include land under preparation for potential planting with oil palm or cleared as a result of illegal settlement (burnt and in preparation for crop planting), typically having little vegetation cover, although some grasses and herbaceous plants occur among the tree stumps]. (*B*) The predicted number of IUCN Red Listed species with a >50% probability of being observed on a given 200-m transect walked once each day for a year. (*C*) The OCC (assuming high-productivity management regime) shown in thousands of Indonesian Rupiah per hectare per month. (*D*) Optimal cost-effective allocation of land to three sizes of conservation scheme.

Asia. We use data from our 4-y field study of a 32,000-ha palm-oil concession and its environs in central Sumatra to calculate cost-effectiveness and opportunity costs of conservation (OCC) in one of the world's richest areas of biodiversity (20). Our biodiversity surveys were conducted across the study period through >670 km of transect walks across a mosaic of palm plantations, palm nurseries, secondary forest, and recently cleared lands (Fig. 1*A*). Our analysis focuses on the various species of International Union for Conservation of Nature (IUCN) Red Listed mammals that were observed during the course of these walks (analyses of other species are given in *SI Appendix*). These data permitted the estimation of models relating the probability of observing these mammals to the spatial distribution of land uses and other features within and surrounding the concession.

Data necessary to calculate the OCC (foregone profits) were obtained through unconstrained access to all company financial records, including costs and revenues for all operations on each of the ~400 planted and unplanted subcompartments of the concession, geo-referenced and recorded monthly for the entire study period. These data were supplemented by information on the direct costs of restoring degraded land in tropical areas obtained from a review of previous studies (*SI Appendix*). The combined dataset allowed a spatially explicit analysis of the overall cost-effectiveness of conservation in terms of both biodiversity benefits and private costs. We complete our analysis by examining the impacts on company revenues of a conservation-grade price premium [assessed via a multitreatment choice experiment (21, 22)] and comparing this to the costs of conservation to reveal the net effects upon profitability.

Our approach considers three interrelated issues: (*i*) conservation potential (assessed via spatial modeling of the impacts of land use in and around the concession on the presence of threatened species); (*ii*) conservation costs (again, spatially modeled from unconstrained access to all company financial records); and (*iii*) potential price premium (analyzed via choice experiments of the value of goods produced by using certified conservation-grade palm oil). Other comparable studies typically operate at broad scales and at a resolution beyond that which is relevant to the individual landowner responding to market forces can do when faced with a potential profit–conservation tradeoff (23, 24). Applications that simultaneously collect primary cost and biophysical data are still few and far between, and our access to such fine-grained corporate financial data is particularly rare, given the sensitivities involved in providing such data to third parties. Here, by focusing on how the private benefits of consumers may offset the private costs of conservation-grade palm-oil production, our study also circumvents problems associated with studies that assume the intervention of a "social planner," typically backed by national or international government tax transfers to offset conservation costs (23–25).

Results

Biodiversity Effectiveness of Conservation. The species of IUCN Red Listed mammal observed were agile gibbon (*Hylobatres agilis*), pig-tailed macaques (*Macaca nemestrina*), long-tailed macaque

(*Macaca gascicularis*), East Asian porcupine (*Hystrix brachyuran*), smooth-coated otter (*Lutrogale perspicillata*), siamang (*Symphalangus syndactylus*), and pangolin (*Manis javanica*). Models were built relating observations of these different mammals to land uses, natural and physical features both in the immediate vicinity of the observation and across the landscape mosaic within and surrounding the concession (see *Materials and Methods* and *SI Appendix* for details). These models are used to predict the probability of sighting different species at each location (200-m grid cell) across the study. Fig. 1*B* shows the total number of Red Listed species for which the probability of sighting (or "potential presence") is ≥50% for a daily 200-m walk at that location aggregated over a year (again, see *Materials and Methods* and *SI Appendix* for details).

Comparing our predictions of the probability of sighting Red Listed species with the land-use information shown in Fig. 1*A* clearly shows the highly negative impact of intensive oil palm plantation upon such endangered mammals (illustrated by the low probabilities of sighting dominating the central plantation area of the concession). These mammals also fare poorly in highly fragmented landscapes characterized by substantial elements of both plantation and recently cleared land (as in the western arm of the concession). However, the same species perform much better within secondary forest, as shown in the southern area of the concession (contrasting this result with the low probabilities of observation shown on the northeastern edge of the concession, bordering farmland and plantation, clearly shows the impact of surrounding land use). Such findings conform well with previous observations (26) and illustrate the vital importance of spatial targeting for conservation effectiveness.

The Costs of Conservation. Variation in land use and other features results in substantial diversity in biodiversity across the concession. However, relative homogeneity in terrain, soils, and other natural determinants of oil palm output meant that productivity levels were found to be reasonably similar across the plantation. Despite this lack of spatial variation, the introduction of improved management practices raised output of crude palm oil (CPO) across the plantation from ∼220 to just over 300 kg/ha per month over the period of our study. Such a range would clearly affect our estimates of the OCC, and, given that concessions operate at a variety of efficiency levels, we decided to use these extremes as examples of low- and high-production regimes in our subsequent analysis. These rates of output were applied to both currently planted and unplanted areas, with the costs of road development being modeled for those latter areas that were not currently served by roads (*SI Appendix*).

Combining our estimates of the opportunity costs of foregone profits with information on the direct costs of land restoration (*SI Appendix*) allowed us to generate an OCC surface for the entire concession by using a geographical information system (GIS) to bring together spatially referenced data on the location of planted areas, other habitat types, existing roads, and the processing mill. Assuming the high-productivity scenario, we obtain the OCC results illustrated in Fig. 1*C*. This figure shows that the OCC is highest within existing, mature palm plantations near to the processing plant (where transport costs are lowest). We also observe that the presence of existing roads raises the OCC because there is less need for road construction in such areas, and potential profits are higher. Even allowing for the loss of potential future profits inherent in dedicating present secondary forest to permanent conservation, such costs are three to five times higher (depending on output levels) than if conservation land were to be located on present productive plantation areas (see detailed analysis in *SI Appendix*).

The Cost-Effectiveness of Conservation. Integrating our biodiversity effectiveness and cost assessments allows us to undertake a cost-effectiveness analysis for conservation across the concession. This analysis is achieved for each hectare by dividing the predicted biodiversity effectiveness of conversion to conservation (Fig. 1*B*) by the cost of that conversion (Fig. 1*C*). We then rank the resulting "value for money" measure from highest to lowest. Fig. 1*D* illustrates the resulting cost-effectiveness map, with darker shading indicating areas that deliver higher value for money invested in conservation. Inspection of this map shows that the most cost-effective areas for conservation are situated toward the south and west edges of the concession, in areas both in and near to extensive secondary forest within and surrounding the concession, and outside the mature oil palm plantation where conversion costs would be highest. Corresponding population effects were estimated by using scaling models (27), which suggested that conservation in such areas had the potential to make a substantial contribution to the viability of the species concerned (*Materials and Methods* and *SI Appendix*).

We now consider the adequacy of incentives to undertake such conservation actions by assessing the likely scale of a conservation-grade price premium and its net effect upon profitability.

Private Benefits of Conservation: Price Premium for Conservation-Grade Products. Although cost-effectiveness analysis significantly reduces the costs of conservation, these costs remain nontrivial, and therefore incentives are needed to ensure the uptake of such schemes on commercially used private lands. Consideration of the alternatives available for incentivizing producers (discussed in *Materials and Methods*) suggested that these incentives might best be delivered through a price premium associated with certified "conservation-grade" products. Certification might reasonably be provided through an extension of existing initiatives, such as the Roundtable on Sustainable Palm Oil Certified Sustainable Palm Oil scheme (28, 29). To assess the extent to which such certification of products might result in a price premium, we designed a multitreatment choice experiment (21), implementing this assessment through a field survey of developed world supermarket shoppers (see *SI Appendix* for details).

Our study presented shoppers with choices between pairs of a common household good (margarine) that were physically identical except for whether the palm oil they contained was conservation-grade or conventionally produced. The price differential between the two goods was varied across shoppers, allowing us to observe the premium that consumers were prepared to pay for the conservation-grade good. Multiple treatments revealed that the absolute level of price premium was greatest for higher-quality products. Together, our results indicate that people would be willing to pay a conservation-grade premium ranging from 15% to 56%, with a central value of 36% (full details are given in *SI Appendix* and ref. 22)—values that we used in our subsequent analysis of impacts on profitability.

The Profitability of Cost-Effective Conservation Schemes in the Presence of a Price Premium. Our cost-effectiveness analysis illustrated that substantial reductions in the private costs of conservation could be achieved through spatial targeting. However, residual costs remain nontrivial and will deter many private landowners unless adequately compensated by higher prices for certified, conservation-grade production. To investigate this issue, we compared the additional costs faced by firms undertaking cost-effective conservation schemes (as per Fig. 1*D*) with the higher revenues associated with conservation-grade production for each of the price premiums identified in our consumer survey. The resulting net benefits (i.e., change in profitability) to the firm are summarized in Fig. 2. Here, Fig. 2*A* considers a concession of the same size as that studied (32,000 ha), showing that larger conservation schemes progressively remove areas of productive palm plantation, raising costs and causing the net-benefit curve to decline. Nevertheless, even at the lowest

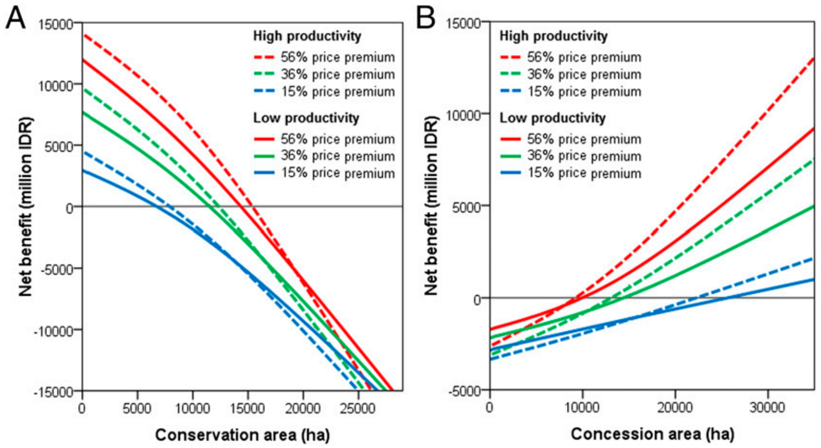

Fig. 2. The profitability of cost-effective conservation schemes in the presence of differing price premiums and productivity levels. (*A*) The net benefit (change in profits) accrued by a concession of a constant size (32,000 ha) with varying conservation areas. (*B*) The net benefit accrued by concessions of differing sizes with a constant conservation area (5,000 ha).

price premium, conservation areas of up to 6,000 ha increase profits. Concessions with higher productivity make larger profits from such levels of conservation because the price premium attaches to their higher levels of output. However, this differential switches with larger conservation areas because higher levels of productivity mean that reductions in the size of oil palm plantation result in a greater loss of output. As expected, higher price premiums incentivize larger conservation schemes, but even given the most favorable conditions, the firm still devotes the majority of land toward production.

Of course, not all concessions are of the same size as the one we studied. Fig. 2*B* shows the net benefits associated with a conservation scheme of 5,000 ha as the concession area increases (assuming that the distribution of habitat types at our study site is representative of other concessions). Our results show that both the level of price premium and concession size are important determinants of the private incentives for conservation. Higher price premiums again improve the incentives for conservation, but for small plantations of <10,000 ha, even the highest price premium fails to make conservation schemes financially attractive. Indeed, at the smallest price premium, only concessions >25,000 ha have an incentive to engage in this (albeit substantial) level of conservation. The impact of higher levels of productivity also varies by concession size, being positive for larger concessions for which high output levels reap greater rewards from the price premium. Overall, the analysis reveals that larger, high-productivity firms generally have substantially greater incentives to engage in conservation activities. Given this finding, the engagement of smaller producers might require cooperative agreements spanning groups of similar-sized firms.

Discussion

By jointly considering the spatial variability of both the cost-effectiveness and OCC, and linking these with the price premiums that developed-world consumers are willing to pay, we have demonstrated the potential for a mixture of market forces, spatial targeting, and certification to incentivize private producers to engage in levels of conservation effort that are relevant to sustaining populations of the IUCN Red Listed vertebrates observed in our case study. The principle of trying to use incentives to increase the provision of habitat on private lands and hold back the conversion of secondary forest into intensive plantation seems vital in areas where primary forests have already been reduced to low levels. However, for this potential to be realized, the certification of conservation-grade production requires careful design, both to avoid the creation of fragmented ribbons of habitat [isolated within intensive plantations and yielding little biodiversity value (26, 30)] and to reduce conversion of secondary forest to oil palm [which remains a vulnerability of the current Roundtable on Sustainable Palm Oil scheme (31, 32)]. The downward sloping net-benefit curves illustrated in Fig. 2*A* indicate that the profit-maximizing strategy of the private producer is to engage in the minimal level of conservation consistent with certification. It is therefore imperative that any certification scheme should not only prohibit the inclusion of newly deforested areas but also require a minimum conservation area. Furthermore, the higher profits accruing to high-productivity larger concessions means that there is scope to augment this minimum area threshold with a requirement for increases in absolute conservation areas for larger concessions and still maintain the profit incentive. The analysis conducted above provides some useful results in this respect, showing that areas that substantially exceed the minimum thresholds for conservation suggested by prior studies (33) can still be profitable if suitably incentivized by price premiums.

Although drawing upon a substantial amount of economic, consumer, and biodiversity data, the findings presented in this work need to be replicated across a diversity of geographical sites and economic conditions. Consequently, our study cannot be considered as definitive in terms of the precise level of economic returns, but it nevertheless demonstrates the potential for adding a further complementary approach to addressing the vitally important issue of biodiversity loss. Given this finding, the fact that our results suggest that such an approach might be sufficient to incentivize conservation is encouraging, particularly because we see this approach as a supplement to—rather than replacement for—other initiatives such as Reducing Emissions from Deforestation and Forest Degradation, which, to date, appear underfunded (12). Furthermore, some relatively simple extensions should substantially enhance both the incentives and biodiversity effectiveness of conservation schemes on private lands. Allowing the establishment of contiguous conservation areas that span concessions may further reduce costs and improve incentives for landowners to participate in such undertakings. Simple design principles that trade off improvements in the overall size, spatial coherence (including linkage with surrounding forested areas), and contiguity of conservation areas (31, 34) against reductions in the land contribution made by each participating concession provide win–win outcomes for both biodiversity and landowners. The potential for such gains to be further enhanced through the funding of even larger off-site conservation reserves (35) is also worthy of consideration.

In conclusion, our findings directly address the joint challenge that ecosystem science needs to become both operational and integrated within its wider socioeconomic context if it is to change decisions and resource use (2, 36, 37). Through analyses such as the cost-effectiveness and conservation profitability assessments reported here, we demonstrate that the integration of both ecological and economic research yields insights that neither can illuminate alone. Moreover, through the integration of financial, ecological, and environmental information in a concise, consistent, and comparable format, we have provided an approach that addresses calls to provide business with tools and metrics to understand the benefits that nature can bring to their operations (38).

Materials and Methods

Biodiversity Effectiveness of Conservation. Data regarding the relationship between species and the matrix of land uses within and surrounding the study area were gathered from a series of 16 transects located across the concession to sample all of its land-use types from secondary forest to intensive palm-oil plantation. Transects had a mean length of 1.5 km and were walked on average 28 times over the sampling period, including both day and night, across all months of the year and in a range of weather conditions. This process provided a total of ∼670 km of transect walks. To allow for variation in spatial characteristics along a walk, each transect was divided into 200-m segments, yielding >3,300 such segments in all.

A variety of species was observed, including the IUCN Red Listed mammals listed previously and a number of other species analyzed in *SI Appendix*. The location of each observation was recorded by using a global positioning systems device with an approximate resolution accuracy of 3 m. A GIS was used to integrate the location of observations with data from local map and satellite images to generate a range of >30 variables that might reflect determinants of species observations, including the predominant habitat within each transect segment, distance- and area-based habitat measures, human disturbance indicators, etc. (see details in *SI Appendix*).

Models of the probability of observing different IUCN Red Listed species were estimated by using a generalized linear model with a logistic link function and a binomial distribution (see details in *SI Appendix*). Observation data were structured as a panel dataset to account for repeated sampling of transect segments and fit with robust SEs to account for spatial and temporal autocorrelation. Explanatory variables were obtained from observations or calculated in the GIS (e.g., distance to each habitat type). Model selection was based on theoretical considerations in conjunction with a quasi-likelihood criterion to compare nested specifications. Models were then used to predict the probable presence of different species across the study area. To do this prediction, the concession was divided into 200- × 200-m grid cells, corresponding to the spatial resolution of the regression model, with predictor variables obtained from the GIS and model coefficients used to yield predictions.

Our various IUCN mammal models are used to predict the probability of sighting different species at each location (200-m grid cell), assuming a single daily walk across that cell over the duration of 1 y. Fig. 1*B* shows the total number of species for which the probability of a sighting is ≥50%. This is constructed by using the models to predict the probability of sighting a given species and assigning a value of 1 if the probability of a sighting is ≥50% and 0 otherwise. These values are then summed for all Red Listed species to yield the probability measure given in Fig. 1*B*.

The presence of a species within an area does not imply its long-term survival, but, all other things being equal, larger conservation areas should deliver larger populations of species. Estimates of this relationship were provided by mechanistic scaling models (27), linking expected population to animal body mass, trophic level, and the various extents of conservation area considered in our study and shown in Fig. 1*D* (see *SI Appendix* for details). The application of such models is at best a rough approximation of response, because the accuracy of this approximation may vary substantially across locations, and consequently results should not be overinterpreted. Accepting this limitation, these models suggest that the various conservation areas are expected to yield populations of Red Listed species ranging from <100 for larger carnivorous mammals to well over 5,000 individuals for some herbivores (see *SI Appendix* for results). At various times, it has been suggested that populations of the order of 50, 500, and 5,000 might enable long-term persistence (39, 40), although Flather et al. (41) questioned whether data or theory support such generalizations. It has also been suggested that for species such as those reported here with a body mass of 5–23 kg that the minimum area requirement to contribute to the viability of species is of the order of 10,000 ha (42). We do not claim that the conservation measures taken here would ensure the viability of the species' populations. However, it is clear from the population estimates and the area of land being set aside for conservation in this analysis that the measures advocated here have the potential to make a substantial contribution to the viability of the species concerned. Furthermore, we would not expect that profitable schemes (as outlined subsequently) would be confined to single concessions, and the potential for enhanced conservation coordinated across multiple sites enhances the likelihood that they would deliver sustainable populations for the species concerned.

Production and Financial Data. The concession contained large areas of mature and immature oil-palm plantation, secondary forest, and bamboo-dominated scrubland. To the northern edge of the concession, farming, small settlements, and government oil-palm plantations create an agricultural mosaic (*SI Appendix*). By contrast, the southern edge was mainly secondary forest. The private revenues and costs associated with the production of CPO in both planted and unplanted areas were assessed by applying the principles of agricultural economics (43). The concession management granted full access to all cost and revenue data broken down to the field unit for the years 2002–2006. These data consisted of highly disaggregated, spatially referenced, financial and physical quantity information, environmental characteristics, and meteorological condition records for each of the nearly 400 subcompartments (averaging ∼30 ha each) of the concession (planted and unplanted). More than 90 variables were provided for each subcompartment ,with these data being collected every month throughout the study, yielding a total of >1.5 million data records over the full period. These data included the following: average price at which the concession sold its CPO; total kilograms of oil-palm fresh fruit bunches (FFBs) harvested; total number of kilograms of CPO sold; income from CPO sales; administrative costs; fixed costs of the processing mill; debt servicing and other outgoings; cost of producing CPO from FFBs at the mill; general maintenance costs such as pruning, weeding, fertilizing, and censuses; wages; cost of transporting FFBs to the mill; field office costs; area of productive oil palms; etc. Further statistics such as productivity measures were calculated from these data. Selected summary statistics aggregated at an annual level are presented in *SI Appendix*.

OCC. The OCC of each area of the concession comprised following components: (*i*) the actual (for planted areas) or predicted potential (for unplanted areas) gross margin (revenue minus variable costs other than those mentioned subsequently) for that area; (*ii*) transport cost from the area to the processing mill; (*iii*) the annuitized predicted cost of road construction to that area from the existing road network; and (*iv*) the restoration cost for area. Further details on these calculations are given in *SI Appendix*.

Although output varied substantially in response to changes in inputs such as fertilizer, an analysis of FFB data showed insignificant spatial variation in yield across the planted areas of the concession. Although this result is unsurprising given the absence of substantial differences in soil, elevation, watershed, and other physical characteristics over that area, research from other contexts shows that, where such variation does occur, analysts should expect and allow for a yield response (see, for example, ref. 44). Given the results of this analysis, in calculating the potential profitability (and hence OCC) of currently unplanted areas, it was assumed that, if converted to plantation, they would provide similar levels of output to existing planted areas. Expected FFB output was then related to data on the proportion of fruit mass converted to oil to calculate monthly output of CPO. Combining these data with data on prices provided our revenue estimates. Cost data on inputs, maintenance, development, and processing were combined with spatially disaggregated estimates of site-specific transportation costs, the latter being predicted by using GIS to apply per-kilometer cost estimates to road network data. As part of this calculation, we incorporated, within the potential profits of unplanted areas, the costs of constructing new roads. We took local construction-cost values from the literature and account for the fact that, as an unplanted area is developed, new roads will spur off each other. Subtracting the sum of these costs from revenues provided our predicted profits for both planted and currently unplanted areas. Overall cost estimates were completed by adding in local restoration costs, again taken from the literature, which also provided indications of the relevant time profiles and discount rates for Indonesian investment projects. Details of calculations and information sources are provided in *SI Appendix*.

Private Benefits of Conservation. A variety of approaches can be identified as potential means for incentivizing producers to engage in conservation. One approach would be to fund such incentives through a social planner backed by international transfers. However, such approaches are vulnerable to problems such as the corrupt divergence of funds, failure of donors to pay, and changes in donor priorities (12, 45). In this work, we consider the potential for alternative (or, ideally, supplementary) incentives provided by the price premium attached to "conservation-grade," "fair-trade," "certified," and similar goods. Such differentiated goods have arisen in response to demand, primarily from developed world consumers, who are prepared to pay a premium for preferred methods of production and the perceived positive externalities that they bring (46). Given that Europe, the United States, and Australia alone consume close to 20% of the world's palm oil (47), the potential exists for a substantial portion of that production to generate conservation-grade price premiums.

The choice-modeling valuation technique was used to estimate the price premium that might be attached to products containing conservation-grade as opposed to conventionally produced palm oil. Survey subjects were presented with a choice between two standard-size (500 g) tubs of vegetable margarine, chosen because it has high consumer recognition and palm oil is a major ingredient. The questionnaire was extensively piloted (n = 150), and field data (n = 600) were collected by using survey techniques applied at UK supermarkets. "Next-to-pass" interviewing techniques were applied to ensure a random sample. The price and quality of the two products, as well as the degree of information about the conservation-grade good, were all varied independently across subjects (details are provided in *SI Appendix*). Treatments themselves were randomized, such that each respondent had an equal probability of facing any permutation of our experiment. Individuals were asked a number of other questions regarding their socioeconomic and demographic characteristics, as well as various other issues that might affect preferences. These factors were controlled for in subsequent analyses.

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1. Hoffmann M, et al. (2010) The impact of conservation on the status of the world's vertebrates. *Science* 330(6010):1503–1509.
2. Tedesco PA, et al. (2014) Estimating how many undescribed species have gone extinct. *Conserv Biol* 28(5):1360–1370.
3. Foley JA, et al. (2005) Global consequences of land use. *Science* 309(5734):570–574.
4. Naeem S, Duffy JE, Zavaleta E (2012) The functions of biological diversity in an age of extinction. *Science* 336(6087):1401–1406.
5. Hansen MC, Stehman SV, Potapov PV (2010) Quantification of global gross forest cover loss. *Proc Natl Acad Sci USA* 107(19):8650–8655.
6. Phalan B, et al. (2013) Crop expansion and conservation priorities in tropical countries. *PLoS ONE* 8(1):e51759.
7. Hansen MC, et al. (2013) High-resolution global maps of 21st-century forest cover change. *Science* 342(6160):850–853.
8. FAO (2010) *The Global Forest Resources Assessment 2010* (Food and Agriculture Organization of the United Nations, Rome).
9. Miettinen J, Shi C, Liew SC (2011) Deforestation rates in insular Southeast Asia between 2000 and 2010. *Glob Change Biol* 17:2261–2270.
10. Lee JSH, et al. (2014) Environmental impacts of large-scale oil palm enterprises exceed that of smallholdings in Indonesia. *Conserv Lett* 7:25–33.
11. Wilcove DS, Giam X, Edwards DP, Fisher B, Koh LP (2013) Navjot's nightmare revisited: Logging, agriculture, and biodiversity in Southeast Asia. *Trends Ecol Evol* 28(9): 531–540.
12. Edwards DP, et al. (2014) Land-sharing versus land-sparing logging: Reconciling timber extraction with biodiversity conservation. *Glob Change Biol* 20(1):183–191.
13. Margono BA, et al. (2012) Mapping and monitoring deforestation and forest degradation in Sumatra (Indonesia) using Landsat time series data sets from 1990 to 2010. *Environ Res Lett* 7(3):034010.
14. Vandermeer J, Perfecto I (2007) The agricultural matrix and a future paradigm for conservation. *Conserv Biol* 21(1):274–277.
15. Butchart SH, et al. (2010) Global biodiversity: Indicators of recent declines. *Science* 328(5982):1164–1168.
16. Secretariat of the Convention on Biological Diversity (2010) *Global Biodiversity Outlook 3* (Convention on Biological Diversity, Montreal).
17. Waldron A, et al. (2013) Targeting global conservation funding to limit immediate biodiversity declines. *Proc Natl Acad Sci USA* 110(29):12144–12148.
18. Nelson E, et al. (2008) Efficiency of incentives to jointly increase carbon sequestration and species conservation on a landscape. *Proc Natl Acad Sci USA* 105(28):9471–9476.
19. Fisher B, et al. (2011) The high costs of conserving Southeast Asia's lowland rainforests. *Front Ecol Environ* 9(6):329–334.
20. Myers N, Mittermeier RA, Mittermeier CG, da Fonseca GA, Kent J (2000) Biodiversity hotspots for conservation priorities. *Nature* 403(6772):853–858.
21. Hess S, Daly A (2013) *Choice Modelling: The State of the Art and the State of Practice* (Edward Elgar, Cheltenham, UK).
22. Bateman IJ, et al. (2010) Tigers, markets and palm oil: Market potential for conservation. *Oryx* 44(2):230–234.
23. Bateman IJ, et al. (2013) Bringing ecosystem services into economic decision-making: Land use in the United Kingdom. *Science* 341(6141):45–50.
24. Lawler JJ, et al. (2014) Projected land-use change impacts on ecosystem services in the United States. *Proc Natl Acad Sci USA* 111(20):7492–7497.
25. Polasky S, Nelson E, Pennington D, Johnson KA (2011) The impact of land-use change on ecosystem services, biodiversity and returns to landowners: A case study in the state of Minnesota. *Environ Resour Econ* 48(2):219–242.
26. Edwards DP, Fisher B, Wilcove DS (2012) High conservation value or high confusion value? Sustainable agriculture and biodiversity conservation in the tropics. *Conserv Lett* 5:20–27.
27. Jetz W, Carbone C, Fulford J, Brown JH (2004) The scaling of animal space use. *Science* 306(5694):266–268.
28. RSPO (2007) *RSPO Certification Systems* (Roundtable on Sustainable Palm Oil, Kuala Lumpur, Malaysia).
29. RSPO (2013) *Principles and Criteria for the Production of Sustainable Palm Oil* (Roundtable on Sustainable Palm Oil, Kuala Lumpur, Malaysia).
30. Hill JK, et al. (2011) Ecological impacts of tropical forest fragmentation: How consistent are patterns in species richness and nestedness? *Philos Trans R Soc Lond B Biol Sci* 366(1582):3265–3276.
31. Edwards DP, Laurance SG (2012) Green labelling, sustainability and the expansion of tropical agriculture: Critical issues for certification schemes. *Biol Conserv* 151:60–64.
32. Greenpeace (2013) *Certifying Destruction* (Greenpeace, Amsterdam).
33. Kadoya T (2009) Assessing functional connectivity using empirical data. *Popul Ecol* 51(1):5–15.
34. Rayfield B, Fortin M-J, Fall A (2011) Connectivity for conservation: A framework to classify network measures. *Ecology* 92(4):847–858.
35. Carpenter SR, et al. (2009) Science for managing ecosystem services: Beyond the Millennium Ecosystem Assessment. *Proc Natl Acad Sci USA* 106(5):1305–1312.
36. Polasky S (2008) Why conservation planning needs socioeconomic data. *Proc Natl Acad Sci USA* 105(18):6505–6506.
37. Nelson E, et al. (2009) Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. *Front Ecol Environ* 7:4–11.
38. Ecosystem Markets Task Force (2013) *Realising Nature's Value: The Final Report of the Ecosystem Markets Task Force* (Defra, London).
39. Franklin IR (1980) Evolutionary change in small populations. *Conservation Biology: An Evolutionary–Ecological Perspective*, eds Soule ME, Wilcox BA (Sinauer Associates, Sunderland, MA), pp 135–150.
40. Traill LW, et al. (2010) Pragmatic population viability targets in a rapidly changing world. *Biol Conserv* 143:28–34.
41. Flather CH, Hayward GD, Beissinger SR, Stephens PA (2011) Minimum viable populations: Is there a 'magic number' for conservation practitioners? *Trends Ecol Evol* 26(6):307–316.
42. Pe'er G, et al. (2014) Toward better application of minimum area requirements in conservation planning. *Biol Conserv* 170:92–102.
43. Barkley A, Barkley A (2013) *Principles of Agricultural Economics* (Routledge, New York).
44. Bateman IJ, Lovett AA (1998) Using geographical information systems (GIS) and large area databases to predict yield class. *Forestry* 71(2):147–168.
45. Smith RJ, Muir RD, Walpole MJ, Balmford A, Leader-Williams N (2003) Governance and the loss of biodiversity. *Nature* 426(6962):67–70.
46. Treves A, Jones SM (2010) Strategic tradeoffs for wildlife-friendly eco-labels. *Front Ecol Environ* 8:491–498.
47. Wilcove DS, Koh LP (2010) Addressing the threats to biodiversity from oil-palm agriculture. *Biodivers Conserv* 19(4):999–1007.