LETTER

Conservation through Chocolate: a win-win for biodiversity and farmers in Ecuador's lowland tropics

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Keywords
Cocoa; cacao; trade-offs; conservation outside protected areas; Chocó; wildlife-friendly farming; agroforestry; certification.

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Received
7 June 2011
Accepted
8 February 2012

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Editor
James Aronson

doi: 10.1111/j.1755-263X.2012.00230.x

Abstract

Global biodiversity conservation significantly depends on bringing conservation measures to the agricultural production systems that dominate the earth's surface. One of the leading candidates for wildlife-friendly farming in the megadiverse lowland tropics is shade-grown cocoa. However, tropical farmers increasingly believe that shade reduces yield and consequently, are removing most shade trees from their farms. Conservation goals therefore conflict with production imperatives. Nevertheless, we tested the trade-off between production and biodiversity conservation in the critical conservation area of the Ecuadorean Chocó and found that both farmers and biodiversity would benefit from an increase in shade. This rare partial win-win situation in wildlife-friendly farming permits the creation of a sustainable, economically sensitive certification and geographic indication for biodiversity-friendly chocolate. We suggest that similar trade-off studies be carried out in other agroforestry regions of conservation importance, not least to establish the probable sustainability of conservation initiatives in production-centered landscapes.

Protected areas cover only 12% of global land and have proven insufficient to conserve biodiversity (Secretariat of the Convention on Biodiversity 2010). Our final conservation legacy now depends critically on how well we can enhance habitat and connectivity in the large agricultural matrix surrounding protected areas (Perfecto*et al.* 2009). However, conservation-driven measures to increase habitat on farmlands can easily imply production losses, with major negative consequences for human well-being (Donald 2004; Green *et al.* 2005; Fischer *et al.* 2006; Norris 2008). A key conservation challenge is therefore to find ways of enhancing biodiversity conservation in the agricultural matrix without negatively affecting production and livelihoods (Green *et al.* 2005, Fischer *et al.* 2006, Perfecto *et al.* 2009). This challenge is particularly acute in the megadiverse but economically less-developed countries of the wet tropics.

One of most biodiversity-friendly agricultural crops in the wet tropics is thought to be cocoa – the crop from which chocolate and cocoa butter are made (see reviews in Rice & Greenberg 2000; Schroth *et al.* 2004, 2011; Schroth & Harvey 2007). Cocoa has traditionally been grown as part of an agroforestry system where cocoa trees are intermixed with rainforest trees (and some fruiting trees), henceforth "shade" for short (Ruf & Schroth 2004). Well-shaded cocoa contains high diversities of many birds, invertebrates, and important mammals, although comparisons with other land uses have not always been available (Rice & Greenberg 2000; Schroth*et al.* 2004; Harvey *et al.* 2006; Harvey & Gonzalez Villalobos 2007; Delabie *et al.* 2007; Cassano *et al.* 2009; Clough *et al.* 2011). Shade-grown cocoa could also be critical to providing connectivity or buffer zones for the remaining forests, reducing extinction at the landscape scale (Laurance *et al.* 2002; Siebert 2002; Schroth*et al.* 2004; Donald 2004; Delabie *et al.* 2007; Schroth *et al.* 2011).

However, cocoa farmers and government technicians now widely believe that felling shade trees increases

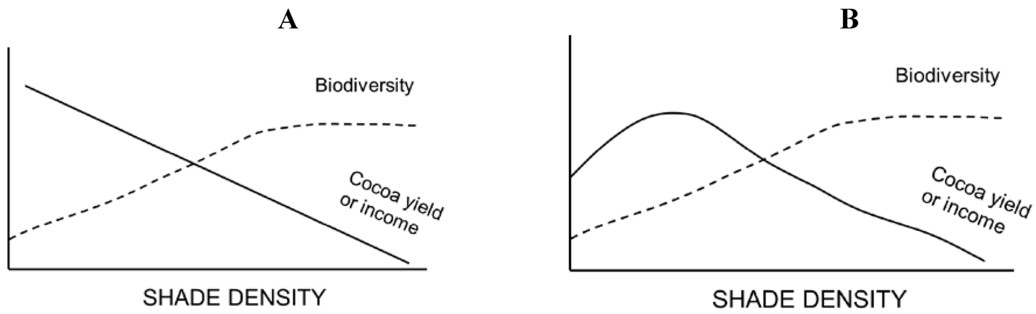

Figure 1 Theoretical models of the trade-off between biodiversity conservation (dashed line) and production (solid line) in an agroforestry landscape. A: Goals always conflict—as shade increases, biodiversity also increases but production decreases. B: Goals congruent over some shade values—both biodiversity and production interests are served by increasing shade up to a certain point but conflict beyond that point.

cocoa productivity and consequently, most cocoa-producing regions have dramatically reduced shade tree densities in recent years (Wood & Lass 2001; Siebert 2002; Ruf & Schroth 2004; Zuidema *et al.* 2005; Steffan-Dewenter *et al.* 2007; Clough *et al.* 2011; Schroth *et al.* 2011; Ruf 2011). Recent research indeed suggests that removing shade causes a linear or near-linear increase in crop yield (Wood & Lass 2001; Steffan-Dewenter*et al.* 2007; Clough *et al.* 2011). Production goals are therefore in direct opposition to biodiversity conservation goals (Figure 1A, adapted from Norris 2008). Farmers will naturally gravitate towards the level of shade that gives the highest yield, which unfortunately may be the level of shade that gives the lowest conservation benefit (Schroth *et al.* 2004; Ruf 2011). One of the main strategies for biological conservation outside protected areas in the megadiverse tropics therefore seems to have a very unpromising future (Ruf 2011).

Incentivizing biodiversity-friendly cocoa production

Well-shaded cocoa could still be made to work as a conservation tool if farmers were given an economic reason to replant shade trees (or to stop cutting them down). One interesting but little-explored possibility is that in some growing areas, smallholders have been influenced by general, global trends to remove more shade trees that are locally optimal for production.

Alternatively, farmers have an economic reason to increase shade if they are paid directly for the associated biodiversity conservation benefits (Payments for Ecosystem Services, hereafter PES). This study is indeed part of an applied conservation strategy by the local Ecuadorean NGO Fundacion Maquipucuna to create a biodiversity-friendly chocolate certification, as part of the standards underlying a geographic indication (GI) for the Chocó-Andes Biological Corridor (R. Justicia personal communication). GI gives a competitive market advantage by protecting intellectual property rights associated with specific local conditions. In developing countries where those local conditions include high biodiversity, GI could be a way to internalize biodiversity value, thus combining economic development with hotspot conservation (Bramley *et al.* 2009; R. Justicia personal communication). Certified farmers would receive a price premium (perhaps between 5% and 35% before costs, based on shade-grown coffee experiences reviewed by Giovannucci & Koekoek (2009) or other assistance of indirect economic value (Millard 2011).

Quantifying tradeoffs for sustainability

At least medium-density shade is probably needed for meaningful biodiversity conservation, for example, some current certifications demand 40% canopy cover (Millard 2011). On average, farmers would not normally choose such high levels of shade because of the significant production loss (-L) implied (Ruf 2011). The premium (P) alters the farmer's economic incentives by creating a net income increase ($P - L > 0$). Certificates are unsustainable whenever $P - L < 0$ (a farmer makes a net loss from entering the conservation scheme; Perfecto *et al.* 2005). It therefore seems wise to quantify the shade/yield and shade/biodiversity relationships in advance of standard setting, to estimate sustainability thresholds and the associated conservation/production trade-offs.

The parameters of the shade/yield function for a region will be difficult to estimate exactly. However, even the approximate shade/yield function shape gives an immediate indication of the probable success and sustainability of shade-based conservation initiatives in a region. Under a linear function, yield loss at medium shade is so large that shade-based conservation programs are almost certainly unsustainable (see Figure 1A). Convex functions (Figure 1B), however, suggest a much better chance of sustainability because conservation and production requirements are partially congruent. Indeed, only in regions with promisingly convex functions, and only by combining PES with a clear indication of excessive shade removal locally, are we likely to generate sufficient incentives to sustainably prevent farmers from switching over to low-shade systems, especially now that low-shade, high-yielding hybrids are being developed (Ruf 2011).

From a biodiversity conservation point of view, it would particularly be worthwhile to search for excessive shade removal, convex functions, and certification sustainability thresholds in agroforestry regions of critical conservation importance. Here, we explore the trade-off between shade/yield and shade/biodiversity relationships in cocoa farms occupying one of the top global conservation hotspots, the Chocó in northwest Ecuador. The Ecuadorean Chocó may have more heavily threatened plant species than any other place in South America, with 20% endemism but less than 10% of forests remaining and a deforestation rate exceeding 4% per year in some areas (Dodson & Gentry 1991; Davis *et al.* 1997; Sierra & Stallings 1998; CEPF 2001). The Chocó is recognized as a critical conservation area by numerous organizations (e.g., Myers 1988; Olson & Dinerstein 1998; Stattersfield *et al.* 1998) and is also directly connected along an altitudinal gradient to the highly valued and megadiverse Andes hotspot (Myers 1988, Justicia 2007). Cocoa traditionally provided the major export crop of the Chocó and is still a mainstay of smallholder agriculture despite rapidly spreading palm oil plantations (CEPF 2001; Justicia 2007).

Methods

The study was carried out in Esmeraldas province in northwest Ecuador, which lies in the Chocó bioregion. We selected 16 cocoa smallholdings (mean size 1.5 ha) that used a wide range of shade densities (Supplementary Online Material, hereafter SOM). On each farm, we measured mean shade tree density and mean planting density in a stratified sample of three 30 m × 50 m quadrats (0.45 ha total). (For comparison with other studies, we give approximate canopy cover equivalents to shade tree density in Section "Results" and SOM). We measured shade tree diameter at breast height (dbh) per farm using a random sample (mean $n_{\text{perfarm}} = 61$). We determined annual cocoa production per hectare and other revenues and costs by interviewing the smallholder (Table 1).

We created two categories of farmer income that might be affected by shade. The first, "physical net income," is the net difference between physical farm revenues (cocoa, other fruit and timber) and physical farm costs (Table 1). The second, "effective net income," adds the value of income that farmers can earn outside of cocoa onto physical net income. The ability to earn extra noncocoa income implies that farmers are saving time on their main cocoa work, potentially thanks to labor-saving ecological services flowing from shade. We therefore refer to the value of noncocoa labor time as an "opportunity credit" (SOM).

Table 1 Factors included in economic analysis of cocoa farmers' net income

General data
Size of farm (hectares) and size of cocoa area within farm
Age of farmer
Age of cocoa trees
Revenue data (all expressed per hectare per year)
Cocoa harvest
Fruit sales from fruit-bearing shade trees
Timber sales from exploited shade trees
Estimated value of fruit eaten by the family from shade trees
Estimated value of timber from shade trees used in personal construction (net of processing charges)
Opportunity credit for hours weekly that farmer can work outside cocoa farm—calculated as the difference between full work week and farmer's work week
Cost data (all expressed per hectare per year)
Cost of fertilizer
Cost of other chemical inputs
Cost of hired farm labor
Transport costs
Estimated value of family labor (which reduces the need for hired labor)

We used bird species diversity as our biodiversity measure. We visited each smallholding several times (usually six, see SOM) and counted all bird individuals seen or heard during a 40-minute transect. Farms were located in two distinct landscape types: (1) an area of continuous forest surrounded by cocoa fields and (2) semi-open agriculture with no forest. Farms in area (1) might be expected to have greater bird diversity simply because they draw from a richer species source pool in the landscape. To correct for source pool effects, each individual farm transect was paired with a near-simultaneous (±1 hour) baseline transect in the local landscape. Baseline transects for the forested areas were carried out in local forest; baselines for the semi-open area were carried out in a homogeneous semi-open zone (SOM). To check for landscape-specific bias in baseline corrections and shade levels, we included landscape type in our regression analyses. We also categorized farm position as (1) adjacent to continuous primary forest; (2) within a forested landscape but not directly adjacent to forest; and (3) in a deforested landscape.

Final bird diversity is expressed as mean (on-farm diversity/ baseline diversity) for each farm. The paired simultaneous baselines also control for daily weather effects on observed diversity. We discarded any data points where weather conditions changed notably between a farm transect and its baseline ($n = 1$).

Analysis

We built multiple regression models to explore the relationship between shade density and (1) yield per tree; (2) cocoa production per hectare; (3) farmer's physical net income per hectare; (4) farmer's effective net income per hectare; (5) avian diversity (total and threatened). For the analyses of (1–4), we regressed the dependent variable on subsets of the terms: shade density (linear term and quadratic term); planting density; cocoa tree age; and mean shade tree dbh (Table 2 and SOM), using an information theoretic approach (Burnham & Anderson 2002).

For bird species diversity (analysis 5), we regressed (i) total diversity (a total of 2,910 bird records) and (ii) threatened diversity (223 records based on the national Red List, Granizo *et al.* 2002) on subsets of the terms shade density, shade tree dbh, farm position, and landscape type. For total diversity, QQ plots diagnosed heavy-tailed distributions and so we fitted nonparametric generalized additive models (GAMs) with smoother functions for shade density. For Red-listed diversity, zeroes make baselines uninformative so we instead regressed the raw number of threatened species per transect against shade density and farm position, using a Poisson generalized linear mixed model (GLMM) (Laplace approximation) with shade density and farm position as fixed effects and farm position nested in landscape type as random effects (SOM). There was no evidence of overdispersion (dispersion parameter = 1).

Sample size was 16 for analyses (1, 2, and 5b), 15 for analyses (3 and 4) and 14 for (5a), because of one farmer being unable to give full economic data and two baseline areas being inaccessible. Shade density, threatened bird numbers and cocoa planting density are count data and were square root-transformed; diagnostic plots did not suggest problems with these transformations. The dependent variable was ln-transformed in analyses (2 and 4) and $\ln(x + 1000)$-transformed in analysis (3) after examining diagnostic plots. Shade tree dbh was ln-transformed. All analyses were carried out using the R programming language (R Core Development Team 2009).

We used diagnostic plots to identify potential outliers and points of extreme leverage and performed all analyses both with and without these points (with one exception, the topmost bird diversity record in Figure 4 was greatly inflated by multiple visits from a mixed feeding flock and this point was excluded *a priori*).

Results

In analyses (1–3), cocoa yield and farmer income initially increased with increasing shade density, then seemed to reach a tipping point beyond which they started to decrease again, that is, a convex function (Figures 2 and 3). There was repeated support for models that included a convex quadratic term, although not to the complete exclusion of positive linear models (Table 2). The fitted quadratic models suggest that the tipping point (maximum yield) lies at about 144 shade trees per hectare (12 on the square root scale in Figures 2 and 3), equivalent to approximately 40% canopy cover (but see Section "Discussion" and SOM).

Of the dependent variables (1–3), shade tree dbh only predicted yield per hectare, explaining 5% additional variance in that case (Table 2). Planting density had a small negative effect on yield in several models (Table 2) and was negatively correlated with shade density (Spearman's $\rho = -0.59$, $P = 0.015$). This notably implies that more densely shaded farms achieved higher yield per hectare in spite of a lower crop density (up to the tipping point).

Unlike yield and physical net income, effective net income increased linearly with shade, showing no tipping point (Table 2, Figure 3B). It also strongly increased with shade dbh (Table 2). There was a strong correlation between effective net income and the amount of time a farmer was able to spend earning money outside of his/her cocoa plot (Pearson's $r = 0.87$).

Bird diversity, both total and threatened, significantly increased with increasing shade density (Table 2). For total diversity, the fitted GAMs suggest that the function is curved or asymptotic in shape (Figure 4A). For threatened bird diversity, data were too sparse to distinguish potentially nonlinear function shapes (Figure 4B). Landscape type was not a significant predictor of total diversity ($P = 0.68$, SOM), suggesting that baselines had adequately corrected for landscape effects.

Discussion

Our results suggest that an increase in average shade levels in Chocó cocoa would achieve meaningful biodiversity benefits and also increase many farmer incomes (Figures 2–4). Chocó cocoa therefore represents a rare case where yield and biodiversity could both benefit from a wildlife-friendly farming measure. We term this

Table 2 Statistical results from model fitting. All models shown can be considered an equal best fit to data (Delta AICc < 2); see SOM for results from full set of candidate models. Shade = shade density. ":" indicates an interaction.

Analysis #	Candidate regression models	*K*	*AICc*	Δ AICc	*AICc Wt*	*Cum Wt*	r^2 adj.
1	**Yield per tree**						
	shade (quadratic)	4	22.81	0.00	0.39	0.39	0.62
	shade (linear) + planting density + age + age:shade	6	24.72	1.91	0.15	0.54	0.72
	Yield per tree excluding outliers						
	shade (quadratic)	4	17.98	0.00	0.39	0.39	0.72
	shade(quadratic) + planting density	5	19.58	1.91	0.15	0.54	0.76
2	**Yield per hectare**						
	shade (quadratic)	4	28.76	0.00	0.37	0.37	0.48
	shade (quadratic) + shade dbh	5	30.01	1.25	0.20	0.57	0.53
	Yield per hectare excluding outliers						
	shade (quadratic)	4	20.15	0.00	0.81	0.81	0.69
3	**Physical net income**						
	shade (quadratic)	4	0.07	0.00	0.27	0.27	0.29
	shade (linear) + planting density + age + age:shade	6	1.29	1.21	0.15	0.42	0.55
	shade (linear) + planting density + age	5	1.38	1.31	0.14	0.56	0.42
	planting density	3	1.63	1.56	0.12	0.68	0.06
	Physical net income excluding outliers						
	shade(quadratic) + age + age:shade	6	−16.93	0.00	0.94	0.94	0.90
4	**Effective net income**						
	shade + age + shade dbh	5	231.01	0.00	0.46	0.46	0.73
	shade	3	232.04	1.03	0.27	0.73	0.57
	shade + age	4	232.84	1.82	0.18	0.91	0.62
	Effective net income excluding outliers						
	shade + age + shade dbh	5	212.55	0.00	0.74	0.74	0.81
5	**Bird diversity**		**F**	**P**	**% deviance explained**	**r^2 adj**	
	Shade (smoother)		11.87	0.0014	88		0.79
	Bird diversity excluding riverine farm outlier						
	Shade (smoother)		16.25	0.0007	88		0.79
	Threatened bird diversity		**z**	**p**			
	Shade		2.53	0.011			
	Farm position (forest proximity)		−4.00	<0.0001			

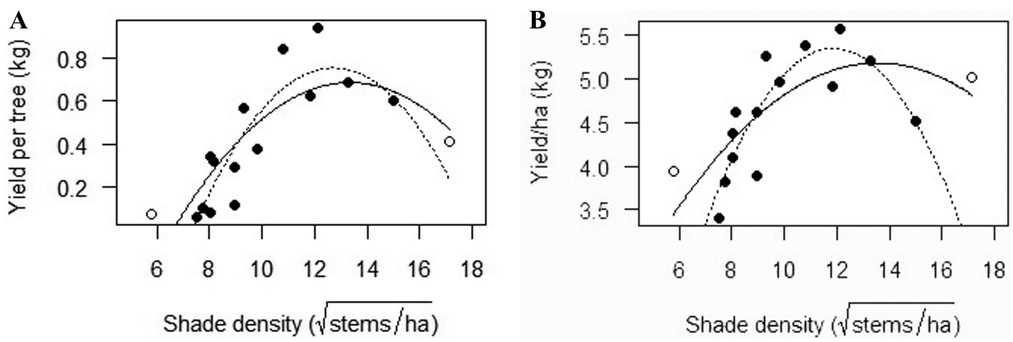

Figure 2 A: The relationship between shade density and yield. A: yield per cocoa tree. B: yield per hectare (ln-transformed). Solid lines show a fitted quadratic model using all data. Dashed lines show the same model after removing outliers. Open symbols show potential outliers.

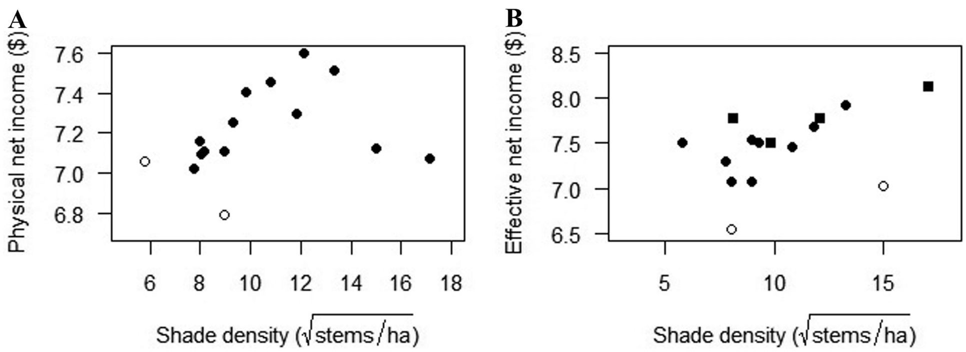

Figure 3 The relationship between shade density and (A) Physical net income per hectare (ln-transformed); (B) Effective net income per hectare ln(x + 1000)-transformed). In (B), squares = farmer had family help; circles = farmer worked alone (SOM). Open symbols indicate potential outliers.

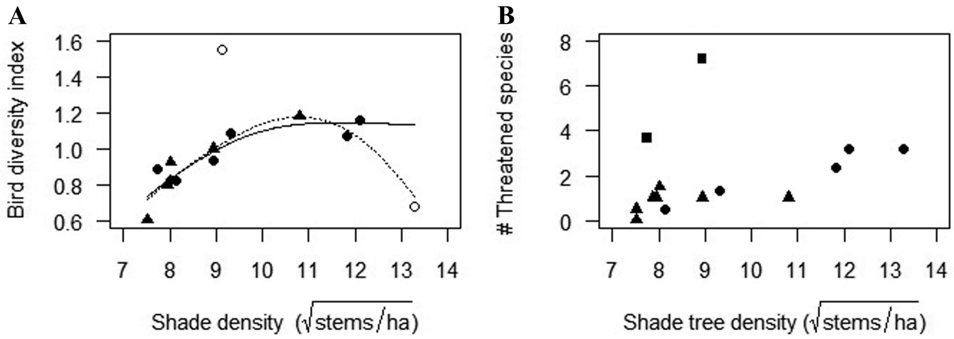

Figure 4 The relationship between shade density and bird diversity in Chocó cocoa. A: Total diversity. Triangles = farms in semi-open areas; circles = farms in forested areas. Open symbols = outliers and high-leverage points (see text). Solid line shows prediction excluding lower high-leverage point, dashed line shows prediction including it. B: Threatened diversity: triangles = farms in semi-open areas, circles = farms near to primary forest, squares = farms adjacent to primary forest.

a "partial win-win" situation because there is a level of shade density beyond which productivity does indeed start to decline, as might be expected in (Figure 2). We caution that the yield maximum and curve coefficients would be more precisely established with more data, particularly at high shade densities.

Effective net income continued to rise with shade density even after yield and physical income started to decline (Figure 3B). This change in function shape must indicate the influence of the opportunity credit, that is, the labor time saved thanks to ecological services flowing from shade. Manual weed control (by machete) was the main use of farmer time, so the ecological service of weed suppression is the most likely to have generated such time savings. A weed suppression effect would also explain why effective income strongly increased with increasing shade tree size (larger trees reduce weed growth more). The strategic management implication is that farmers would have more incentive to use high levels of shade if there were given better access to other income-generating opportunities.

Most studies to date have related shade to production alone or to biodiversity alone, rarely exploring the trade-off or indeed opportunity credits from ecosystem services (but see Bisseleua *et al.* 2009; Clough *et al.* 2011). For the yield function, the Chocó optimum and rate of change are noticeably higher than the global average (anonymous reviewer, personal communication) but very similar to studies from unfertilized cocoa in Africa and Trinidad, where yield also declined sharply away from an optimum of 50% canopy cover (Wood & Lass 2001; Bisseleua *et al.* 2009). We suspect that the convex curve itself arises as the negative effects of shade, such as a reduction in sunlight reaching the crop, trade-off along a shade gradient with positive ecological services such as pollinator habitat, enhanced soil nutrition, weed suppression, and the mitigation of weather extremes (Beer *et al.* 1998; Schroth *et al.* 2004). Chocó smallholders, who use no fertilizer and in general lack technified inputs, would then have a relatively high shade optimum and perhaps a steeper curve because their dependency on free ecological services will be relatively strong.

Nontechnified smallholders may therefore be good candidates when looking for similar win-win situations in other conservation-critical regions, although we think it is worth testing without preconception.

Many (though not all) studies concur with our finding that biodiversity increases with increasing shade (e.g., Rice & Greenberg 2000; Steffan-Dewenter *et al.* 2007; Cassano *et al.* 2009; Schroth *et al.* 2011). We caution against overinterpretation of the threatened bird outcome: threatened species are by definition rare, so robust analysis of their shade response would require an extremely large survey that was beyond our capacity. However, the observation of 33 threatened species on farms does suggest that Chocó cocoa has some conservation value.

Most farmers interviewed barely exploit shade timber and many remote farmers do not sell the fruit from their shade trees either. Full exploitation of noncocoa crops and timber (including improved market access) would likely alter shade/income relationships, although modeling would be needed to test whether it altered the economically optimal level of shade. Similarly, adding in ecosystem payment services for shade, for example, carbon credits or market premiums for certified biodiversity-friendly chocolate (Gockowski & Sonwa 2011; Millard 2011) could well shift the economic optimum away from the yield optimum and towards denser shade.

Implications and recommendations

Our study was based on the belief that it is critically important to quantify the trade-offs between conservation and production before applying a conservation strategy to an agricultural region. In particular, we wanted to ensure that a new certification for biodiversity-friendly chocolate achieved sustainability by taking economic, social, and cultural factors into account. If we had only quantified the shade/biodiversity curve and not the shade/production curve, the certificate would run the risk of demanding high shade, which is obviously the "best answer" for biodiversity but which has negative impacts on production. Indeed, in places where yield declines as a negative linear function of shade density (Figure 1A) it seems unlikely that any conservation program advocating dense shade would be acceptable to farmers. Our results suggest that the Chocó is a promising hotspot for certification because efficient production requires shade densities that also give significant conservation benefits (Figures 2–4).

It seems that farmers in the Chocó are cultivating at an inappropriately low level of shade, under the influence of a powerful technical/governmental discourse that shade is bad for production. The currently extensive focus on the conservation and climate change benefits of shade (Rice & Greenberg 2000; Schroth *et al.* 2004; Minang *et al.* 2008; Norris 2008; Gockowski & Sonwa 2011) is creating a new discourse by influential conservation-and-development organizations that advocates for dense shade. This discourse, combined with promises of development, could easily push farmers into using unsustainably high levels of shade instead (e.g., if yield losses exceed price premium gains in certification schemes).

In the long-term, promoting unsustainably high shade is wholly counter productive for conservation. Cocoa smallholdings, being economically precarious with little access to credit, are often abandoned and replaced by more profitable but biodiversity-poor land uses such as oil palm monocultures (Schroth *et al.* 2004, A. Waldron personal observation). Any inefficiency imposed by conservation interests could only accelerate this conservation-negative conversion process. In political terms, certifiers would also become guilty of visiting tremendous neocolonial injustice on the small farmers who grow most of the cocoa in the world (Schroth *et al.* 2004).

We believe that respecting production and income imperatives will make certification sustainable, widely adopted, and socially just. Indeed, in a world where biodiversity-friendly labels sit on the shelf alongside fair trade marketing initiatives, it would seem contradictory to have a conservation-friendly label that inflicted economic hardship on producers. Currently, it seems that the economic consequences of certification criteria are not routinely assessed, and so their sustainability is hard to predict accurately. The same may be true of other conservation initiatives in production landscapes.

Before all else, however, we need to maintain the economic health of the smallholders around whom all these conservation projects revolve. The rapid rate of abandonment among shade-grown cocoa smallholders represents a novel but critical type of "conservation threat" in the wet lowland tropics (Ruf 2011). Simple development help, specifically targeted at cocoa smallholders, may therefore be conservation biologists' best short-term weapon in these production-based tropical lowlands.

Acknowledgments

A big thanks to Nestor Lemos, Virginia Borja, and the staff and members of APROCANE, whose assistance was key in setting up the study; and to Jacinto Coroso, Pastor Arroyo, Charlie Vogt, Patricio Herrera, Ider Valencia, Luis Kaiser, and Bernardo Castro for their excellent assistance in the field. This study was funded grants to Fundacion Maquipucuna by the MacArthur Foundation and BID-MINIFOMIN.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1: Details of the farms studied. Two bird surveys could not be baselined and so appears as "na" in the final column

Table S2: Full results from analyses of candidate models relating shade tree density to the five main variables (yield per tree; yield per hectare; physical net income; effective net income; bird diversity). *K* is the number of parameters; *AICc Wt* is the proportional likelihood of model; *Cum Wt* is the cumulative proportional likelihood of model. The best-fit model set, defined as all candidate models with $\Delta AICc < 2$, is shown in italics for each variable (and in the main text). Intercept models and adjusted r^2 values (r^2 adj) from the best-fit model set are also shown for illustration at the request of a referee. Burnham and Anderson (2002) caution that AICc approaches and concepts of significance should not be mixed at the moment of interpreting model fits. See main text for data transformations carried out prior to analysis

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