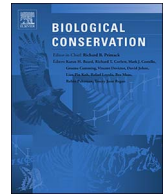




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Where are commodity crops certified, and what does it mean for conservation and poverty alleviation?

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ABSTRACT

Voluntary sustainability standards have expanded dramatically over the last decade. In the agricultural sector, such standards aim to ensure environmentally and socially sustainable production of a variety of commodity crops. However, little is known about where agricultural certification operates and whether certified lands are best located for conserving the world's most important biodiversity and benefiting the most vulnerable producers. To examine these questions we developed the first global map of commodity crop certification, synthesizing data from over one million farms to reveal the distribution of certification in unprecedented detail. It highlights both geographical clusters of certification as well as spatial bias in the location of certification with respect to environmental, livelihood and physical variables. Excluding organic certification, for which spatial data were not available, most certification of commodity crops is in tropical regions. Certification appears to be concentrated in areas important for biodiversity conservation, but not in those areas most in need of poverty alleviation, although there were exceptions to each of these patterns. We argue that the impact of sustainability standards could be increased by identifying places where it would be most beneficial to strengthen, consolidate, and expand certification. To achieve this, standards organizations will need to undertake more rigorous collection of spatial data, and more detailed analysis of their existing reach and impacts, with attention to potential trade-offs between different objectives. Efforts to promote spatial prioritization will require new partnerships to align specific conservation aims with the interests and capabilities of farmers.

1. Introduction

Improving the environmental and social sustainability of agriculture is an ongoing challenge worldwide (Tilman and Clark, 2015). Governments have responded to this challenge by developing legislation and initiatives such as agri-environment schemes (Batáry et al., 2015). Alongside these government-led initiatives, the work of multiple stakeholders has led to the creation and promotion of voluntary sustainability standards systems, also referred to as certification schemes (Potts et al., 2014; Rueda et al., 2017). These standards typically define the practices of sustainable agriculture, and identify actions producers must take to be certified as environmentally and socially responsible

(Milder et al., 2015). Over the last decade, there has been a near-exponential increase in area managed under certification (Tayleur et al., 2016). Certification is often promoted as a way for individual consumers to make more ethical purchasing decisions (Dauvergne and Lister, 2010). It is also proposed as a way to mitigate negative impacts of commodity production and improve the wellbeing of farmers and farm workers in the developing world (Lenzen et al., 2012). Many multi-national companies now use certification to help achieve and demonstrate progress towards public sustainability commitments (Dauvergne and Lister, 2012; Levin and Stevenson, 2012). Land under certification has also been adopted as an indicator of progress towards Aichi Target 7, which calls for “areas under agriculture... [to be]

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managed sustainably” by 2020 (Tittensor et al., 2014). Impact evaluations, while still sparse, suggest that standards are likely to vary considerably in their effectiveness. The need for more widespread and systematic evaluation of impacts – taking account of issues such as selection bias in recruitment of farmers – is well established and has been discussed in detail elsewhere (Blackman and Rivera, 2011; Milder et al., 2015). Although there is a need for improved evaluations, there is accumulating evidence (reviewed by Milder and Newsom, 2015; Steering Committee of the State of Knowledge Assessment of Standards and Certification, 2012; Tschamtko et al., 2015) that certification can contribute to both conservation and livelihood benefits. The analyses that follow are grounded in the assumption that certification can make such a contribution.

Despite the increasing prominence of certification, there is little information about its geographical distribution at sub-national scale. Globally, certification is estimated to cover just 1.1% of all cropland (Tayleur et al., 2016). Because coverage is limited, it is crucial that certification is targeted towards those areas where it can have most impact or additionality (Garrett et al., 2016), in line with the priorities and criteria of different standards. For example, standards whose priority is to reduce social inequality, such as Fairtrade, may wish to know whether they are reaching the poorest farmers, while those that also prioritize biodiversity conservation, such as Rainforest Alliance/SAN, may wish to know that they are certifying farmers in areas important for conservation. Other factors, such as literacy or a supportive policy environment, as well as consideration of other possible interventions, will also influence where certification is most appropriate and feasible. While crop-specific schemes include some unique criteria – such as restrictions on planting oil palm on peatland – there has also been some convergence of standards, and most schemes now include both environmental and social criteria (UNEP-WCMC, 2011). Therefore, most standards have some capacity to address biodiversity conservation, habitat loss (including deforestation) and livelihood protection, although they differ considerably in their specific requirements and in how these are implemented and audited (Tayleur et al., 2016).

1.1. What influences the spatial distribution of certification?

To the extent that spatial targeting of certification can be said to have occurred to date, it has largely been a by-product of the management of specific supply chains (Garrett et al., 2016; Getz and Shreck, 2006; Renard, 2010; Vellema et al., 2015). Companies that have committed to responsible practices have worked to ensure that those producing the agricultural commodities they use are certified. Some of these efforts have been reactive, responding to civil society campaigns, regulatory requirements, or anticipation of campaigns or regulations. Others have been more proactive, aiming to increase the security or quality of commodity supply, or reputational benefits to a company's brand. Such efforts reflect to some extent the imperative to target certification to places of greatest social and environmental risk. For instance, civil society campaigns have highlighted egregious instances of deforestation and infringements of community rights. Another mechanism is the use of certification as a policy proxy by governments. For instance, the US state of Pennsylvania obtains FSC certification for its state forests, and some government procurement policies preference or require responsibly sourced products, including certified products (Steering Committee of the State of Knowledge Assessment of Standards and Certification, 2012). Although indirect and often reactive, both supply chain commitments and procurement policies therefore offer some opportunities to effect spatial targeting. The creation of sustainability standards focused on specific crops implicated in environmental and social problems has also resulted in spatial targeting at a very coarse scale (it is notable that all of the certification schemes for which we obtained data are concentrated in tropical countries).

Despite these examples, there do not yet appear to have been co-ordinated strategic efforts to systematically identify the places where

the impact of certification could be greatest. There are considerable opportunities to do so, to identify priorities for future civil society campaigns, corporate efforts, and government interventions. Currently, at the country level, agricultural certification has poor representation in the world's 31 poorest countries (those classified by the World Bank as low income) and for staple crops of low export value (Tayleur et al., 2016). Analogously, within the forestry sector, certification has been criticized for failing to protect tropical forests that are most at risk, with the majority of certified wood coming from temperate developed countries (Gullison, 2003). Without a more strategic approach to strengthening, consolidating, and expanding agricultural certification, there is a risk that it may not reach those areas and producers where the greatest additionality can be gained.

1.2. Spatial prioritization as a conservation and poverty alleviation tool

While global coverage of certification is still limited, its rapid uptake by producers of some of the most environmentally-damaging commodity crops indicates its potential to contribute to conservation and development. Given sparse resources, certification, like other voluntary incentive schemes, should be prioritized to where its introduction could have most additional beneficial impact (Wünscher et al., 2008). One of the few studies to explore how well standards are targeted found that adoption of two schemes (the Round Table on Responsible Soy (RTRS) and the Roundtable on Sustainable Palm Oil (RSPO)) was better directed towards places where they could reduce deforestation in some countries but less so in others, and that the standards were disproportionately adopted by large producers rather than smallholders (Garrett et al., 2016). While there has been some targeting of high-risk commodities for certification such as palm oil and soybeans, little is known about whether certification reaches those areas of greatest conservation and poverty alleviation need within the global ranges of these crops. Although the areas of greatest need are not always those where certification can have most impact – because supporting conditions for certification also vary, and alternative interventions may sometimes be more effective – identifying such areas provides an initial basis for spatial targeting.

We aimed to: (1) develop the first detailed global map showing where certification is located, synthesizing data from all of the main standards for which data were available; and (2) characterize biodiversity and poverty in landscapes in which certification currently operates, globally, regionally and within countries, using as case studies crops for which sufficient data exist. We use these analyses to illustrate methods for identifying priority areas that could be targeted to maximize the incremental benefits of improving, consolidating, and expanding certification, and outline how doing so could increase the contribution of certification to global sustainability. We have assumed that the expansion of certification has been too recent and limited to have yet had a detectable influence on the biodiversity and poverty datasets we used, and our analysis should thus be interpreted as an aid to priority-setting, rather than implying any causal influence of certification on these variables.

2. Materials & methods

2.1. Obtaining spatial data on certified producers

Data on the spatial location of certified farms were obtained through publicly available datasets and via direct approaches to standards bodies (see Supplementary materials for details). We sought data from all major standards and codes of practice covering the certified commodity crops with the highest levels of certification: banana, cocoa, coffee, cotton, tea, soybean, sugar, and palm oil (Potts et al., 2014). The scope of the data search was not limited to any particular geography, but the standards for which data were available operate primarily in tropical countries. Not all schemes were able or willing to provide data

(see Supplementary Materials for details). In some cases, permission was granted only on condition that data were used in aggregate with other standards so that the specific locations for individual schemes and producers could not be identified. To meet this requirement our maps are at the resolution of 30 km × 30 km cells, after first standardizing all data by converting them into point localities. The format of data available from each standard varied considerably: while most were able to provide a coordinate for each certificate, a few schemes had postal address data only. RSPO was the only standard that routinely collects polygon data outlining plantation boundaries. Usable spatial data were not available for certified cotton, so this commodity was excluded from further analyses.

2.2. Validation and standardization of spatial certification data

Several factors influenced the accuracy of the spatial data: 1) In some standards, multiple farms (e.g. within a co-operative) are represented by a single certificate and coordinate, often referred to as a ‘group certificate’; 2) Occasionally the coordinate for a certificate is associated with an administrative office rather than the actual farm; 3) Some farms hold multiple certifications, e.g. Rainforest Alliance/SAN and Fairtrade, but because spatial data are often imprecise, many certified farms are small, and common identifiers are not used across standards, such overlaps cannot be identified by spatial coincidence of points. We converted address data into point locations using the ESRI Online World Geocode service which identified coordinates for 23% of all addresses entered. We tested the sensitivity of our results to the inclusion of these data by repeating analyses with and without them. As certification patterns did not change significantly, we report the results including the geocoded data.

To improve accuracy, we undertook a number of data cleaning steps. First we checked whether the coordinate location corresponded to the country named in the accompanying metadata. Where points were not located in the correct country, simple transformations (swapping latitude and longitude, and hemisphere) were attempted. If this did not locate the coordinate in the correct country, the point was discarded. Points that did not fall within the relevant crop growing area as defined by our crop cover map (see 2.5) were also discarded. Excluding the geocoded address data mentioned above, 93% of the data provided met these validation requirements.

To account for spatial inaccuracies and to protect the privacy of individual producers, we summarized data using 30 km × 30 km grid cells created with the Fishnet tool in ArcMap 10.2 using an equal-area projection. Each grid cell was classified as either containing certified land or not.

2.3. Biodiversity variables

We obtained breeding range maps for all the world's amphibians and mammals (IUCN, 2014) and birds (BirdLife International and NatureServe, 2014). We excluded parts of species' ranges where they have been extirpated, as well as areas where they are not native. We determined the potential presence/absence of each species in each 30-km cell using *gIntersects* in the *rgeos* package (Bivand et al., 2016) in R (R Development Core Team, 2016). The range maps represent the distribution boundaries and are likely to contain commission and omission errors (Rodrigues et al., 2004), but these were minimized by our use of 30-km cells. We calculated a metric of the importance of each grid cell for biodiversity by summing the inverse range size for each species present. Using this metric, a cell would receive a value of 1 for a species if it contained its entire global distribution, and a value of 0.0001 if it was one of 10,000 cells within the distribution of the species. The metric is a measure of the relative contribution each cell makes to global biodiversity (of the three vertebrate groups considered), and is thus indicative of the global conservation value of each cell.

In addition to species range maps we obtained shapefiles from the

World Database on Protected Areas (IUCN and UNEP-WCMC, 2015) as well as shapefiles for Important Bird and Biodiversity Areas (IBAs; sites of international significance for birds) (BirdLife International, 2015). For both of these datasets we calculated the percentage cover within each 30-km grid cell in ArcMap.

2.4. Deforestation

High-resolution maps of Global Forest Change (GFC) were obtained from Hansen et al. (2013). These maps were derived from Landsat imagery and were accessed via the cloud computing environment, Google Earth Engine (Google Earth Engine Team, 2015). The GFC maps report annual loss and gross gain in tree cover during the period 2000–2012, at 30-m resolution. We also used the “treecover2000” map from Hansen et al. (2013), representing the percentage tree cover in the year 2000. We combined this with the “lossyear” map to identify pixels which lost their tree cover during 2000–2012. We estimated the area of tree cover lost in each 30-m pixel, following Hansen et al. (2013). We used the Google Earth Engine platform to process the data, after first resampling to a resolution of 200 m (see Tracewski et al., 2016 for more details). These data were then summarized for every 30-km grid cell as the percentage of original tree cover lost within the grid cell, and this was converted to an average annual rate of net tree cover loss. This metric provides a proxy for deforestation of natural forest, but may also include tree cover loss and gain in plantations.

2.5. Crop cover

The mean percentage of crop cover for each 30-km grid cell was calculated using the value from Monfreda et al. (2008) who provide estimates for the year 2000. In instances when sub-country yield statistics were not available, Monfreda et al. averaged country level yields over large areas leading to obvious errors in crop distribution. For example, their maps show cocoa growing across Ghana despite this crop in reality being excluded from the arid northern two-thirds of the country. Therefore we used the Global Agro-Ecological Zone climatic suitability maps (IIASA/FAO, 2012) to clip the Monfreda maps to define the likely limits of crop production.

2.6. Variables relevant to poverty alleviation

We chose three variables for which global spatial data at a fine-scale resolution were available. The first was mean travel time to closest city of > 50,000 people as calculated by Nelson (2008) in his global map of accessibility, which we used as a proxy for market access. Secondly, we calculated the mean percentage of the population in poverty for each 30-km grid cell using the global poverty map created by Elvidge et al. (2009) from satellite data on night-time lighting. Finally we calculated mean field size for each 30-km grid cell as calculated by Fritz et al. (2015). Field size has been shown to correlate with farm size (Levin, 2006) and so we used grid cells with small field sizes as a proxy for the presence of smallholder farmers.

2.7. Other variables

To investigate other factors that might characterize or influence the location of certified crops we also calculated mean altitude and slope from the global SRTM dataset (USGS, 2004).

2.8. Analyses

We used bootstrap resampling tests to examine patterns in those grid cells containing certification versus those that did not, for a number of different variables. Because data were summarized at the 30-km scale, covariate values within each grid cell could not be attributed directly to certified farms, so our tests examined how the local

landscapes in which certification exists differ compared to non-certified landscapes, without implying causation. To run the resampling tests we first defined our certified sample as all the 30-km grid cells containing certified farms for each crop. The test statistic was then calculated as the mean of covariate values from the certified sample. To create our test distribution we then obtained a random sub-sample without replacement from non-certified grid cells of the same size as our certified sample and calculated the mean for the sub-sample. We sampled without replacement as we were using a finite population. We weighted the probability of a grid cell being included in the random sample by the proportion cover of the commodity crop of interest. This allowed us to generate the values that might be expected for each variable if certification was located randomly within the distribution of each crop. We ran our resampling routine using the *wrswoR* package in R (Müller, 2016). We repeated the resampling procedure 10,000 times in order to create our test distribution and then calculated the quantile in which our test statistic fell. Our test was two-tailed as we had no prior expectation as to whether certified values would be higher or lower than non-certified, so we considered anything below 2.5% or above 97.5% significant.

We carried out our bootstrap resampling tests at the global level to examine broad biases in the spatial distribution of certification. To examine regional and within-country spatial bias we then examined a subset of three commodities with the highest levels of certification in those geographical regions in which their certification was concentrated: coffee in Central America, cocoa in West and Central Africa and palm oil in Southeast Asia (details in Supplementary materials). When examining certification patterns within countries, only 30-km grid cells that fell wholly within the country were included. Patterns within countries were examined only when there were more than six certified cells and when the number of certified cells was not greater than the number of non-certified.

3. Results

Across all standards we mapped a total of 84,853 individual and group certificates covering 1,042,734 farms. Once we restricted our data to the primary commodity crops of interest, this reduced to 83,860 certificates, and after validation, to 78,544. A list of all certified crops is provided in the supplementary materials. When summarized at the 30-km scale, 1873 cells contained certified farms out of 45,717 cells where these crops were cultivated (4.1%, Fig. 1). Global levels of certification were highest for coffee (at 9.0% of coffee-growing cells) but much lower for other crops (banana: 0.3%, cocoa: 2.2%, oil palm: 2.2%, sugarcane: 0.6%, soy: 0.2%, tea: 2.0%). There were clear large-scale aggregations of certification in Central America, Brazil, West Africa, parts of East Africa and Southeast Asia.

3.1. Global certification coverage by crop

The distribution of grid cells containing certification in relation to our variables of interest varied considerably between crops (Table 1). For some crops, cells with certification coincided with higher importance for biodiversity conservation than was typical of cells with the same crop without certification. Certified coffee, tea, and cocoa all occurred in cells with higher importance for birds, on average, than that in non-certified cells. The distribution of coffee, both certified and not, included areas of particularly high conservation importance for birds (Fig. 2). Certified tea occurred in cells with higher importance for amphibians, while the soy production cells with highest amphibian value were less likely to be certified. For mammals, coffee certification occurred in cells with higher conservation importance than that in coffee cells without certification. However, for all other crop-taxon combinations, there were no significant differences between cells with certification and without, in respect to their importance for birds, amphibians or mammals.

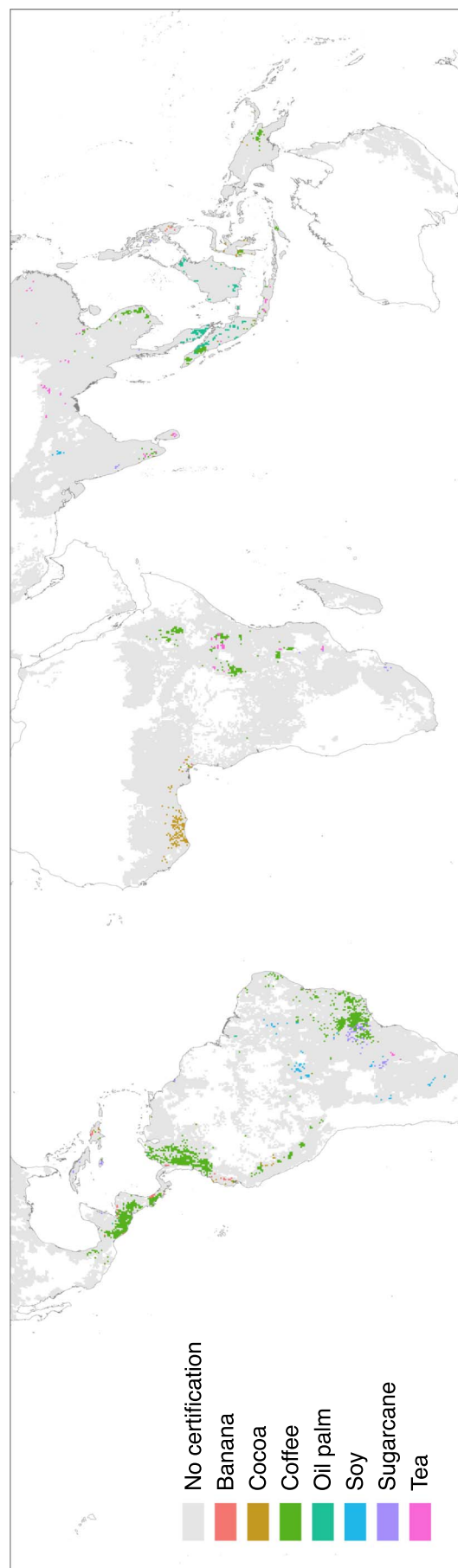


Fig. 1. Global distribution of certified commodity crops based on their presence within 30 km × 30 km grid cells. Colours indicate the crop with the most certificates in each grid cell. The combined distribution of the named crops, from Monfreda et al. (2008), is shown in pale grey, and the map is cropped to the distribution of certificates with spatial data, which were predominantly in the tropics. Map produced using QGIS 2.18.2 (QGIS Development Team, 2017). An interactive version of these data is available in the online article.

Table 1

Results from bootstrap resampling tests comparing the distribution of certified grid cells with non-certified crop growing cells. Where the value for certified cells was significantly lower than for non-certified cells, the results are shown in light grey, while significantly higher certified values are shaded in dark grey. The values represent the significance value calculated as the number of non-certified values smaller or larger than the certified test statistic divided by the number of permutations (10,000). As tests were two-tailed, the significance threshold was set at 0.025. The fraction of certified to non-certified cells is given under the crop name.

Crop	Biodiversity and Environmental parameters						Livelihoods parameters			Physical parameters		
	Importance for birds	Importance for amphibians	Importance for mammals	% Protected Area	% IBA coverage	Rate of net tree cover loss	Field size	Travel time to market	% of population in poverty	Altitude	Slope	% crop cover
Coffee 1299/14397	Higher <0.0001	ns	Higher 0.0102	Lower 0.0200	ns	Lower <0.0001	Higher <0.0001	Lower <0.0001	Lower <0.0001	Higher <0.0001	Higher <0.0001	Higher 0.0032
Banana 50/14159	ns	ns	ns	ns	ns	ns	Higher <0.0001	Lower 0.0207	Lower <0.0001	ns	Higher 0.0160	Lower 0.0202
Soy 66/28179	ns	Lower 0.0075	ns	ns	ns	Higher <0.0001	Higher <0.0001	Higher <0.0001	Higher 0.0003	ns	ns	Lower <0.0001
Tea 104/5164	Higher <0.0001	Higher 0.0024	ns	Higher 0.0010	Higher 0.0001	Lower 0.0003	Higher 0.0175	ns	ns	Higher <0.0001	ns	Higher <0.0001
Oil Palm 145/6631	ns	ns	ns	Lower 0.0027	ns	Higher <0.0001	Higher <0.0001	ns	Lower 0.0121	Lower <0.0001	Lower <0.0001	ns
Cocoa 202/8087	Higher 0.0247	ns	ns	ns	Lower 0.019	Higher 0.0020	Lower <0.0001	Lower 0.0001	Lower 0.0016	ns	Higher 0.0245	Lower <0.0001
Sugar 110/19339	ns	ns	ns	ns	ns	ns	Higher <0.0001	Lower 0.0065	ns	Higher 0.0007	ns	Higher 0.0001

Certified tea occurred on average in grid cells with greater protected area coverage, while certified oil palm and coffee occurred in cells with less protected area coverage than non-certified cells. Cells with certified tea coincided to a greater extent with IBAs than non-certified cells, while cells with certified cocoa had less overlap with IBAs than non-certified cells. There were differing patterns between crops with respect to rates of tree cover loss. Cells with certified soy, oil palm, or cocoa coincided with higher rates of loss, while cells with certified coffee or tea coincided with lower rates of loss compared to cells growing uncertified crops of the same type.

For most crops, grid cells with certification tended to have larger fields, be closer to market towns, and have a lower percentage of the population in poverty than the distribution of the crop more generally. Although cells with certified soy tended to have larger field sizes, they were also further from towns, and in poorer areas. Certified cocoa was found in cells with smaller field sizes, although still closer to towns, and in wealthier areas than non-certified cocoa. Physically, certified crops often occupied cells with significantly different (higher, lower, or similar, depending on the crop) altitude, slope, and crop cover compared to the crops' global distributions (Table 1).

3.2. Case study: cocoa in West and Central Africa

We explored the extent to which these global patterns persist at regional and national scales, focusing on three data-rich case study areas. Across the West and Central African cocoa-growing region, Cameroon, Cote d'Ivoire, Ghana, Nigeria, Sierra Leone, and Togo all grew certified cocoa, although certification was restricted to only a single grid cell in Togo and two in Sierra Leone. Across the region as a whole, cells with certified cocoa had similar importance for birds to cocoa cells without certification. The global-level pattern of higher importance for birds in certified cells was reflected in some countries (Côte d'Ivoire, Ghana and Cameroon), but not in Nigeria (Table 2). For amphibians, certified cells had higher importance in some countries,

but not globally or across the West African cocoa-growing region as a whole. For mammals, cells with certified cocoa had higher conservation value at a regional level in West Africa, and in most of the cocoa-growing countries within it, whereas at a global level there was no difference from cells without certification.

In West Africa as a whole, grid cells with certified cocoa did not have significantly greater cover of either protected areas or IBAs but were closer to market towns and had lower levels of poverty. When examining patterns in individual countries, cells with certification tended to have higher conservation value and to occur closer to towns and in areas of lower poverty than cocoa-growing cells without certification. Landscapes with certification tended to be in grid cells with lower levels of cocoa cover than the control. Patterns at the country level were not always reflected at the regional (West Africa) level. For example, cells with certified cocoa had higher importance for birds and amphibians for three of the four countries examined in Table 2, but no significant relationship was found at the regional level, likely because of variation within and between countries.

3.3. Case study: coffee in Central America

Grid cells containing certified coffee are most prevalent in several Central American countries (Costa Rica, El Salvador, and Guatemala), outnumbering non-certified coffee-growing cells. In the remaining countries, certification presence is still high with the exception of Panama where it is absent. The general pattern for the both the Central American region and the individual countries was for certification to occur in cells with higher levels of conservation importance compared with non-certified coffee-growing cells (Table 3). Rates of tree cover loss were lower in most cells with certification, while the incidence of certification in cells with protected areas varied by country. In Central America overall, certified cells tended to be closer to markets, while poverty levels in certified cells were higher than in non-certified cells in Honduras and Nicaragua, and lower in Mexico. Certified cells

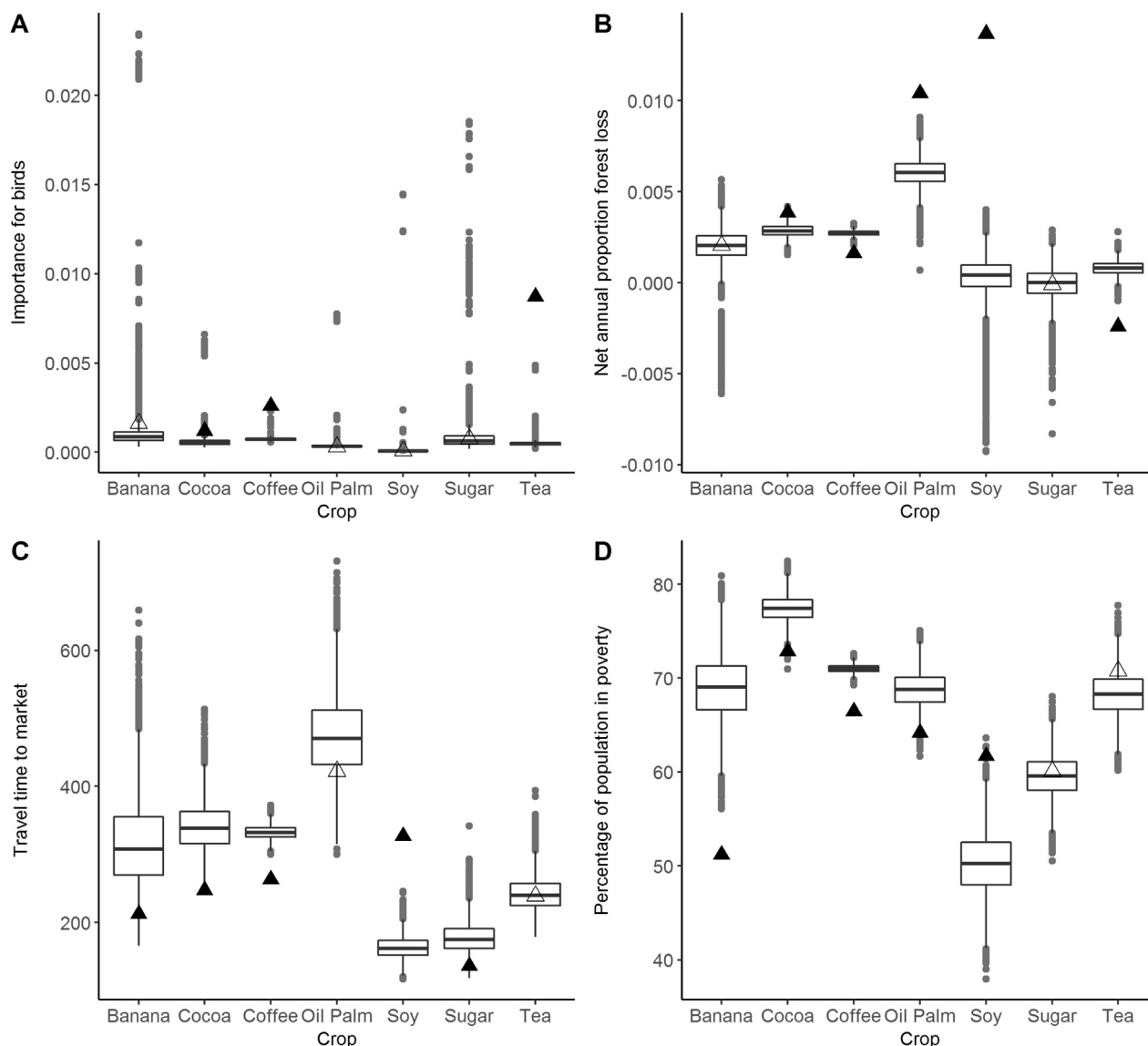


Fig. 2. The distribution of values for a selection of variables across their global crop-growing range, shown using box plots. The value for certified grid cells is signified by either an open triangle where the value was not significantly different from the global distribution, or a solid triangle when it was significantly different. Each box plot represents 10,000 random subsamples, equal in area to our certified sample, drawn without replacement from non-certified grid cells.

consistently occupied regions of higher altitude, slope and crop cover, perhaps due to greater suitability of these conditions for high-quality shade-grown coffee, which is more likely than sun-grown coffee to be marketed as a premium product to consumers for whom certification has resonance.

3.4. Case study: oil palm in Southeast Asia

Certified oil palm in Southeast Asia (SE Asia) was found solely in Malaysia and Indonesia and tended to be located in grid cells with lower than average importance for bird conservation than non-certified oil palm and in areas with lower coverage of IBAs and protected areas (Table 4). Rates of tree cover loss were higher in certified cells in SE Asia. From a livelihoods perspective, certified cells were closer to towns and had lower levels of poverty. Cells with certified oil palm were also in areas with lower altitudes and slope and higher percentage of crop cover, suggesting that these might be more favourable crop-growing areas. Patterns at the SE Asia regional level appeared primarily influenced by patterns of certification in Malaysia. Certified oil palm cells in Indonesia appeared to have few differences compared with non-

certified cells, although they were perhaps located in more favourable, intensively-farmed agricultural areas, as altitude and slopes were lower but field size and percentage crop cover were higher.

Full graphical results for all crops and countries are available in the Supplementary materials along with additional crop by region case studies.

4. Discussion

We developed the most detailed global map of commodity crop certification yet produced. It shows that certification for each crop is concentrated in certain geographical areas, and largely absent from others (Fig. 1). According to available spatial data, most commodity crop certification is in tropical countries, although this is a pattern that would change if spatial data were available for organic schemes (Tayleur et al., 2016). Our analysis quantified biases in each crop's certified locations compared with gradients of conservation importance, tree cover loss and poverty (Table 1). Patterns varied on a crop-by-crop and country-by-country basis, but overall, certification appears to be concentrated in areas that are important for biodiversity

Table 2

Results from bootstrap resampling tests comparing the distribution of certified cocoa grid cells versus non-certified cocoa growing cells. Where the value for certified cells was significantly lower than for non-certified cells, the results are shown in light grey, while significantly higher certified values are shaded in dark grey. The values represent the significance value calculated as the number of non-certified values smaller or larger than the certified test statistic divided by the number of permutations (10,000). As tests were two-tailed, the significance threshold was set at 0.025. The fraction of certified to non-certified cells is given under the crop name.

Crop	Biodiversity and Environmental parameters					Livelihoods parameters				Physical parameters		
	Importance for birds	Importance for amphibians	Importance for mammals	% Protected Area	% IBA	Rate of net tree cover loss	Field size	Travel time to market	% of population in poverty	Altitude	Slope	% crop cover
West Africa 109/929	ns	ns	Higher 0.0001	ns	ns	Higher <0.0001	ns	Lower <0.0001	Lower 0.0037	Lower 0.0007	ns	Lower <0.0001
Ghana 26/127	Higher <0.0001	Higher <0.0001	ns	ns	Lower 0.0066	ns	Lower <0.0001	Lower 0.0023	ns	ns	Higher 0.0190	Lower <0.0001
Cameroon 8/170	Higher <0.0001	ns	Higher <0.0001	ns	ns	ns	Lower <0.0001	Lower 0.0163	ns	ns	Higher 0.0171	Lower 0.0199
Côte d'Ivoire 65/225	Higher <0.0001	Higher 0.0005	Higher 0.000	ns	ns	Higher <0.0001	ns	Lower <0.0001	Lower <0.0001	Lower <0.0001	Lower 0.0023	Lower <0.0001
Nigeria 7/180	ns	Higher 0.0008	Higher 0.0188	ns	ns	ns	ns	ns	ns	ns	ns	ns

conservation, relatively close to markets, and with lower poverty levels (Figs. 2, 3; Tables 1–4). These patterns suggest that existing standards may be well-positioned to have a conservation impact if they promote the right practices, but are less well-positioned to assist the very poorest farmers. However, there were exceptions to each of these patterns, and relationships between certification and other variables were less consistent (Tables 1–4). Some of the patterns found when data were pooled at global or regional levels persist within individual countries, while others do not (Tables 2–4). This underlines the importance of selecting the most appropriate decision-relevant scale for analysis of spatial patterns.

4.1. Explaining patterns of certification

Some of the patterns likely reflect geographical differences in growing practices, some of which are more amenable to certification than others. For example, shade-grown coffee is more likely to meet requirements of speciality coffee buyers and many certification standards, and growers may be more likely to seek certification, compared with sun-grown coffee (Takahashi and Todo, 2014). The higher conservation value of certified coffee cells in Central America might be because shade-grown coffee, and thus certified coffee, is more common in remote, high altitude locations with steep slopes (Table 3): locations where many restricted-range species could be expected to occur. Other

Table 3

Results from bootstrap resampling tests comparing the distribution of certified coffee grid cells versus non-certified coffee growing cells. Where the value for certified cells was significantly lower than for non-certified cells, the results are shown in light grey, while significantly higher certified values are shaded in dark grey. The values represent the significance value calculated as the number of non-certified values smaller or larger than the certified test statistic divided by the number of permutations (10,000). As tests were two-tailed, the significance threshold was set at 0.025. The fraction of certified to non-certified cells is given under the crop name. We did not have spatial data on IBAs in Mexico or Honduras, hence the N/As in the IBA column.

Crop	Biodiversity and Environmental parameters					Livelihoods parameters				Physical parameters		
	Importance for birds	Importance for amphibians	Importance for mammals	% Protected Area	% IBA	Rate of net tree cover loss	Field size	Travel time to market	% of population in poverty	Altitude	Slope	% crop cover
Central America 191/627	Higher <0.0001	Higher 0.0040	Higher <0.0001	Higher 0.0166	N/A	Lower <0.0001	ns	Lower <0.0001	ns	Higher <0.0001	Higher <0.0001	Higher <0.0001
Honduras 39/89	ns	Higher <0.0001	Higher <0.0001	Lower <0.0001	N/A	Lower <0.0001	Higher <0.0001	Lower <0.0001	Higher <0.0001	Higher <0.0001	Higher <0.0001	Higher <0.0001
Mexico 47/299	ns	ns	Higher <0.0001	Higher 0.0002	N/A	ns	ns	ns	Lower 0.0139	Higher 0.0017	ns	Higher <0.0001
Nicaragua 29/74	Higher 0.0002	Higher <0.0001	Higher <0.0001	Lower <0.0001	Lower <0.0001	Lower <0.0001	Lower <0.0001	Lower <0.0001	Higher 0.0098	Higher <0.0001	Higher <0.0001	Higher <0.0001

Table 4

Results from bootstrap resampling tests comparing the distribution of certified oil palm grid cells versus non-certified oil palm growing cells. Where the value for certified cells was significantly lower than for non-certified cells, the results are shown in light grey, while significantly higher certified values are shaded in dark grey. The values represent the significance value calculated as the number of non-certified values smaller or larger than the certified test statistic divided by the number of permutations (10,000). As tests were two-tailed, the significance threshold was set at 0.025. The fraction of certified to non-certified cells is given under the crop name.

Crop	Biodiversity and Environmental parameters					Rate of net tree cover loss	Livelihoods parameters			Physical parameters		
	Importance for birds	Importance for amphibians	Importance for mammals	% Protected Area	% IBA		Field size	Travel time to market	% of population in poverty	Altitude	Slope	% crop cover
Oil Palm												
SE Asia 109/1728	Lower <0.0001	ns	ns	Lower 0.0076	Lower 0.0054	Higher 0.0022	ns	Lower <0.0001	Lower <0.0001	Lower <0.0001	Lower <0.0001	Higher <0.0001
Malaysia 51/196	Lower <0.0001	ns	Higher 0.0014	Lower 0.0151	Lower 0.0036	Higher 0.0039	ns	Lower <0.0001	Lower <0.0001	Lower <0.0001	Lower <0.0001	Higher <0.0001
Indonesia 58/1212	Lower 0.0002	ns	ns	ns	ns	ns	Higher 0.0141	ns	ns	Lower <0.0001	Lower <0.0001	Higher <0.0001

patterns are more difficult to explain, such as higher rates of tree cover loss in cells with certified cocoa, palm oil, and soy. In the case of palm oil and soy especially, halting deforestation is a key objective for certification standards. It may be that certification is reaching these crops in recent frontiers, while being associated with more established areas of cultivation for other crops, such as tea and coffee. If land at high risk from forest clearance is becoming certified, this could be good news for conservation, as long as certification proves effective at preventing deforestation (e.g. Rueda et al., 2014). Another possible interpretation is that this pattern reflects a failure by standards to prevent deforestation, either because the deforestation occurred prior to certification; because of incomplete certification coverage within the landscape; or because of weaknesses in the standards and their application (e.g. Jurjonas et al., 2016; Tejeda-Cruz et al., 2010). Many standards do not exclude all deforestation, and protect only primary forest or areas of High Conservation Value (Edwards and Laurance, 2012; Tayleur et al., 2016). A third explanation for the global pattern, at least in the case of soy, is the fact that certification has concentrated in some countries (e.g. Brazil) and not others (e.g. the United States). An improvement in the quality of the spatial data, including accurate farm boundaries, would allow the relative importance of these different explanations to be explored in more detail.

Lower levels of certification in grid cells with the highest poverty rates and that are most isolated from markets might be the result of certification having focused on highly exported commodities (Tayleur et al., 2016) where supply chains are highly organized and exporters encourage or require certification (Getz and Shreck, 2006; Neilson, 2008; Vellema et al., 2015). Certification has been criticized as having high barriers to entry for smallholders (e.g. Brandi et al., 2015) although increasing efforts are being made to include smallholders (Fernando et al., 2015), and there is some evidence of social benefits (Hendriksen and Tholen, 2013). Certified farmers may also be those who are wealthier and more educated, and therefore better able to meet certification requirements and costs. Alternatively, the pattern might indicate that certification has already contributed to reducing poverty in some areas (e.g. Rueda and Lambin, 2013) although many studies have failed to demonstrate economic benefits (e.g. Ibanez and Blackman, 2016; Vellema et al., 2015). Finally, the failure of some standards to reach the very poorest areas might be explained by a greater focus on environmental rather than social criteria. Disentangling these contrasting explanations, using more precise spatial data, and longitudinal environmental and socio-economic data, would help to inform efforts to improve rural livelihoods through certification. Our analysis is just a first step towards understanding patterns of

certification, and how it might be leveraged to improve agricultural sustainability.

4.2. Strengthen, consolidate or expand?

Certification bodies, and other organizations that use and promote their sustainability standards, have several strategic (and not mutually exclusive) options by which they can increase their impact: 1) improving standards on farms that are already certified; 2) consolidating efforts by certifying a higher proportion of farms in landscapes where they are already active, and 3) expanding certification into new areas. Mapping the coincidence of certified locations with environmental and social variables can help to prioritize these actions. We discuss opportunities for each of these three strategies in detail.

To improve standards on certified farms, for example, it might be worthwhile for coffee certification standards to incorporate stronger protection for wild species and their habitats in landscapes identified as having especially high importance for conservation, such as those in Honduras (Table 3). This could be achieved by incentivising farmers to 'step up' from entry-level schemes, such as the 4C coffee standard, to more comprehensive standards, such as Rainforest Alliance/SAN. It could be fostered by varying scheme requirements geographically, demanding compliance with key biodiversity criteria in relevant areas or by ensuring more frequent or more thorough audits of practices relevant to biodiversity. Audit data, in combination with spatial biodiversity data, could be used to identify as high priorities for intervention any farms that are performing poorly against environmental criteria in areas of conservation importance; the same analyses could be used to reward farmers performing well in priority areas. Training programmes aimed, for instance, at reducing specific threats such as hunting, or at habitat management for threatened species, could be targeted towards producers in areas identified as being of especially high value for biodiversity conservation. There might be specific opportunities for NGOs to engage with producers: for example, certified tea in Kenya, and certified bananas in Costa Rica coincide with cells containing IBAs (Supplementary materials) suggesting an opportunity for bird conservation organizations to work with certification organizations and certified farmers to improve conservation in these locations.

Second, consolidation might be a good strategy in landscapes where certification already occurs in areas with specific issues that it can help to address. For example, consolidating the coverage of soybean-growing areas by standards that have effective criteria for avoiding deforestation could help address this issue, as soybean certification is already taking place in landscapes with high levels of tree cover loss.

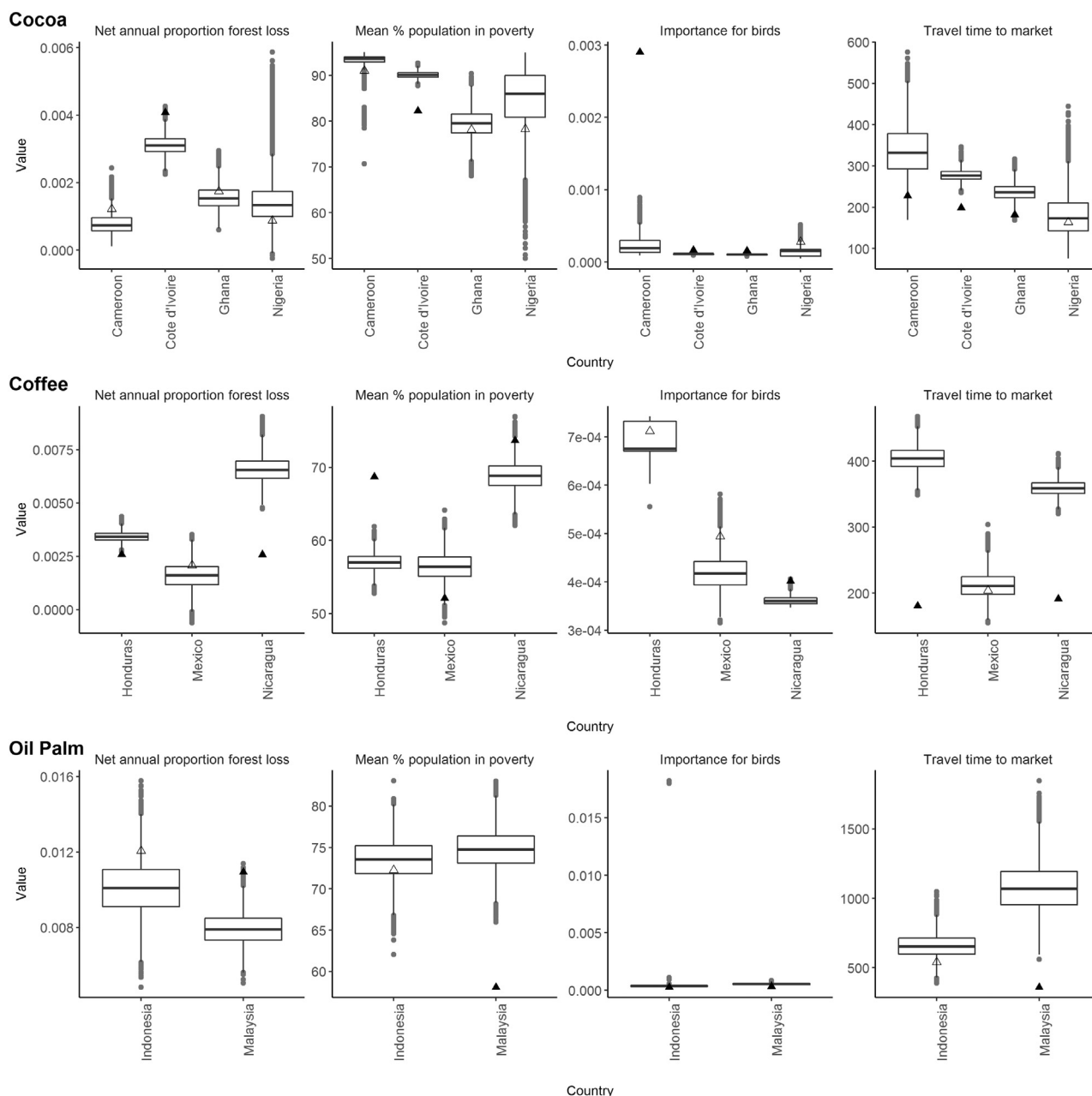


Fig. 3. The distribution of values for a selection of variables across their crop-growing range within selected countries shown using box plots. The value for certified grid cells is signified by either an open triangle where the value was not significantly different from the global distribution, or a solid triangle when it was significantly different. Each box plot represents 10,000 random sub-samples, equal in area to our certified sample, drawn without replacement from non-certified grid cells.

Consolidation could be facilitated by certification bodies taking a broad-scale landscape approach as advocated by Tschardt et al. (2015) whereby conservation outcomes are promoted at a scale greater than farm level. Consolidation could also be supported by third parties such as governments or NGOs, if they set requirements for adoption of certified practices, or provide technical assistance to encourage their uptake. One example of this ‘jurisdictional’ approach is being promoted by the RSPO and local government in Central Kalimantan (Nepstad et al., 2013; RSPO, 2015).

Third, expanding certification into new areas would be most useful in cases where certification is currently missing the areas of highest priority for specific issues, where voluntary standards are more rigorous than legislation (Garrett et al., 2016), and where there is good reason to expect positive impacts of standards. Certification of oil palm in Malaysia, for example, appears not to reach the oil-palm-growing areas where poverty levels are highest, perhaps because it is unattractive or

inaccessible to smallholders (Reitberg and Slingerland, 2016). Schemes could reduce social and economic obstacles to uptake in poorer regions by providing targeted training, support for producer cooperatives, and policies that simplify requirements and reduce certification fees for smallholders. The RSPO is adopting some of these approaches in an attempt to increase smallholder uptake. Comparing regional with country-level patterns of importance for birds and mammals suggests that certification in West and Central Africa misses some of those cocoa-growing areas that are most important for biodiversity. Extending certification to cocoa-growing countries it has barely reached, such as Sierra Leone and Togo, while strengthening biodiversity-related criteria, could play a role in conservation efforts. However, expansion would need to be linked to an appropriate market, because while some certified products such as coffee and cocoa now have mainstream markets – 40% and 22% of production respectively – demand has tended to lag supply. For example, less than one third of certified coffee

was sold as such in 2012, which may limit future expansion and financial benefits for farmers (Potts et al., 2014). Efforts to expand certification can also go further to consider crops which have been neglected. One point of entry would be for food companies to expand certification requirements to all ingredients in their supply chains, including those such as rice, maize and livestock products which have been poorly covered by standards (Newton et al., 2015; Tayleur et al., 2016).

4.3. Key data challenges and limitations

The accuracy of our analyses was limited by data quality. Many schemes have not yet developed rigorous protocols for the collection and/or sharing of spatial data. As a result, spatial data were often available for only a subset of the certificates within each standard. For some standards, no spatial data were available. For example, we contacted > 200 organizations that certify organic agriculture, but received few positive responses covering only a handful of producers. For some crops (cotton, and in some cases sugarcane) certification locations referred to processing mills, not to farms. Other schemes were only able to provide addresses. The use of non-standard address formats and non-Roman alphabets meant that the success rate of geocoding was low and those coordinates that were created could not be ground-truthed. For our analysis we summarized data at the 30-km scale. This was primarily to ensure farmer confidentiality, but also reduced the impact of imprecise spatial coordinates and farms with multiple certifications. A disadvantage of aggregation at this scale is that a large proportion of land within each cell is likely not certified. Our decision to use the Monfreda map, clipped with the GAEZ map, was also an imperfect representation of crop distribution for our ‘control’ distributions, but these were the best global data available. Finer-resolution analyses would be preferable in order to reflect the true spatial patterns for individual standards. It is important to recognize that our analyses show only correlation, and not causation, but correlations are useful for identifying gaps and priorities.

Our difficulties in locating and assembling a spatial database of certification lead us to recommend that greater resources be invested by certification organizations in collecting and organizing such information. While during the course of this study we found that spatial data were often lacking and poorly curated, there is a growing awareness within the industry of its value (Mallet et al., 2016). Improving the provision of spatial data is consistent with the commitments of certification organizations to transparency and traceability. Challenges remain, such as ensuring that the right to privacy of producers is respected, and that commercially-sensitive data are handled appropriately. However, these challenges are surmountable, and putting certified producers on the map also has several benefits. Transparency can be used to deflect criticism: for example, open RSPO data have been used to show that most fires are not on RSPO concessions (<http://www.rspo.org/news-and-events/news/rspo-statement-on-the-indonesian-forest-fires>). Good spatial data are essential for demonstrating and auditing compliance with some criteria, such as adherence to restrictions on deforestation (Tayleur and Phalan, 2016). Being able to cross-reference spatial data from different standards could help to identify overlaps and streamline audit processes. Bodies such as the ISEAL Alliance, which supports the sustainability standards community to define and implement best practices, could request minimum transparency guidelines for membership, and define best practice for spatial data management and dissemination.

5. Conclusions

Certification is an increasingly ubiquitous tool, promoted by both the private sector and civil society as important for improving the conservation and socio-economic impacts of agriculture. Our global data synthesis revealed a number of concentrations of certification,

both geographically and also with respect to gradients of biodiversity, tree cover loss and poverty. While certification appeared to coincide with areas important for biodiversity, it showed less overlap with areas of greatest poverty. These results suggest either a mismatch between the objectives of sustainability standards studied here and their potential to achieve them, or a greater emphasis on environmental than social sustainability. Regional and country-level crop-specific analyses demonstrated different spatial patterns, highlighting specific opportunities for increasing the impact of standards.

We describe three types of activities that could be targeted using spatial analyses to improve the outcomes of certification: strengthening standards on certified farms, consolidating the coverage of farms in already-certified landscapes, and expanding certification into new priority areas. As a market-driven mechanism, certification will require support from a range of actors in the private and public sector to enable spatial targeting. This would require private companies to consider alternative and potentially riskier sourcing locations, financial institutions to strengthen the environmental and social components of their lending criteria, NGOs to effectively advocate for those areas that would benefit most and, finally, governments to provide favourable conditions and requirements for sustainable production and trade. Better targeting in future would also be facilitated by improved collection of spatial data, benchmarking across standards, and a renewed commitment to transparency.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found in the online version, at doi: <https://doi.org/10.1016/j.biocon.2017.09.024>. These data include maps of the distribution of certification, in 30 × 30 km grid cells, as described in this article. The maps are provided in KML format and can be viewed in Google Earth.

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