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An assessment of high carbon stock and high conservation value approaches to sustainable oil palm cultivation in Gabon

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Abstract

Industrial-scale oil palm cultivation is rapidly expanding in Gabon, where it has the potential to drive economic growth, but also threatens forest, biodiversity and carbon resources. The Gabonese government is promoting an ambitious agricultural expansion strategy, while simultaneously committing to minimize negative environmental impacts of oil palm agriculture. This study estimates the extent and location of suitable land for oil palm cultivation in Gabon, based on an analysis of recent trends in plantation permitting. We use the resulting suitability map to evaluate two proposed approaches to minimizing negative environmental impacts: a High Carbon Stock (HCS) approach, which emphasizes forest protection and climate change mitigation, and a High Conservation Value (HCV) approach, which focuses on safeguarding biodiversity and ecosystems. We quantify the forest area, carbon stock, and biodiversity resources protected under each approach, using newly developed maps of priority species distributions and forest biomass for Gabon. We find 2.7–3.9 Mha of suitable or moderately suitable land that avoid HCS areas, 4.4 million hectares (Mha) that avoid HCV areas, and 1.2–1.7 Mha that avoid both. This suggests that Gabon's oil palm production target could likely be met without compromising important ecosystem services, if appropriate safeguards are put in place. Our analysis improves understanding of suitability for oil palm in Gabon, determines how conservation strategies align with national targets for oil palm production, and informs national land use planning.

1. Introduction

Global agricultural production will need to increase by an estimated 60%–110% by 2050, to meet growing demand for food, fiber and fuel (Alexandratos and Bruinsma 2012, Tilman *et al* 2011). Achieving this target without widespread deforestation, biodiversity loss, and greenhouse gas emissions will require a range of innovative strategies including increasing productivity, reducing waste, changing diets, and optimizing land use (Foley *et al* 2011, Godfray *et al* 2010). Palm oil, the world's most commonly used and highest yielding vegetable oil, epitomizes this global challenge (USDA 2014, Sayer *et al* 2012).

In Southeast Asia, where the majority of palm oil is currently produced, industrial-scale plantations have driven the conversion of millions of hectares of forest (Koh *et al* 2011). In Indonesia alone, more than half of oil palm plantations were established on biodiversity- and carbon-rich forests and peat lands since the year 2000 (Ramdani and Hino 2013, Carlson *et al* 2013). Industrial-scale oil palm cultivation is expanding in West and Central Africa, and is seen as a way to promote economic growth, job creation, and rural development. However, in the absence of appropriate safeguards, these benefits could be offset by negative consequences for the environment and local communities (Wich *et al* 2014, Linder 2013).

In this study, we estimate the extent and location of suitable land for oil palm cultivation in Gabon, Central Africa, based on an analysis of recent trends in plantation permitting. We use this map to evaluate two proposed approaches to sustainability: A High Conservation Value (HCV) approach and a High Carbon Stock (HCS) approach. The HCV approach is based on identifying, mapping, and safeguarding priority environmental and social features in a landscape (Brown *et al* 2013). It is widely used in certification schemes in forestry and agriculture, including the Roundtable on Sustainable Palm Oil (RSPO 2016); however it has also been criticized for failing to protect forest areas in non-HCV landscapes (Edwards *et al* 2011). This shortcoming has led to the emergence of new standards for sustainability, beginning with a series of 'zero-deforestation' and 'deforestation-free' pledges made by multi-national retailers, consumer goods companies, manufacturers, and producers of palm oil (United Nations 2014). More than 96% of internationally traded palm oil is controlled by companies with a commitment to zero-deforestation oil palm (Butler 2015). To bring clarity and transparency to these commitments, private sector and civil society stakeholders have proposed an HCS approach to selecting land cover categories or areas of low carbon stock, on which oil palm cultivation is considered deforestation-free.

This study focuses on Gabon, where forests cover 88% of the country's land area (Sannier *et al* 2014). In 2012, the government announced plans to become a leading producer of palm oil in Africa (République Gabonaise 2012). At the same time, the country's national land use plan aims to limit degradation of intact forests, high conservation value areas, and carbon-rich forests (République Gabonaise 2015). This study compares the opportunities and challenges posed by the HCS and HCV criteria, and determines the degree to which these conservation approaches are compatible with the government's production targets. In addition, our analysis improves understanding of the distribution of suitable land for palm oil production, and provides a template for developing sustainable oil palm expansion strategies in the region.

2. Methods

Three maps provided the foundation for our analysis: relative suitability for oil palm cultivation (section 2.1), high carbon stock (HCS) forests (section 2.2), and high conservation value (HCV) areas (section 2.3). We overlaid these maps to identify suitable areas for production that are neither HCS nor HCV, at a scale of 1 km^2 resolution nation-wide.

2.1 Predicting productive land for oil palm plantations

We predicted the relative suitability of land for commercial oil palm plantations using a correlative modelling approach, based on the apparent environmental preferences exhibited by industry and government leasing agencies for land that supports profitable palm oil production. We based our analysis on the assumption that the current portfolio of permits for industrial-scale oil palm cultivation provide an unbiased reflection of the environmental preferences of the industry. This assumption may be limiting if we included many permits that turn out to be unprofitable, or if investments in improvements such as regionally adapted seed varieties and input management substantially expand the suitability envelope for the crop.

We used maps of exiting plantation permits in the region as the response variable. At the time of writing there were only 130 000 ha of permits in Gabon (MEFEPA 2015), so we expanded our analysis to include more than 1 Mha of permits in Cameroon and Republic of Congo (Global Forest Watch 2015), to capture a more inclusive range of site-selection preferences (figure S1, available at stacks.iop.org/ERL/12/014005/mmedia). We then selected explanatory variables known to affect productivity and cost, as both of these influence permitting decisions (Austin *et al* 2015). Productivity is determined by climate and soil properties, and costs are determined by the local labor market, distance to infrastructure, and biophysical features of a landscape which determine the need for inputs such as terracing, irrigation, or fertilizer. To represent these determinants, we included a set of candidate environmental variables which we screened for pairwise correlations and significance (SI section 2 for detailed discussion of the variable selection process). Based on this screening, we included thirteen variables describing temperature, precipitation, and their extremes (Hijmans *et al* 2005), elevation and topography (Jarvis *et al* 2008), soil properties (ISRIC 2013), and distance to infrastructure (Open Street Map 2015) (table S1). To generate observations to fit the models, we drew a random sample of 1 km^2 pixels from the provinces that currently contain palm plantations.

We built five models to predict the relative suitability of land for commercial oil palm plantations: a generalized linear model (GLM), a generalized additive model (GAM), a random forest model (RF), a generalized boosted model (GBM) and a maximum entropy model (MaxEnt). We categorized the continuous predictions from each of the five models into suitability classes using the Boyce Index as a guide (Hirzel *et al* 2006), and created an ensemble suitability map by averaging the resulting classifications (figure S2). We chose these models because they span a range of model complexity, from fitting relatively simple linear relationships, to more complex relationships that incorporate non-linearities and compensatory interactions among variables (Merow *et al* 2014). This allowed us to build an ensemble projection spanning a range of fitted complexity, thereby taking advantage of the independent information contained in each model, and present final suitability estimates with lower mean error than the constituent single predictions (Marmion *et al* 2009). We provide additional detail on our modeling procedure, including input data, pseudo-absence selection, model specification, evaluation (table S2), thresholding, and creating a model ensemble, in the supplementary information.

2.2 Mapping high carbon stock forests

Our assessment of HCS forests in Gabon is informed by two recent efforts to define 'high carbon stock'. The 'High Carbon Stock Approach' distinguishes forests from shrub and open land on former forests, and recommends that zero-deforestation cultivation be restricted to shrub and open lands (HCS Approach 2015). The 'High Carbon Stock+ Study' recommends an above-ground carbon stock threshold of 75 tC ha^{-1}, above which oil palm developments are not permitted (High Carbon Stock Science Study 2015). We mapped HCS using a national biomass map from Gabon's National Resource Inventory (Burton *et al* 2016). We report the area lower than carbon stock thresholds of 75 tC ha^{-1}, recommended by the HCS+ Study, and 118 tC ha^{-1}, the average carbon stock in secondary forests and similar to the recommendation of the HCS Approach (Burton *et al* 2016). RSPO Next also provides a definition of HCS areas as those with carbon stocks less than or equal to the carbon stock gains within the development area, including vegetation in undeveloped set-asides (RSPO 2015). As this definition provides for offsetting forest losses, without specifying a maximum carbon stock threshold, we do not consider it in the present analysis.

2.3. Mapping high conservation value areas

To identify and map HCV areas, we used generic guidance from the HCV Resource Network, guidance tailored for West and Central Africa (ZSL 2013), and Gabon's Draft National Interpretation of HCV (Stewart and Rayden 2008). We focused on criteria 1–3, whose concepts and definitions have been better developed in practice in Gabon than criteria 4–6. We base this analysis on many of the same datasets and definitions as those used by scientific advisors and policymakers in-country (see Supplementary Information).

HCV 1: Biological diversity—We used four indicators to delineate HCV 1 areas in Gabon:

a. Protected areas: This includes all national parks, presidential reserves, hunting domains, and faunal reserves (ANPN 2015).

b. Threatened or endangered species: Previous research mapped suitable habitat for 28 reptiles, birds and mammals that are considered globally threatened or endangered, or likely to be nationally threatened in Gabon (Lee 2014, IUCN 2001). We classify an area as HCV 1.b if it supports suitable habitat for one of these species.

c. Rare or restricted range species: Using maps of suitable habitat for rare or restricted-range reptiles, birds or mammals from Lee (2014), we classify an area as HCV 1.c if it supports suitable habitat for species present in less than 5% of the country.

d. Habitat for endemic species: In Gabon, endemic species are frequently associated with high altitude forests (Stewart and Rayden 2008); therefore we classify forests above 700 m as HCV 1.d (Jarvis *et al* 2008).

HCV 2 Landscape-level ecosystems—Using a map of Intact Forest Landscapes from 2013, we defined HCV 2 as forests at least 1 km from human-dominated areas (e.g. settlements, infrastructure, agriculture, mining), with an area of at least 50 000 hectares and a minimum width of 10 km (Intact Forest Landscapes Mapping Team 2013, Potapov *et al* 2008). These areas represent the largest and least disturbed forest expanses in the country, able to sustain natural ecosystem processes and functions, including viable populations of plant and animal species (Ferraz *et al* 2003). A large portion of these intact forest landscapes have been or are currently licensed for logging (MEFEPA 2015). However, as logging intensity in Gabon is low and selectively logged forests retain high carbon stocks (Medjibe *et al* 2011), we did not exclude areas from HCV 2 on the basis of logging.

HCV 3 Rare ecosystems—We use a map that delineates 30 land types in Gabon on the basis of geology, topography, rainfall regime, surface water, and land cover (Lee 2014). We defined rare ecosystems as those occurring in $<1\%$ of Gabon, which includes hyper-humid flooded forest, hyper-humid rugged forest, mangrove forests, flat well-drained grasslands of the central coastal plateau, well-drained grasslands of the coastal basin, and humid calcareous grasslands.

3. Results

3.1. Plantation suitability

Our predictive models of relative plantation suitability performed well, with areas under the receiver operating characteristic (ROC) curve for each model ranging between 0.74–0.89, and model sensitivities ranging between 0.78–0.86 (table S2). Based on cross validation, the models are robust to alternative presence and pseudo-absence records used to build each model. The main determinants of suitability in Gabon are precipitation extremes and altitude, with high elevation and low dry season precipitation precluding agriculture (figure S2).

We estimate that there are 7.8 Mha of suitable land, 7.2 Mha of moderately suitable land, 6.4 Mha of marginally suitable land, and 4.7 Mha of unsuitable

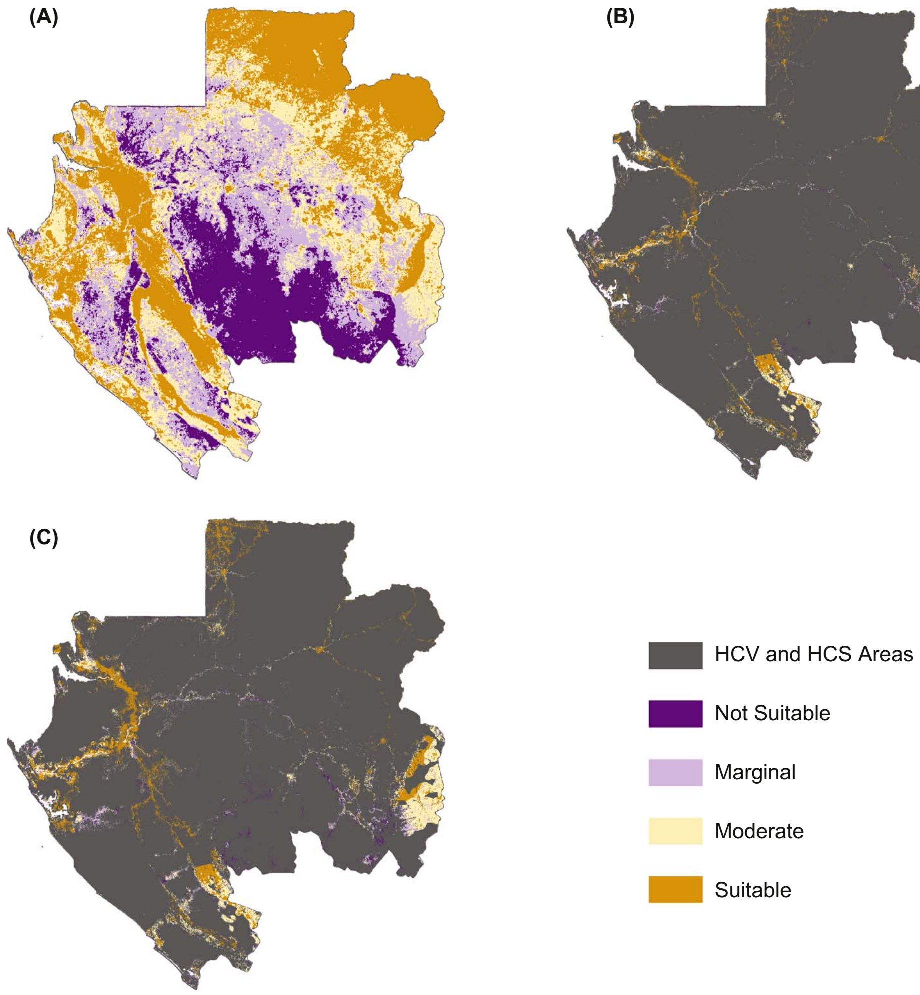

Figure 1. Suitability for industrial-scale oil palm plantations in Gabon based on (*a*) ensemble average of five suitability models. (*b*) unavailable HCV and HCS areas greater than 75 tC ha^{-1} masked in grey and (*c*) unavailable HCV and HCS areas greater than 118 tC ha^{-1} masked in grey.

land for industrial oil palm plantations in Gabon (figure 1(*a*)). In total, 58% of Gabon's land area is suitable or moderately suitable for oil palm production at an industrial scale, concentrated in the northeastern region of Gabon, the southeast including the Batéké plateau, the corridor between Libreville and Ndendé, and along the coast.

3.2. Synthesis of suitable, high carbon stock and high conservation value areas

Only 13% percent of Gabon's land area, or 3.3 Mha, contains less than 75 tC ha^{-1} in above ground biomass, and only 20% of the country, or 5.2 Mha, contains less than 118 tC ha^{-1} in above ground biomass (figure 2). Consequently, 80%–87% of Gabon's land is considered HCS at these thresholds. Protecting areas with more than 75–118 tC ha^{-1} would result in the protection of between 93%–99% of the country's forest carbon stocks.

Just over one-quarter of Gabon's land, or 6.9 Mha, lies outside HCV areas according to the criteria used in this study (figure 3, table 1). Conversely, 73% of the country, or 19.2 Mha, would be protected by the HCV approach. Habitats for threatened or endangered species, HCV criterion 1.b, protects the largest area, while rare species distributions, HCV criterion 1.c, protects the smallest area (table 1). Overlap of areas meeting each HCV criterion is large, with 48% of all HCV areas containing multiple HCV criteria. Together, the HCV criteria included in this assessment protect 76% of Gabon's forest carbon stocks.

Overlap between HCV and HCS areas ranges between 23%–99%, depending on the HCV criterion considered (figure 4). Between 78%–99% of protected areas (criterion 1.a), threatened or endangered species distributions (criterion 1.b), high elevation forests (criterion 1.d), and intact forest (criterion 2), are also considered HCS areas. Yet only 23%–34% of rare species distributions (criterion 1.c) and 34%–43% of rare habitats (criterion 3), are also considered HCS areas. In a highly forested country like Gabon, rare species live outside forests and rare habitats are largely non-forested, and thus these two HCV criteria would be afforded limited protection by an HCS approach.

Approximately 2.7–3.9 Mha of suitable and moderately suitable land also avoid HCS areas, 4.4 Mha also avoid HCV areas, and 1.2–1.7 Mha would be

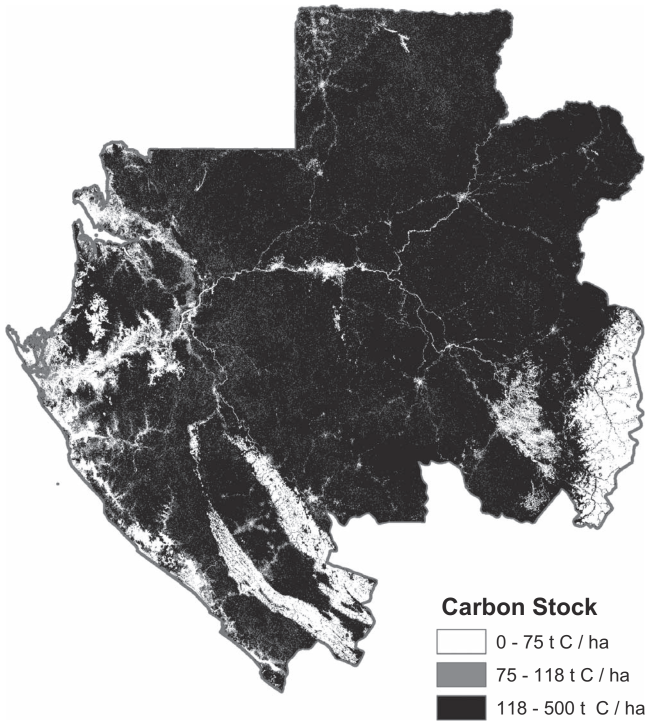

Figure 2. Forest Carbon Stock in Gabon at thresholds of 75 and 118 tC ha^{-1}.

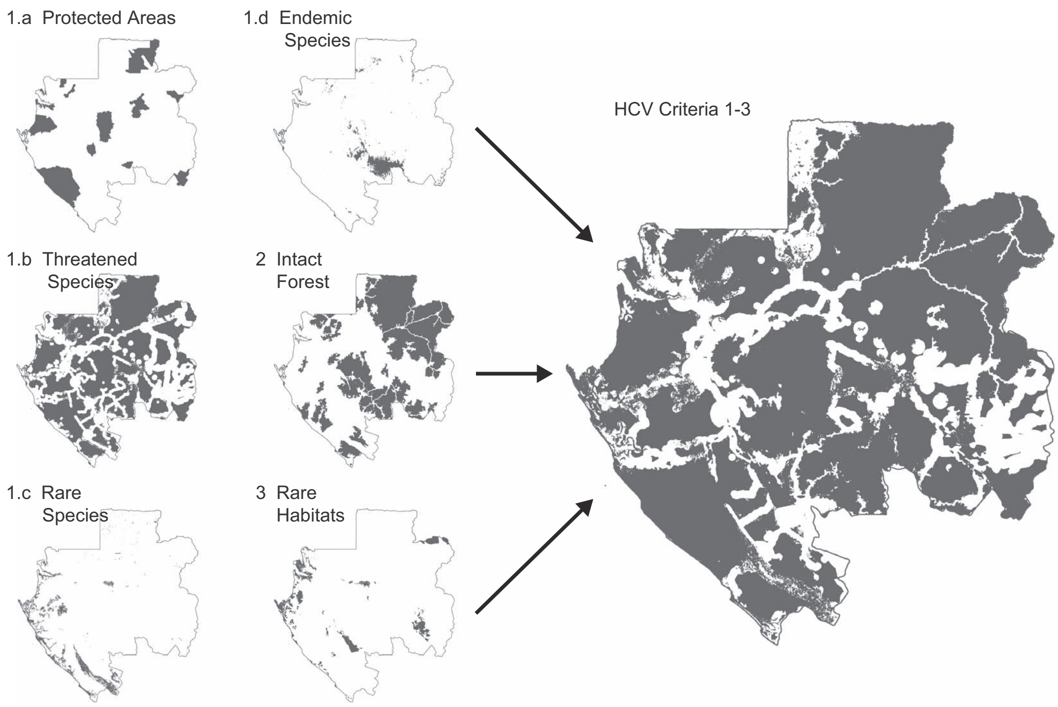

Figure 3. Components of HCV criteria 1–3 (areas considered HCV are shaded in grey).

possible to develop without compromising either HCS or HCV standards (figures 1(*b*) and (*c*)). Increasing the carbon threshold beyond 118 tC ha^{-1} would result in more area eligible for zero-deforestation production. This increase plateaus at approximately 170 tC ha^{-1}, above which the large majority of land is either already HCV or not estimated to be suitable for oil palm (figure 5).

4. Discussion

4.1. Tradeoffs between agricultural production and environmental conservation

In Gabon's 2011 national strategic development plan the government included a target of producing 280 000 tons of crude palm oil (CPO) per year (République Gabonaise 2012). More recently, the Investment Agency

Table 1. Proportion of national land area and national forest carbon stocks overlapping with HCV criteria 1–3. The area and carbon stocks protected by each individual HCV criterion add up to more than the total protected by all HCV criteria because of overlap between criteria.

	Area (Mha)	Land area overlapping HCV criterion	Forest carbon stock overlapping HCV criterion
HCV 1.a Protected Areas	3.85	15%	15%
HCV 1.b Threatened Species	15.41	59%	64%
HCV 1.c Rare Species	1.00	4%	1%
HCV 1.d Endemic Species	0.84	3%	4%
HCV 2 Intact Forests	10.85	41%	47%
HCV 3 Rare Ecosystems	1.15	4%	2%
All HCV Criteria	19.20	73%	76%

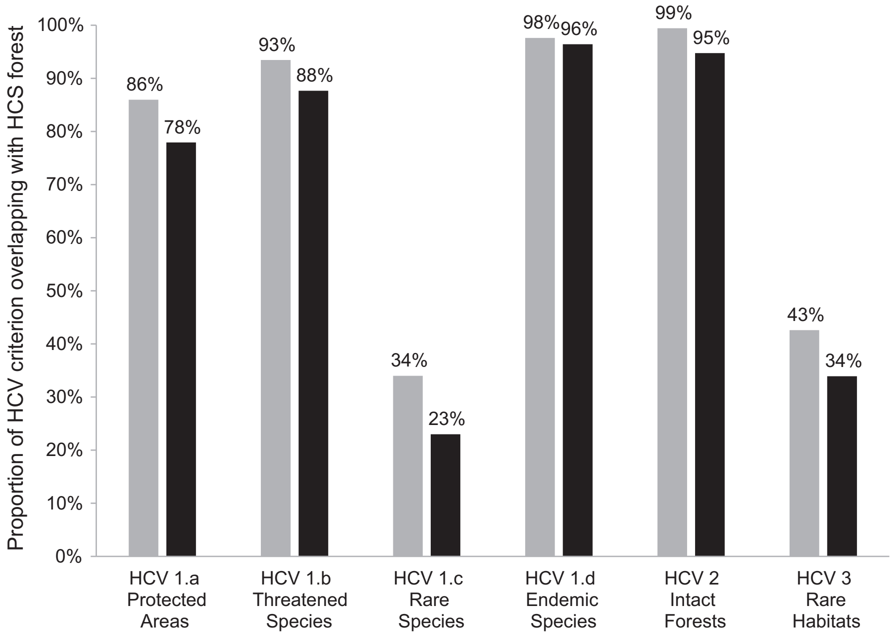

Figure 4. Proportion of HCV criteria 1–3 overlapping with HCS forest at a carbon threshold of 75 tC ha^{-1} (grey) and 118 tC ha^{-1} (black).

of Gabon has also announced a more ambitious goal of 1 million tons produced per year (APIEX 2014). At the same time, the government intends to protect HCV and HCS areas, thus conceding a large area for oil palm expansion. Nonetheless, we estimate that 1.2–1.7 Mha of suitable and moderately suitable land for oil palm avoids both HCV and HCS areas, and could be sufficient to support the government's stated production goals, assuming plantations in Gabon achieve yields on par with those reported in Cameroon of 1–2 tons CPO per hectare (Nkongho *et al* 2014, Konsager and Reenberg 2012). This additionally assumes that suitable non-HCV areas according to the criteria and national-scale data used in this study are not subsequently determined to be unsuitable or HCV by comprehensive local-scale evaluations.

The government of Gabon has additionally pledged to increase production of several other agricultural commodities including rice, corn, soy, plantain, coffee, cocoa, and rubber (République Gabonaise 2012). In addition, there may be increasing competition for land among the agriculture, mining, oil and gas, and timber industries in the country. Subsequent research is needed to take into account production of these other commodities, which may reduce the availability of non-HCV and non-HCS land for sustainable oil palm.

4.2. Overlap between HCV and HCS

Although HCV and HCS approaches largely overlap, we find that less than half of rare species distributions and rare habitats (HCV criteria 1.c and 3) overlap with HCS at the carbon thresholds evaluated (figure 4). This demonstrates the potential shortcomings of an oil palm expansion strategy that focuses only on preventing deforestation. Prioritizing forest conservation may put rare and ecologically important grassland, savannah, or wetland species and landscapes at risk, if additional safeguards for their protection are not put in place (Bond 2015).

There is the potential that HCS and HCV approaches will not always be applied together. Companies controlling more than 90% of palm oil have committed to eliminating deforestation from

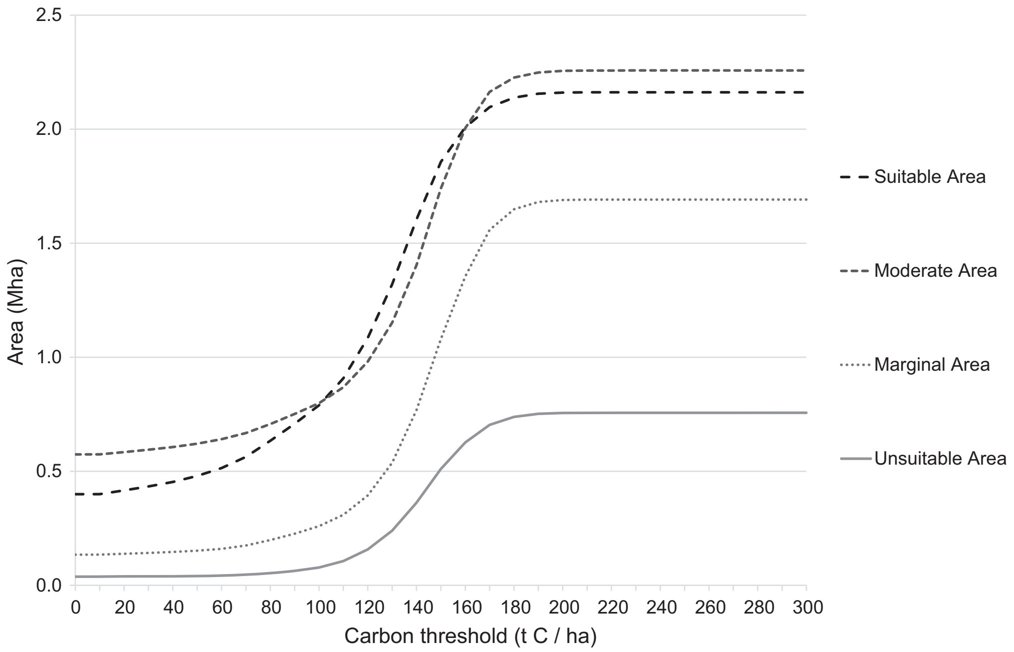

Figure 5. Area (Mha) meeting HCV and HCS criteria across a range of carbon stock thresholds, by suitability class. In total there are 1.2–1.7 Mha of suitable or moderately suitable land for oil palm cultivation that is neither HCV nor HCS at thresholds of 75 tC ha^{-1} and 118 tC ha^{-1} (dashed lines).

their supply chains within the next five years, and are likely to apply some form of HCS to delineate areas meeting this commitment (United Nations 2014). On the other hand, only 20% of palm oil is currently certified by the RSPO, indicating that, among other requirements, it meets HCV criteria (RSPO 2016). Although the share of RSPO certified palm oil will also increase in the near future, it is not clear whether this will keep pace with the implementation of zero-deforestation pledges. Integrating HCS with HCV safeguards, as has been proposed by the HCS Approach, the HCS+ study, and RSPO Next, ensures that important non-forest habitats and ecosystems are protected.

4.3. Implementation challenges

Due to the relative novelty of zero-deforestation commitments and accompanying HCS guidance, there are still several outstanding questions regarding implementation that could have a significant impact on the extent and location of forest protection. For example, zero-deforestation commitments vary in terms of whether they refer to gross zero-deforestation, which prevents clearing of any forests meeting the HCS definition, or net zero-deforestation, which allows some clearing of forests as long as this loss is offset by equivalent gains in another area (Brown and Zarin 2013). The HCS+ study and RSPO Next guidance allow companies to offset greenhouse emissions from deforestation by protecting 'set-asides' within their concession boundaries where forests are protected and greenhouse gas emissions are sequestered. A potential risk of allowing net accounting is that artificially large permits will be granted, inflating the area of set-asides providing offsets and enabling a larger area of forest clearing while still meeting a net zero-deforestation target. In order to receive credit for carbon sequestration within a set aside, it is crucial that it would have been degraded in the absence of additional protection, and that its protection does not result in leakage of forest-degrading activities outside the accounting boundary. Ultimately HCS accounting rules should be strict enough to prevent unnecessary deforestation, while encouraging companies to set aside and protect areas within their permits on the basis of HCS or HCV.

In addition, many palm oil companies in the region have pledged to support smallholder enterprises by providing technical training in agriculture and material support, such as seedlings. Yet it is not clear whether smallholders will be held to the same social and environmental standards as large companies. A crucial next step for researchers and policy makers is to consider the roles and responsibilities of smallholders and identify appropriate environmental guidelines for small-scale farmers in addition to industrial-scale enterprises.

4.4. Next steps for plantation management

This study illustrates an approach to national land use planning that considers HCS and HCV conservation approaches, using the most up-to-date and available data. We recommend further steps to refine this analysis to ensure that appropriate management decisions are carefully applied. For example, the National Parks Agency of Gabon (ANPN) is developing guidance which outlines the requirements for site selection, environmental and social impact assessments (ESIA), and monitoring and adaptive management for oil palm plantations within Peripheral Zones, which are large buffer areas around National Parks that are under the jurisdiction of ANPN. This guidance will refine the national-scale maps included in this study by incorporating field information, in addition to outlining steps for conducting scale-appropriate ESIAs, identifying locally important ecological, social, and cultural features for site-level planning, conducting participatory mapping to incorporate the values of local communities (ZSL 2013), and mitigating off-site impacts of plantation operation. In this context, our study provides a first-cut at determining how HCS and HCV strategies align with national targets for oil palm production and forest protection, which can be used as a guide to inform priority areas for more intensive data collection and analysis. Detailed field analyses will be essential for reducing uncertainty and improving the basis for land use planning at the scale of implementation.

5. Conclusion

Global palm oil production has doubled every decade since 1970 (FAOSTAT 2015), and will likely increase at this rate in the near future (Corley 2009). Cultivation is currently expanding in Gabon, a country with a large area of suitable or moderately-suitable land for industrial-scale oil palm plantations, and home to one of the highest proportions of forest cover in the world. Without appropriate safeguards, oil palm expansion threatens these forests, and the biodiversity resources and carbon stocks that they support. Our analysis demonstrates that Gabon's current oil palm production target of 280 000 to 1 million tons CPO per year can likely be met on suitable or moderately-suitable land without compromising HCS and HCV areas. It additionally suggests that compliance with industry zero-deforestation commitments is possible even in highly forested countries like Gabon, if appropriate rules and standards are put in place. However, we emphasize the importance of including HCV criteria to ensure that ecologically rare ecosystems and species in low carbon stock areas are protected. Our analysis illustrates an approach to national land use planning that combines spatial analysis of potential suitable land with environmental conservation criteria. This general approach can be applied to other crops in Gabon or in other countries facing similar challenges of reconciling agricultural growth with environmental conservation.

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