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The Coffee Compromise: Is Agricultural Expansion into Tree Plantations a Sustainable Option?

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Abstract: In tropical regions, land-use pressures between natural forest, commercial tree plantations, and agricultural land for rural communities are widespread. One option is to increase the functionality of commercial plantations by allowing agroforestry within them by rural communities. Such land-sharing options could address wider societal and environmental issues and reduce pressure on natural forest. To investigate the trade-offs involved, we used InVEST to model the ecosystem services provided by growing coffee under commercial pine plantations in Indonesia against other land-use options. Pine–coffee agroforestry provided worse supporting and regulating services (carbon, sediment and nitrogen retention, catchment runoff) than natural forest; however, it provided greater provisioning services (product yield) directly to smallholders. Converting pine monoculture into pine-coffee agroforestry led to increases in all ecosystem services, although there was an increased risk to water quality. Compared with coffee and root crop monocultures, pine–coffee agroforestry provided higher levels of supporting and regulating services; however, product yields were lower. Thus, opening up pine plantations for agroforestry realises additional income-generating opportunities for rural communities, provides wider ecosystem service benefits, and reduces pressure for land-use change. Lower smallholder yields could be addressed through the management of shade levels or through Payments for Ecosystem Services schemes.

Keywords: agroforestry; InVEST; Indonesia; ecosystem services; land-use change; trade-offs

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Citation: Fitch, A.; Rowe, R.L.; McNamara, N.P.; Prayogo, C.; Ishaq, R.M.; Prasetyo, R.D.; Mitchell, Z.; Oakley, S.; Jones, L. The Coffee Compromise: Is Agricultural Expansion into Tree Plantations a Sustainable Option? *Sustainability* **2022**, *14*, 3019. https://doi.org/10.3390/su14053019

Academic Editor: Elena Brunori

Received: 31 January 2022
Accepted: 1 March 2022
Published: 4 March 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

1. Introduction

Land-use change for agriculture is the fundamental threat for tropical forest ecosystems [1]. In Southeast Asia, plantations for palm oil, pulp wood, and rubber products are expanding due to global demand [2,3], resulting in the deforestation of primary and secondary forests [4,5]. With a growing population needing access to land combined with increased scrutiny to preserve forested lands, pressure on the natural resources within these ecosystems continues to increase [6], leading to conflict and trade-offs in product yields, ecosystem function, and biodiversity conservation [7–9]. Thus, the challenge exists to find sustainable development options that can reduce land-use pressures or minimize impacts, and agroforestry has been proposed as one such solution [10].

Combining shade trees and crops can provide secondary products, such as timber and fruits [11,12], enabling the diversification of income and protection against crashes in crop prices [13]. Often, this takes the form of adding or retaining shade trees in a system where the understory crop is the focus. Coffee is commonly grown in an agroforestry system in tropical areas and the incorporation of shade trees provides benefits such as pest and disease control, carbon storage, and biodiversity [14–16], amongst others [17,18]. An alternative form of agroforestry, which can be practiced in areas where plantation forestry dominates, is to incorporate shade-tolerant crops such as coffee or cocoa into existing tree plantations. Such approaches offer opportunities for land-sharing agreements between rural communities and commercial forestry, thus enhancing rural livelihoods for those with limited access to cultivatable land, and potentially mitigating forest clearance for agriculture [19,20].

Converting commercial forestry into agroforestry systems is not straightforward. Commercial plantation forest is a valuable resource [4,20], and trees may be affected through competition for resources with interplanted crop [21] or require changes in management. The ecological and economic benefits of agroforestry within a commercial forestry plantation may differ from 'typical' agroforestry systems and are poorly understood. In land-sharing systems, the income crop for the farmer is secondary to the trees which are grown at a higher density and owned by a second party. This produces a distinct difference in the system set-up and the actors involved compared to other agroforestry systems. To date, few studies have directly studied this complex agroforestry arrangement. Before encouraging the expansion of community agroforestry within commercial tree plantations as a sustainable development strategy, the impacts on the functioning of the ecosystem and the benefit to rural communities need to be understood [22,23].

An example of agroforestry within commercial plantations can be found on Java, Indonesia, where coffee is grown under native pine (*Pinus merkusii*) plantations. The pine is grown for resin and timber, with resin tapping contracted to rural villagers by allocating land-use rights of approximately 1-hectare plots to workers [24]. Villagers' livelihoods are often dependent on growing food crops and coffee within allocated plots, a practice not always viewed favourably from a commercial forestry perspective [25]. In some cases, coffee farming within government pine plantations has been encouraged (under informal agreements) by the state forestry company Perum Perhutani to enable rural villages to obtain an income from the land and prevent the clearance of their trees for other crops [26,27]. This setup appears to be a 'win-win' situation for all actors involved, with smallholders cultivating an income-generating crop: Indonesia produced 636,000 tons of coffee in 2018/2019, predominately from smallholders [28]. Meanwhile, the state forestry company is able to maintain its source of income from pine resin and timber [29]. However, the trade-offs in ecosystem function and impact on smallholders against alternative land uses have not been evaluated.

Ecosystem service models are one method to understand trade-offs in ecosystem services associated with land use (e.g., [30]). Modelling alternative land-use scenarios allows a picture to be built up of the impact of land-use choice, and the measures needed to compensate for the loss of services (e.g., [31]). Currently, few studies have incorporated agroforestry within landscape-scale models, due to the complexity of modelling this land use. Zheng et al. [32] employed a similar approach to compare the differences in ecosystem service provision between intercropped and non-intercropped rubber in China. Kay et al. [33] incorporated cherry orchard agroforestry to explore how agroforestry affects the landscape provision of ecosystem services compared to monocropping.

Therefore, we investigated whether pine–coffee agroforestry is truly a 'win-win' scenario both environmentally and for the multiple actors involved, by incorporating pine–coffee agroforestry as a land-use class in a widely used landscape-scale ecosystem service model, InVEST. At a catchment scale, we modelled five ecosystem services (carbon storage, nitrogen retention, sediment retention, water yield, and smallholder product yield) for five alternative scenarios for commercial production forest pine plantation in part of East Java, Indonesia. The land-use scenarios were: secondary forest, pine monoculture, pine–coffee agroforestry, full-sun coffee, and an annual agricultural crop. We aimed to address the question of whether pine–coffee agroforestry achieves a balance in ecosystem service outputs and can be considered as a sustainable development strategy.

2. Materials and Methods

2.1. Study Site

Located in East Java, the study area consists of four catchments on the slopes of stratovolcanoes Arjuno-Welirang and Kawi-Butak, and is located in the Upper Brantas Watershed (Figure 1). The source of the Brantas River is the stratovolcano Mount Arjuno-Welirang, and tributaries stem from the surrounding stratovolcanoes. The catchments are a source of water supply to springs within Batu City [34]: population 170,000 [35]. The area has a tropical monsoon climate with two distinct seasons: rainy season from November to April and dry season from May to September. Average precipitation is 1900–2000 mm per year, of which 80% occurs in the rainy season [34].

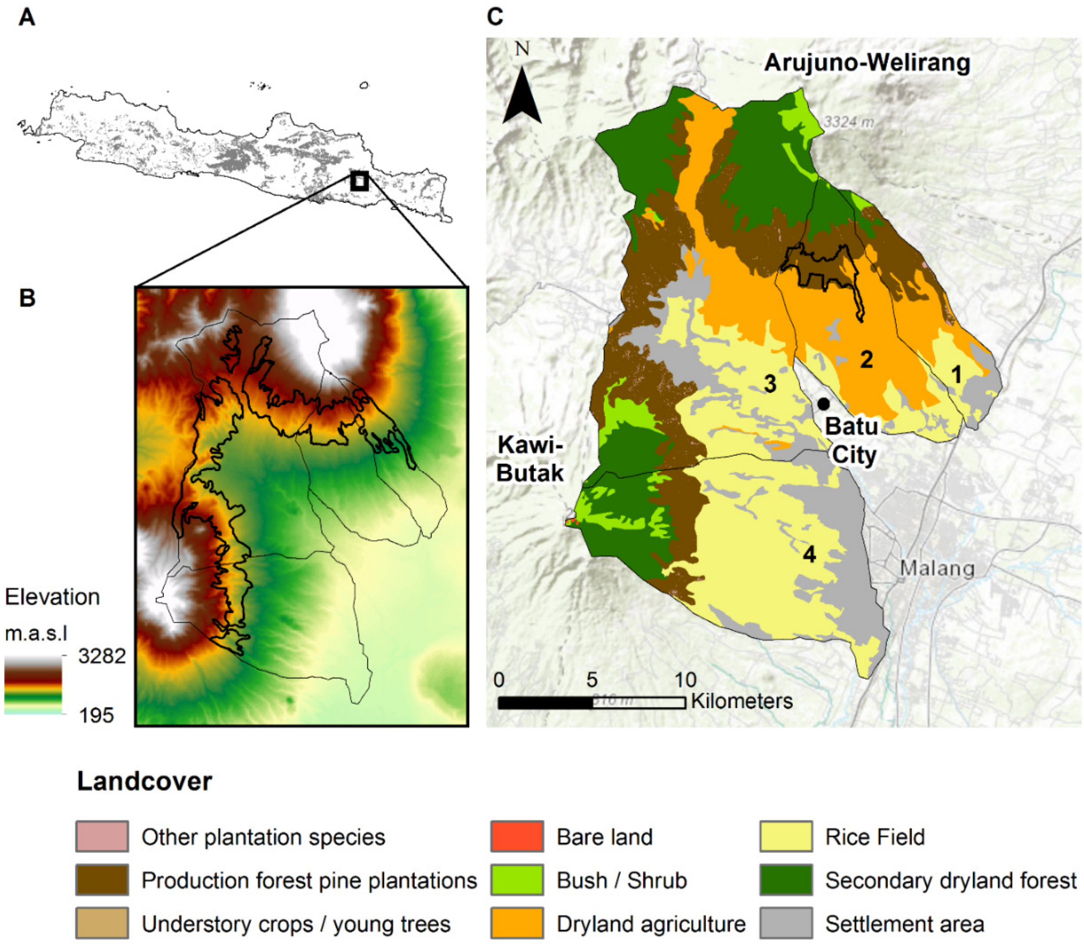

Figure 1. (**A**) Location of study area on Java. (**B**) Elevation across the study area with production forest band picked out. (**C**) Study area within Upper Brantas Watershed, with location of UB forest and land cover. Catchments are numbered for identification. Background map copyright Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnace Survey, Esri Japan, METI, Esri Chrina (Hong Kong), swisstopo.

Land cover within the catchments is based on the Ministry of Environment and Forestry land-cover map [36] combined with a classification of tree type within their production forest class. Within the catchments, the land cover consists predominately of agriculture, followed by production forest pine plantations and human settlements, with secondary forest located higher up the stratovolcano slopes. Pine plantations make up 29% of the land use in catchment 1, 16% in catchment 2, 27% in catchment 3, and 9% in catchment 4.

The agroforestry research platform of Brawijaya University, Malang, known as UB forest, sits within these catchments in which pine–coffee agroforestry is the dominant land use. Originally owned by Perum Perhutani, the land has been granted to Brawijaya University to undertake educational research around agroforestry practices within state forests. The forest is home to a number of communities who cultivate coffee under the plantation forest [25].

2.2. Scenarios

Within the study area, five scenarios were created to explore alternative land uses for pine plantations in the production forest band. These five scenarios cover a management intensity gradient ranging from low to high intensity, described below (with scenario abbreviations in brackets):

1. Secondary forest (forest)—the most likely natural forest state in the area, given historical disturbance.
2. Monoculture pine plantation (pine)—*Pinus merkusii* with no ground cover vegetation.
3. Pine–coffee agroforestry (agroforestry)—*Pinus merkusii* with coffee (*Coffea arabica*) as an understory.
4. Monoculture sun coffee (coffee)—Arabica coffee (*Coffea arabica*) with no understory or interplanting.
5. Annual crop (crop)—generic root vegetable crop modelled on taro (*Colocasia esculenta*) and with no interplanting.

Scenarios other than secondary forest are referred to in the text as 'managed', reflecting the human cultivation aspect. The key assumption applied within the scenarios is that the system is at its peak, i.e., coffee and pine trees are mature.

2.3. Modelling

We used the Integrated Valuation of Ecosystem Services and Trade-offs (InVEST software version 3.8.1) suite of spatially explicit ecosystem service models. InVEST utilises land-use land-cover maps and provides a biophysical output value for each service [37]. The strengths and weaknesses of InVEST compared to other spatially explicit ES models have been investigated by Sharps et al. [38]. We chose InVEST as it is open-source, able to be used with global datasets, has relatively few input parameters, and has been applied across the globe (e.g., [30,39,40]). As such, is it particularly useful for addressing research and development questions in more data-poor regions of the world. Four ecosystem services were modelled using InVEST (carbon storage, nitrogen retention, sediment retention, and water yield), with the fifth (product yield) modelled separately. Due to the mismatch in landscape scale of the models and plot scale for limited field data, not all model outputs were calibrated.

2.3.1. Carbon Storage

The InVEST carbon storage and sequestration model uses lookup tables of carbon values, summing carbon from above ground biomass (bark, trunk, branches, and leaves), belowground biomass (roots), dead organic matter (standing deadwood and litter), and soil carbon. As the amount of carbon in each pixel is not dependent upon neighbouring pixels, only carbon within the production forest band under the different scenarios was calculated.

Aboveground biomass or carbon values for land uses of secondary forest, pine monoculture, full-sun coffee, and agriculture were obtained from the literature for Indonesia (Table S1, Supplementary Materials). Aboveground biomass data for agroforestry were obtained using data from UB forest with pine- and coffee-specific allometric equations from Hairiah et al. [41]. Agroforestry aboveground biomass was converted to aboveground carbon using a conversion factor of 0.46, which differs from the default of 0.47 [42] based on the manual produced by Hairiah and Rahayu [43] for measuring stored carbon in Indonesia.

Belowground biomass, and consequently carbon, was calculated as a fraction of aboveground biomass, using root-to-shoot ratios for tropical ecosystems provided in IPCC guidelines [42]. Dead litter carbon was assumed to be 2% of aboveground carbon. Global soil organic carbon was obtained from Hiederer and Kochy [44]. These data were assumed to be soil organic carbon stored under natural conditions; consequently, a reduction factor was applied to each managed land use according to the work of Hairiah et al. [45] on soil organic carbon change under different systems in Indonesia. Carbon values applied in the study and soil organic carbon reduction factors are listed in Table S1.

2.3.2. Nitrogen Retention

The nitrogen retention of each scenario was calculated by modelling nitrogen export using the Nutrient Delivery Ratio (NDR) model and subtracting catchment export from catchment total load. The model applies a simple mass balance approach representing the steady-state flow of nutrients from land to river [37]. Nutrient input (load) into the system was modelled as atmospheric deposition plus fertiliser quantities obtained from the Food and Agriculture Organisation (FAO, Rome, Italy) for Indonesia [46]. Three atmospheric deposition classes were generated to account for different heights, and therefore interception ability, of vegetation: low-growing vegetation (grass, 8.59 Kg N ha^{-1} year^{-1}); medium-height vegetation (10.70 Kg N ha^{-1} year^{-1}); and tall vegetation (23.45 Kg N ha^{-1} year^{-1}). Baseline atmospheric deposition for the area was obtained from Galloway et al. [47], and values were scaled according to the deposition velocities of Jones et al. [48] to obtain a value appropriate for medium and tall classes.

Nitrogen was modelled as surface flow through each pixel, with pixel-level export (export defined here as the nutrients that will reach the stream) calculated based on upslope area and retention efficiencies of land-use land-cover types downstream. Pixels with natural vegetation retain a higher percentage of nutrients passing through.

Gridded data of elevation [49] and annual precipitation [50] (as a proxy for nutrient runoff) were used in the model, along with biophysical variables of retention efficiencies and retention lengths of each land use. Land-use–land-cover-specific biophysical variables for the scenarios are provided in Table S2 in Supplementary Materials. Further detail and equations underlying the model can be found in Sharp et al. [37]. The model outputs were the total annual nutrient exported per pixel and for the watershed.

2.3.3. Sediment Retention

The Sediment Delivery Ratio (SDR) model of InVEST models sediment exported from the catchment by calculating the annual soil loss per pixel using the revised universal soil loss equation (RUSLE) and multiplying this by the proportion of soil loss that actually reaches the stream. Only rill/inter-rill erosion processes are modelled, and all sediment that reaches the stream is assumed to leave the catchment; hence, no in-stream processes are incorporated. See Sharp et al. [37] for further detail and equations underlying the model.

Gridded datasets of elevation [49], rainfall erosivity [51], and soil erodibility [52] were inputted into the model, along with cover-management and support practice factors applicable to different land uses. Cover-management values were obtained from Panagos et al. [53] and support practice factors derived from Stone and Hilborn [54] for each scenario. Values applied are provided in Table S3 in Supplementary Materials.

2.3.4. Water Yield

Water yield (also described as catchment runoff) was modelled using InVEST water yield model, in which it is assumed that water is lost from the catchment by evapotranspiration or abstraction only. Water remaining after evapotranspiration is calculated to reach the river irrespective of pathway travelled: surface, subsurface, or baseflow. This model uses annual average precipitation [50], with evapotranspiration modelled based on the Budyko curve [55].

To calculate evapotranspiration, gridded datasets of potential evapotranspiration [56], root-restricting layer depth [52], and plant available water fraction [52] were utilised, as well as biophysical values for each land-use class of root depth where 95% of roots occur and crop evapotranspiration coefficient (Kc). Biophysical values applied to each scenario are listed in Table S4 in Supplementary Materials. Kc is less clear-cut for pine–coffee agroforestry and pine monoculture. Based on information concerning shaded coffee plantations, pine–coffee agroforestry is assumed to have higher evapotranspiration than full-sun coffee or annual crop, between that of rain-fed crop and natural forest [57]. With the density of pine assumed to remain unchanged, and with no ground cover, pine monoculture is assumed to have lower evapotranspiration than natural forest and pine–coffee agroforestry. The resulting differences in the Kc modelled were minor and deemed appropriate, as Cristiano et al. [58] found that plantations have similar evapotranspiration losses to natural forest in subtropical climates.

A key parameter for modelling evapotranspiration is the Z parameter, an empirical constant which conceptualises local hydrological characteristics. Z was estimated as the average number of rain days per year multiplied by 0.2, following Donohue et al. [59], producing a value of 25. This method has been shown to result in a good agreement between modelled and measured data [60]. Further detail concerning the calculations can be found in Sharp et al. [37].

2.3.5. Products

For each scenario, the potential yield of crop or product was calculated. Coffee produced under pine–coffee agroforestry was taken as an average yield for smallholdings within UB forest [61,62]. Indonesian yields were only available as aggregated values including both sun and shade coffee; thus, full-sun coffee yield data were taken from Vietnam, where coffee plantations are primarily in full sun and are often used for comparisons with Indonesian yields. Turpentine and rosin produced from pine resin is a main source of income for the state forestry company Perum Perhutani, and smallholders receive a form of payment based on resin tapped. When pine cannot be tapped further, wood is felled and sold mostly on domestic markets [29]. Rosin and turpentine yields from pine resin were obtained from Perum Perhutani [63], and taro yield was obtained from FAO [64]. Although taro production for Asia is estimated at 12.6 tons yr^{-1} ha, we selected the more conservative global average of 6.2 tons yr^{-1} ha to account for the less-optimal growth conditions for taro across the elevation band. Resin yield was assumed to be unaffected with the addition of coffee agroforestry. Timber yield was not accounted for due to the complexity required concerning quality and class, and smallholders do not gain any revenue from felled timber.

3. Results

The results presented here are predicted outcomes, based on input data for each scenario. Scenarios were compared against the pine scenario, which was taken as the baseline to reflect the current situation.

3.1. Carbon Storage

The quantities of carbon stored in the forest scenario were higher than all of the managed land-use scenarios. Agroforestry led to a lower (4%) increase in the carbon storage compared with monoculture pine plantations (Figure 2). By contrast, other agriculture options had substantially lower carbon storage than pine (43–55%). Changes in the spatial pattern of carbon storage across the production forest band within scenarios reflected the combined influence of land cover and underlying soil type (Figure 3).

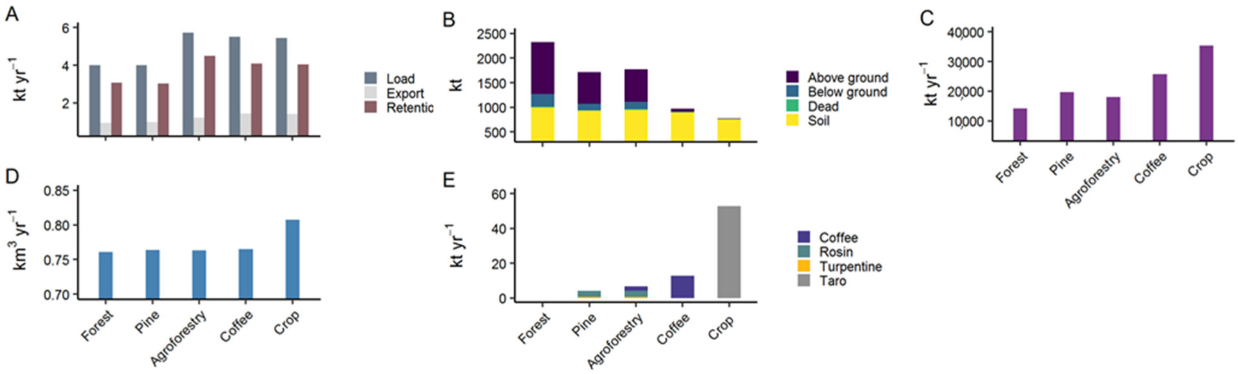

Figure 2. Total values across catchments for different ecosystem services of (**A**) nitrogen load, export and retention; (**B**) carbon stock according to different carbon stores; (**C**) sediment exported; (**D**) water yielded; and (**E**) product yield per scenario. Note different y axes for each plot, and that carbon refers to production forest band only.

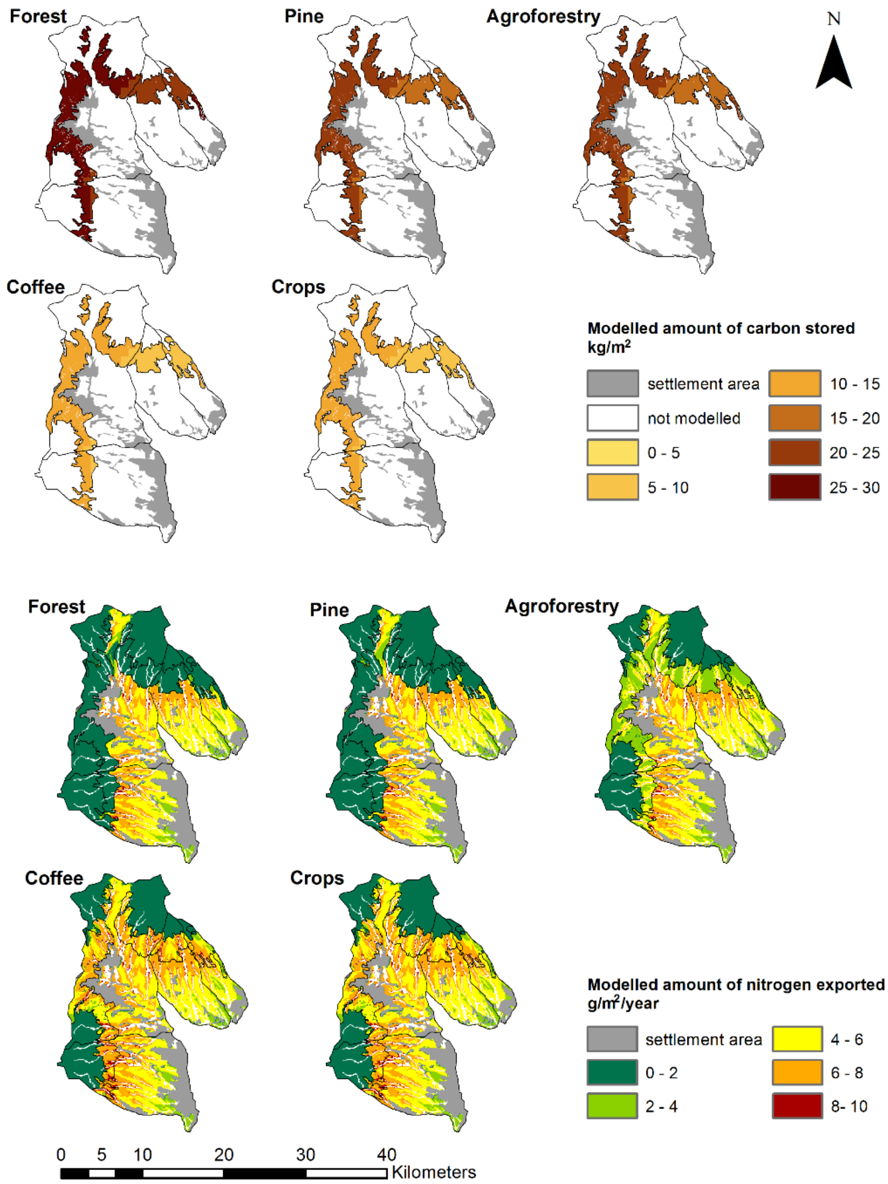

Figure 3. Model outputs of carbon stored and nitrogen exported for different land-use change options of the pine production band.

3.2. Nitrogen Retention

All scenarios involving agriculture, including agroforestry, had a higher nitrogen load and export than pine or forest. However, the fraction of nitrogen load retained within the agricultural systems varied, with higher retention in the agroforestry scenario compared with coffee or crop, leading to a lower export despite a higher load (Figure 2). We mapped nitrogen export rather than retention in Figure 3 because the former has the greatest impact on water quality. On the spatial impact of land use, steeper areas closer to flow paths had a higher export of nitrogen (Figure 3). Considering the production forest band only, the rate of average nutrient export was 370 g N km^2 yr^{-1} under agroforestry, intermediate between the tree scenarios (30 g N km^2 yr^{-1} under forest; 60 g N km^2 yr^{-1} under pine) and the monoculture crop scenarios (590 g N km^2 yr^{-1} under coffee; 580 g N km^2 yr^{-1} under crop).

3.3. Sediment Retention

Forest had the lowest sediment loss out of the scenarios (28% lower than pine), followed by agroforestry (8% lower than pine) (Figure 2). Under crop, total sediment lost was almost double the amount lost under pine. The spatial patterns showed that areas with higher slope gradients within the production forest band displayed higher quantities of sediment loss (Figure 4). Considering the production forest band only, the average rate of sediment export within the band for agroforestry was 3190 kg km^2 yr^{-1}, intermediate between forest (160 kg km^2 yr^{-1}) and managed scenarios (4880 kg km^2 yr^{-1} under pine; 11,280 kg km^2 yr^{-1} under coffee; 21,490 kg km^2 yr^{-1} under crop). Taking an average rate of sediment export for the catchment as a whole under each scenario, the order remained the same, though the rates reduce to: 680 kg km^2 yr^{-1} under forest; 940 kg km^2 yr^{-1} under pine; 860 kg km^2 yr^{-1} under agroforestry; 1240 kg km^2 yr^{-1} under coffee; and 1700 kg km^2 yr^{-1} under crop.

3.4. Water Yield

Managed land-use scenarios increased the quantity of water exiting the catchment compared with forest, with agroforestry having the lowest increase at 0.27% (Figure 2). Spatially, the changes in water yield between the scenarios were more pronounced in areas of higher precipitation (Figure 4).

3.5. Products

Focusing on smallholder yields, the largest yields came from the crop scenario. This provided an increase in yield quantity of 2000% compared with agroforestry (Figure 2). The potential yield attainable under the coffee scenario was 400% greater compared with that attained under agroforestry. Pine provided no smallholder benefit other than through payment for resin tapping, which is not quantified here. Agroforestry provided a greater diversity of products, with additional state-owned products of rosin and turpentine. Assuming resin quantities from pine trees within agroforestry are not affected by the presence of coffee plants, state-owned income remained the same as pine and agroforestry.

3.6. Trade-Offs

Illustrated in Figure 5, forest supplied high levels of ecological function but provided no substantial income to smallholders or the state. In opposition to this scenario was crop, which provided the highest level of product yield for smallholders but resulted in the highest levels of nutrients, sediment, and water lost from the catchment along with minimal carbon storage. Agroforestry sat between these extremes. It did not provide the highest product yield for smallholders; however, it did provide the highest carbon storage option across the managed scenarios along with income for both smallholders and the state, while minimising the negative impacts of managed land use to a larger extent than pine on its own. Agroforestry had lower sediment, nitrogen, and water losses from the catchment compared with the crop and coffee scenarios.

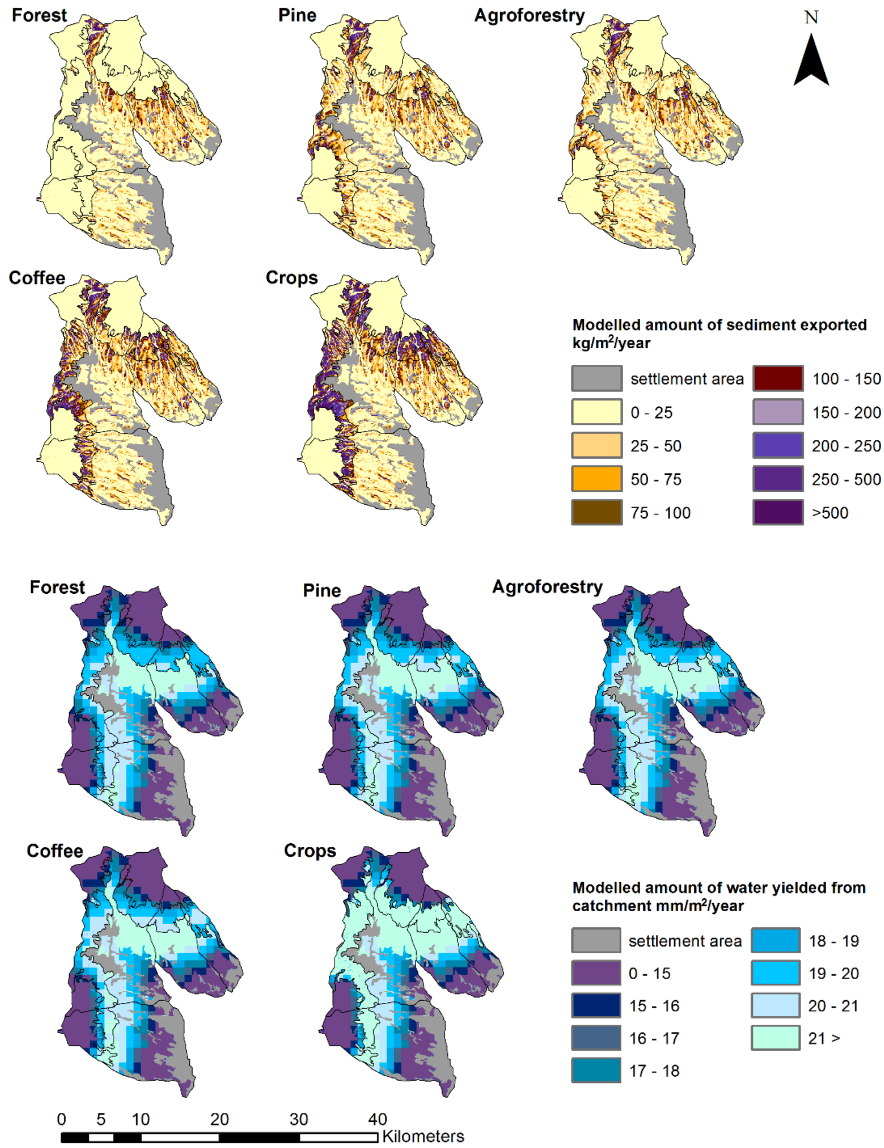

Figure 4. Model outputs of sediment loss and water yielded for different land-use change options of the pine production band.

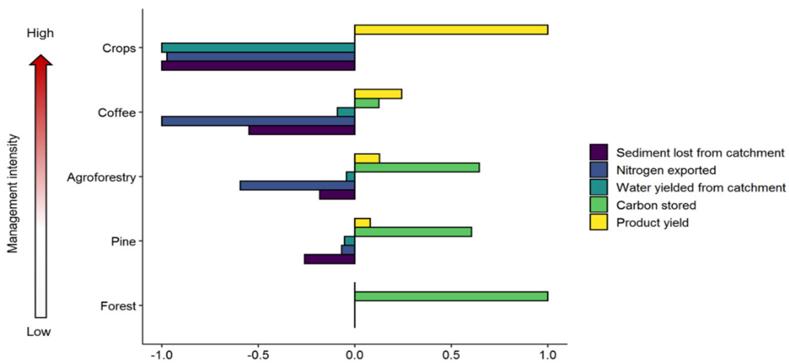

Figure 5. Minimum–maximum normalisation of results from ecosystem service modelling. Where higher values in modelled outputs are negative, worse-performing scenario is scaled to -1 and best-performing scenario is scaled to 0. Where higher values in modelled output are positive, worse-performing scenario is scaled to 0 and best-performing scenario is scaled to 1.

4. Discussion

We found that incorporating agroforestry coffee within pine plantations has a balanced impact on ecosystem service delivery at the landscape level, compared with other scenarios. Agroforestry provided higher levels of ecological function over crop monocultures with lower adverse impacts, while also providing socioeconomic benefits to smallholders absent within state pine plantations and secondary forest.

There is a considerable amount of literature showing the ability of agroforestry to sequester more carbon than conventional agriculture (e.g., [16,17]); however, studies comparing agroforestry with tree plantations are scarce, and in Southeast Asia mostly concern jungle rubber [9,65]. In our study, carbon storage was higher under the agroforestry system than pines alone, since tree density remained the same between agroforestry and timber monoculture—a factor unique to these systems, where the primary focus of the land use is maintaining timber productivity. The differential between carbon stored in natural forest and agroforestry was not as pronounced as seen elsewhere in the literature [9], as the natural forest type modelled to otherwise exist at this location is disturbed secondary-growth forest rather than primary forest. Although unable to attain the carbon levels achievable through natural reforestation, agroforestry within commercial plantations has the potential to contribute towards carbon storage targets.

The improved nitrogen retention, and therefore lower leaching losses, of agroforestry compared with crops is due to the belowground root safety net provided by the trees [17]. The 35% lower leaching modelled is lower than that reported for other silvoarable studies in the literature, where agroforestry reduces nutrient losses compared to conventional agriculture by 40–70% [17,33,57]. The steepness of the production forest band may contribute to the smaller difference between agriculture and agroforestry in this study. Whilst pine–coffee agroforestry retains a higher proportion of nitrogen compared with other managed scenarios, the quantities of fertiliser applied to the coffee crop may still cause substantial amounts of nitrogen to enter into the water system. The leaching of fertiliser can increase riverine loads [66] or result in groundwater contamination [67], which will have consequences for human health [68]. In reality, the actual amounts of fertiliser applied may be lower than what was modelled. The internal cycling of nitrogen via litter decomposition from pine trees [69] combined with the higher retention ability of pine–coffee agroforestry could result in less fertiliser being required by smallholders. At the landscape level, however, differences in nutrient losses were less pronounced between scenarios due to the relatively small (9–29%) proportion of the total catchment area that is production forest, and the significant contribution to catchment nitrogen load from agricultural land outside of the forest area. Nevertheless, finding the optimal level of fertiliser application for pine–coffee agroforestry would help reduce the risk to water quality downstream if this land use expands, and will require additional data to be collected from the relatively new UB forest research platform [25].

Borrelli et al. [70] estimate a soil erosion rate of 0.01 to 0.5 t km^2 yr^{-1} on Java (average of 0.035 t km^2 yr^{-1} for Asia), and the rates in this study sit in the upper range of this band or exceed the estimates. The higher rates are most likely due to differences in land-cover type (with associated RUSLE parameters) and resolution resulting from the scale of the study: the area modelled is smaller than the pixel size of the MODIS land cover used by Borrelli et al. [70] in their global study. Analysing the difference in soil erosion between agroforestry and an annual crop within the production forest band, the differential is similar to the average difference of 86% reported by Zhu et al. [57]. Soil loss impacts upon other ecosystem services of carbon storage, nutrient retention, infiltration, and yields [70]. Already accelerated under monocultures, soil loss and associated consequences are exacerbated for monocultures located on steep slopes, such as Javanese pine plantations. Landslides [71] and lake siltation have been widely observed on Java and directly attributed to land-use conversion and monocultures. In these locations, agroforestry has considerable potential to improve erosion control [17,69,72] and wider ecosystem service benefits.

Replacing forest has impacts on water retention, with choices altering groundwater recharge rates and mechanisms [73,74], and affecting flood risk [75] and water supply costs [76]. The loss of forest cover within the study catchments has decreased spring discharge in the lower catchments and exacerbated flood events on the Brantas river [34,77]. Pine–coffee agroforestry provides the closest water yield to natural conditions and should minimise the negative impacts of land-use change on water supply and retention. However, the impact of pine–coffee agroforestry on groundwater is more complex than can be captured in this study. Cannavo et al. [78] found that, while coffee agroforestry decreased runoff compared to coffee monoculture, drainage was also decreased. Additionally, Kay et al. [33] found that the groundwater recharge rate was lower for agroforestry dominated landscapes compared with agriculture. Further modelling of pine and coffee interactions would clarify the impact agroforestry could have on groundwater water supply.

Although coffee agroforestry within commercial plantations provides an opportunity for smallholder income in conditions of scarce land availability, there are two major potential disadvantages from the perspective of the smallholder. The first is gross crop yields and translation into income. Agroforestry often does not provide the same economic returns as monoculture [9,79]. In this study, higher gross yields (at least in the short term) are produced under monocultures of coffee or annual root crop; in the case of annual root crop this negates the lower farmgate price. These yield gaps are likely exacerbated by current shade levels within pine–coffee agroforestry systems. However, agroforestry does offer opportunities to increase or diversify existing income. Within the UB forest enclave, smallholders typically grow cash crops in small plots of land outside the forest, so the utilisation of the forest resource in an agroforestry context can provide additional income benefits.

The relationship between coffee yields and shading is not straightforward, as it depends on local environmental conditions and shade tree species [80,81]. Shading has been found to negatively impact coffee yields [82], although intermediate levels of shade have been shown to increase coffee yield (e.g., [83]) or not affect yields compared with full-sun plantations [12,84]. Greater yields do not always result in greater profit, particularly for coffee, where factors such as environmental conditions, production processes, and routes to market determine the type of coffee that can be grown and the bean quality—factors that rank above yield when determining profit [85]. Shade levels within the pine–coffee agroforestry systems of UB forest are around 70%, a level at which they are negatively impacting yields to an extent which is not balanced by improvements in coffee quality [25]. The yield gap due to shading could be reduced through research to find a compromise shade level which improves coffee yield or quality [23] while not adversely affecting resin or timber production [81,84]. Indeed, such research is currently being undertaken within the UB forest research platform [25]. For pine–coffee agroforestry to be a 'win' for smallholders, a compromise with the state forestry company regarding pine management may be needed to produce better coffee-growing conditions.

The second disadvantage is the felling of the pines at the end of their rotational period, since the land-owners' primary aim is still commercial forestry. The felling of pine trees requires the removal of, or damage to, the coffee plants, and therefore a temporary loss of income to smallholders. The optimal pine rotation length for resin is 35 years, though stands are often left for up to 50 years [86], while the economic lifespan of a coffee plants is approximately 30 years [87]. Harmonising the growth cycles could reduce the negative impacts of felling, as subsistence crops could be grown while both the replanted pine trees and coffee trees are young. In this study, the effects over a full production cycle were not captured. A time-averaged assessment of ecosystem services, such as that undertaken by Guillaume et al. [65], incorporating the growth and felling of pine and coffee over the rotational period, would provide a clearer picture of the long-term impacts of pine–coffee agroforestry [88,89]. Insights from Guillaume et al. [65] suggest that greater losses in ecosystem services will be observed, with rotation length having an impact as well as ecosystem services with slow dynamics, such as soil carbon stores.

To be a viable sustainable development pathway for rural communities, the impact of climate change also needs to be considered. In the long term, smallholders may have an advantage in farming coffee within pine plantations. In addition to the ecosystem services provided by an agroforestry system that will reduce the need for extensive input, pine trees protect coffee from less-favourable climatic conditions [90]. Climate change is threatening coffee production, with declines predicted in the predominate growing areas of Central and South America as well as Indonesia [91,92]. Within Indonesia, Ovalle-Rivera et al. [93] predict that suitable Arabica coffee growing climates will shift from 500–2000 m elevation to 800–2300 m elevation. Since the production forest pine plantations in East Java are predominately found between 1000 m and 2000 m elevation, and with added protection from climate extremes provided by the pine canopy, farming coffee within these plantations may become an attractive future economic prospect.

Ultimately, plantation forestry is managed for profit. As such, resource-use complementarity between tree and understory crop is vital to ensure success [94]. Investigating the economic feasibility of growing rubber within an agroforestry system, Warren-Thomas et al. [95] found that yields of a high-yielding rubber variety did not decrease when grown in an agroforest system. By contrast, there is some evidence that the growth of pine trees is affected by nutrient and water competition with coffee plants [61], but further work is required in this area.

Legal rights are also an important issue, particularly considering the history of land-use conflicts between governments and rural communities in Indonesia [96]. Currently, no formal policy exists that protects agroforestry systems in Indonesia. To ensure that agroforestry within commercial plantations is beneficial for smallholders in the long term, a clear policy framework protecting rights and land allocations is required rather than informal agreements [97,98]. One mechanism that may provide this structure without conceding land ownership is a form of a Payments for Ecosystem Services (PES) scheme, centred on security tenure for smallholders. A scheme could also consider additional income or start-up funding to recognise the wider ecosystem service benefits provided by smallholder agroforestry to downstream catchments. Numerous existing schemes provide a range of models to follow [99], and PES schemes have been previously implemented in Indonesia, though these tend to focus on one service only and implementation has been limited [100].

Our findings have implications beyond the pine plantations on Java. In Indonesia, around 30 million people are estimated to directly depend upon access to forest resources [101,102], and within Southeast Asia, forests support the livelihoods of around 70 million people [103]. Agroforestry schemes adapted to different tree species plantations could provide a benefit to rural communities with wider ecosystem service benefits [94]—there is certainly no 'one setup fits all'. Secondly, plantation forestry will increase in Southeast Asia [104,105], and in Indonesia it is likely that natural forest will be converted [106,107]. The expansion of forest plantations is not without biological and sociological cost [9,97]. Though we found that pine–coffee agroforestry offered the best ecological and economic balance—provided that the management of pine–coffee agroforestry is undertaken for smallholder benefit—this does not justify the expansion of this land use into natural forest or the replacement of more complex, biodiverse agroforestry systems or other forest ownership schemes [95,98,108]. Rather, as pressure on forest resources and access increases, the expansion into existing plantations is a feasible forest policy.

5. Conclusions

Meeting economic needs while providing wider ecosystem services results in a compromise between ecological and economic function. In the case of pine–coffee agroforestry, this land use is not a substitute for natural forest regarding supporting or regulating ecosystem services; conversely, the economic benefit for smallholders is lower, at least in the short to medium term. However, being able to ensure a greater provision of ecological function while at the same time meeting smallholder needs and forestry requirements means that pine–coffee agroforestry has the potential to be a ‘win-win’ land-use option environmentally and for the multiple actors involved—provided that management/a form of PES is undertaken for smallholder benefit. How likely changes to pine plantation management are, or the feasibility of implementing PES scheme, are questions outside the scope of this study. If this land use expands throughout monoculture pine plantations, there could be a risk to water quality through increased fertiliser application, and further research into this area would be beneficial. Ultimately, provided that the risks to water quality are understood and mitigated, the expansion of coffee within existing tree plantations is a sustainable option.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su14053019/s1, Table S1: Table of mean carbon stocks for production forest band per scenario of InVEST carbon model. Table S2: Table of biophysical input values for production forest band per scenario for InVEST nutrient retention model. Table S3: Table of biophysical input values for production forest band per scenario for InVEST sediment retention model. Table S4: Table of biophysical input values for production forest band per scenario for InVEST water yield model. References [38,41,88,109–114] are cited in the supplementary materials.

Author Contributions: Conceptualization, A.F., R.L.R., N.P.M., C.P., S.O. and L.J.; data curation, R.L.R., R.M.I., R.D.P., Z.M. and S.O.; formal analysis, A.F., R.L.R., Z.M. and S.O.; funding acquisition, N.P.M. and L.J.; investigation, A.F., C.P., R.M.I., R.D.P. and Z.M.; methodology, A.F. and L.J.; project administration, R.L.R. and N.P.M.; supervision, R.L.R., N.P.M., C.P. and L.J.; visualization, A.F.; writing—original draft, A.F.; writing—review and editing, R.L.R., N.P.M., C.P., S.O. and L.J. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Natural Environment Research Council, grant number NE/R000131/1, as part of the SUNRISE programme delivering National Capability.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data used for this study are provided within the manuscript and tables in Supplementary information.

Acknowledgments: We thank Kurniatun Hairiah for her assistance and the numerous students working in UB forest. We also thank the three anonymous reviewers for their comments to improve the manuscript.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

References

1. Gibbs, H.K.; Ruesch, A.S.; Achard, F.; Clayton, M.K.; Holmgren, P.; Ramankutty, N.; Foley, J.A. Tropical forests were the primary sources of new agricultural land in the 1980s and 1990s. *Proc. Natl. Acad. Sci. USA* **2010**, *107*, 16732. [CrossRef] [PubMed]
2. Carlson, K.M.; Curran, L.M.; Ratnasari, D.; Pittman, A.M.; Soares-Filho, B.S.; Asner, G.P.; Trigg, S.N.; Gaveau, D.A.; Lawrence, D.; Rodrigues, H.O. Committed carbon emissions, deforestation, and community land conversion from oil palm plantation expansion in West Kalimantan, Indonesia. *Proc. Natl. Acad. Sci. USA* **2012**, *109*, 7559. [CrossRef] [PubMed]
3. Ahrends, A.; Hollingsworth, P.M.; Ziegler, A.D.; Fox, J.M.; Chen, H.; Su, Y.; Xu, J. Current trends of rubber plantation expansion may threaten biodiversity and livelihoods. *Glob. Environ. Chang.* **2015**, *34*, 48–58. [CrossRef]
4. Barr, C.; Resosudarmo, I.A.P.; Dermawan, A.; McCarthy, J.F.; Moeliono, M.; Setiono, B. *Decentralization of Forest Administration in Indonesia*; Center for International Forestry Research (CIFOR): Bogor, Indonesia, 2006.
5. Margono, B.A.; Turubanova, S.; Zhuravleva, I.; Potapov, P.; Tyukavina, A.; Baccini, A.; Goetz, S.; Hansen, M.C. Mapping and monitoring deforestation and forest degradation in Sumatra (Indonesia) using Landsat time series data sets from 1990 to 2010. *Environ. Res. Lett.* **2012**, *7*, 034010. [CrossRef]
6. Laurance, W.F.; Sayer, J.; Cassman, K.G. Agricultural expansion and its impacts on tropical nature. *Trends Ecol. Evol.* **2014**, *29*, 107–116. [CrossRef]
7. Koh, L.P.; Ghazoul, J. Spatially explicit scenario analysis for reconciling agricultural expansion, forest protection, and carbon conservation in Indonesia. *Proc. Natl. Acad. Sci. USA* **2010**, *107*, 11140. [CrossRef]

8. Lee, J.S.H.; Garcia-Ulloa, J.; Ghazoul, J.; Obidzinski, K.; Koh, L.P. Modelling environmental and socio-economic trade-offs associated with land-sparing and land-sharing approaches to oil palm expansion. *J. Appl. Ecol.* **2014**, *51*, 1366–1377. [CrossRef]
9. Clough, Y.; Krishna, V.V.; Corre, M.D.; Darras, K.; Denmead, L.H.; Meijide, A.; Moser, S.; Musshoff, O.; Steinebach, S.; Veldkamp, E.; et al. Land-use choices follow profitability at the expense of ecological functions in Indonesian smallholder landscapes. *Nat. Commun.* **2016**, *7*, 13137. [CrossRef]
10. Waldron, A.; Garrity, D.; Malhi, Y.; Girardin, C.; Miller, D.C.; Seddon, N. Agroforestry Can Enhance Food Security While Meeting Other Sustainable Development Goals. *Trop. Conserv. Sci.* **2017**, *10*, 1940082917720667. [CrossRef]
11. Rice, R.A. Fruits from shade trees in coffee: How important are they? *Agrofor. Syst.* **2011**, *83*, 41–49. [CrossRef]
12. Jezeer, R.E.; Santos, M.J.; Boot, R.G.A.; Junginger, M.; Verweij, P.A. Effects of shade and input management on economic performance of small-scale Peruvian coffee systems. *Agric. Syst.* **2018**, *162*, 179–190. [CrossRef]
13. Rice, R.A. Agricultural intensification within agroforestry: The case of coffee and wood products. *Agric. Ecosyst. Environ.* **2008**, *128*, 212–218. [CrossRef]
14. Coltri, P.P.; Zullo Junior, J.; Dubreuil, V.; Ramirez, G.M.; Pinto, H.S.; Coral, G.; Lazarim, C.G. Empirical models to predict LAI and aboveground biomass of Coffea arabica under full sun and shaded plantation: A case study of South of Minas Gerais, Brazil. *Agrofor. Syst.* **2015**, *89*, 621–636. [CrossRef]
15. Pumariño, L.; Sileshi, G.W.; Gripenberg, S.; Kaartinen, R.; Barrios, E.; Muchane, M.N.; Midega, C.; Jonsson, M. Effects of agroforestry on pest, disease and weed control: A meta-analysis. *Basic Appl. Ecol.* **2015**, *16*, 573–582. [CrossRef]
16. Jezeer, R.E.; Santos, M.J.; Verweij, P.A.; Boot, R.G.A.; Clough, Y. Benefits for multiple ecosystem services in Peruvian coffee agroforestry systems without reducing yield. *Ecosyst. Serv.* **2019**, *40*, 101033. [CrossRef]
17. Jose, S. Agroforestry for ecosystem services and environmental benefits: An overview. *Agrofor. Syst.* **2009**, *76*, 1–10. [CrossRef]
18. Tscharntke, T.; Clough, Y.; Bhagwat, S.A.; Buchori, D.; Faust, H.; Hertel, D.; Hölscher, D.; Juhrbandt, J.; Kessler, M.; Perfecto, I.; et al. Multifunctional shade-tree management in tropical agroforestry landscapes—A review. *J. Appl. Ecol.* **2011**, *48*, 619–629. [CrossRef]
19. Jain, S.K.; Singh, P. Economic analysis of industrial agroforestry: Poplar (Populus deltoides) in Uttar Pradesh (India). *Agrofor. Syst.* **2000**, *49*, 255–273. [CrossRef]
20. Phimmavong, S.; Maraseni, T.N.; Keenan, R.J.; Cockfield, G. Financial returns from collaborative investment models of Eucalyptus agroforestry plantations in Lao PDR. *Land Use Policy* **2019**, *87*, 104060. [CrossRef]
21. Mercer, D.E.; Frey, G.E.; Cubbage, F.W. Economics of agroforestry. In *Handbook of Forest Resource Economics*; Routledge: London, UK, 2014; pp. 188–209.
22. Coe, R.; Sinclair, F.; Barrios, E. Scaling up agroforestry requires research 'in' rather than 'for' development. *Curr. Opin. Environ. Sustain.* **2014**, *6*, 73–77. [CrossRef]
23. Blaser, W.J.; Oppong, J.; Hart, S.P.; Landolt, J.; Yeboah, E.; Six, J. Climate-smart sustainable agriculture in low-to-intermediate shade agroforests. *Nat. Sustain.* **2018**, *1*, 234–239. [CrossRef]
24. Pirard, R.; Petit, H.; Baral, H. Local impacts of industrial tree plantations: An empirical analysis in Indonesia across plantation types. *Land Use Policy* **2017**, *60*, 242–253. [CrossRef]
25. Cahyono, E.D.; Fairuzzana, S.; Willianto, D.; Pradesti, E.; McNamara, N.P.; Rowe, R.L.; Noordwijk, M.V. Agroforestry Innovation through Planned Farmer Behavior: Trimming in Pine–Coffee Systems. *Land* **2020**, *9*, 363. [CrossRef]
26. Iskandar, B.S.; Iskandar, J.; Partasamita, R.; Alfian, R.L. Planting coffee and take care of forest: A case study on coffee cultivation in the forest carried out among people of Palintang, highland of Bandung, west Java, Indonesia. *Biodiversitas J. Biol. Divers.* **2018**, *19*, 2183–2195. [CrossRef]
27. Rahmanulloh, A.; McDonald, G. *Indonesia Coffee Annual Report 2018*; USDA: Washington, DC, USA, 2018.
28. Rahmanulloh, A.; McDonald, G. *Indonesia Coffee Annual Report 2019*; USDA: Washington, DC, USA, 2019.
29. Perum Perhutani. *Laporan Tahunan*; Annual Report 2018; Perhutani: Jakarta, Indonesia, 2018.
30. Nelson, E.; Mendoza, G.; Regetz, J.; Polasky, S.; Tallis, H.; Cameron, D.; Chan, K.M.A.; Daily, G.C.; Goldstein, J.; Kareiva, P.M.; et al. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. *Front. Ecol. Environ.* **2009**, *7*, 4–11. [CrossRef]
31. Goldstein, J.H.; Caldarone, G.; Duarte, T.K.; Ennaanay, D.; Hannahs, N.; Mendoza, G.; Polasky, S.; Wolny, S.; Daily, G.C. Integrating ecosystem-service tradeoffs into land-use decisions. *Proc. Natl. Acad. Sci. USA* **2012**, *109*, 7565. [CrossRef]
32. Zheng, H.; Wang, L.; Peng, W.; Zhang, C.; Li, C.; Robinson, B.E.; Wu, X.; Kong, L.; Li, R.; Xiao, Y.; et al. Realizing the values of natural capital for inclusive, sustainable development: Informing China's new ecological development strategy. *Proc. Natl. Acad. Sci. USA* **2019**, *116*, 8623–8628. [CrossRef]
33. Kay, S.; Crous-Duran, J.; García de Jalón, S.; Graves, A.; Palma, J.H.N.; Roces-Díaz, J.V.; Szerencsits, E.; Weibel, R.; Herzog, F. Landscape-scale modelling of agroforestry ecosystems services in Swiss orchards: A methodological approach. *Landsc. Ecol.* **2018**, *33*, 1633–1644. [CrossRef]
34. Maulidiyah, E.; Anggoro, S.; Suherman, S. Groundwater Conservation in Batu City East Java: An Ecohydrological Approach. *Adv. Sci. Lett.* **2017**, *23*, 2299–2301. [CrossRef]
35. Badan Pusat Statistik. Sensus Penduduk. 2010. Available online: https://sp2010.bps.go.id/index.php/site?id=3579000000&wilayah=Kota-Batu (accessed on 2 January 2020).

36. Ministry of Environment and Forestry. Penutupan Lahan. 2015. Available online: http://webgis.dephut.go.id/ArcGIS/rest/services/Penutupan_Lahan_2015/MapServer (accessed on 19 August 2019).
37. Sharp, R.; Tallis, H.T.; Ricketts, T.; Guerry, A.D.; Wood, S.A.; Chaplin-Kramer, R.; Nelson, E.; Ennaanay, D.; Wolny, S.; Olwero, N.; et al. *InVEST 3.8.1 User's Guide*; The Natural Capital Project, Stanford University: Stanford, CA, USA, 2020.
38. Sharps, K.; Masante, D.; Thomas, A.; Jackson, B.; Redhead, J.; May, L.; Prosser, H.; Cosby, B.; Emmett, B.; Jones, L. Comparing strengths and weaknesses of three ecosystem services modelling tools in a diverse UK river catchment. *Sci. Total Environ.* **2017**, *584–585*, 118–130. [CrossRef]
39. Chacko, S.; Kurian, J.; Ravichandran, C.; Vairavel, S.M.; Kumar, K. An assessment of water yield ecosystem services in Periyar Tiger Reserve, Southern Western Ghats of India. *Geol. Ecol. Landsc.* **2019**, *5*, 32–39. [CrossRef]
40. Resende, F.M.; Cimon-Morin, J.; Poulin, M.; Meyer, L.; Loyola, R. Consequences of delaying actions for safeguarding ecosystem services in the Brazilian Cerrado. *Biol. Conserv.* **2019**, *234*, 90–99. [CrossRef]
41. Hairiah, K.; Kurniawan, S.; Aini, F.K.; Lestari, N.D.; Lestariningsih, I.D.; Widianto; Zulkarnaen, T.; van Noordwijk, M. Carbon Stock assessment for a forest-to-coffee conversion landscape in Kalikonto Watershed (East Java, Indonesia): Scaling up from plot to landscape level. In Proceedings of the International Conference on Coffee Science (ASIC), Denpasar, Indonesia, 3–8 October 2010.
42. IPCC. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*; National Greenhouse Gas Inventories Programme, Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T., Tanabe, K., Eds.; Institute for the Global Environmental Strategies (IGES): Kanagawa, Japan, 2006; Volume 4.
43. Hairiah, K.; Rahayu, S. Petunjuk praktis Pengukuran karbon tersimpan di berbagai macam penggunaan lahan. In *World Agroforestry Centre–ICRAF*; SEA Regional Office, University of Brawijaya: Unibraw, Indonesia, 2007; p. 77.
44. Hiederer, R.; Kochy, M. Global Soil Organic Carbon Estimates and the Harmonized World Soil Database. In *EUR Scientific and Technical Research Series*; European Commission Joint Research Centre: Brussels, Belgium, 2012.
45. Hairiah, K.; van Noordwijk, M.; Sari, R.R.; Saputra, D.D.; Widianto; Suprayogo, D.; Kurniawan, S.; Prayogo, C.; Gusli, S. Soil carbon stocks in Indonesian (agro) forest transitions: Compaction conceals lower carbon concentrations in standard accounting. *Agric. Ecosyst. Environ.* **2020**, *294*, 106879. [CrossRef]
46. FAO. *Fertilizer Use by Crop in Indonesia*; Food and Agriculture Organization of the United Nation: Rome, Italy, 2005.
47. Galloway, J.N.; Dentener, F.J.; Capone, D.G.; Boyer, E.W.; Howarth, R.W.; Seitzinger, S.P.; Asner, G.P.; Cleveland, C.C.; Green, P.A.; Holland, E.A.; et al. Nitrogen cycles: Past, present, and future. *Biogeochemistry* **2004**, *70*, 153–226. [CrossRef]
48. Jones, L.; Vieno, M.; Fitch, A.; Carnell, E.; Steadman, C.; Cryle, P.; Holland, M.; Nemitz, E.; Morton, D.; Hall, J.; et al. Urban natural capital accounts: Developing a novel approach to quantify air pollution removal by vegetation. *J. Environ. Econ. Policy* **2019**, *8*, 413–428. [CrossRef]
49. Lehner, B.; Verdin, K.; Jarvis, A. New Global Hydrography Derived from Spaceborne Elevation Data. *Eos Trans. Am. Geophys. Union* **2008**, *89*, 93–94. [CrossRef]
50. Fick, S.E.; Hijmans, R.J. WorldClim 2: New 1-km spatial resolution climate surfaces for global land areas. *Int. J. Climatol.* **2017**, *37*, 4302–4315. [CrossRef]
51. Panagos, P.; Borrelli, P.; Meusburger, K.; Yu, B.; Klik, A.; Jae Lim, K.; Yang, J.E.; Ni, J.; Miao, C.; Chattopadhyay, N.; et al. Global rainfall erosivity assessment based on high-temporal resolution rainfall records. *Sci. Rep.* **2017**, *7*, 4175. [CrossRef]
52. Fischer, G.; Nachtergaele, F.; Prieler, S.; van Velthuizen, H.T.; Verelst, L.; Wiberg, D. *Global Agro-Ecological Zones Assessment for Agriculture*; IIASA: Laxenburg, Austria; FAO: Rome, Italy, 2008.
53. Panagos, P.; Borrelli, P.; Meusburger, K.; Alewell, C.; Lugato, E.; Montanarella, L. Estimating the soil erosion cover-management factor at the European scale. *Land Use Policy* **2015**, *48*, 38–50. [CrossRef]
54. Stone, R.P.; Hilborn, D. Universal Soil Loss Equations (USLE), Order No. 12-051 [Factsheet]. Available online: http://www.omafra.gov.on.ca/english/engineer/facts/12-051.htm (accessed on 1 May 2018).
55. Zhang, L.; Hickel, K.; Dawes, W.R.; Chiew, F.H.S.; Western, A.W.; Briggs, P.R. A rational function approach for estimating mean annual evapotranspiration. *Water Resour. Res.* **2004**, *40*. [CrossRef]
56. Zomer, R.J.; Trabucco, A.; Bossio, D.A.; Verchot, L.V. Climate change mitigation: A spatial analysis of global land suitability for clean development mechanism afforestation and reforestation. *Agric. Ecosyst. Environ.* **2008**, *126*, 67–80. [CrossRef]
57. Zhu, X.; Liu, W.; Chen, J.; Bruijnzeel, L.A.; Mao, Z.; Yang, X.; Cardinael, R.; Meng, F.-R.; Sidle, R.C.; Seitz, S.; et al. Reductions in water, soil and nutrient losses and pesticide pollution in agroforestry practices: A review of evidence and processes. *Plant Soil* **2020**, *453*, 45–86. [CrossRef]
58. Cristiano, P.M.; Campanello, P.I.; Bucci, S.J.; Rodriguez, S.A.; Lezcano, O.A.; Scholz, F.G.; Madanes, N.; Di Francescantonio, D.; Carrasco, L.O.; Zhang, Y.-J.; et al. Evapotranspiration of subtropical forests and tree plantations: A comparative analysis at different temporal and spatial scales. *Agric. For. Meteorol.* **2015**, *203*, 96–106. [CrossRef]
59. Donohue, R.J.; Roderick, M.L.; McVicar, T.R. Roots, storms and soil pores: Incorporating key ecohydrological processes into Budyko's hydrological model. *J. Hydrol.* **2012**, *436–437*, 35–50. [CrossRef]
60. Redhead, J.W.; Stratford, C.; Sharps, K.; Jones, L.; Ziv, G.; Clarke, D.; Oliver, T.H.; Bullock, J.M. Empirical validation of the InVEST water yield ecosystem service model at a national scale. *Sci. Total Environ.* **2016**, *569–570*, 1418–1426. [CrossRef]

61. Suprayogo, D.; Azmi, E.N.; Ariesta, D.A.; Sutejo, Y.A.; Hakim, A.L.; Prayogo, C.; McNamara, N.P. Tree and plant interactions in the agroforestry system: Does the management of coffee intensification disrupt the soil hydrological system and pine growth? *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *449*, 012045. [CrossRef]
62. Fardiansyah, I.; Wicaksono, K.P. Growth and Production Response of Coffee Plants (Coffea arabica) at Different Levels of Cultivation Management in Agroforestry Systems. *J. Prod. Tanam.* **2019**, *7*, 2053–2060.
63. Perum Perhutani. *Statistik Tahun 2014–2018*; Perum Perhutani: Jakarta, Indonesia, 2019.
64. FAO FAOSTAT Online Statistical Service. Available online: http://www.fao.org/faostat/en/#home (accessed on 1 May 2018).
65. Guillaume, T.; Kotowska, M.M.; Hertel, D.; Knohl, A.; Krashevska, V.; Murtilaksono, K.; Scheu, S.; Kuzyakov, Y. Carbon costs and benefits of Indonesian rainforest conversion to plantations. *Nat. Commun.* **2018**, *9*, 2388. [CrossRef]
66. David, M.B.; Drinkwater, L.E.; McIsaac, G.F. Sources of Nitrate Yields in the Mississippi River Basin. *J. Environ. Qual.* **2010**, *39*, 1657–1667. [CrossRef]
67. Debernardi, L.; De Luca, D.A.; Lasagna, M. Correlation between nitrate concentration in groundwater and parameters affecting aquifer intrinsic vulnerability. *Environ. Geol.* **2008**, *55*, 539–558. [CrossRef]
68. Wu, J.; Sun, Z. Evaluation of Shallow Groundwater Contamination and Associated Human Health Risk in an Alluvial Plain Impacted by Agricultural and Industrial Activities, Mid-west China. *Expo. Health* **2016**, *8*, 311–329. [CrossRef]
69. Muchane, M.N.; Sileshi, G.W.; Gripenberg, S.; Jonsson, M.; Pumariño, L.; Barrios, E. Agroforestry boosts soil health in the humid and sub-humid tropics: A meta-analysis. *Agric. Ecosyst. Environ.* **2020**, *295*, 106899. [CrossRef]
70. Borrelli, P.; Robinson, D.A.; Fleischer, L.R.; Lugato, E.; Ballabio, C.; Alewell, C.; Meusburger, K.; Modugno, S.; Schütt, B.; Ferro, V.; et al. An assessment of the global impact of 21st century land use change on soil erosion. *Nat. Commun.* **2017**, *8*, 2013. [CrossRef] [PubMed]
71. Lavigne, F.; Gunnell, Y. Land cover change and abrupt environmental impacts on Javan volcanoes, Indonesia: A long-term perspective on recent events. *Reg. Environ. Chang.* **2006**, *6*, 86–100. [CrossRef]
72. Béliveau, A.; Lucotte, M.; Davidson, R.; Paquet, S.; Mertens, F.; Passos, C.J.; Romana, C.A. Reduction of soil erosion and mercury losses in agroforestry systems compared to forests and cultivated fields in the Brazilian Amazon. *J. Environ. Manag.* **2017**, *203*, 522–532. [CrossRef] [PubMed]
73. Ilstedt, U.; Bargués Tobella, A.; Bazié, H.R.; Bayala, J.; Verbeeten, E.; Nyberg, G.; Sanou, J.; Benegas, L.; Murdiyarso, D.; Laudon, H.; et al. Intermediate tree cover can maximize groundwater recharge in the seasonally dry tropics. *Sci. Rep.* **2016**, *6*, 21930. [CrossRef]
74. Han, D.; Currell, M.J.; Cao, G.; Hall, B. Alterations to groundwater recharge due to anthropogenic landscape change. *J. Hydrol.* **2017**, *554*, 545–557. [CrossRef]
75. Schilling, K.E.; Gassman, P.W.; Kling, C.L.; Campbell, T.; Jha, M.K.; Wolter, C.F.; Arnold, J.G. The potential for agricultural land use change to reduce flood risk in a large watershed. *Hydrol. Process.* **2014**, *28*, 3314–3325. [CrossRef]
76. Lele, S. Watershed services of tropical forests: From hydrology to economic valuation to integrated analysis. *Curr. Opin. Environ. Sustain.* **2009**, *1*, 148–155. [CrossRef]
77. Sulistyaningsih, T. Sulardi, S.; Sunarto, S. Problems in Upper Brantas Watershed Governance: A Case Study in Batu Indonesia. *J. Gov. Politics* **2017**, *8*, 383–410.
78. Cannavo, P.; Sansoulet, J.; Harmand, J.M.; Siles, P.; Dreyer, E.; Vaast, P. Agroforestry associating coffee and Inga densiflora results in complementarity for water uptake and decreases deep drainage in Costa Rica. *Agric. Ecosyst. Environ.* **2011**, *140*, 1–13. [CrossRef]
79. Temani, F.; Bouaziz, A.; Daoui, K.; Wery, J.; Barkaoui, K. Olive agroforestry can improve land productivity even under low water availability in the South Mediterranean. *Agric. Ecosyst. Environ.* **2021**, *307*, 107234. [CrossRef]
80. DaMatta, F.M. Ecophysiological constraints on the production of shaded and unshaded coffee: A review. *Field Crop. Res.* **2004**, *86*, 99–114. [CrossRef]
81. Jha, S.; Bacon, C.M.; Philpott, S.M.; Ernesto Méndez, V.; Läderach, P.; Rice, R.A. Shade Coffee: Update on a Disappearing Refuge for Biodiversity. *BioScience* **2014**, *64*, 416–428. [CrossRef]
82. Steffan-Dewenter, I.; Kessler, M.; Barkmann, J.; Bos, M.M.; Buchori, D.; Erasmi, S.; Faust, H.; Gerold, G.; Glenk, K.; Gradstein, S.R.; et al. Tradeoffs between income, biodiversity, and ecosystem functioning during tropical rainforest conversion and agroforestry intensification. *Proc. Natl. Acad. Sci. USA* **2007**, *104*, 4973–4978. [CrossRef] [PubMed]
83. Soto-Pinto, L.; Perfecto, I.; Castillo-Hernandez, J.; Caballero-Nieto, J. Shade effect on coffee production at the northern Tzeltal zone of the state of Chiapas, Mexico. *Agric. Ecosyst. Environ.* **2000**, *80*, 61–69. [CrossRef]
84. Cerda, R.; Allinne, C.; Gary, C.; Tixier, P.; Harvey, C.A.; Krolczyk, L.; Mathiot, C.; Clément, E.; Aubertot, J.-N.; Avelino, J. Effects of shade, altitude and management on multiple ecosystem services in coffee agroecosystems. *Eur. J. Agron.* **2017**, *82*, 308–319. [CrossRef]
85. Hameed, A.; Hussain, S.A.; Suleria, H.A.R. "Coffee Bean-Related" Agroecological Factors Affecting the Coffee. In *Co-Evolution of Secondary Metabolites*; Merillon, J.-M., Ramawat, K.G., Eds.; Springer International Publishing: Cham, Switzerland, 2018; pp. 1–67.
86. Prasetyo, A.R.; Saleh, M.B.; Soedomo, S. Optimization Pine Plantation Forest Management in Kediri FMU Regional Division II East Java. *J. Manaj. Hutan Trop.* **2017**, *23*, 171–181. [CrossRef]
87. Wintgens, J. The coffee plant. In *Coffee: Growing, Processing, Sustainable Production*; Wintgens, J., Ed.; Wiley-VCH: Weinheim, Germany, 2004.

88. van Noordwijk, M.; Rahayu, S.; Hairiah, K.; Wulan, Y.C.; Farida, A.; Verbist, B. Carbon stock assessment for a forest-to-coffee conversion landscape in Sumber-Jaya (Lampung, Indonesia): From allometric equations to land use change analysis. *Sci. China* **2002**, *45*, 75–86.
89. Feliciano, D.; Ledo, A.; Hillier, J.; Nayak, D.R. Which agroforestry options give the greatest soil and above ground carbon benefits in different world regions? *Agric. Ecosyst. Environ.* **2018**, *254*, 117–129. [CrossRef]
90. Lin, B.B.; Perfecto, I.; Vandermeer, J. Synergies between Agricultural Intensification and Climate Change Could Create Surprising Vulnerabilities for Crops. *BioScience* **2008**, *58*, 847–854. [CrossRef]
91. Bunn, C.; Läderach, P.; Ovalle Rivera, O.; Kirschke, D. A bitter cup: Climate change profile of global production of Arabica and Robusta coffee. *Clim. Chang.* **2015**, *129*, 89–101. [CrossRef]
92. Schroth, G.; Läderach, P.; Blackburn Cuero, D.S.; Neilson, J.; Bunn, C. Winner or loser of climate change? A modeling study of current and future climatic suitability of Arabica coffee in Indonesia. *Reg. Environ. Chang.* **2015**, *15*, 1473–1482. [CrossRef]
93. Ovalle-Rivera, O.; Läderach, P.; Bunn, C.; Obersteiner, M.; Schroth, G. Projected Shifts in Coffea arabica Suitability among Major Global Producing Regions Due to Climate Change. *PLoS ONE* **2015**, *10*, e0124155. [CrossRef]
94. Hombegowda, H.C.; Köhler, M.; Röll, A.; Hölscher, D. Tree species and size influence soil water partitioning in coffee agroforestry. *Agrofor. Syst.* **2020**, *94*, 137–149. [CrossRef]
95. Warren-Thomas, E.; Nelson, L.; Juthong, W.; Bumrungsri, S.; Brattström, O.; Stroesser, L.; Chambon, B.; Penot, É.; Tongkaemkaew, U.; Edwards, D.P.; et al. Rubber agroforestry in Thailand provides some biodiversity benefits without reducing yields. *J. Appl. Ecol.* **2020**, *57*, 17–30. [CrossRef]
96. Fay, C.; Sirait, M.; Kusworo, M. *Getting the Boundaries Right: Indonesia's Urgent Need to Redefine its Forests Estate*; World Agroforestry Center: Bogor, Indonesia, 2000.
97. Vermeulen, S.; Cotula, L. Over the heads of local people: Consultation, consent, and recompense in large-scale land deals for biofuels projects in Africa. *J. Peasant Stud.* **2010**, *37*, 899–916. [CrossRef]
98. Malkamäki, A.; D'Amato, D.; Hogarth, N.J.; Kanninen, M.; Pirard, R.; Toppinen, A.; Zhou, W. A systematic review of the socio-economic impacts of large-scale tree plantations, worldwide. *Glob. Environ. Change* **2018**, *53*, 90–103. [CrossRef]
99. Calvet-Mir, L.; Corbera, E.; Martin, A.; Fisher, J.; Gross-Camp, N. Payments for ecosystem services in the tropics: A closer look at effectiveness and equity. *Curr. Opin. Environ. Sustain.* **2015**, *14*, 150–162. [CrossRef]
100. Suich, H.; Lugina, M.; Muttaqin, M.Z.; Alviya, I.; Sari, G.K. Payments for ecosystem services in Indonesia. *Oryx* **2016**, *51*, 489–497. [CrossRef]
101. Ministry of Forestry. *Rencana Strategis 2010–2014 Kementerian Kehutanan; Jakarta: Kementerian Luar Negeri Republik Indonesia*; Ministry of Forestry: Jakarta, Indonesia, 2010.
102. The World Bank. World Bank Approves $22 Million Grant to Help Forest Communities in Indonesia. Available online: https://www.worldbank.org/en/news/press-release/2016/05/27/world-bank-approves-22-million-grant-to-help-forest-communities-in-indonesia (accessed on 5 August 2020).
103. Himawan, H. *Community Forestry: Key to Solving Current and Emerging Challenges, Second Regional Forum for People and Forests, Bangkok, Thailand, 2011*; RECOFTC–The Center for People and Forests: Bangkok, Thailand, 2011.
104. Byerlee, D. The fall and rise again of plantations in tropical Asia: History repeated? *Land* **2014**, *3*, 574–597. [CrossRef]
105. Payn, T.; Carnus, J.-M.; Freer-Smith, P.; Kimberley, M.; Kollert, W.; Liu, S.; Orazio, C.; Rodriguez, L.; Silva, L.N.; Wingfield, M.J. Changes in planted forests and future global implications. *For. Ecol. Manag.* **2015**, *352*, 57–67. [CrossRef]
106. Santika, T.; Meijaard, E.; Wilson, K.A. Designing multifunctional landscapes for forest conservation. *Environ. Res. Lett.* **2015**, *10*, 114012. [CrossRef]
107. Gaveau, D.L.A.; Sheil, D.; Husnayaen; Salim, M.A.; Arjasakusuma, S.; Ancrenaz, M.; Pacheco, P.; Meijaard, E. Rapid conversions and avoided deforestation: Examining four decades of industrial plantation expansion in Borneo. *Sci. Rep.* **2016**, *6*, 32017. [CrossRef]
108. Myers, R.; Ardiansyah, F. *Who Holds Power in Land-use Decisions? Implications for REDD+ in Indonesia*; Center for International Forestry Research (CIFOR): Bogor, Indonesia, 2014.
109. Uryu, Y.; Mott, C.; Foead, N.; Yulianto, K.; Budiman, A.; Setiabudi; Takakai, F.; Nursamsu.; Sunarto.; Purastuti, E.; et al. *Deforestation, Forest Degradation, Biodiversity Loss and CO_2 Emissions in Riau, Sumatra, Indonesia*; WWF Indonesia: Jakarta, Indonesia, 2008.
110. Miyakuni, K.; Heriyanto, N.M.; Heriansyah, I.; lmanuddin, R.; Kiyono, Y. Allometric equations and parameters for estimating the biomass of planted Pinus merkusii Jungh. et de Vr. forests. *Jpn. J. Environ.* **2005**, *47*, 95–104.
111. Yulistyarini, T.; Sofiah, S. Valuing quality of vegetation in recharge area of Seruk Spring, Pesanggrahan Valley, Batu City, East Java. *Biodiversitas J. Biol. Divers.* **2011**, *12*, 229–234. [CrossRef]
112. Allen, R.G.; Pereira, L.S.; Raes, D.; Smith, M. *Crop Evapotranspiration—Guidelines for Computing Crop Water Requirements*; FAO—Food and Agriculture Organization of the United Nations: Rome, Italy, 1998.
113. Defrenet, E.; Roupsard, O.; Van den Meersche, K.; Charbonnier, F.; Pastor Perez-Molina, J.; Khac, E.; Prieto, I.; Stokes, A.; Roumet, C.; Rapidel, B.; et al. Root biomass, turnover and net primary productivity of a coffee agroforestry system in Costa Rica: Effects of soil depth, shade trees, distance to row and coffee age. *Ann. Bot.* **2016**, *118*, 833–851. [CrossRef]
114. Tumuhimbise, R. Plant Spacing and Planting Depth Effects on Corm Yield of Taro (*Colocasia esculenta* (L.) Schott). *J. Crop Improv.* **2015**, *29*, 747–757. [CrossRef]