Spatial Assessment of Ecosystem Services from Planted Forests in Central Vietnam

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Abstract: Globally, planted forests are increasing, providing increased resources to forest industries and ecosystem services (ES) to local and wider communities. However, assessment of the impacts of plantations on ES has been limited. Planted forests have expanded rapidly in Vietnam over the last 20 years, with much of the planting undertaken by smallholder growers using exotic *Acacia* and *Eucalyptus* species. This study aimed to test a framework to assess changes in four ES due to an increase in *Acacia* plantations from 2005–2015 in central Vietnam: carbon sequestration, sediment retention, water yield and habitat. Quantitative and qualitative indicators for each service were derived from the literature. Results showed that the area of planted forests in Quảng Trị and Thừa Thiên-Huế Provinces increased from 130,930 hectares (ha) to 182,508 ha, mostly replacing non-forest areas (degraded lands, grasslands and agricultural lands) and poor forests. The framework demonstrated capacity to assess the effect of planted forests on wood flow, carbon stocks, sediment retention, streamflow and the extent of wildlife habitat. Apart from the wood supply and carbon sequestration, more research is required to translate biophysical indicators to benefit relevant indicators related to human welfare. The study also revealed that the area of rich forests decreased by 20% over the ten years, mostly through degradation to poorer quality natural forests. Therefore, at the landscape scale, improvement in ES due to conversion of non-forests to planted forests was offset by a reduction in some services as a result of degradation of native forest from rich to poorer condition. Assessment of changes in ES due to planted forests also needs to consider other landscape changes. These analyses can inform policymakers, forest owners and managers, environmental organizations and local communities of the benefits and impacts of planted forests and provide an improved basis for payments for ES and potential additional income for smallholder tree growers.

Keywords: Vietnam; planted forests; land use and land cover; ecosystem services; spatial assessment

1. Introduction

Planted forests are defined as 'forest predominantly composed of trees established through planting and deliberate seeding' [1]. Globally, natural forests are decreasing while planted forests expanded by about 12.3 million hectares (ha) between 2010 and 2015 [2] or the current area of planted forests is about 7% of total forest cover. Planted forest established on degraded land can reduce industry

pressures on natural forests and provide other benefits and services [3–6]. The Asia Pacific region has been a focus for expansion of intensively managed planted forests [7] due to demand for wood in new processing plants and policies to rehabilitate degraded land. Increasing global population and wealth has also escalated demand of planted forests and the potential of provide ecosystem services (ES) from planted forests [8–15]. Some studies suggest that planted forests generally supply low level of ES compared to natural forests and may be more susceptible to soil erosion or other impacts [16]. However, conversion of agricultural or degraded forest land to plantations may result in improved supply of ES. Baral et al. 2016 [16] proposed a framework for the assessment of ES resulting from the conversion of land to planted forests, but this has not been implemented and tested widely.

Planted forests in Vietnam have increased rapidly from about two million ha in 2000 to about 4.2 million ha in 2018 [17,18] or more than 26% of the total forest area, with approximately two-thirds of the plantations area managed by smallholders [19,20]. This rapid expansion of plantations in recent years is due to the Government of Vietnam (GOV) implementing reforestation programs that have been initiated from the 1980s in response to extensive deforestation and forest degradation during and after the American war [21]. These programs also aimed to fulfil the timber demands of industries and increase income to rural populations [22]. They have been considered a major success, increasing forest cover by about 2.37% annually from 1990 to 2010 [23–25] and Vietnam is one of few countries in Asia to achieve a forest transition [26,27]. Increase in planted forests is considered to have improved general forest quality, biodiversity and enhanced ecological functions [28]. However, the change in ES depends on the extent of change in forest cover, previous land cover, management practices in planted forests and the type of ES being assessed [16,29].

The north-central coastal region has been a center for rapid plantations establishment and now has some of largest areas of planted forests in Vietnam. Plantations are predominantly Acacia species. These grow rapidly, with strong markets for pulpwood, veneer and saw logs. The region is identified in the Forestry Development Strategy as a major supply area for timber and non-timber forest products (NTFPs). This study focused on two provinces in this region: Thừa Thiên-Huế (TTH) and Quảng Trị (QT). This study aimed to test a framework for ES assessment in planted forests [16] to assess the effects of land cover change on important ES and identify potential trade-offs and synergies between different ES in a landscape undergoing rapid land use and land cover change. It provides the first analysis for this region of the impact of plantations on ES using readily available data and published estimates on the relationship between tree cover and different types of services.

2. Materials and Methods

2.1. Study Region

TTH and QT provinces are located between 106°30′49.47″–108°11′39.58″ E and 15°59′40.11″–17°10′4.83″ N (Figure 1). The total land area is 979,000 ha (503,320 ha in TTH and 474,570 ha in QT Province). In 2014 the population of TTH was 1.13 million people, with 0.6 million in QT province. The topography of the region is diverse, with high mountainous regions in the west and flatter, sandy coastal areas to the east [30]. The average annual temperature is 25 °C, and the annual average precipitation is 2540 mm. The climate is tropical monsoon with a dry season and a heavy monsoon season. The region has a strong wet season, and rainfall can reach 1000 mm in some months [31]. The heavy rainfall, in a short period and steep catchments, results in severe flooding with mountainous areas prone to high rates of soil erosion and landslides, causing major disaster risks [31,32].

The GOV has had major programs for soil conservation and timber production in the region since the 1980s. Recent statistical data indicates that planted forest areas in these two provinces increased from 147,311 ha in 2005 to 196,216 ha in 2015.
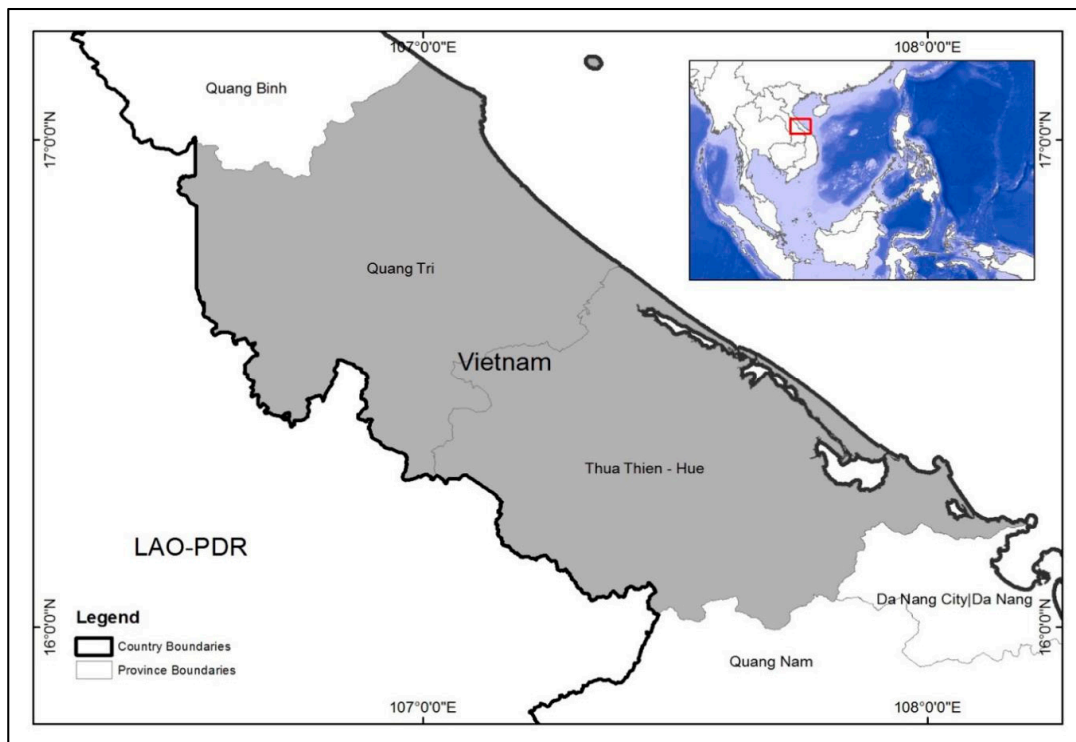
Figure 1. Map of the study area: Quảng Trị and Thừa Thiên-Huế Provinces in Central Vietnam.

2.2. Framework for ES Assessment from Planted Forests

As planted forests provide many ES beyond timber production, an improved evidence base is required for effective planning and management of ES from planted forest forests [16]. Studies show that planted forests supply low level of ES values than natural forests mainly resulting from intensive, large-scale monocultures and are more susceptible to soil erosion [3,33]. However, overall ES benefits from mixed plantations were highest in comparison to coniferous and broadleaf plantations [3]. Further, multi-purposed mixed plantations can help mitigate climate change as a result of high carbon sequestration, preventing deforestation as well as protecting remaining natural forests at the same time through increased productivity [33]. In the context, reliable assessment of ES at different spatial and temporal scales is required for further investment in planted forests. However, there has not been focused on the assessment of ES from planted forests due to a lack of suitable local frameworks, methods and evaluation tools [16,34–36]. Hence, the assessment framework proposed by Baral et al. 2016 [16] and used by Paudyal et al. 2019 [32] (Figure 2) was used to assess changes in ES resulting from the establishment of planted forests in this region. Conceptually, the framework consists of three components such as (i) silviculture and management for planted forests (Figure 2a); (ii) ES provisions based on categories of The Economics of Ecosystems and Biodiversity (TEEB) (Figure 2b); and (iii) ES assessing approaches and methods (Figure 2c).
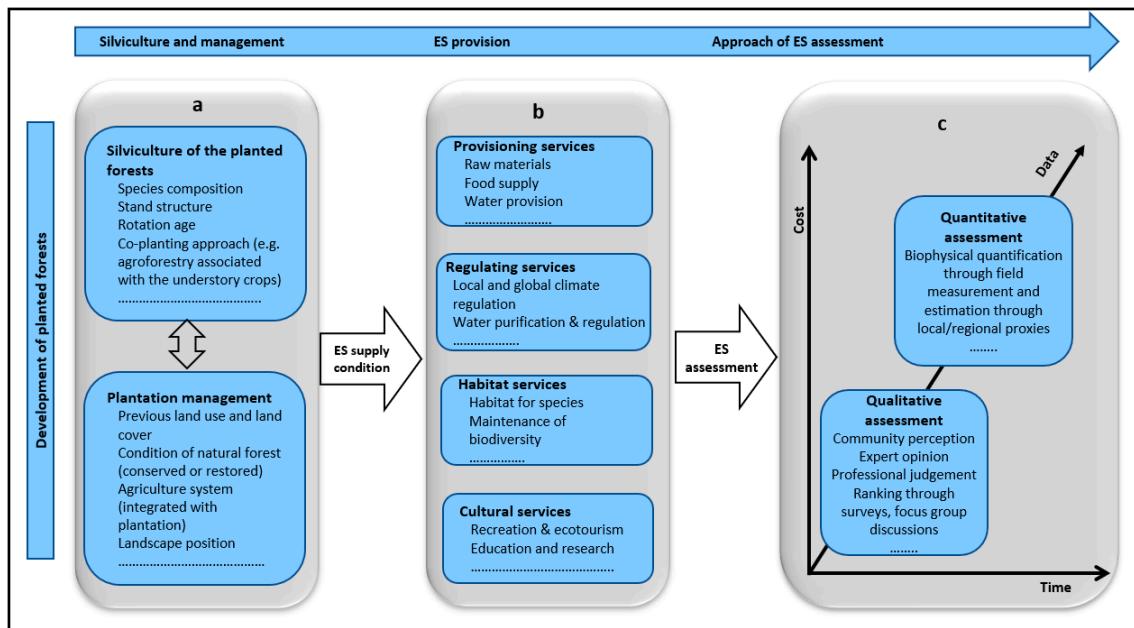
Figure 2. A framework for assessing ecosystem services (ES) from planted forests in Vietnam. The framework consists of three main components: (**a**) silviculture and management of planted forests that influences the quality of forests and supply of ES; (**b**) potential provisioning of ES based on the classification system proposed by The Economics of Ecosystems and Biodiversity (TEEB), and (**c**) the main approach of assessing ES which is associated with cost, time and data. The selection of approach/method and the assessment of ES depends on the available cost, time and data requirement for the assessment (Adapted from [16,34–36]). Valuation of ES depends on the scale of benefit, which varies from local to wider scales (Adapted from [37]).

2.3. Land Use and Land Cover Classification

This study used land use and land cover data of National Forest Inventory, Monitoring and Assessment Program (NFIMAP) developed by Forest Inventory and Planning Institute (FIPI) of Vietnam. The data were generated from medium resolution satellite imagery such as Sentinel and Landsat image using object-based image analysis that was combined with visual interpretation method. The reference points for interpretation and accuracy assessment were gathered from field survey and high-resolution images such as SPOT 7 or other equivalent images. The overall accuracy of land use change detection results shows confidence level at 95% [38]. The land cover classification used by the FIPI of Vietnam was used for this study. Five categories of land cover types were found in the study area (Table 1). The land cover information of 2005 and 2015 was also retrieved from the same source based on available satellite imagery data and the MARD 2017 [38] report.

Table 1. Land cover types in the study area.

Land Cover Type	Description
Rich forests	These are natural evergreen and broadleaf forests with average standing timber stock > 200 m^3 ha^{-1} that include principally old trees, also shrubs, bushes and understory. These types of forests are close to the primary forests.
Medium forests	These are natural evergreen and broadleaf forests with average standing timber stock 100–200 m^3 ha^{-1} that include a range of uneven-aged trees, also shrubs, bushes and understory. These forests have been influenced by human activities such as logging.

Table 1. *Cont.*

Land Cover Type	Description
Poor forests	These are natural evergreen and broadleaf forests with average standing timber stock < 100 m^3 ha^{-1} that have been altered by logging and human activities. They have started to revive through the process of natural regeneration. These forests can be considered degraded forests.
Planted forests	All kind of plantations are considered planted forest that include trees planted according to set pattern and management for production function; mainly timber and some NTFPs.
Other lands/Non-forest areas	Land cover not classified into one of the above categories, including agriculture lands, bare lands, residential areas and water bodies.

2.4. Ecosystem Services Assessment

Many different ecosystem services can be assessed, including provisioning services (ecosystem goods such as timber, pulp, food or biomass-based energy); regulating services (water regulation, reduced erosion and effects on local climate and carbon sequestration; habitat services (wildlife habitat and increased species and genetic diversity); and cultural services (recreation, ecotourism, education and spiritual values). Provision of ES is strongly influenced by silviculture and management.

ES identified in the study area are not of equal priority for the community. It is also not feasible to assess all ES, given limited resources [35,39,40]. ES relevant to Vietnam were compiled from recent studies [41–45] and discussed at a stakeholder workshop organized in TTH province on 17 March 2018 to identify priorities for assessment. Using participatory approaches, the participants ranked different services and selected locally important ES for detailed study (Table 2).

Table 2. Important forest ecosystem services (ES) from planted forests identified in Thừa Thiên-Huế and Quảng Trị provinces.

Category	Important ES	Description	Beneficiaries	Scale of Benefits	Indicator
Provisioning services	Wood supply	Supply of wood for domestic and international timber and furniture industries and international pulp and study manufacturers	Private (smallholder growers and state forest companies, timber industry owners, traders, workers)	Local, regional, global	Increased wood volume production (m^3/ha/year)
	Freshwater	Reduced siltation and increased freshwater for domestic use, paddy irrigation or hydropower	Public and private (hydropower and water companies and users	Local, regional	Increased volume of water supply (megaliters/year)
Regulating services	Reduced atmospheric greenhouse gases	Increased forest carbon stock and reduced greenhouse gas emissions	Public (national and international community)	Local, regional, global	tCO$_2$/year carbon sequestration
	Reduced soil erosion	Erosion protection and reduced sedimentation	Public	Local, regional	Reduced mass of soil loss (t/year)
	Water regulation	Increased evapotranspiration may reduce water supply for irrigation but reduce flood risks.	Private water downstream users	Local, regional	Increased evapotranspiration (mm/year)
Habitat services	Habitat provision	Improved habitat for birds, mammals or other functional groups	Public (existence value, recreation value)	Local, global	Increased habitat area (Qualitative scale)

ES assessment can be qualitative and quantitative [16]. We carried out mostly quantitative assessments of priority services using existing data. These are described below.

2.4.1. Wood Supply

The increased plantation area on wood supply was assessed using a simple indicator of average annual plantation timber production [25]—21 m^3/ha/year. This is a simplification, but data were not available on the productivity classes for plantation areas.

2.4.2. Carbon Stocks

Carbon (C) storage and sequestration are important forest ES in Vietnam and globally [46]. C stocks were estimated using a Tier 3 approach of IPCC 2013—national allometric equations [47] and plot measurement data (diameter at breast height and height of trees), using data from the NFIMAP of Vietnam [38] (Table 3). Average carbon stocks varied between different types of land cover and between the two assessment years for the same land cover type. The average C stock for natural forest classifications was lower in 2015 compared to 2005, while average C stock for planted forests increased.

Table 3. Carbon stock estimates for 2005–2015 by land cover.

Land Cover Type	Carbon Stock (tC/ha) 2005	Carbon Stock (tC/ha) 2015
Rich forest (evergreen broadleaf forest)	171.2	148.5
Medium forest (evergreen broadleaf forest)	73.4	71.2
Poor forest (evergreen broadleaf forest)	31.7	29.2
Planted forest	21.0	23.6
Non-forest land	0	0

2.4.3. Freshwater

We assessed the potential freshwater yield for different land cover types. Estimated values for water use for different land use and land cover types [48] were integrated into a GIS and assigned to five classes: very low, low, medium, high and very high. The rich forest was assumed to have very low water yield because it has a generally high leaf area, while the medium forest was valued to have low water yield [49–54]. Poor forest and planted forest were assessed to have medium water yield. The non-forest land was ranked to have very high-water yield.

2.4.4. Sediment Retention

Soil loss is a function of land cover type, rainfall intensity, soil erosivity, land cover types, the degree of steepness, crop management and conservation practices tree cover [36,55–58]. Soil erosion and sediment retention are inversely related [59]. Land cover types and their corresponding rate of erosion can be used to estimate the sediment-retention capacity of a landscape where forest quality and density is considered as the primary indicator [36,37,60].

Previous studies have developed five soil erosion classes in Vietnam. There was no data or lack of published information linking soil erosion or sediment retention to land cover for the study region. Data from a study in Bon River, Central Vietnam was used to determine the sediment-retention capacity, which assumes they have similar topography, soil and climatic conditions [61]. This study shows that average soil loss of rich forest is 8.92 ton ha^{-1} year^{-1}, medium forest 10.51 ton ha^{-1} year^{-1}, poor forest 11.76 ton ha^{-1} year^{-1}, and planted forest is 12.76 ton ha^{-1} year^{-1} [61]. Similarly, the average loss of non-forest area is considered about 30.33 ton ha^{-1} year^{-1} [61].

2.4.5. Habitat Provision

Vietnam is rich in biodiversity with more than 7000 plants species and more than 3800 vertebrate species recorded in the country [62]. Much of this biodiversity was heavily impacted by the American

war and subsequent deforestation and forest degradation. Planted forests can support a higher abundance of native fauna and flora compared to agricultural land, but generally have lower biodiversity value than native vegetation [29,63–69]. Conversion of natural forests to planted forests will generally reduce habitat for biodiversity, although this depends on the condition of the natural forests [5].

2.5. Spatial and Temporal Analysis of Ecosystem Services

For spatial assessment, we developed a simple ranking system to integrate quantitative and qualitative information. The level of ES supply capacity of the different land cover types was then classified into five categories, 'very low', 'low', 'medium', 'high' and 'very high'. This was combined with an associated confidence level for spatial and temporal assessment of ES. Biophysical data with different categories of the capacity of land cover type were presented to the expert meeting. Experts discussed the capacity each land cover type to supply ES and agreed on a ranking. The estimated quantity and associated value class information were transferred into GIS for spatial assessment and mapping of relative capacity of land cover to supply ES. Value classes were transferred into GIS for comparison between the two time periods and to map the relative capacity of different parts of the study area to supply ES.

3. Results

3.1. Change in Land Use and Land Cover in Quảng Trị and Thien-Hue Provinces

There were observable changes in land cover in two provinces between 2005 and 2015 (Tables 4 and 5, Figure 3). Planted forest area increased by a 51,578 ha (31,680 ha in QT and 19,898 ha in TTH province), mostly through establishment on non-forest land. In QT Province, total natural forest declined by 6.4%, largely through the conversion of poor forests to the plantations. The dynamics were different in TTH Province, the overall area of natural forests increased by 12.2%, largely through the conversion of non-forest to the poor forest area. Further, Rich forest area increased by 9.5% in QT province but decreased by 32.4% in TTH Province.

Table 4. Land cover change between 2005–2015 in Quảng Trị and Thừa Thiên-Huế Provinces. Unit area is in hectares (ha); the percentage of the area is indicated in the parenthesis.

Land Cover Classes	Areas of Land Cover				Change in Land Cover Area	
	Quảng Trị		Thừa Thiên-Huế		Quảng Trị	Thừa Thiên-Huế
	2005	2015	2005	2015	2005–2015	2005–2015
Rich forest	15,411 (3.3)	16,869 (3.6)	36,412 (7.4)	24,606 (5.0)	1459 (9.5)	−11,805 (32.4)
Medium forest	56,396 (11.9)	58,414 (12.3)	47,499 (9.7)	51,860 (10.5)	2018 (3.6)	4.362 (9.2)
Poor forest	76,650 (16.2)	64,191 (13.5)	103,000 (21.0)	133,276 (27.1)	−12,459 (16.3)	30,276 (29.4)
Planted forest	63,239 (13.3)	94,919 (20.0)	67,691 (13.8)	87,589 (17.8)	31,681 (50.1)	19,897 (29.4)
Non-forest land	262,421 (55.3)	239,724 (50.6)	237,046 (48.2)	194,316 (39.5)	−22,698 (8.6)	−42,730 (18)
Total	474,117 (100)	474,117 (100)	491,647 (100)	491,647 (100)		
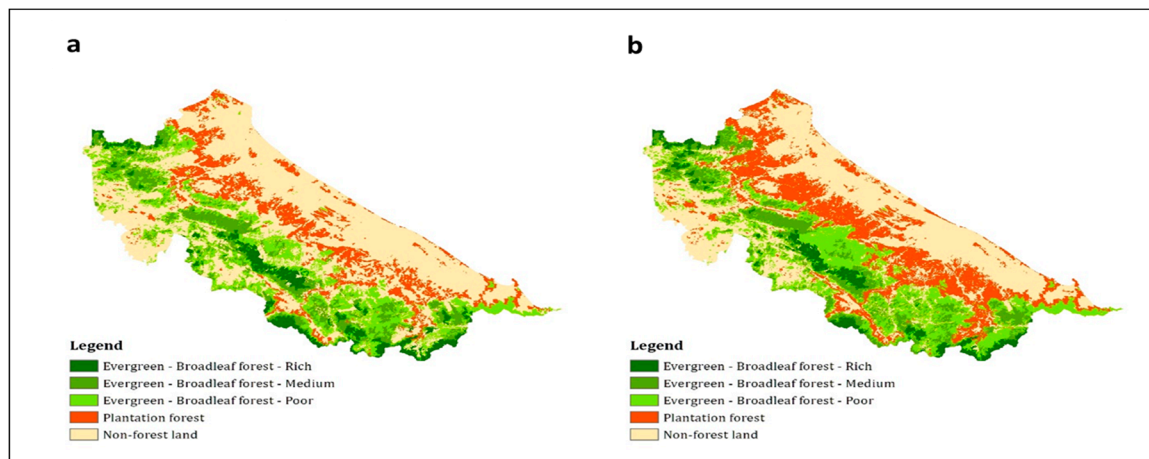
Figure 3. Change of forest land cover on different types of forest from (**a**) 2005 to (**b**) 2015.

Table 5. Land cover transition matrix from 2005 to 2015 (ha) for the two provinces.

| Land Cover in 2005	Land Cover in 2015					
	Rich Forest	Medium Forest	Poor Forest	Planted Forest	Non-Forest Land	Total
Rich forest	36,504	12,854	2034	274	157	51,822
Medium forest	4972	74,109	22,708	124	1982	103,895
Poor forest	0	23,310	131,990	1148	23,201	179,650
Planted forest	0	0	473	106,050	24,407	130,930
Non-forest land	0	1	40,262	74,912	384,292	499,467
Total	41,476	110,274	197,467	182,508	434,039	965,764

3.2. Assessment of Ecosystem Services

3.2.1. Timber Production

Spatial assessment of timber production capacity was beyond the scope of this study, and an average timber production figure was applied to the increased plantation area. The increased plantation area could potentially provide an increased volume of 1.08 million m^3/year of timber across the two provinces. This would depend on the site quality and management of the plantations. Returns to growers vary from 16% to 32%, but the poorest sites provide lower returns [25]. The increased timber volume would provide net income after costs of US$11 million/year to the smallholder growers. Assuming an average of 5 ha of plantations for each smallholder, this is a potential additional income of over US$1,000 per year to each landowner. Additional economic benefits are generated through labor payments during management, harvest and transport of timber and through the supply chain.

3.2.2. Freshwater Provision

The landscape capacity to supply freshwater may have decreased in the studied period because of non-forest area decreased and planted, and natural forest areas increased (Figure 4). Central to western hilly region showed had higher forest cover and therefore reduced freshwater supply capacity. It was not possible to quantify this reduced water use.
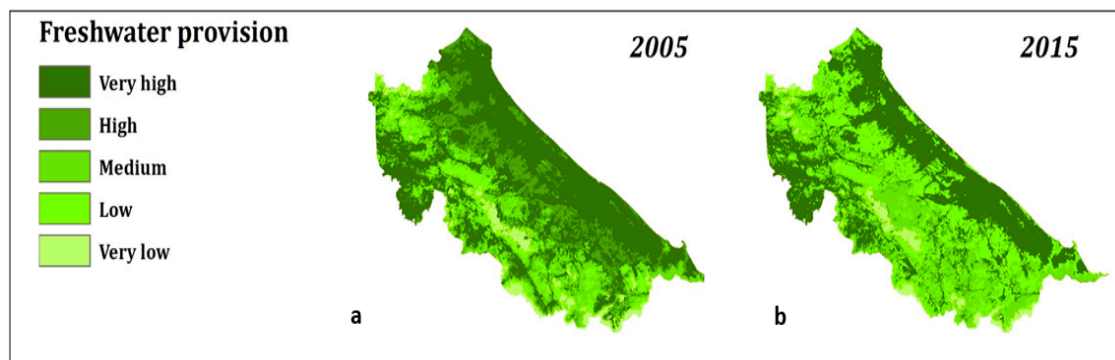
Figure 4. Distribution of landscape capacity to supply freshwater provision across the study area. (**a**) Landscape capacity to supply freshwater provision in 2005; (**b**) the landscape capacity to supply freshwater provision in 2015. The area with dark green colors shows the low capacity to supply freshwater, where the area with light green indicates the medium capacity and the area with yellowish-green designates the high capacity to supply freshwater provision.
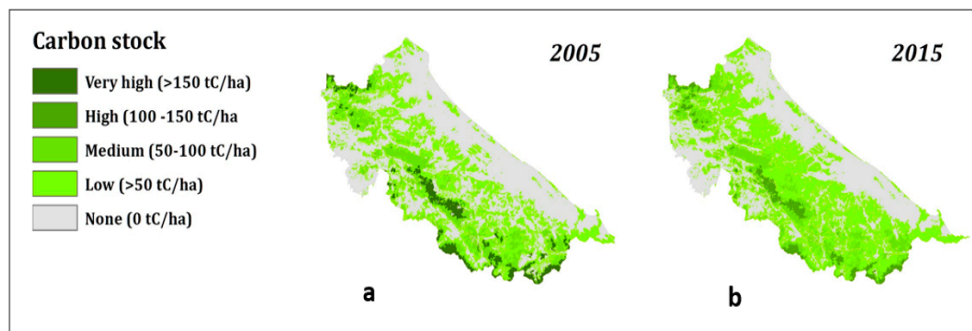
3.2.3. Carbon Stock

Forest carbon stock in planted forests increased between 2005 and 2015 from 2.7 million tC to 4.3 million tC (56.7%) due to increases in the area and average carbon stock in planted forests. This represents net sequestration of 5.7 million tCO_2 over the ten years, an average of 0.57 million tCO_2 per year or about 1.2% of Vietnam's estimated national emissions [70]. However, across the study region, forest carbon stocks decreased by 3.4% (from 24.9 million tons in 2005 to 24.1 million tons in 2015 (Table 6) due to conversion of rich forest (20%) to medium or poor forests and reduced average carbon stocks in the rich forest. Carbon stocks in medium and poor forests increased slightly during this assessment period.

Table 6. Change in forest carbon stock in Quảng Trị and Thừa Thiên-Huế Provinces from 2005 to 2015. Unit of carbon stock is in tons (tC), and the percentage is indicated in the parenthesis.

Land Cover Classes	C stocks (tC)		Change in C Stock (tC)
	2005	**2015**	
Rich Forest	8,873,300 (35.6)	6,159,000 (25.6)	−2,714,300 (−30.6)
Medium forest	7,626,900 (30.6)	7,853,700 (32.6)	226,800 (3.0)
Poor forest	5,694,900 (22.8)	5,770,000 (24.0)	75,100 (1.3)
Planted forest	2,745,600 (11.0)	4,303,500 (17.9)	1,557,900 (56.7)
Non-forest land	0	0	0
Total	24,942,700 (100)	24,0868,200 (100)	−854,500 (−3.4)

The distribution of carbon stock varied across the study area (Figure 5). The carbon stock in 2005 was concentrated in central to the western hilly area, whereas the area of carbon stock shifted towards central to eastern cost due to the expansion of planted forest in that region.

Figure 5. Distribution of carbon stock (tC/ha) across the study area. (**a**) Carbon stock in 2005; (**b**) carbon stock in 2015. The area with dark green colors shows the high carbon stock region; light green area shows the medium capacity and yellowish-green indicates the area without carbon stock.

3.2.4. Sediment Retention

Sediment-retention capacity (inverse of soil loss) was highly influenced by the change in land cover in the study area (Table 7, Figure 6). Rich forest decreased (by 20%), and planted forests increased between 2005 and 2015 and both had a major impact on overall sediment retention. The conversion of non-forest to planted forest reduced soil loss, while degradation of the rich forest increased soil loss. The aggregate sediment-retention capacity increased by 13.1% due to the conversion of non-forest to the forest. The sediment-retention capacity of natural forests was enhanced by 20% (>92,000 tons) due to the conversion of rich forest (20%) to medium or poor forests. This is an anomaly of the assessment approach. Overall, sediment-retention capacity across the two provinces increased by 5.69%, with total soil loss reducing from ~20.5 million tons in 2005 to ~19.3 million tons in 2015 (Table 7).

Table 7. Estimate change in soil loss in Quảng Trị and Thừa Thiên-Huế Provinces from 2005 to 2015 associated with the change in the area of different types of land cover. In thousands of tons per year (t/year) and the percentage is indicated in the parenthesis.

Land Cover Classes	Soil Loss (KT/Year)		Change in Soil Loss (KT/Year)
	2005	**2015**	
Rich Forest	462 (2.3)	370 (1.9)	−92 (−20)
Medium forest	1092 (5.3)	1159 (6.0)	67 (6.1)
Poor forest	2112(10.3)	2322 (12.0)	210 (9.9)
Planted forest	1672 (8.2)	2329 (12.0)	657 (39.4)
Non-forest land	15149 (73.9)	13164 (68.1)	−19845 (−13.1)
Total	20486 (100)	19344 (100)	−1142 (−5.6)
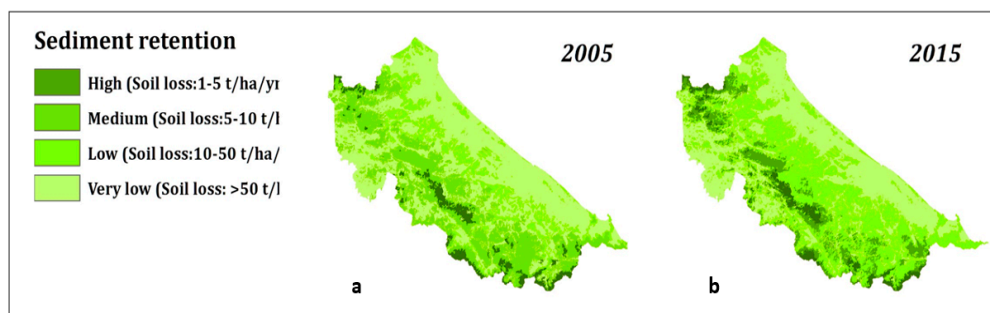
Figure 6. Distribution of sediment retention (mapped based on soil loss of various land use and land cover types measured in tC/ha/year) across the study area. (**a**) Sediment retention in 2005; (**b**) sediment retention in 2015. The area with dark green colors shows the high sediment retention region; light green area shows the medium capacity of sediment retention and yellowish-green indicates the area without sediment retention.

3.2.5. Habitat Provision

Habitat provision was highly influenced by the land use and land cover types and their change over the period (Figure 7). Results revealed that dark green area in the landscape had a high habitat provision area which was mostly an area with rich forest and planted forests. In addition, the medium or secondary forests that had almost reached their maximum productivity stage were judged to have a high habitat condition. The light green in the ES map indicated the medium capacity of habitat provision in the poor forest or young secondary forest and planted forest. Almost all non-forest area provided very low habitat value. Yellowish green pigments in spatial map showed that low to the very low capacity of habitat provision limited around the degraded land old agricultural area.
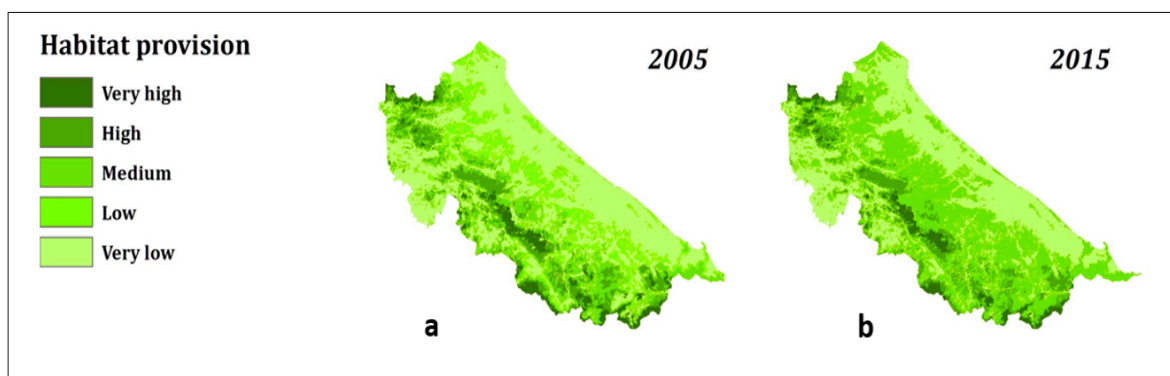
Figure 7. Distribution of habitat provision across the study area. (**a**) Habitat provision in 2005; (**b**) habitat provision in 2015. Area with dark green colors shows the area with high habitat provision; light green indicates the area with a medium capacity of habitat provision and yellowish-green shows the area has inadequate habitat provision.

4. Discussion

4.1. Land Use and Land Cover Change

This study indicated that land cover change, primarily conversion of non-forest land to planted forest, between 2005 and 2015 in the central region of Vietnam improved the capacity of the landscape to supply ES. Expansion of planted forests, as well as the increased area of poor forest on non-forest land, reduced landscape capacity to supply freshwater, but increased sediment retention, habitat provision and carbon stocks.

However, the study also identified a loss of services associated with the degradation of rich forests to medium or poor forests in TTH province. This type of degradation is occurring in most of the provinces of Vietnam, where the degradation of rich forests has accelerated since the 1950s [71]. National statistics show about 2500 ha of forest illegally destroyed every year during the period 2010–2013 [18] due to ill-defined property rights and ineffective laws enforcement mechanisms [71]. Positive changes to ES associated with planted forests were not great enough to offset impacts of degradation of rich natural forest to medium and poor forests on the provision of some ES. Here we discuss these results in relation to comparable studies.

4.1.1. Freshwater

Impact of converting non-forest land to planted forests on downstream water availability has been a concern of water managers in some parts of the world for quite some time [72–75]. Higher Leaf Area Index in planted forests means they consume more water than other vegetation types, although infiltration may be higher in these high rainfall conditions on steep slopes [76] and levels of low flows may increase in some systems [77]. In addition, where the planted forests are harvested when quite young (4–6 years old), significant parts of the landscape, about 20–30%, will have no trees or young

seedlings that use less water. Increased evaporation and retention of water higher in the landscape can help reduce flood risks and related soil erosion (see below). Catchments, where most trees are planted, are highly flood-prone, and the expansion of plantations on non-forest land can reduce flood risks. More research is required to understand the impact of afforestation on the water for irrigation and hydropower and for reducing flood risks in these types of high rainfall, subtropical environments.

4.1.2. Sediment Retention

Areas covered by natural forest have the highest soil loss, followed by medium and low forests, planted forests and non-forest land (agriculture area), respectively. Soil loss is strongly influenced by topography, and most of natural forests are located in steep topography, while most of the non-forest areas are located in relatively flat land [30]. This can be different in other settings. A study in Yen Bai province showed that reducing forest cover caused significant soil loss, while research in Hoa Binh province showed that afforestation reduced soil erosion rates [78,79]. Forest cover loss increased average runoff by about 87%, and sediment yield has increased about 46% annually due, while runoff and sediment yield were decreased for about 50% due increasing of forest cover and soil conservation application [79].

Hence, the soil loss was decreased or sediment retention was increased in our study area as a result of increasing forest cover from conversion of non-forests to the plantations. However, timber harvesting, transport practices and the extent of the bare ground after harvesting of the planted forest have the potential to increase soil erosion and long-term productivity loss unless good practice and mitigation measures are implemented [80]. This can include restricting harvesting on steep slopes, controlling skid trail construction and management with water flow controls, good road construction and maintenance and the use of appropriate equipment for harvesting in different types of terrain.

It should be noted that the forest canopy does not provide direct protection against erosion; rather the forest canopy minimizes the erosive power of rainwater into the soil [72,81]. Additionally—in relation to water consumption—an increasing area of forest vegetation can increase infiltration and reduce runoff on the soil surface [48]. A study case in Japan indicated that rainfall intensity is the main driver of soil loss, with slope and tree species also being important factors [82]. Other studies in Vietnam show that soil erosion varies greatly between the wet season and dry season [58] and different agriculture crops have different soil erosion rate [58]. These factors need to be considered in future assessments of the impacts of land cover change on soil erosion.

4.1.3. Carbon

While the study showed that carbon stocks in planted forests increased over the assessment period, this was not enough to offset losses of carbon in the landscape due to the degradation of natural forests. This indicates that stronger policy measures, such as monitoring, regulation and incentives, are required to reduce natural forest degradation. The carbon stock can be affected by different forms of management practices in planted forests. For example, species choice and rotation length also affect carbon stock [41]. Planted forest could be managed on longer rotations for higher carbon stock. For example, *Acacia* plantations can be used to facilitate the restoration of natural forests by underplanting native species [83] that will achieve higher carbon stock in the long term. Uneven-aged and multi-storied planted forests can potentially sequester more carbon in total [84]. Longer rotation *Acacia* plantations in Vietnam may potentially be more profitable than those managed on shorter rotations [19] but take more time to generate income. Hence, smallholders prefer short-rotation planted forest. Given planted forests are managed by smallholder on short rotations, the actual carbon stock at any point in time will vary with harvesting and management decisions.

4.1.4. Habitat Provision

Land cover changes between 2005 and 2015 both increased and decreased habitat for many species. Conversion of non-forest to planted forests would result in a more suitable habitat for many wildlife

species, although this depends on management intensity and understory retention [9]. Although undisturbed natural forests are generally likely to provide the best habitat conditions, these comprise a relatively small proportion of the total forest area in Vietnam and conservation objectives will need to be met from a diversity of forest conditions. Biodiversity could be improved by better protecting native forests and integrating native forest restoration into planted forests [9,85] is required for Forest Stewardship Council (FSC) certification. Smallholders should be properly compensated to improve biodiversity in planted forests. In Vietnam, where a large area of planted forest is operated by smallholders, different types of incentives will be required.

Planted forests on degraded land can provide alternative resources and reduce pressures on natural forests [4,86]. *Acacia* plantations in this region have significantly increased incomes for smallholder households and this also reduces pressures to clear or hunt in, natural forests.

4.2. Application of the ES in the Planted Forests Assessment Framework

The framework developed by Baral et al. 2016 [16] provided a starting point to assess ES from planted forests. The study indicated it was possible with available data to undertake an assessment using established relationships between priority ES and factors such as previous land use, the extent of planting, species, position in the catchment, proximity of natural forest and management intention. Different kinds of data are required to assess tree plantings that are integrated with agriculture (trees outside forests or agroforestry), and to assess the effect of varying stand structures, rotation lengths, management treatments such as spacing, pruning or thinning and the extent and composition of the understory. Assessing conservation and habitat value is particularly problematic as this will depend on the extent of planting, proximity to natural forests, management intensity, understory development and the impact of hunting and other local uses of biodiversity.

The framework provides a sound conceptual base for assessing the potential ES of land use change to planted forests but requires more intensive local data collection to provide a complete picture of the various types of services or disservices provided by planted forests. Research is also required to establish benefit relevant indicators for the assessment of benefits from the planted forests [87]. In addition, the study demonstrated that in applying the framework, it is important to assess the effects of land use change across a catchment or study area. While planted forests themselves may be resulting in improvements to many ES, broader changes in forest condition may mean that these are offset by negative impacts on vegetation in other parts of the study area.

4.3. Enhancing Ecosystem Services from Planted Forests in Vietnam

Managing planted forests for maintaining or improving raw materials supply and enhancing other ES for long-term sustainability requires thorough assessment and documentation [16,42,88]. Payment for Ecosystem Services (PES) presents an opportunity to enhance ES from planted forests [89]. The Vietnamese government is the first in Asia to implement PES that has successfully improved livelihoods and forest resources in Vietnam [90]. However, some challenges for the implementation remain there such as the very low payment; too small area of the project for significant improvements and quantification of services [90]. This study can provide a guide for ES assessment and improve the basis for payment arrangements. PES programs are providing resources for local communities to patrol and manage natural forest [91,92], but the efficiency of these programs could be improved through better targeting [93]. Examination of different management systems, particularly the type of management that can improve the conditions for water or habitat, is needed to develop a complete understanding of the ES from planted forests.

Forest certification helps to enhance ES in Vietnam. The Vietnamese government has encouraged certification by providing a subsidy for the planted forest. At the same time, certain companies have offered higher prices for certain qualities of logs from certified forests, but the costs are also high [94,95]. Example from the FSC certification for timber is highly adaptable and can incorporate forest ES, e.g., biodiversity conservation, carbon storage, watershed protection, etc [96]. In addition, FSC certification

for *Acacia* plantations in QT province provides higher return compared to the non-FSC certified planted forests, although this comes at some cost to growers in terms of changes in management cost, lack of technical knowledge, annual surveillance audit fees, difficult paperwork, complicated procedures for selling wood and loss of market flexibility [20,94]. The government has a clear policy on sustainable forest management (SFM) and forest certification. Vietnam has also signed a voluntary partnership agreement (VPA) with the European Union (EU) for legal trade that is driving the need for certification and provides an opportunity to incorporate ES approach in the planted forest [96].

5. Conclusions

The study identified that a significant change in land cover occurred from non-forest or poor forest to planted forests between 2005 and 2015 in TTH and QT provinces in Central Vietnam that resulted in significant improvement in ES. The area of rich forest decreased by 20%, mostly through degradation to poorer quality natural forests. Planted forests on non-forest land increased carbon stock, habitat provision, reduced erosion and increased sediment retention. Conversion of non-forest areas to planted forests may decrease water yield, but could also increase infiltration, increase low flows and reduce flood risks. The provision of ES at a landscape scale also depends on the changes occurring in natural forests and the agricultural landscape. These changes need to incorporate into ES assessments. The management regime of planted forests also affects the provision of ES.

This initial assessment can be used to quantify the economic value and communicate the wider benefits of ES from planted forests to raise awareness and guide priorities for future investment in planted forests among policymakers, forest owners and managers, environmental organizations and local communities. The results can also provide a basis for new funding opportunities for ES produced from planted forest and other landscape restoration programs.

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