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Meet the editor

Dr. Ling Zhang obtained his Ph.D in Soil Science from Nanjing Agricultural University, China, and visiting Department of Ecology and Evolutionary Biology, Rice University, USA, from July 2012 to December 2013. Dr. Zhang is now working as professor at the College of Forestry, Jiangxi Agricultural University, China, supervising graduate students. Dr. Zhang studies global change biology, forest ecology, plant invasion, and soil carbon and nitrogen cycling. He has published more than 50 papers related to global change ecology or forest ecology, and authored or coauthored several books on forest ecology or soil ecology in recent years. Dr. Zhang is serving as associate editor of ISI journal Plant Ecology and reviewer for more than 10 ISI journals.

Contents

Preface

Forest ecosystems are functionally important with respect to their crucial roles played in supplying forest production for human society, regulating global climate, and improving ecological environment. Efficient forest management will guarantee sustainable development of the human society, and should be focused on. Under the context of global change, soil nutrients, especially nitrogen, should be carefully managed and monitored in plantations experiencing intensive nitrogen input, and forests with exotic plant invasion disturbance, considering its substantial contribution to global nitrous oxide. One negative effect of global change could be loss of biodiversity, which could be maintained or restored by forest management *in situ* or in established reserves. In addition, advanced technologies should be developed to prevent fire in forests considering the increased frequency under extreme climate events. Importantly, associate policies and technologies will also be vital in successful and advanced forest management, such as deep learning in plant disease prevention, and quantitative strategic planning matrix in efficient management of forest conservation.

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Section 1

Forest Management and Nutrient Cycling

Chapter 1

Nitrogen Cycling and Soil Amelioration in *Camellia oleifera* Plantations

Bangliang Deng and Ling Zhang

Abstract

Camellia oleifera Abel. is one of the four woody edible oil trees around the world, which is also an important economic species in subtropical China. It is mainly cultivated in subtropical region, where the soil constrains the yield of *C. oleifera* oil due to its low fertility and pH. Thereby, intensive management including fertilization practice, especially intensive nitrogen (N) input, has been developed as a vital way to enhance oil yield in *C. oleifera* plantations. However, excessive nitrogen input increases soil nitrous oxide (N_2O) emissions and soil acidification, limiting sustainable development of economic forests. As one of the important greenhouse gases, N_2O is 265 times greater than carbon dioxide in global warming potential on 100-year scale. To mitigate soil N_2O emissions and soil acidification, soil amelioration, including applications of biochar, nitrification inhibitors, and urease inhibitors, played an important role in sustainable management of *C. oleifera* plantations. This chapter reviewed soil nitrogen cycling, N_2O emissions, and soil amelioration in *C. oleifera* plantations, which will benefit the sustainable management of *C. oleifera* plantations and hence the development of *C. oleifera* industries.

Keywords: *Camellia oleifera*, biochar, nitrification inhibitor, soil amelioration, sustainable forest management, urease inhibitor

1. *Camellia oleifera*

Camellia oleifera Abel. as a native edible oil tree has a long cultivation history in subtropical China [1]. It is a perennial and evergreen species with synchronous flowers and fruits. The cultivation area and total product value of *C. oleifera* have reached 4.47 million ha and 102.4 billion Chinese yuan, respectively [2]. With rapid development, the *C. oleifera* oil accounted for 80% domestic high-end vegetable edible oils in 2018 from China. High habitat suitability area for *C. oleifera* cultivation in China has been up to 4.94% [3].

Specially, *C. oleifera* oil and oils derived from palm, olive, and coconut are the four major woody edible oils in the world [4]. The *C. oleifera* oil is characterized by remarkable antioxidant activity [5] and high content of unsaturated fatty acids (about 83%) [6].

Camellia oleifera can survive and adapt to low-fertility acid soil. Generally, it usually is used in the conservation of soil and water as well as afforestation in barren hill. Therefore, *C. oleifera* is an excellent species with both ecological and economic advantages. Development of *C. oleifera* industry would be beneficial for the safety of edible oil and the conservation of soil and water in China.

As a typical economic tree, intensification such as water management, fertilization, and trimming takes an important part in the management of *C. oleifera* plantations. Notably, organic matter, available phosphorus, and pH value was low in *C. oleifera* plantation soils [7], constraining the yield of *C. oleifera* oil. Therefore, intensive management with fertilization is often performed in *C. oleifera* plantations [1].

2. Challenges

Fertilization is the major way of intensive management, efficiently improving the yield of oil in *C. oleifera* plantations. However, a large amount of nitrogen (N) input increased the risk of soil N leaching and gaseous N (e.g., nitrous oxide (N_2O), nitric oxide (NO), ammonia (NH_3)) losing [8]. In addition, excessive N input induced soil acidification [9].

2.1 Nitrous oxide emissions

Nitrous oxide, as the major ozone-depleting substance [10], has been recognized to be an important greenhouse gas. Especially, the potential of N_2O for global warming is 265 times than that of carbon dioxide [11]. The concentration of N_2O is ranging from 270 ppb in pre-industrial period to 329.9 ppb in 2017 [12].

Soil systems contributed the largest source of N_2O emissions (13 Tg N_2O-N yr^{-1}), of which human activities accounted for 54% [13]. Nitrogen input such as N deposition and N fertilization often increased N_2O emissions and altered the process of N transformation [14–17]. Generally, soil N_2O emissions had a positive and linear relationship with N input [18]. About 120 Tg N was contributed by human activities per year [13]. Therefore, intensive N input often leads to high emissions of soil N_2O [19].

2.1.1 Nitrification and denitrification

Nitrification and denitrification are the two main pathways of N_2O emissions (**Figure 1**) [20–22], which produced global 70% soil N_2O emissions [13].

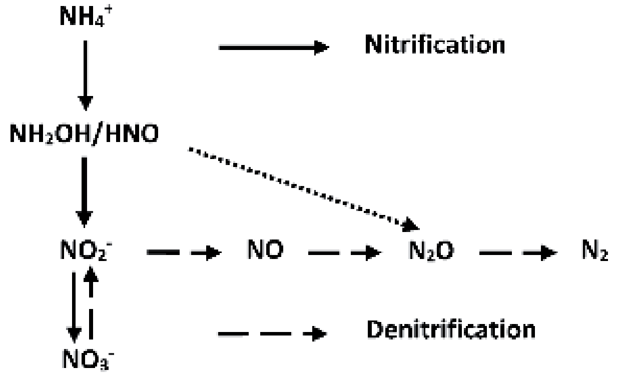

Figure 1.
Nitrification- and denitrification-related pathways [20–22].

2.1.2 Influence factors

Soil N_2O emissions can be influenced by soil environmental factors such as soil moisture, temperature, oxygen (O_2), and pH condition [23, 24].

2.1.2.1 Soil moisture

Soil moisture is a vital factor that affects soil N_2O emissions. Generally, soil N_2O emission rates reached the peak when soil water-filled pore space (WFPS) was 60–70% [25]. For example, soil N_2O emissions were significantly higher under 60% WFPS conditions than that under flooded conditions [26].

2.1.2.2 Soil temperature

Effects of soil temperature on N_2O emissions were more complex than that of soil moisture. For example, warming increased soil N_2O emissions from boreal peatland [27] and alpine meadow [28]. Soil N_2O emissions had an exponential increased relationship with incubation temperatures [29]. A significant positive correlation was presented in N_2O emissions and soil temperature from different soil types (paddy, orchard, forest, and mountain) [30]. Although warming did not affect soil N_2O emissions from northern peatlands, it suppressed N_2O emissions under N addition conditions [31]. By contrast, the effects of warming on soil N_2O emissions from alpine meadow soil were not observed [32]. Consistently, no significant increase of soil N_2O emissions was found with increasing incubation temperatures [33]. Previous study reported that soil moisture and temperature can explain 86% of soil N_2O emissions [34].

2.1.2.3 Soil O_2 concentration

Soil O_2 concentration was closely related with soil moisture and soil mechanical composition. Generally, soil with higher water content and larger clay fraction had lower soil O_2 concentrations. Lower soil O_2 concentrations mainly promoted soil N_2O emissions via denitrification [20, 35]. The production of N_2O and NO was increased when O_2 concentration decreased from 21% to 0.5% in a laboratory study [36]. Similarly, field study reported that soil N_2O emissions increased with increasing soil O_2 concentrations in wetland [37].

2.1.2.4 Soil pH

pH played an important role in the activity of microbes [38]. Indeed, soil acidification [39] and soil pH amelioration [40] significantly influenced soil N_2O emissions. However, other researchers reported that there was no significant correlation between N_2O emissions and pH [41].

pH influenced the activity of nitrification- and denitrification-related enzymes [42]. Generally, soil acidification increased N_2O emissions [42]. Compared with ammonia-oxidizing bacteria (AOB), ammonia-oxidizing archaea (AOA) were higher in activity and resistance from acid soil [43]. However, the domination of AOB was increased by increasing soil pH [44]. Additionally, archaeal *amoA* genes had a wide pH range of about 3.7–8.65, which had high activity in extreme environments such as high temperature and extreme acid [45].

2.1.3 *Nitrous oxide emissions from* Camellia oleifera *plantation soils*

Our previous field study (1 year) found that soil N_2O emissions were 92.14 ± 47.01 mg m^{-2} in control treatment and were 375.10 ± 60.30 mg m^{-2} in fertilization treatment (400 kg NH_4NO_3-N ha^{-1}) from *C. oleifera* plantations [1].

2.2 Soil acidification

Acid soil (pH < 5.5) as a main soil type covers about 30% free ice land [46]. However, soil acidification has been becoming more and more serious [47]. Soil acidification should be taken into consideration due to its constraint in the sustainable development of agricultural sector [48]. In China, soil pH (except alkaline soils at pH 7.10–8.80) from crop fields reduced by 0.13–0.76 during the year 1980–2000 [49]. For example, soil pH (surface layer) decreased by 0.30 units from 1981 to 2012 in Sichuan Province, China [47].

With a long cultivation history, *C. oleifera* was widely cultivated in acid or strongly acid soil in subtropical China [7]. The optimum pH for the growth of *C. oleifera* is 5.5–6.5 [50]. However, acid deposition [51] and intensive N input [49] may stimulate soil acidification from *C. oleifera* plantations. Additionally, long-term N input may also increase the toxicity of aluminum (Al) [52], limiting the sustainable development of *C. oleifera*.

Soil acidification from *C. oleifera* plantations is mainly related to the following factors.

2.2.1 *Precipitation*

Long-term precipitation increased the loss of base cations such as Ca^{2+}, Mg^{2+}, K^+, and Na^+, reducing the soil pH buffering capacity. In addition, long-term precipitation promoted the accumulation of Al^{3+} and Fe^{3+} in soil, which could further hydrolyze to $Fe(OH)_3$ or $Al(OH)_3$ and release $3H^+$.

2.2.2 *Plant physiology*

When plant roots absorb a NH_4^+ from soil, an H^+ will release into soil; in turn, absorbing a NO_3^- from soil will release an OH^- into soil [53].

Organic acid (R–COOH) from root exudates can release an H^+ after hydrolysis. In addition, anions of organic acids (e.g., citric acid and malic acid) can chelate with Al^{3+} in the soil and inhibit the root system that absorbs Al^{3+}, alleviating Al^{3+} toxicity to plant growth [48, 54, 55].

Plants such as *C. oleifera* [56] can uptake Al^{3+} by roots, promoting the accumulation of Al^{3+} in surface soil via litter decomposition [57]. The accumulation of Al^{3+} can replace the base cations such as Ca^{2+}, Mg^{2+}, K^+, and Na^+ and accelerate leaching, hence reducing the pH buffering capacity of top soil.

2.2.3 *Microbial-mediated nitrification*

For example, NH_4^+ transfers to NO_3^- along with the $2H^+$ release ($NH_4^+ + 2O_2 \rightarrow NO_3^- + H_2O + 2H^+$) [53]. AOB, AOA, and fungi can participate in the process of nitrification [20]. Nitrification includes the pathway of ammonia oxidation to hydroxylamine, the pathway of hydroxylamine oxidation to nitrite, and the pathway of nitrite oxidation to nitrate (**Figure 1**) [58]. Ammonia can be oxidized by AOA or AOB to hydroxylamine via ammonia monooxygenase (*amo*).

Hydroxylamine can be oxidized to nitrite by hydroxylamine oxidoreductase. Nitrite can be oxidized to nitrate by nitrite oxidoreductase.

2.2.4 Oxidation of sulfur-containing organics

Oxidation of sulfur mineral, for example, oxidation of FeS_2, will produce $2H^+$ ($2FeS_2 + 7O_2 + 2H_2O \rightarrow 2Fe^{2+} + 4SO_4^{2-} + 4H^+$).

Oxidation of sulfur-containing organics will release $4H^+$ (2Organic-S + $3O_2$ + $2H_2O \rightarrow 2SO_4^{2-} + 4H^+$).

2.2.5 Intensive nitrogen fertilization

Intensive NH_4^+ input can replace the base cations such as Ca^{2+}, Mg^{2+}, K^+, and Na^+ and accelerate leaching, reducing the pH buffering capacity of top soil [59]. Hydrolysis of soil NH_4^+ will generate NH_3 (gas) and consume an OH^- ($NH_4^+ + OH^- = NH_3\uparrow + H_2O$) [60].

Acidic fertilizers such as $Ca(H_2PO_4)_2$ will gradually release H^+, hence increasing soil acidification ($Ca(H_2PO_4)_2 \rightarrow CaHPO_4 + H_3PO_4$, $H_3PO_4 \rightarrow H^+ + H_2PO_4 \rightarrow 2H^+ + HPO_4^{2-} \rightarrow 3H^+ + PO_4^{3-}$).

2.2.6 Acid deposition

Acid deposition (water-soluble acid gases such as CO_2 and sulfur dioxide) and N deposition (especially NH_4^+-N) increased soil acidification [51]. Precipitation with H^+ can replace the soil base cations such as Ca^{2+}, Mg^{2+}, K^+, and Na^+, which directly reduce the soil pH buffering capacity [51].

2.2.7 Other factors

For example, deforestation and other land uses can reduce litter accumulation in surface soil, hence declining the accumulation of base cations such as Ca^{2+}, Mg^{2+}, K^+, and Na^+ that generate from litter decomposition [61].

2.3 Effects of soil acidification on nitrous oxide emissions

Acid soils have been facing an increased risk of acidification due to human activities, especially intensive N fertilization [47, 49, 62]. For example, after 6 years of application of 600 kg Urea-N ha^{-1} yr^{-1}, soil pH was significantly decreased (soil pH in control and fertilization treatment was 5.1 and 4.9, respectively) from a tea plantation in Yixing City, Jiangsu Province, China [63]. A meta-analysis of 1104 field data showed that a negative correlation between soil N_2O emissions and pH (3.34–8.7) ($N_2O\text{-}N = -0.67x + 6.55$, $R = 0.22$) is negatively related with N fertilization [9]. Moreover, deposition of sulfur dioxide increased soil acidification, stimulating soil N_2O emissions [64].

The mechanism of soil acidification on the stimulation of soil N_2O emissions is complex, which may include (but not limited to) the following points.

2.3.1 Chemical decomposition of nitrous acid

Under acidic conditions, pH < 5.5, NO_2^- (HNO_2, $pK_a = 3.3$) will naturally decompose into NO and/or NO_2 ($3HNO_2 \rightleftharpoons 2NO + HNO_3 + H_2O$ or $2HNO_2 \rightleftharpoons NO + NO_2 + H_2O$) [65]. Soil NO can be further transformed to N_2O with Fe^{2+} when it was not escaping soil [65].

2.3.2 Shifts in microbial communities and abundance

Generally, the abundance of AOB was lower in soil pH < 5.5 than that in neutral soil pH. Here, nitrification was weak and almost disappears at soil pH < 4 [66]. However, AOA could mediate the process of ammonia oxidation in extremely strong acidity soil (pH: 4.2–4.47) [43]. Another study reported that the abundance of AOB was positively correlated with pH (R^2 = 0.2807), while the abundance of AOA was negatively correlated with pH (R^2 = 0.2141) [67]. For example, AOA dominated in acid paddy soil (pH 5.6), while AOB dominated in alkaline soil (pH 8.2) [68]. Previous research indicated that fungi were the main microbial community that mediated N_2O emissions in acid soil [69, 70]. Additionally, fungi-mediated denitrification accounted for 70% soil N_2O emissions from a 100-year-old tea plantation (soil pH 3.8) [71].

In acid soils, the activity of N_2O reductase was inhibited, leading to higher N_2O emissions in lower soil pH [72]. Indeed, there was a positive correlation between the abundance of *nirS*, *nirK*, or *nosZ* and soil pH (4.0–8.0) and a negative correlation between $N_2O/(N_2O + N_2)$ and soil pH [73]. In agreement, $N_2O/(N_2O + N_2)$ was negatively correlated with soil pH (3.7–8.0) (R^2 = 0.759, P < 0.001), and lime addition decreased $N_2O/(N_2O + N_2)$ [74]. The ratio of $N_2O/(N_2O + N_2)$ increased with decreasing pH (5.57–7.06) (R^2 = 0.82) [75]. Consistently, soil pH was negatively correlated with N_2O/N_2 [76]. Intensive management consistently decreased soil pH and increased the ratio of $N_2O/(N_2O + N_2)$ [77]. Increasing dolomite dosage increased soil pH and hence increased the transcription of *nosZ* genes and reduced the potential of N_2O production in acid soils [26].

2.3.3 Microbes increased resistance to soil acidification

Laboratory study showed that the potential of soil N_2O emissions was increased with decreasing pH (soil pH ranging from 2.96 to 6.26) from tea plantations in Japanese [78]. In addition, higher soil N_2O emissions and lower abundance of *nosZ* genes were observed in soil pH at 3.71 (control) than in pH at 5.11, 6.19, and 7.41 (lime amelioration) under NO_3^--N fertilization (50, 200, and 1000 mg kg^{-1}) from a 100-year-old tea plantation [79]. Field study found a negative correlation between soil N_2O emissions and pH (pH 3.6–5.9) ($N_2O\text{-}N = 636.6^{*}\ e^{-0.8028\ *\ pH}$, $R = -0.93$) from *Betula pendula* Roth forest [80]. Thus, denitrifying microorganisms may have been adapted extremely to acid soil environments, resulting in high N_2O emissions when soil acidification happened.

3. Sustainable forest management

Soil amelioration (e.g., application of lime, biochar nitrification inhibitors, and urease inhibitors) plays an important role in mitigation of soil acidification and N_2O emissions.

3.1 Lime

Lime as an ameliorant was often used to amend acid soils in southern China due to increasing soil pH. It can relieve the toxic effect of soil Al^{3+} on plant growth by reducing soil exchangeable H^+ [81]. Lime addition increased soil pH and salt saturation [82]. In addition, application of lime can reduce soil N_2O emissions [40]. For example, under 60% WFPS or flooded conditions, dolomite addition at medium- or high-dose levels (1 or 2 g kg^{-1} soil) can reduce N_2O emissions and increase the transcription of *nosZ* genes ($N_2O \rightarrow N_2$) by increasing acid soil pH from a rice-rapeseed

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rotation system [26]. However, lime addition reduced the content of soluble organic carbon in the soil layer 10–30 cm [83]. Consistently, long-term lime addition increased the soil pH but stimulated the decomposition of soil organic carbon [84].

3.2 Biochar

Biochar was stable in the soil from Amazon basin of Brazil, and biochar input improved soil fertility [85]. This discovery accelerated the development of technologies for biochar application in soil amelioration.

Biochar is a carbon (C)-rich solid material by pyrolyzing of organic biomass such as crop straw, forestry by-products, urban waste, industrial by-products, animal manure, and urban sludge at low oxygen and high temperature (250–700°C) condition [86]. Biochar has been characterized by a high pH, specific surface area, degree of aromatization, and porosity. In addition, biochar is rich in C-containing functional groups (e.g., C−H, C−O, C=C and C=O) and relatively stable organic C. The physicochemical properties of biochar were mainly determined by pyrolysis temperature [87].

Presently, biochar was widely used as a soil ameliorant in agriculture and forestry field. For example, our previous studies reported that *C. oleifera* fruit shells are ideal feedstock for producing biochar as they are rich in C and N [1, 88]. Biochar includes the following advantages:

1. Carbon recalcitrance of biochar can increase soil C pool. The potential of biochar in mitigation of greenhouse gas emissions was 1.0–1.8 Pg CO_2-C_{eq} yr^{-1} [89].

2. Biochar had excellent physicochemical characteristics in soil nutrient retention and utilization [90, 91] and water conservation [92]. Additionally, biochar can increase the plant resistance to Al^{3+} toxicity [81], the clone of arbuscular mycorrhizal fungi, and crop yield [93, 94]. It can decrease continuous cropping obstacles such as root-knot nematode [95] and *Ralstonia solanacearum* [96].

3. Biochar is rich in macro- and microelements [97], which can reduce the dosage of fertilizer.

3.2.1 Effects of biochar on soil nitrous oxide emissions

The physicochemical properties of biochar and soil can interactively influence soil N_2O emissions [98]. However, the effects of biochar on soil N_2O emissions varied, including positive effects [99], negative effects [100], and no effects [101].

Biochar addition increased soil N_2O emissions with the release of N from biochar [102]. By contrast, biochar reduced soil N_2O emissions with (1) increased NO_3^--N immobilization [103]; (2) increased copy numbers of *nos*Z gene [104, 105]; and (3) increased toxic effects of polycyclic aromatic hydrocarbons and other toxic substances (pyrolysis by-products) on N-cycle microorganisms [106].

3.2.2 Effects of biochar on soil pH buffer capacity

Biochar that increased soil pH buffer capacity may predominantly correlate with biochar riches in oxygen-containing functional groups in surface. The anions of weakly acidic functional groups can associate with H^+, hence increasing soil pH. Meanwhile, exchangeable base cations can release into the solution, thus increasing soil pH buffer capacity [107, 108]. In addition, soluble silicon (Si) such as $H_3SiO_4^-$ (present at a high pH) can combine with H^+ and generate H_2SiO_3 precipitation [107, 108].

3.3 Nitrification inhibitor

Nitrification inhibitors are a class of organic compounds that can inhibit the activity of nitrifying bacteria.

Nitrification inhibitors, especially synthetic nitrification inhibitors (e.g., dicyandiamide (DCD) and 3,4-dimethylpyrazole phosphate (DMPP)), were widely used in agriculture for improving N use efficiency. Ammonia-oxidizing bacteria and AOA are the major microbial communities in nitrification and denitrification, and both contain *amo* enzyme that can catalyze ammonia oxidation (NH_4^+-N → NH_2OH). Synthetic nitrification inhibitors such as DCD and DMPP mainly inhibit nitrification by suppressing the activity of *amo* enzyme (a Cu-copper cofactor enzyme). In addition, biological nitrification inhibitors also can inhibit soil nitrification [109, 110]. In the mid-1980s, researchers found that *Brachiaria humidicola* cv. Tully (CIAT 679), a single community forage, had lower nitrification rates than a single legume community or bare land [111]. This phenomenon stimulated further studies on biological nitrification inhibitors. The first biological nitrification inhibitor (methyl 3-(4-hydroxyphenyl) propionate: MHPP) was identified from the root exudate of *Sorghum bicolor* in 2008, which mainly inhibited the activity of *amo* enzyme [112]. Subsequently, biological nitrification inhibitor (brachialactone) from the root exudate of *Brachiaria humidicola* was found to inhibit the activity of *amo* enzyme [113]. The Nanjing Soil Research Institute of China firstly found and identified a biological nitrification, 1,9-decanediol, from the root exudate of rice, which can inhibit the activity of *amo* enzyme [114].

Ammonium N can be adsorbed by soil colloids, while soil NO_3^--N (the end product of nitrification) easily can be leached to groundwater by precipitation. In addition, microbial-mediated nitrification is closely related with soil N_2O emissions [20–22]. Nitrification inhibitors can effectively inhibit soil nitrification, slowing the transformation of NH_4^+-N to NO_3^--N and hence reducing the NO_3^--N leaching and N_2O emissions.

An evaluation from 62 field studies showed that although nitrification inhibitors increased 20% NH_3 emissions, they reduced 48% inorganic N leaching, 44% N_2O emissions, and 24% NO emissions and increased 58% plant N utilization, 9% grain yield, 5% straw yield, and 5% vegetable yield [115]. Consistently, other studies evaluated that nitrification inhibitors decreased by 38% [116], 50% [117], or 73% [118] N_2O emissions and decreased by 0.3 t CO_{2e} ha^{-1} yr^{-1} [119]. Similarly, DCD did not increase crop yields but reduced 35% N_2O emissions [120]. A meta-analysis showed that DCD rather than DMPP significantly increased 6.5% crop yield as well as DCD and DMPP decreased N_2O emissions by 44.7% and 47.6%, respectively [121].

Therefore, application of nitrification inhibitors could reduce N_2O emissions and mitigate environmental pollution after intensive N inputs.

3.4 Urease inhibitors

Urease inhibitors are a class of compounds that can slow soil urease activity (**Figure 2**). Addition of urease inhibitors after urea input can inhibit the hydrolysis

$$(NH_2)_2CO + 2H_2O \xrightarrow{Urease} (NH_4)_2CO_3 = NH_4^+ + NH_3\uparrow + CO_2\uparrow + OH^-$$

Figure 2.
The chemical equation of urea hydrolysis with urease catalysis.

of urea via inhibiting the activity of urease, hence reducing NH_3 volatilizations and N_2O emissions. Additionally, the application of urease inhibitors also contributes to increase N utilization efficiency and reduce NO_3^--N leaching. *N*-(*n-butyl*) thiophosphoric triamide (NBPT) is one of the most wide and effective urease inhibitors.

Urease, a Ni-copper enzyme, has two Ni—O bidentate ligands, specifically catalyzing urea into NH_3 and CO_2. Urea only can bind with one specific Ni—O ligand of urease, but NBPT can bind with two Ni—O bidentate ligands of urease and generate a tridentate ligand [122], hence inhibiting the activity of urease.

Presently, a meta-analysis reported that a nonlinear response was presented in soil NH_3 volatilizations and N input [123]. Application of NBPT can effectively inhibit NH_3 volatilizations. For example, 530 mg NBPT kg^{-1} urea treatment delayed NH_3 volatilizations and decreased accumulation of NH_3 volatilizations compared with the control treatment. NH_3 volatilizations were linearly related with the NBPT dosage in the range of 0–1000 mg NBPT kg^{-1} Urea (0, 530, 850, 1500, and 2000 mg NBPT kg^{-1} Urea) [124]. Other study reported that NBPT increased 27% oat yield and 33% crop N uptake [120].

The effects of NBPT on N_2O emissions were controversial. For example, NBPT can reduce 80% N_2O emissions [117]. No effects of NBPT (0.07%, NBPT/Urea-N, w/w) on N_2O emissions were observed [125]. Similarly, there was no change of N_2O emissions with NBPT (250 mg NBPT kg^{-1} Urea) addition from urea-fertilized (50 kg Urea-N ha^{-1}) soil [126].

Additionally, NBPT can reduce N_2O emissions from alkaline soils but has no effects on acidic soils [127], which indicated that pH plays a key role in the regulation of NBPT effects on N_2O emissions. Further laboratory study showed that NBPT inhibited nitrification, stimulating N_2O emissions from alkaline soils (pH 8.05) but not affecting N_2O emissions from acid soils (pH 4.85). This finding suggested that the effect of NBPT on soil N_2O emissions is not only influenced by pH but also by other unknown factors [127].

Generally, urease inhibitors correlated with nitrification inhibitor could mitigate N_2O emissions. A meta-analysis showed that urease inhibitors and nitrification inhibitors interactively reduced 30% N_2O emissions [116]. For example, a field study reported that the combination of NBPT (0.3%, NBPT/Urea-N, w/w) and DCD (0.3%, DCD/Urea-N, w/w) reduced 32.1% soil N_2O emissions with the addition of 519 kg Urea-N ha^{-1} from banana plantation, but did not affect the yield of banana [128].

4. Sustainable management in *Camellia oleifera* plantations

Our previous incubation study found that although biochar application increased N_2O emissions, DCD addition decreased soil N_2O emissions under urea fertilization from *C. oleifera* field [88]. Our field study showed that N_2O emission rates were inhibited by biochar or DCD application and the effects of biochar application on mitigation of cumulative N_2O were comparable to DCD addition in *C. oleifera* plantations [1]. Compared with control treatment, available N (NH_4^+-N and NO_3^--N) was not affected by NH_4NO_3, NH_4NO_3 + DCD, or NH_4NO_3 + biochar treatment [1]. In addition, the seed yield of *C. oleifera* was higher in NH_4NO_3 or NH_4NO_3 + biochar treatment than that in control or NH_4NO_3 + DCD treatment (**Figure 3**). Soil amelioration is necessary and improves N use efficiency and pH, mitigating N_2O emissions. Soil amelioration plays an important role in the sustainable management of oil safety in *C. oleifera* plantations.

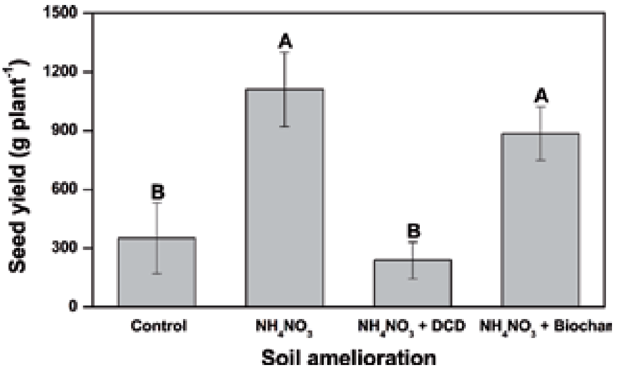

Figure 3.
The seed yield of Camellia oleifera *with nitrogen fertilization, in combination with nitrification inhibitor (DCD) or biochar. Bars connected by different letters indicate significant difference in post-hoc tests at* $\alpha = 0.05$ *(means ± se).*

5. Conclusions

Soil acidification, especially induced by N fertilization, will inhibit the activity of N_2O reductase and increase the abundance of N_2O-producing fungi as well as the acid resistance of N_2O-producing microorganisms, hence the ratio of $N_2O/(N_2O + N_2)$. In addition, NO_2^- will generate NO under soil pH < 5.5 condition, which will further transform into N_2O. Under the background of global acidification, the soil from *C. oleifera* forest also suffers the potential risks of soil acidification and N_2O emissions. Mitigation of soil acidification and N_2O emissions by soil amelioration is necessary and improves N use efficiency and soil pH from *C. oleifera* plantations. Soil amelioration such as biochar and nitrification inhibitor plays an important role in sustainable forest management in *C. oleifera* plantations.

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Conflict of interest

The authors declare no conflict of interest.

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References

[1] Deng B, Fang H, Jiang N, Feng W, Luo L, Wang J, et al. Biochar is comparable to dicyandiamide in the mitigation of nitrous oxide emissions from *Camellia oleifera* Abel. fields. Forests. 2019;**10**:1076. DOI: 10.3390/f10121076

[2] Yuan Z, Liu Y. The national conference on the development of *Camellia oleifera* industries was held in Jiangxi province [Internet]. 2019. Available from: http://www.jxly.gov.cn/id_402848b76e3b763f016e6cbad7e259c9/news.shtml [Accessed: 20 January 2020]

[3] Liu C, Chen L, Tang W, Peng S, Li M, Deng N, et al. Predicting potential distribution and evaluating suitable soil condition of oil tea *Camellia* in China. Forests. 2018;**9**:487. DOI: 10.3390/f9080487

[4] Dong B, Wu B, Hong W, Li X, Li Z, Xue L, et al. Transcriptome analysis of the tea oil camellia (*Camellia oleifera*) reveals candidate drought stress genes. PLoS ONE. 2017;**12**:e0181835. DOI: 10.1371/journal.pone.0181835

[5] Lee C, Yen G. Antioxidant activity and bioactive compounds of tea seed (*Camellia oleifera* Abel.) oil. Journal of Agricultural and Food Chemistry. 2006;**54**:779-784. DOI: 10.1021/jf052325a

[6] Ma J, Ye H, Rui Y, Chen G, Zhang N. Fatty acid composition of *Camellia oleifera* oil. Journal für Verbraucherschutz und Lebensmittelsicherheit. 2011;**6**:9-12. DOI: 10.1007/s00003-010-0581-3

[7] Liu J, Wu L, Chen D, Li M, Wei C. Soil quality assessment of different *Camellia oleifera* stands in mid-subtropical China. Applied Soil Ecology. 2017;**113**:29-35. DOI: 10.1016/j.apsoil.2017.01.010

[8] Martins MR, Sant Anna SAC, Zaman M, Santos RC, Monteiro RC, Alves BJR, et al. Strategies for the use of urease and nitrification inhibitors with urea: Impact on N_2O and NH_3 emissions, fertilizer-^{15}N recovery and maize yield in a tropical soil. Agriculture, Ecosystems & Environment. 2017;**247**:54-62. DOI: 10.1016/j.agee.2017.06.021

[9] Wang Y, Guo J, Vogt RD, Mulder J, Wang J, Zhang X. Soil pH as the chief modifier for regional nitrous oxide emissions: New evidence and implications for global estimates and mitigation. Global Change Biology. 2017;**24**:e617-e626. DOI: 10.1111/gcb.13966

[10] Ravishankara AR, Daniel JS, Portmann RW. Nitrous oxide (N_2O): The dominant ozone-depleting substance emitted in the 21st century. Science. 2009;**326**:123-125. DOI: 10.1126/science.1176985

[11] IPCC. Synthesis report, climate change 2014. In: Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change; Geneva, Switzerland. 2014. pp. 1-164

[12] WMO. WMO Greenhouse Gas Bulletin: The State of Greenhouse Gases in the Atmosphere Based on Global Observations through 2017. Geneva: Atmospheric Environment Research Division; 2018. pp. 1-8

[13] Fowler D, Coyle M, Skiba U, Sutton MA, Cape JN, Reis S, et al. The global nitrogen cycle in the twenty-first century. Philosophical Transactions of the Royal Society B: Biological Sciences. 2013;**368**:20130164. DOI: 10.1098/rstb.2013.0164

[14] Hu Y, Zhang L, Deng B, Liu Y, Liu Q, Zheng X, et al. The non-additive

effects of temperature and nitrogen deposition on CO_2 emissions, nitrification, and nitrogen mineralization in soils mixed with termite nests. Catena. 2017;**154**:12-20. DOI: 10.1016/j.catena.2017.02.014

[15] Deng B, Li Z, Zhang L, Ma Y, Li Z, Zhang W, et al. Increases in soil CO_2 and N_2O emissions with warming depend on plant species in restored alpine meadows of Wugong Mountain, China. Journal of Soils and Sediments. 2016;**16**:777-784. DOI: 10.1007/s11368-015-1307-z

[16] Jiang L, Zhang L, Deng B, Liu X, Yi H, Xiang H, et al. Alpine meadow restorations by non-dominant species increased soil nitrogen transformation rates but decreased their sensitivity to warming. Journal of Soils and Sediments. 2017;**17**:2329-2337. DOI: 10.1007/s11368-016-1488-0

[17] Wang S, Luo S, Li X, Yue S, Shen Y, Li S. Effect of split application of nitrogen on nitrous oxide emissions from plastic mulching maize in the semiarid Loess Plateau. Agriculture, Ecosystems & Environment. 2016;**220**:21-27. DOI: 10.1016/j.agee.2015.12.030

[18] Shcherbak I, Millar N, Robertson GP. Global meta-analysis of the nonlinear response of soil nitrous oxide (N_2O) emissions to fertilizer nitrogen. Proceedings of the National Academy of Sciences. 2014;**111**:9199-9204. DOI: 10.1073/pnas.1322434111

[19] Syakila A, Kroeze C. The global nitrous oxide budget revisited. Greenhouse Gas Measurement and Management. 2011;**1**:17-26. DOI: 10.3763/ghgmm.2010.0007

[20] Pauleta SR, Dell Acqua S, Moura I. Nitrous oxide reductase. Coordination Chemistry Reviews. 2013;**257**:332-349. DOI: 10.1016/j.ccr.2012.05.026

[21] Hu H, Chen D, He J. Microbial regulation of terrestrial nitrous oxide formation: Understanding the biological pathways for prediction of emission rates. FEMS Microbiology Reviews. 2015;**39**:729-749. DOI: 10.1093/femsre/fuv021

[22] Zhang L, Liu X. Nitrogen transformations associated with N_2O emissions in agricultural soils. In: Amanullah K, Alexander M, editors. Nitrogen in Agriculture. London: IntechOpen; 2017. pp. 17-31. DOI: 10.5772/intechopen.71922

[23] Butterbach-Bahl K, Baggs EM, Dannenmann M, Kiese R, Zechmeister-Boltenstern S. Nitrous oxide emissions from soils: How well do we understand the processes and their controls? Philosophical Transactions of the Royal Society B: Biological Sciences. 2013;**368**:20130122. DOI: 10.1098/rstb.2013.0122

[24] Oertel C, Matschullat J, Zurba K, Zimmermann F, Erasmi S. Greenhouse gas emissions from soils—A review. Geochemistry. 2016;**76**:327-352. DOI: 10.1016/j.chemer.2016.04.002

[25] Davidson EA, Keller M, Erickson HE, Verchot LV, Veldkamp E. Testing a conceptual model of soil emissions of nitrous and nitric oxides. BioScience. 2000;**50**:667-680. DOI: 10.1641/0006-3568(2000)050[0667,TACMOS]2.0.CO;2

[26] Shaaban M, Wu Y, Khalid MS, Peng Q, Xu X, Wu L, et al. Reduction in soil N_2O emissions by pH manipulation and enhanced *nosZ* gene transcription under different water regimes. Environmental Pollution. 2018;**235**:625-631. DOI: 10.1016/j.envpol.2017.12.066

[27] Cui Q, Song C, Wang X, Shi F, Yu X, Tan W. Effects of warming on N_2O fluxes in a boreal peatland of Permafrost region, Northeast China. Science of the Total Environment. 2018;**616-617**:427-434. DOI: 10.1016/j.scitotenv.2017.10.246

[28] Shi F, Chen H, Chen H, Wu Y, Wu N. The combined effects of warming and drying suppress CO_2 and N_2O emission rates in an alpine meadow of the eastern Tibetan Plateau. Ecological Research. 2012;**27**:725-733. DOI: 10.1007/s11284-012-0950-8

[29] Schaufler G, Kitzler B, Schindlbacher A, Skiba U, Sutton MA, Zechmeister-Boltenstern S. Greenhouse gas emissions from European soils under different land use: Effects of soil moisture and temperature. European Journal of Soil Science. 2010;**61**:683-696. DOI: 10.1111/j.1365-2389.2010.01277.x

[30] Lin S, Iqbal J, Hu R, Ruan L, Wu J, Zhao J, et al. Differences in nitrous oxide fluxes from red soil under different land uses in mid-subtropical China. Agriculture, Ecosystems & Environment. 2012;**146**:168-178. DOI: 10.1016/j.agee.2011.10.024

[31] Gong Y, Wu J, Vogt J, Le TB. Warming reduces the increase in N_2O emission under nitrogen fertilization in a boreal peatland. Science of the Total Environment. 2019;**664**:72-78. DOI: 10.1016/j.scitotenv.2019.02.012

[32] Hu Y, Chang X, Lin X, Wang Y, Wang S, Duan J, et al. Effects of warming and grazing on N_2O fluxes in an alpine meadow ecosystem on the Tibetan plateau. Soil Biology and Biochemistry. 2010;**42**:944-952. DOI: 10.1016/j.soilbio.2010.02.011

[33] Zhang J, Peng C, Zhu Q, Xue W, Shen Y, Yang Y, et al. Temperature sensitivity of soil carbon dioxide and nitrous oxide emissions in mountain forest and meadow ecosystems in China. Atmospheric Environment. 2016;**142**:340-350. DOI: 10.1016/j.atmosenv.2016.08.011

[34] Schindlbacher A. Effects of soil moisture and temperature on NO, NO_2, and N_2O emissions from European forest soils. Journal of Geophysical Research. 2004;**109**:1-12. DOI: 10.1029/2004JD004590

[35] Quick AM, Reeder WJ, Farrell TB, Tonina D, Feris KP, Benner SG. Nitrous oxide from streams and rivers: A review of primary biogeochemical pathways and environmental variables. Earth-Science Reviews. 2019;**191**:224-262. DOI: 10.1016/j.earscirev.2019.02.021

[36] Zhu X, Burger M, Doane TA, Horwath WR. Ammonia oxidation pathways and nitrifier denitrification are significant sources of N_2O and NO under low oxygen availability. Proceedings of the National Academy of Sciences. 2013;**110**:6328-6333. DOI: 10.1073/pnas.1219993110

[37] Burgin AJ, Groffman PM. Soil O_2 controls denitrification rates and N_2O yield in a riparian wetland. Journal of Geophysical Research: Biogeosciences. 2012;**117**:1-10. DOI: 10.1029/2011JG001799

[38] Levy-Booth DJ, Prescott CE, Grayston SJ. Microbial functional genes involved in nitrogen fixation, nitrification and denitrification in forest ecosystems. Soil Biology and Biochemistry. 2014;**75**:11-25. DOI: 10.1016/j.soilbio.2014.03.021

[39] Cuhel J, Simek M, Laughlin RJ, Bru D, Cheneby D, Watson CJ, et al. Insights into the effect of soil pH on N_2O and N_2 emissions and denitrifier community size and activity. Applied and Environmental Microbiology. 2010;**76**:1870-1878. DOI: 10.1128/AEM.02484-09

[40] McMillan AMS, Pal P, Phillips RL, Palmada T, Berben PH, Jha N, et al. Can pH amendments in grazed pastures help reduce N_2O emissions from denitrification? The effects of liming and urine addition on the completion of denitrification in fluvial and volcanic soils. Soil Biology and Biochemistry.

2016;**93**:90-104. DOI: 10.1016/j.soilbio.2015.10.013

[41] Pilegaard K, Skiba U, Ambus P, Beier C, Brüggemann N, Butterbach-Bahl K, et al. Factors controlling regional differences in forest soil emission of nitrogen oxides (NO and N_2O). Biogeosciences. 2006;**3**:651-661. DOI: 10.5194/bg-3-651-2006

[42] Blum J, Su Q, Ma Y, Valverde-Pérez B, Domingo-Félez C, Jensen MM, et al. The pH dependency of N-converting enzymatic processes, pathways and microbes: effect on net N_2O production. Environmental Microbiology. 2018;**20**:1623-1640. DOI: 10.1111/1462-2920.14063

[43] Zhang L, Hu H, Shen J, He J. Ammonia-oxidizing archaea have more important role than ammonia-oxidizing bacteria in ammonia oxidation of strongly acidic soils. The ISME Journal. 2012;**6**:1032-1045. DOI: 10.1038/ismej.2011.168

[44] Nicol GW, Leininger S, Schleper C, Prosser JI. The influence of soil pH on the diversity, abundance and transcriptional activity of ammonia oxidizing archaea and bacteria. Environmental Microbiology. 2008;**10**:2966-2978. DOI: 10.1111/j.1462-2920.2008.01701.x

[45] Erguder TH, Boon N, Wittebolle L, Marzorati M, Verstraete W. Environmental factors shaping the ecological niches of ammonia-oxidizing archaea. FEMS Microbiology Reviews. 2009;**33**:855-869. DOI: 10.1111/j.1574-6976.2009.00179.x

[46] von Uexküll HR, Mutert E. Global extent, development and economic impact of acid soils. Plant and Soil. 1995;**171**:1-15. DOI: 10.1007/BF00009558

[47] Li Q, Li S, Xiao Y, Zhao B, Wang C, Li B, et al. Soil acidification and its influencing factors in the purple hilly area of southwest China from 1981 to 2012. Catena. 2019;**175**:278-285. DOI: 10.1016/j.catena.2018.12.025

[48] Kochian LV, Piñeros MA, Liu J, Magalhaes JV. Plant adaptation to acid soils: The molecular basis for crop aluminum resistance. Annual Review of Plant Biology. 2015;**66**:571-598. DOI: 10.1146/annurev-arplant-043014-114822

[49] Guo JH, Liu XJ, Zhang Y, Shen JL, Han WX, Zhang WF, et al. Significant acidification in major Chinese croplands. Science. 2010;**327**:1008-1010. DOI: 10.1126/science.1182570

[50] Shu QL. Cultivation techniques of *Camellia oleifera*. Heifei: University of Science and Technology of China Press; 2013. pp. 1-201

[51] Zheng S, Bian H, Quan Q, Xu L, Chen Z, He N. Effect of nitrogen and acid deposition on soil respiration in a temperate forest in China. Geoderma. 2018;**329**:82-90. DOI: 10.1016/j.geoderma.2018.05.022

[52] Singh S, Tripathi DK, Singh S, Sharma S, Dubey NK, Chauhan DK, et al. Toxicity of aluminium on various levels of plant cells and organism: A review. Environmental and Experimental Botany. 2017;**137**:177-193. DOI: 10.1016/j.envexpbot.2017.01.005

[53] Matson PA, McDowell WH, Townsend AR, Vitousek PM. The globalization of N deposition: Ecosystem consequences in tropical environments. Biogeochemistry. 1999;**46**:67-83. DOI: 10.1023/A:1006152112852

[54] Delhaize E, Ryan PR, Randall PJ. Aluminum tolerance in wheat (*Triticum aestivum* L.) (II. Aluminum-stimulated excretion of malic acid from root apices). Plant Physiology. 1993;**103**: 695-702. DOI: 10.1104/pp.103.3.695

[55] Hue NV, Craddock GR, Adams F. Effect of organic acids on aluminum toxicity in subsoils. Soil Science Society of America Journal. 1986;**50**:28-34. DOI: 10.2136/sssaj1986.03615995005000010006x

[56] Zeng QL, Chen RF, Zhao XQ, Wang HY, Shen RF. Aluminium uptake and accumulation in the hyperaccumulator *Camellia Oleifera* Abel. Pedosphere. 2011;**21**:358-364. DOI: 10.1016/S1002-0160(11)60136-7

[57] Verstraeten G, Vancampenhout K, Desie E, De Schrijver A, Hlava J, Schelfhout S, et al. Tree species effects are amplified by clay content in acidic soils. Soil Biology and Biochemistry. 2018;**121**:43-49. DOI: 10.1016/j.soilbio.2018.02.021

[58] Kuypers MMM, Marchant HK, Kartal B. The microbial nitrogen-cycling network. Nature Reviews Microbiology. 2018;**16**:263-276. DOI: 10.1038/nrmicro.2018.9

[59] Matschonat G, Matzner E. Soil chemical properties affecting NH_4^+ sorption in forest soils. Journal of Plant Nutrition and Soil Science. 1996;**159**:505-511. DOI: 10.1002/jpln.1996.3581590514

[60] Kunhikrishnan A, Thangarajan R, Bolan NS, Xu Y, Mandal S, Gleeson DB, et al. Functional relationships of soil acidification, liming, and greenhouse gas flux. In: Sparks DL, editor. Advances in Agronomy. San Diego, USA: Academic Press; 2016. pp. 1-71. DOI: 10.1016/bs.agron.2016.05.001

[61] Yue K, Yang W, Peng Y, Zhang C, Huang C, Xu Z, et al. Dynamics of multiple metallic elements during foliar litter decomposition in an alpine forest river. Annals of Forest Science. 2016;**73**:547-557. DOI: 10.1007/s13595-016-0549-2

[62] Tian D, Niu S. A global analysis of soil acidification caused by nitrogen addition. Environmental Research Letters. 2015;**10**:24019. DOI: 10.1088/1748-9326/10/2/024019

[63] Cheng Y, Wang J, Zhang J, Müller C, Wang S. Mechanistic insights into the effects of N fertilizer application on N_2O-emission pathways in acidic soil of a tea plantation. Plant and Soil. 2015;**389**:45-57. DOI: 10.1007/s11104-014-2343-y

[64] Cai Z, Zhang J, Zhu T, Cheng Y. Stimulation of NO and N_2O emissions from soils by SO_2 deposition. Global Change Biology. 2012;**18**:2280-2291. DOI: 10.1111/j.1365-2486.2012.02688.x

[65] Cleemput O, Samater AH. Nitrite in soils: Accumulation and role in the formation of gaseous N compounds. Fertilizer Research. 1995;**45**:81-89. DOI: 10.1007/BF00749884

[66] De Boer W, Kowalchuk GA. Nitrification in acid soils: Micro-organisms and mechanisms. Soil Biology and Biochemistry. 2001;**33**:853-866. DOI: 10.1016/S0038-0717(00)00247-9

[67] Xiao H, Schaefer DA, Yang X. pH drives ammonia oxidizing bacteria rather than archaea thereby stimulate nitrification under *Ageratina adenophora* colonization. Soil Biology and Biochemistry. 2017;**114**:12-19. DOI: 10.1016/j.soilbio.2017.06.024

[68] Jiang X, Hou X, Zhou X, Xin X, Wright A, Jia Z. pH regulates key players of nitrification in paddy soils. Soil Biology and Biochemistry. 2015;**81**:9-16. DOI: 10.1016/j.soilbio.2014.10.025

[69] Rütting T, Huygens D, Boeckx P, Staelens J, Klemedtsson L. Increased fungal dominance in N_2O emission hotspots along a natural pH gradient in organic forest soil. Biology and Fertility of Soils. 2013;**49**:715-721. DOI: 10.1007/s00374-012-0762-6

[70] Chen H, Mothapo NV, Shi W. The significant contribution of

fungi to soil N_2O production across diverse ecosystems. Applied Soil Ecology. 2014;**73**:70-77. DOI: 10.1016/j.apsoil.2013.08.011

[71] Huang Y, Xiao X, Long X. Fungal denitrification contributes significantly to N_2O production in a highly acidic tea soil. Journal of Soils and Sediments. 2017;**17**:1599-1606. DOI: 10.1007/s11368-017-1655-y

[72] Bergaust L, Mao Y, Bakken LR, Frostegard A. Denitrification response patterns during the transition to anoxic respiration and posttranscriptional effects of suboptimal pH on nitrogen oxide reductase in *Paracoccus denitrificans*. Applied and Environmental Microbiology. 2010;**76**:6387-6396. DOI: 10.1128/AEM.00608-10

[73] Liu B, Mørkved PT, Frostegård Å, Bakken LR. Denitrification gene pool, transcription and kinetics of NO, N_2O and N_2 production as affected by soil pH. FEMS Microbiology Ecology. 2010;**3**:407-417. DOI: 10.1111/j.1574-6941.2010.00856.x

[74] Qu Z, Wang J, Almøy T, Bakken LR. Excessive use of nitrogen in Chinese agriculture results in high $N_2O/(N_2O + N_2)$ product ratio of denitrification, primarily due to acidification of the soils. Global Change Biology. 2014;**20**:1685-1698. DOI: 10.1111/gcb.12461

[75] Samad MS, Bakken LR, Nadeem S, Clough TJ, de Klein CAM, Richards KG, et al. High-resolution denitrification kinetics in pasture soils link N_2O emissions to pH, and denitrification to C mineralization. PLoS ONE. 2016;**11**:e0151713. DOI: 10.1371/journal.pone.0151713

[76] Simek M, Cooper JE. The influence of soil pH on denitrification: Progress towards the understanding of this interaction over the last 50 years. European Journal of Soil Science. 2002;**53**:345-354. DOI: 10.1046/j.1365-2389.2002.00461.x

[77] Raut N, Dörsch P, Sitaula BK, Bakken LR. Soil acidification by intensified crop production in South Asia results in higher $N_2O/(N_2 + N_2O)$ product ratios of denitrification. Soil Biology and Biochemistry. 2012;**55**:104-112. DOI: 10.1016/j.soilbio.2012.06.011

[78] Tokuda S, Hayatsu M. Nitrous oxide emission potential of 21 acidic tea field soils in Japan. Soil Science and Plant Nutrition. 2001;**47**:637-642. DOI: 10.1080/00380768.2001.10408427

[79] Huang Y, Long X, Chapman SJ, Yao H. Acidophilic denitrifiers dominate the N_2O production in a 100-year-old tea orchard soil. Environmental Science and Pollution Research. 2015;**22**:4173-4182. DOI: 10.1007/s11356-014-3653-6

[80] Weslien P, Kasimir Klemedtsson Å, Börjesson G, Klemedtsson L. Strong pH influence on N_2O and CH_4 fluxes from forested organic soils. European Journal of Soil Science. 2009;**60**:311-320. DOI: 10.1111/j.1365-2389.2009.01123.x

[81] Zhang K, Chen L, Li Y, Brookes PC, Xu JM, Luo Y. The effects of combinations of biochar, lime, and organic fertilizer on nitrification and nitrifiers. Biology and Fertility of Soils. 2017;**53**:77-87. DOI: 10.1007/s00374-016-1154-0

[82] Reid C, Watmough SA. Evaluating the effects of liming and wood-ash treatment on forest ecosystems through systematic meta-analysis. Canadian Journal of Forest Research. 2014;**44**:867-885. DOI: 10.1139/cjfr-2013-0488

[83] Wang X, Tang C, Baldock JA, Butterly CR, Gazey C. Long-term effect of lime application on the chemical composition of soil organic carbon in acid soils varying in texture and liming history. Biology and Fertility of

Soils. 2016;**52**:295-306. DOI: 10.1007/s00374-015-1076-2

[84] Aye NS, Butterly CR, Sale PWG, Tang C. Residue addition and liming history interactively enhance mineralization of native organic carbon in acid soils. Biology and Fertility of Soils. 2017;**53**:61-75. DOI: 10.1007/s00374-016-1156-y

[85] Sombroek WG. Amazon Soils: A Reconnaissance of the Soils of the Brazilian Amazon Region. Wageningen: Centre for Agricultural Publications and Documentation; 1966. pp. 1-292

[86] Johannes L, Stephen J. Biochar for Environmental Management. 2nd ed. New York, USA: Routledge; 2015. pp. 1-944

[87] Deng B, Shi Y, Zhang L, Fang H, Gao Y, Luo L, et al. Effects of spent mushroom substrate-derived biochar on soil CO_2 and N_2O emissions depend on pyrolysis temperature. Chemosphere. 2020;**246**:125608. DOI: 10.1016/j.chemosphere.2019.125608

[88] Deng B, Wang S, Xu X, Wang H, Hu D, Guo X, et al. Effects of biochar and dicyandiamide combination on nitrous oxide emissions from *Camellia oleifera* field soil. Environmental Science and Pollution Research. 2019;**26**:4070-4077. DOI: 10.1007/s11356-018-3900-3

[89] Woolf D, Amonette JE, Street-Perrott FA, Lehmann J, Joseph S. Sustainable biochar to mitigate global climate change. Nature Communications. 2010;**1**. DOI: 10.1038/ncomms1053

[90] Sun HJ, Lu HY, Chu L, Shao HB, Shi WM. Biochar applied with appropriate rates can reduce N leaching, keep N retention and not increase NH_3 volatilization in a coastal saline soil. Science of the Total Environment. 2017;**575**:820-825. DOI: 10.1016/j.scitotenv.2016.09.137

[91] Gul SM, Whalen JK. Biochemical cycling of nitrogen and phosphorus in biochar-amended soils. Soil Biology and Biochemistry. 2016;**103**:1-15. DOI: 10.1016/j.soilbio.2016.08.001

[92] Castellini M, Giglio L, Niedda M, Palumbo AD, Ventrella D. Impact of biochar addition on the physical and hydraulic properties of a clay soil. Soil and Tillage Research. 2015;**154**:1-13. DOI: 10.1016/j.still.2015.06.016

[93] Zhang AF, Liu YM, Pan GX, Hussain Q, Li LQ, Zheng JW, et al. Effect of biochar amendment on maize yield and greenhouse gas emissions from a soil organic carbon poor calcareous loamy soil from Central China Plain. Plant and Soil. 2012;**351**:263-275. DOI: 10.1007/s11104-011-0957-x

[94] Zhang AF, Bian RG, Pan GX, Cui LQ, Hussain Q, Li L, et al. Effects of biochar amendment on soil quality, crop yield and greenhouse gas emission in a Chinese rice paddy: A field study of 2 consecutive rice growing cycles. Field Crops Research. 2012;**127**:153-160. DOI: 10.1016/j.fcr.2011.11.020

[95] Huang W, Ji H, Gheysen G, Debode J, Kyndt T. Biochar-amended potting medium reduces the susceptibility of rice to root-knot nematode infections. BMC Plant Biology. 2015;**15**:267. DOI: 10.1186/s12870-015-0654-7

[96] Gu Y, Hou Y, Huang D, Hao Z, Wang X, Wei Z, et al. Application of biochar reduces *Ralstonia solanacearum* infection via effects on pathogen chemotaxis, swarming motility, and root exudate adsorption. Plant and Soil. 2017;**415**:269-281. DOI: 10.1007/s11104-016-3159-8

[97] Zhao Y, Zhao L, Mei Y, Li F, Cao X. Release of nutrients and heavy metals from biochar-amended soil under environmentally relevant conditions.

Environmental Science and Pollution Research. 2018;**25**:2517-2527. DOI: 10.1007/s11356-017-0668-9

[98] He Y, Zhou X, Jiang L, Li M, Du Z, Zhou G, et al. Effects of biochar application on soil greenhouse gas fluxes: A meta-analysis. GCB Bioenergy. 2017;**9**:743-755. DOI: 10.1111/gcbb.12376

[99] Deng B, Zheng L, Ma Y, Zhang L, Liu X, Zhang X, et al. Effects of mixing biochar on soil N_2O, CO_2, and CH_4 emissions after prescribed fire in alpine meadows of Wugong Mountain, China. Journal of Soils and Sediments. 2020. DOI: 10.1007/s11368-019-02552-8

[100] Case SDC, McNamara NP, Reay DS, Stott AW, Grant HK, Whitaker J. Biochar suppresses N_2O emissions while maintaining N availability in a sandy loam soil. Soil Biology and Biochemistry. 2015;**81**:178-185. DOI: 10.1016/j.soilbio.2014.11.012

[101] Case SDC, McNamara NP, Reay DS, Whitaker J. Can biochar reduce soil greenhouse gas emissions from a Miscanthus bioenergy crop? GCB Bioenergy. 2014;**6**:76-89. DOI: 10.1111/gcbb.12052

[102] Mukherjee A, Zimmerman AR. Organic carbon and nutrient release from a range of laboratory-produced biochars and biochar–soil mixtures. Geoderma. 2013;**193-194**:122-130. DOI: 10.1016/j.geoderma.2012.10.002

[103] Case SDC, McNamara NP, Reay DS, Whitaker J. The effect of biochar addition on N_2O and CO_2 emissions from a sandy loam soil—The role of soil aeration. Soil Biology and Biochemistry. 2012;**51**:125-134. DOI: 10.1016/j.soilbio.2012.03.017

[104] Tan G, Wang H, Xu N, Liu H, Zhai L. Biochar amendment with fertilizers increases peanut N uptake, alleviates soil N_2O emissions without affecting NH_3 volatilization in field experiments. Environmental Science and Pollution Research. 2018;**25**:8817-8826. DOI: 10.1007/s11356-017-1116-6

[105] Aamer M, Shaaban M, Hassan MU, Guoqin H, Ying L, Hai Ying T, et al. Biochar mitigates the N_2O emissions from acidic soil by increasing the *nosZ* and *nirK* gene abundance and soil pH. Journal of Environmental Management. 2020;**255**:109891. DOI: 10.1016/j.jenvman.2019.109891

[106] Hale SE, Lehmann J, Rutherford D, Zimmerman AR, Bachmann RT, Shitumbanuma V, et al. Quantifying the total and bioavailable polycyclic aromatic hydrocarbons and dioxins in biochars. Environmental Science & Technology. 2012;**46**:2830-2838. DOI: 10.1021/es203984k

[107] Shi RY, Hong ZN, Li JY, Jiang J, Baquy MA, Renkou X, et al. Mechanisms for increasing the pH buffering capacity of an acidic ultisol by crop residue derived biochars. Journal of Agricultural and Food Chemistry. 2017;**65**:8111-8119. DOI: 10.1021/acs.jafc.7b02266

[108] Dai Z, Zhang X, Tang C, Muhammad N, Wu J, Brookes PC, et al. Potential role of biochars in decreasing soil acidification—A critical review. Science of the Total Environment. 2017;**581-582**:601-611. DOI: 10.1016/j.scitotenv.2016.12.169

[109] Subbarao GV, Sahrawat KL, Nakahara K, Ishikawa T, Kishii M, Rao IM, et al. Biological nitrification inhibition—A novel strategy to regulate nitrification in agricultural systems. Advances in Agronomy. 2012;**114**:249-302. DOI: 10.1016/B978-0-12-394275-3.00001-8

[110] Coskun D, Britto DT, Shi W, Kronzucker HJ. Nitrogen transformations in modern agriculture and the role of biological nitrification inhibition. Nature Plants. 2017;**3**:17074. DOI: 10.1038/nplants.2017.74

[111] Sylvester-Bradley R, Mosquera D, Méndez JE. Inhibition of nitrate accumulation in tropical grassland soils: Effect of nitrogen fertilization and soil disturbance. Journal of Soil Science. 1988;**39**:407-416. DOI: 10.1111/j.1365-2389.1988.tb01226.x

[112] Zakir HA, Subbarao GV, Pearse SJ, Gopalakrishnan S, Ito O, Ishikawa T, et al. Detection, isolation and characterization of a root-exuded compound, methyl 3-(4-hydroxyphenyl) propionate, responsible for biological nitrification inhibition by sorghum (*Sorghum bicolor*). New Phytologist. 2008;**180**:442-451. DOI: 10.1111/j.1469-8137.2008.02576.x

[113] Subbarao GV, Nakahara K, Hurtado MP, Ono H, Moreta DE, Salcedo AF, et al. Evidence for biological nitrification inhibition in *Brachiaria* pastures. Proceedings of the National Academy of Sciences. 2009;**106**:17302-17307. DOI: 10.1073/pnas.0903694106

[114] Sun L, Lu Y, Yu F, Kronzucker HJ, Shi W. Biological nitrification inhibition by rice root exudates and its relationship with nitrogen-use efficiency. New Phytologist. 2016;**212**:646-656. DOI: 10.1111/nph.14057

[115] Qiao C, Liu L, Hu S, Compton JE, Greaver TL, Li Q. How inhibiting nitrification affects nitrogen cycle and reduces environmental impacts of anthropogenic nitrogen input. Global Change Biology. 2015;**21**:1249-1257. DOI: 10.1111/gcb.12802

[116] Thapa R, Chatterjee A, Awale R, McGranahan DA, Daigh A. Effect of enhanced efficiency fertilizers on nitrous oxide emissions and crop yields: A meta-analysis. Soil Science Society of America Journal. 2016;**80**:1121-1134. DOI: 10.2136/sssaj2016.06.0179

[117] Sanz-Cobena A, Lassaletta L, Aguilera E, Prado AD, Garnier J, Billen G, et al. Strategies for greenhouse gas emissions mitigation in Mediterranean agriculture: A review. Agriculture, Ecosystems & Environment. 2017;**238**:5-24. DOI: 10.1016/j.agee.2016.09.038

[118] Gu J, Nie H, Guo H, Xu H, Gunnathorn T. Nitrous oxide emissions from fruit orchards: A review. Atmospheric Environment. 2019;**201**:166-172. DOI: 10.1016/j.atmosenv.2018.12.046

[119] Rees RM, Baddeley JA, Bhogal A, Ball BC, Chadwick DR, Macleod M, et al. Nitrous oxide mitigation in UK agriculture. Soil Science and Plant Nutrition. 2013;**59**:3-15. DOI: 10.1080/00380768.2012.733869

[120] Hube S, Alfaro MA, Scheer C, Brunk C, Ramírez L, Rowlings D, et al. Effect of nitrification and urease inhibitors on nitrous oxide and methane emissions from an oat crop in a volcanic ash soil. Agriculture, Ecosystems & Environment. 2017;**238**:46-54. DOI: 10.1016/j.agee.2016.06.040

[121] Yang M, Fang YT, Sun D, Shi YL. Efficiency of two nitrification inhibitors (dicyandiamide and 3,4-dimethypyrazole phosphate) on soil nitrogen transformations and plant productivity: A meta-analysis. Scientific Reports. 2016;**6**:22075. DOI: 10.1038/srep22075

[122] Manunza B, Deiana S, Pintore M, Gessa C. The binding mechanism of urea, hydroxamic acid and *N-(N-butyl)-*phosphoric triamide to the urease active site. A comparative molecular dynamics study. Soil Biology and Biochemistry. 1999;**31**:789-796. DOI: 10.1016/S0038-0717(98)00155-2

[123] Jiang Y, Deng A, Bloszies S, Huang S, Zhang W. Nonlinear response of soil ammonia emissions to fertilizer nitrogen. Biology and Fertility of Soils. 2017;**53**:269-274. DOI: 10.1007/s00374-017-1175-3

[124] Mira AB, Cantarella H, Souza-Netto GJM, Moreira LA, Kamogawa MY, Otto R. Optimizing urease inhibitor usage to reduce ammonia emission following urea application over crop residues. Agriculture, Ecosystems & Environment. 2017;**248**:105-112. DOI: 10.1016/j.agee.2017.07.032

[125] Volpi I, Laville P, Bonari E, di Nasso NNO, Bosco S. Improving the management of mineral fertilizers for nitrous oxide mitigation: The effect of nitrogen fertilizer type, urease and nitrification inhibitors in two different textured soils. Geoderma. 2017;**307**:181-188. DOI: 10.1016/j.geoderma.2017.08.018

[126] van der Weerden TJ, Luo J, Di HJ, Podolyan A, Phillips RL, Saggar S, et al. Nitrous oxide emissions from urea fertiliser and effluent with and without inhibitors applied to pasture. Agriculture, Ecosystems & Environment. 2016;**219**:58-70. DOI: 10.1016/j.agee.2015.12.006

[127] Fan X, Yin C, Yan G, Cui P, Shen Q, Wang Q, et al. The contrasting effects of N-(*n*-butyl) thiophosphoric triamide (NBPT) on N_2O emissions in arable soils differing in pH are underlain by complex microbial mechanisms. Science of the Total Environment. 2018;**642**:155-167. DOI: 10.1016/j.scitotenv.2018.05.356

[128] Zhu T, Zhang J, Huang P, Suo L, Wang C, Ding W, et al. N_2O emissions from banana plantations in tropical China as affected by the application rates of urea and a urease/nitrification inhibitor. Biology and Fertility of Soils. 2015;**51**:673-683. DOI: 10.1007/s00374-015-1018-z

Chapter 2

Research Progress of Forest Land Nutrient Management in China

Zhi Li, Yanmei Wang, Xiaodong Geng, Qifei Cai and Xiaoyan Xue

Abstract

Forest land fertilization is a supplement and regulation method based on the regular pattern of forest physiological activity and nutrient demand, combined with the ability of soil to supply nutrient elements. We summarized the important achievements and influential events of forest land fertilization and nutrient management in modern times, and discussed the main problems of forest land fertilization at this stage. The main theories of comprehensive nutrition diagnosis method, formula fertilization method, site nutrient effect fertilization model, and ASI-based balanced fertilization method were analyzed. The main scientific research institutions, main tree species, and main research results of forest fertilization research are described. The development trend of the comprehensive nutrition diagnosis method, the combination of forest fertilization theory and environmental ecology principle, the combination of fertilization and forest oriented cultivation goal, the application of precise fertilization technology in forest land, the development of new forest specific fertilizer, the research of plant nutrition molecular genetics, the research of root state and rhizosphere microecosystem, the application of advanced technology and technology, and the development and application of new nonpollution fertilizer were discussed. It is an important research direction to apply the existing research results to forestry production and improve the quality.

Keywords: forest land fertilization, nutrient cycle, forest soil, nutrient management, new fertilizer

1. Introduction

Forest resource is one of the most important resources on earth and the basis of biodiversity. It can not only provide a variety of precious wood and raw materials for production and life but also provide a variety of food for human economic life. More importantly, it can regulate climate; conserve water and soil; prevent and mitigate natural disasters such as drought and flood, sandstorm, hail, etc.; purify air and eliminate noise; and other functions [1, 2]. With the growth of global population and some sudden natural risks, similar events such as the continuous spread of the current COVID-19, people are under the pressure of living space and means of life, which increases the demand for food and timber, and at the same time, the area of forests in many regions is sharply reduced, which requires more forest products to be produced in a short time, especially some economic forests, which require the same production cycle to get more output [3, 4].

At present, China's forestry industry is still in extensive development. Although the state has increased the investment in forestry industry in recent years, the overall quality of forestry industry needs to be improved, which is manifested in the strong singleness of forestry construction and the failure to form a good forestry ecosystem [5, 6]. In addition, in the utilization of forestry resources, the ability of fine finishing of products is not strong, and the technical content of forest products is low, which will inevitably affect the overall economic benefits of forestry and will be detrimental to the sustainable development of forestry industry [7].

Forest fertilization is a supplement and adjustment method based on the regular pattern of forest physiological activities and nutrient demand, combined with the ability of soil to supply nutrient elements [8]. It is also a forest management measure to improve soil fertility, improve forest nutrient status, and promote tree growth, so as to achieve high quality, high yield, high efficiency, and low cost. Some countries began to apply fertilizer to forest land before the Second World War, such as Europe, the United States, Japan, Australia, etc. Due to the rapid economic development after the War, the demand for wood is increasing, and the application of fertilizer measures in forest production is increasingly extensive [9, 10]. China's forestry fertilization research began in the late 1950s and then developed slowly until the 1970s. The fertilization area increased year by year [11]. Through the efforts of generations, people have made significant progress in plant nutrition physiology, nutrition diagnosis, fertilization technology, and fertilizer creation and made outstanding contributions to the protection of human food supply [12]. Forestry fertilization has also been recognized by most forestry producers in production, but up to now, the research on forest fertilization is still in the experimental stage. In addition, the lack of knowledge and technical experience leads to the phenomena of poor afforestation effect, slow growth of trees, high afforestation cost, and low yield [13]. In many developed countries, forest fertilization is regarded as an important means to build fast-growing artificial forest, and the yield-increasing effect of forestry fertilization is very significant [14].

Combined with relevant research results, we reviewed the landmark events and their impacts on forest land fertilization; analyzed the existing problems and put forward corresponding solutions; then looked forward to the future development direction of forest land fertilization, in order to provide basis for domestic and foreign forestry fertilization; and also provided reference for forestry management and fertilizer research.

2. Research progress of forest fertilization

After 1840, Leibig put forward the theory of plant mineral nutrition, which is widely accepted [15]. However, what elements are needed in the process of plant growth and development has become a research hotspot at that time. The essential nutrient elements for plant growth refer to the indispensable nutrient elements in the process of crop growth. If the essential nutrient elements lack, the plant cannot grow and develop normally, blossom, and bear fruit and will cause disease. At present, there are 17 kinds of essential nutrients for crops, which are carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), boron (B), molybdenum (Mo), nickel (Ni), and chlorine (Cl) (**Figure 1**). According to the demand of crops for various elements, 17 elements are divided into a large number of elements (C, H, O, N, P, K), medium elements (Ca, Mg, S), and trace elements (Fe, Mn, Cu, Zn, B, Mo, Ni, Cl). They are equally important in the growth process of plants and irreplaceable. In addition, there are also some nutritional elements called beneficial elements; although these elements are not necessary for plant growth, they have certain nutritional effects on plants, such as cobalt (C_O), which is necessary for nitrogen fixation of legume rhizobia, so it has a good impact on legume growth. Sodium (Na), silicon (Si), iodine (I), selenium (Se), strontium (Sr), and vanadium (V) are also beneficial elements.

France is the first country to carry out the experiment of forest land fertilization. In 1847, French scientists applied fertilizer to forest land with plant ash, ammonium salt, and slag, which increased the growth of trees by 17–26% [16]. In the middle nineteenth century, German scientists found that harvesting dead branches and leaves from forest land would lead to a sharp decline in forest productivity and began some early fertilization experiments [17, 18]. Some other countries in Europe have also carried out afforestation and fertilization experiments and achieved results, but due to the slow effect of forest fertilization, the research process is relatively slow [19, 20]. Forest land fertilization did not enter the practical stage until the 1950s. With the reduction of forest resources, global economic recovery, and the development of fertilizer industry, forest land fertilization-related scientific research and production applications have been developed rapidly [21]. In 1973, the Food and Agriculture Organization of the United Nations (FAO) and the International Union of Forest Research Organizations (IUFRO) held an International Symposium on forest fertilization in Paris, with a wide range of research contents. After that, the research on forest fertilization has become more and more comprehensive and in-depth in the world, which has changed from a single direction to a multi-level and multi-functional comprehensive research. Some countries have carried out long-term

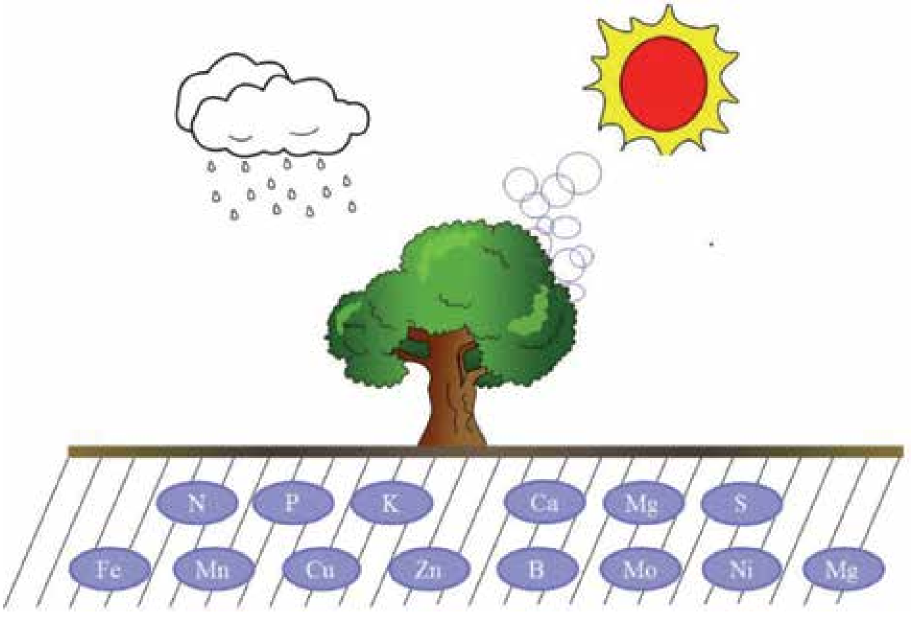

Figure 1.
Nutrient elements for plant growth. Drawing: Zhi Li.

positioning observation on forest fertilization in combination with the research on forest ecosystem [22].

In the 1950s, China began to carry out forest fertilization experiments and small-scale productive fertilization and then gradually developed from economic forest to timber forest [23]. At the national forest fertilization conference held in 1985, there are many species studied, such as *Cunninghamia lanceolata* (Lamb.) Hook, *Phyllostachys edulis* (Carrière) J.Houz, *Vernicia fordii* (Hemsl.) Airy Shaw, *Camellia oleifera* Abel., *Juglans regia* L., *Populus tomentosa* Carrière, *Eucalyptus robusta* Smith, etc. The main research contents covered the effects of different fertilizers, different amounts and proportions on the growth and yield of forest trees; the control of forest diseases through fertilization; the application of isotope tracer technology; the diagnosis of forest nutrition, etc. Until at the end of the twentieth century, the cultivation direction of short-term timber forest was defined, and the special topic of "Research on fertilization technology and measures for maintaining soil fertility of main industrial timber forest" was set up. In 1995, a seminar on forest fertilization and nutrition was held in Beijing. The results of the research were exchanged among the seedlings and young forests of *Cunninghamia lanceolate*, *Ziziphus jujuba* Mill. var. *spinosa* (Bunge) Hu ex H. F. Chow, *Eucalyptus robusta*, *Populus*, *Pinus elliptic*, *Pinus caribaea* Morelet, and the middle-aged and mature forests of some species (*Pinus massoniana* Lamb.). Based on the theory of forest site productivity and nutrient productivity, the model of site nutrient effect fertilization was discussed systematically [24]. Up to now, a set of mature technology of nutrition diagnosis and fertilization has been formed in China's agriculture. However, due to the long cycle of forestry production, the single function of fertilizer, and the short duration of fertilizer effect, the utilization ratio of forest trees to fertilizer is relatively low, and some even pollute the environment. Therefore, the research and promotion of forest-specific fertilizer can improve the nutritional status of trees and promote the growth of trees, which is an important direction of fertilizer research in the new century [25].

Looking at the development of forest fertilization experiment in China, it can be seen that the main research object of fertilization effect at this stage is mostly the young forest period of forest trees, usually using the conventional method of agricultural fertilization, lacking systematic technology, and theoretical support system, so there is a big controversy. Because the growth cycle of forest is long, the natural environment factors of forest are complex, and the amount of fertilization is difficult to control. However, the implementation of large-scale organization is more difficult, which often results in the phenomenon of excessive or insufficient amount of fertilization. Therefore, it is necessary for researchers to conduct in-depth study on the methods and theories of forest fertilization. With the rapid development of modern economy and the continuous improvement of forest intensification, China needs to vigorously carry out in-depth research on forest fertilization technology, strive to develop forest modernization and intensification, create an efficient and high-quality ecological environment, and realize the sustainable development of forestry.

3. Main theories and methods of forest fertilization research in China

The purpose of fertilization is to improve the nutritional status of trees, promote the growth of trees, and increase the unit yield. At the same time, through fertilization, the forest soil status is improved and the soil fertility is improved. Over the years, forestry researchers have studied fertilization technology in the aspects of fertilizer selection, amount and time, and gained valuable experience and achievements.

Comprehensive nutrition diagnosis and steady-state nutrition method are based on plant nutrition mechanism. Forest nutrition diagnosis is a technology to study the correlation and influence between forest nutrition and various nutrients held by forest soil. It is a method to predict, judge, and evaluate fertilization effect [26].

Formula fertilization method is based on field experiment, soil classification, and pre-production ration. According to the regular pattern of plant fertilizer demand, soil fertilizer supply capacity and fertilizer efficiency, the researchers put forward the proportion scheme of microelements and microelements and the corresponding fertilization technology [27]. The main methods are soil fertility grading ratio method, nutrient balance quantitative method, soil fertility difference subtraction method, nutrient abundance and deficiency index method, field experiment proportion method, yield determination by soil, nitrogen determination by yield, fertilizer supplement method due to lack of elements, etc. Before using these methods, there should be a large number of information data about the characteristics of crop fertilizer demand, soil fertilizer supply capacity, fertilizer effect, and so on. In the process of using these methods, we should closely combine the high-yield and high-quality cultivation techniques such as irrigation, cultivation, soil improvement, and soil and water conservation.

Based on the theory of forest environmental productivity and nutrient productivity, a fertilization model of environmental nutrient effect was established [28]. Different from the conventional methods of forest fertilization experiment, the formula fertilization model of forest site nutrient effect is used to determine the necessity of forest land fertilization, the dynamic and static relationship between forest growth and nutrient absorption, the curve of soil nutrient capacity and intensity, and the target benefit equation through the measurement of site and nutrient effect parameters and correlation coefficient. Based on this set of curves and equations, the optimal target yield increase, the increment of effective nutrients required for reaching the target, the corresponding amount and formula of fertilizer application, and the optimal period and method of fertilizer application are determined. It is widely applicable, not limited by the region and the growth stage of trees, and has high accuracy and popularization value in application.

There is also a forest nutrient diagnosis balanced fertilization method, also known as ASI method (the method recommended by the Agro Services International Inc., ASI for short) [29]. It is mainly aimed at the soil conditions in different regions, the fertilizer demand characteristics of different tree species, and the research contents of formula fertilization and balanced fertilization technology. A variety of special compound fertilizers rich in N, P, K, Zn, Fe, Mn, B, and other large, medium, and microelements, organic matter, and humus have been developed. Now, they are mostly used in economic tree species.

At present, the development and application of various compound fertilizers have fundamentally solved and met the needs of fertilization for fast-growing and high-yield forests and economic forests in forestry and made forestry fertilization develop from simple fertilizer, formula fertilizer, to organic multiple special fertilizer to high-tech direction.

4. Main units and species of forest fertilization research in China

According to the reality of China's economic reform and forestry practice, many scientific research institutions and forestry workers in China have done a lot of relevant research and put forward the forestry development theory and practice results of fertilization for different forest management processes. These theories have played a positive role in guiding China's forestry development, such as:

Beijing Forestry University has carried out researches on *Populus* [30], *Castanea mollissima* BL. [31], *Larix gmelinii* (Rupr.) Kuzen. [32], and *Acacia mearnsii* De Will [33]; Nanjing Forestry University has carried out researches on *Populus* [34], *Carya illinoinensis* (Wangenh.) K. Koch [27], *Ginkgo biloba* L. [35], and *Cyclocarya paliurus* (Batal.) Iljinsk. [36]; Northeast Forestry University has carried out researches on *Larix gmelinii* [37], *Fraxinus mandshurica* Rupr. [38], and *Betula platyphylla* Suk. [39]; Northwest Agricultural and Forestry University has carried out researches on *Malus domestica* "Changfu-2" [40], *Ziziphus jujuba* [41], etc.; Hebei Agricultural University has carried out researches on *Juglans regia* [42], *Castanea mollissima* [43], *Malus domestica* Borkh.CV.Red Fuji [44], and others; Central South University of Forestry and Technology has carried out research on *Camellia oleifera* [45], *Vernicia fordii* [46], *Pyrus pyrifolia* "Whangkeumbae" [47], *Cunninghamia lanceolate* [48], *Phyllostachys edulis* [49], etc.; Zhejiang Agriculture and Forestry University has carried out research on *Phyllostachys praecox* C. D. Chu et C. S. Chao "Prevernalis" [50], *Phyllostachys edulis* [51], *Castanea mollissima* [52], *Carya cathayensis* Sarg. [53], *Torreya grandis* Fort.et lindl [54], etc.; Fujian Agriculture and Forestry University has carried out research on *Cunninghamia lanceolata* [55], *Castanea henryi* (Skan) Rehd. et Wils. [56], etc.; Chinese Academy of Forestry has been carried out research on *Populus* [57], *Castanea mollissima* [58], *Paulownia* Sieb.et Zucc. [59], etc.; and Jiangxi Agricultural University has carried out research on *Camellia oleifera* [60], *Phyllostachys edulis* [61], *Eucalyptus robusta* [62], *Cinnamomum camphora* var. *linaloolifera* Fujita [63], *Evodia rutaecarpa* (Juss.) Benth. [64], etc.

Take the research of Jiangxi Agricultural University that I studied as an example. The College of Forestry in Jiangxi Agricultural University is at the forefront

Figure 2.
The College of Forestry, Jiangxi agricultural university, has developed the special fertilizer for Camellia oleifera *to guide the precise fertilization and intensive nutrient management. Photo: Zhi Li. Notes: (A) special formula fertilizer for* Camellia oleifera*. (B) Special fertilizer for organic and inorganic oil tea. (C) the* Camellia oleifera *forest land. (D) Farmers apply special fertilizer for* Camellia oleifera*.*

of the country in terms of high-yield and intensive management measures and balanced fertilization technology of *Camellia oleifera*, and its achievements have reached the international leading level. It has developed the special fertilizer for *Camellia oleifera*, which ensures the high-quality and high-yield of *Camellia oleifera.* It is used to guide the precise fertilization and intensive management of *Camellia oleifera*, and realize the sustainable management of *Camellia oleifera* forest (**Figure 2**) [65].

In recent years, the forest fertilization research team of Jiangxi Agricultural University has also carried out research on balanced fertilization technology and formula of *Eucalyptus robusta*, *Evodia rutaecarpa*, *Ziziphus jujuba*, *Cunninghamia lanceolata*, and other tree species, meeting the needs of Jiangxi forestry production [66]. The vegetation restoration of rare earth mines in South Jiangxi relies on good nutrient management technology, which makes afforestation of barren wasteland successful [67]. The related research results include: (1) establishing the indicators of soil nutrient abundance and deficiency and leaf nutrient diagnosis (critical value) of economic forest species such as *Phyllostachys edulis* (**Figure 3**), *Camellia oleifera*, *Eucalyptus robusta* (**Figure 4**), and *Evodia rutaecarpa*, which provide the basis and scientific basis for the diagnosis and balanced fertilization of main economic forest species in Jiangxi Province; (2) based on this, the balanced fertilization formula for *Phyllostachys edulis* and *Camellia oleifera*, in Jiangxi Province, was formulated, and special fertilizers for *Phyllostachys edulis* and *Camellia oleifera* were developed; (3) the spatial heterogeneity of soil nutrients in *Phyllostachys edulis* and *Camellia oleifera* plantation was studied, which provided scientific

Figure 3.
The College of Forestry, Jiangxi agricultural university, has developed the special fertilizer for Phyllostachys edulis *to guide the reconstruction after freezing disaster, precision fertilization, and intensive nutrient management. Photo: Zhi Li. Notes: (A) the* Phyllostachys edulis *forest suffered from freezing disaster; (B) the special formula fertilizer for* Phyllostachys edulis*; (C) Farmers apply special fertilizer for* Phyllostachys edulis*; and (D) after precision fertilization and intensive nutrient management, the growth of* Phyllostachys edulis *forest was exuberant.*

Figure 4.
Vegetation restoration and afforestation with nutrient management technology in rare earth mines in South Jiangxi Province, China. Photo: Zhi Li. Notes: (A and B) Rare earth tailings are barren. (C and D) Successful afforestation through nutrient management technology.

Figure 5.
Soil nutrient management and vegetation restoration in the subtropical mountain meadow of Wugong Mountain, Jiangxi Province, China. Photo: Zhi Li. Notes: (A and B) Seriously degraded Wugong Mountain meadow. (C and D) Our researchers are doing vegetation restoration experiments.

basis for precise fertilization; (4) using artificial neural network to predict the DBH of *Phyllostachys edulis* forest, the average simulation accuracy is 93.13%; (5) a computer nutrient management information system for balanced fertilization of *Phyllostachys edulis* in a small area has been developed, which provides an advanced technology and decision-making platform for large-scale balanced fertilization and sustainable management of *Phyllostachys edulis*; (6) the coupling technology of water and fertilizer was studied to improve the yield and quality of *Camellia oleifera*; and (7) studies on nutrition and physiological/mechanism of tree growth and development.

In addition, the researchers of Jiangxi Agricultural University have carried out systematic research on soil nutrient management of subtropical mountain meadow [68–71] (**Figure 5**) and obtained a series of scientific research results [72–75], providing a good scientific guidance for the protection and degradation restoration of mountain meadow which was a special ecosystem element [76–78].

5. Characteristics and difficulties of fertilization in forest land

Forest land soil is the soil under forest cover, which is one of the organic components of forest ecosystem. Compared with conventional farmland and other uses of soil, forest land soil has special characteristics because of the impact of forest litter, woody plant root group, forest biological community, and special environmental conditions of forest ecosystem.

5.1 Characteristics of forest fertilizer demand

The regular pattern and absorptive capacity of forest trees are obviously different from that of most crops, with deep root, large root range, and low nutrition demand; most trees are perennial, immobile, and non-intercropped, with long-term and continuous nutrient supply; the growth cycle of general trees is long, with complex influencing factors and difficult nutrition diagnosis; moreover, the growth and development law of different trees is different [79].

5.2 Fertilization requirements for forest land

The fertilization in forest land is mainly based on base fertilizer, supplemented by top dressing; the spacing between plants and rows is large, and hole fertilization is often used, so it is difficult to apply fertilizer in mountainous area, and the times of fertilization are not many; the time, method, and amount of fertilization vary according to the characteristics of tree species [25].

5.3 Difficulties in forest land fertilization

The spatial heterogeneity of forest land nutrients is large, and the difficulty of nutrient diagnosis is large. The growth cycle of forest trees is long, the effect is slow, and the short-term fertilizer effect is not necessarily obvious. The spacing between trees and rows is large; there are many weeds in the forest, which need to be applied in caves; and the workload is large. The trees grow in mountainous areas, but the transportation conditions in mountainous areas are poor, so the cost of fertilization is high. The research on forest fertilization is also relatively late, and the nutrient characteristics of most trees are unknown. The method of fertilization is still in its infancy; at present, there are few special fertilizers for trees in the market [80].

6. Development trend of forest land fertilization

The main direction of forest land nutrient management and fertilizer research is still to improve the utilization efficiency of forest nutrient elements and reduce the environmental pollution caused by nutrient elements or some non-nutrient elements brought in by fertilization [81]. According to the needs of the industry, the targeted cultivation and intensive management of trees will be carried out to realize the fertilization of trees (specialization, long-term, and precision), so as to achieve the development goal of high yield, high quality, and efficiency, taking into account the ecological benefits of the environment and the overall social benefits [82].

At present and in the future, the development mode of forest land fertilization includes using the comprehensive nutrition diagnosis method, combining with the principle of site productivity, improving the accuracy and comparability of analysis, revealing the law of forest nutrition balance, detecting the mechanism of nutrient absorption and utilization, and determining the relationship between the growth and absorption of different growth stages of plants and the rate of soil fertilizer supply [83]. Combining the theory of forest fertilization with the principle of environmental ecology, we can improve the productivity of forest land and keep the human ecological environment in harmony [84, 85]. Fertilization should be combined with the goal of forest-oriented cultivation. As a basic technical measure of forest cultivation, fertilization should be classified under different cultivation goals, and its research results should also be carried out in production according to the cultivation goal [86]. The application of forest land precision fertilization technology and the application of forest nutrition management information system supported by 3S technology in forest land fertilization will achieve precision fertilization for different tree species, different soil, and different development stages and improve fertilizer utilization rate [87]. In view of the long-term nature of the absorption of nutrient elements by trees and in order to meet the demand of large-scale operational fertilization in mountain forest areas, the development of new forest-specific fertilizer will gradually develop to high concentration, slow effect, and special compound fertilizer [88]. In the study of plant nutrition molecular genetics, while improving the fertilization methods, we should focus on the research and cultivation of good varieties to adapt to the specific soil environment, so as to realize the transformation from suitable trees to suitable varieties [89]. The research frontier of root state and rhizosphere micro ecosystem is to explore the dynamics of soil root interface nutrients and their environment, so as to clarify the biological effectiveness of soil nutrients [90]. The application of high-tech technology, such as atomic absorption spectrometer, electron probe, and various automatic analyzers, provides necessary conditions for diagnosis and fertilization [91]. In forest is a very important factor in the formation of water source of rivers and lakes. The safety of fertilizer application in forest land is closely related to the safety of water body, so the research and application of new nonpollution fertilizer is particularly important [92].

7. Conclusion

As an important green raw material, trees are favored under the great development of ecological construction. In recent years, China's demand for wood is growing day by day. The cultivation of artificial forest, timber forest, and the construction of industrial raw material forest have been greatly supported by policies and funds. With the rapid development of plantation and the continuous improvement of its area, it still faces the problems of insufficient total amount of forest resources and poor quality. However, for a long time, the utilization rate of fertilizer in China is low, which has caused great economic losses and also brought great impact on the environment. Research and development of new fertilizer can effectively solve the above problems. Although there are still some problems in the manufacturing process of new fertilizer, due to its outstanding advantages, it will usher in greater development in the near future.

The research of forest land fertilization is developing rapidly, and rational fertilization has become an important technical measure to cultivate short rotation industrial timber forest and accelerate economic forest benefits. At the same time, many forestry workers realize that the simple fertilization cannot achieve the expected effect on greatly improving the growth of trees. In addition to some technical problems that limit the fertilizer effect to a certain extent, how to reasonably apply fertilizer according to the water status of forest land is the key to the problem. It needs to be especially pointed out that at present, most of the research on water and fertilizer balance is in agricultural production and has made great achievements, while the research on water and fertilizer balance in forestry is still in its infancy. Therefore, how to apply the existing research results to the forestry production and speed up the solution to the backward situation of China's forestry production should be one of the future research topics for forestry workers.

In addition, nutrient management in forest ecosystems should consider the ecological effects of fertilization under the context of global climate change, considering the potential interactions among global change factors [93, 94], nutrient input [95], and internal element cycling within forest ecosystems [96–101]. For example, in plantations experiencing intensive management, N input may induce more N leaching due to excessive application, especially in areas characterized by acid soils [101, 102]. To prevent such N loss from soil to happen, soil amelioration should be employed to decrease N leaching via runoffs, trace gas emissions, or volatilization [102, 103], increasing the fertilization efficiency of agricultural practice [101, 102]. Presently, biochar has been widely used in soil amelioration or mitigation of soil trace gas (especially those containing N) [103, 104]. Thereby, future fertilization practice could be combined with soil amelioration strategies to obtain efficient fertilization practice and nutrient management in forest or plantation soils [103, 104].

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Conflict of interest

The authors declare no conflict of interest.

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References

[1] Deng C et al. Functional monitoring and evaluation of forest air quality improvement. Journal of Ecological Environment. 2015;**24**(1):84-89

[2] Li Z et al. Soil and water conservation effects driven by the implementation of ecological restoration projects: Evidence from the red soil hilly region of China in the last three decades. Journal of Cleaner Production. 2020;**260**:121109

[3] Cao G et al. Effect of balanced fertilization on growth and quality of *Pyrus Pyrifolia* 'Whangkeumbae' in desert area. Journal of Applied Ecology. 2018;**29**(8):2477-2484

[4] Chen P et al. Study on soil nutrient capacity and forest sustainability in plateau karst. Earth and Environment. 2017;**45**(1):32-37

[5] Shinjini G et al. Phosphorus limitation of aboveground production in northern hardwood forests. Ecology. 2018;**99**(2):438-499

[6] Aljosa Z et al. Forest soil phosphorus resources and fertilization affect ectomycorrhizal community composition, beech P uptake efficiency, and photosynthesis. Frontiers in Plant Science. 2018;**9**:1-13

[7] Yang C-D. The decrease of soil organic matter content and quality of plantation in China is the key factor to restrict the growth of forest trees. Forestry Sciences. 2016;**52**(12):1-12

[8] Bai Y-L. Thinking on some problems of fertilizer development in China. China Agricultural Information. 2014;**22**:5-9

[9] Burg J. Results and experiences from fertilization experiments in the Netherlands. Fertilizer Research. 1991;**27**(1):107-111

[10] Chunichiro B. Fertilization technology of forest land in Japan. Fujian Forestry Science and Technology. 1993;**20**(3):47-51

[11] Guo X-M et al. Forest land fertilization and efficient forestry. Jiangxi Forestry Science and Technology. 1998;**5**:31-34

[12] Guo X-M et al. Regression analysis of leaf nutrition, soil fertility and yield of *Phyllostachys edulis* (Carrière) J.Houz. forest by balanced fertilization. Forestry Sciences. 2007;**43**(S1):53-57

[13] Wang Z-H. Research process and effect analysis of forest fertilization. Shanxi Forestry. 2015;**3**:27-28

[14] Liao L-P. Study on nutrient internal circulation of foreign trees. Journal of Ecology. 1994;**13**(6):34-38

[15] Li W-B. General situation of forest land fertilization development at home and abroad. Tropical Crop Research. 1995;**4**:37-40

[16] Li Y-Q. Forest fertilization and nutrition diagnosis. Forestry Sciences. 1991;**27**(4):435-442

[17] Evers F. Forest fertilization—Present state and history with special reference to south German conditions. Fertilizer Research. 1991;**27**(1):71-86

[18] Matzner E et al. Effects of liming and fertilization on soil solution chemistry in north German forest ecosystems. Water, Air, and Soil Pollution. 1990;**54**(3):377-389

[19] Liu Y-S. Research progress of forest fertilization in the Netherlands. Shaanxi Forestry Science and Technology. 1993;**2**:58-59

[20] Hiittl RF et al. Forest fertilization effect in the countries of Germany,

France and Nordic. Guangxi Forestry Science and Technology. 1988;**4**:33-39

[21] Zuo H-J et al. Review of forest nutrition diagnosis and forest land fertilization. Journal of Southwest Forestry University. 2010;**30**(6):78-82

[22] Chen W et al. Review on the research progress of fertilization in artificial forest. Guangdong Forestry Science and Technology. 2004;**20**(1):61-66

[23] Liu S-P et al. Theory and practice of forest land fertilization. Advances in Soil Sciences. 1987;**4**:1-8

[24] Liu H-Q. Review of forest fertilization research. Anhui Agronomy Bulletin. 2010;**16**(10):139-141

[25] Guan Y-X et al. Research progress and prospect of forest nutrient properties. Journal of Northwest Agricultural and Forestry University (Natural Science Edition). 2006;**34**(1):51-55

[26] Ding X-G et al. Research progress of forest nutrition diagnosis and fertilization. Guangdong Forestry Science and Technology. 2010;**26**(4):66-71

[27] Zheng X-Q et al. Effect of formula fertilization on nutrient content and photosynthesis of *Carya cathayensis* seedlings. Journal of Nanjing Forestry University (Natural Science Edition). 2019;**43**(5):169-174

[28] Wu X-F et al. Study on the dynamic model of tree growth and nutrition—Site nutrient effect formula fertilization model. Journal of Central South Forestry College. 2002;**22**(3):1-8

[29] Yang L-P et al. Study on the correlation between ASI method and conventional chemical methods in China. Soils Bulletin. 2000;**31**(6):277-279

[30] Liu F et al. Effects of water and fertilizer coupling on soil nitrogen, fine root distribution and biomass of *Populus tomentosa* stand. Journal of Beijing Forestry University. 2020;**42**(1):75-83

[31] Sun H-J et al. Effects of pruning and nitrogen application on photosynthetic characteristics and yield of *Castanea mollissima* trees. Journal of Northeast Forestry University. 2017;**45**(9):40-44

[32] Song X-H et al. Effect of fertilization by bottom infiltration on growth and nutrient status of container seedlings of *Larix principis rupprechtii*. Journal of Northeast Forestry University. 2017;**45**(9):1-4

[33] Sun Y-Y et al. Adaptability of introduced *Acacia mearnsii* from South Africa and its effect of fertilizer. Journal of Anhui Agricultural University. 2010;**37**(1):131-134

[34] Xu J et al. Effect of biochar application on soil physical and chemical properties and enzyme activity of *Poplar* plantation in Dongtai coastal area. Journal of Fujian Agricultural and Forestry University (Natural Science Edition). 2020;**49**(3):348-353

[35] Guo J et al. Effects of fertilization on photosynthesis and nutrient content of *Ginkgo biloba* leaves. Journal of Zhejiang Agricultural and Forestry University. 2016;**33**(6):969-975

[36] Yue X-L et al. Effect of nitrogen level on the content of main secondary metabolites and antioxidant capacity of *Cyclocarya paliurus* leaves. Journal of Nanjing Forestry University (Natural Science Edition). 2020;**44**(2):35-42

[37] Tang Y-K et al. Effect of nitrogen and phosphorus fertilization on nonstructural carbon concentration of *Larix gmelinii* leaves. Forest Engineering. 2018;**34**(4):1-6

[38] Li H-Y et al. Effects of seedling density and fertilization methods

on the growth and development of *Fraxinus mandshurica* seedlings. Journal of Northeast Forestry University. 2018;**46**(9):16-20

[39] Zhang S-N et al. Effects of light and fertilization on the growth of seedlings of *Larix gmelinii* and *Juglans mandshurica* under the canopy of birch forest. Forest Engineering. 2015;**31**(2):51-56

[40] Liu Y-Q et al. The improvement of soil physical and chemical properties and nutrient utilization rate of apple trees by applying different kinds of organic fertilizers to the soil. Journal of Northwest Forestry University. 2020;**35**(1):112-117

[41] Yuan J-J et al. Comprehensive evaluation of the effect of biochar combined with nitrogen fertilizer on soil fertility in *Ziziphus jujuba* garden. Journal of Agricultural Engineering. 2018;**34**(1):134-140

[42] Ren H-M et al. Effects of fertilization methods on soil and fruiting of *Juglans regia* garden and benefit evaluation. Nonwood Forest Research. 2019;**37**(2):120-125

[43] Zhang W et al. Response of *Castanea mollissima* to N, P, K and nutrient fate. Journal of North China Agriculture. 2015;**30**(5):174-179

[44] Li Y et al. Evaluation of soil fertility and fertilization status in Yanshan apple production area, Hebei Province. Fruit Trees in China. 2019;**35**(6):32-37

[45] Li A-L et al. Research progress in fertilization technology of *Camellia oleifera*. China Agronomy Bulletin. 2015;**31**(31):36-40

[46] Li Z et al. Effects of extra root topdressing on growth, photosynthesis and chlorophyll fluorescence parameters of *Vernicia fordii* seedlings. Journal of Central South University of Forestry and Technology. 2016;**36**(2):40-44

[47] Zhou J et al. Nutritional diagnosis and fertilization standard of *Pyrus Pyrifolia* 'Whangkeumbae' leaves. Journal of Zhejiang Forestry University. 2007;**1**:39-43

[48] Zhao Y et al. Effect of N fertilizer application on N and P content of *Cunninghamia lanceolata* (Lamb.) Hook plantation. Hunan Forestry Science and Technology. 2016;**43**(3):49-55

[49] Liu S et al. Study on potassium effect and balanced fertilization of *Phyllostachys edulis* forest. Nonwood Forest Research. 2013;**31**(3):29-34

[50] Hu Y-Y et al. Effects of different fertilization modes on nitrogen and phosphorus loss of *Phyllostachys praecox* C.D. Chu et C.S. Chao 'Prevernalis' forest. Journal of Soil and Water Conservation. 2019;**33**(3):51-57

[51] Mao C et al. Absorption and utilization of N by organs of *Phyllostachys edulis* forest. Scientia Silvae Sinica. 2016;**52**(5):64-70

[52] Zhang J-J et al. Effect of absorption *Castanea mollissima* BL. dynamics. Journal of Plant Nutrition and Fertilizers. 2013;**19**(6):1428-1437

[53] Ding L-Z et al. Effects of soil testing and formula fertilization on the growth and yield of *Carya cathayensis* Sarg. in Lin'an. Nonwood Forest Research. 2018;**36**(4):33-39

[54] Huang Q-Y et al. Effects of boron, zinc, copper and molybdenum on the growth, fruit yield and quality of *Torreya grandis* Fort. et lindl. Nonwood Forest Research. 2015;**33**(3):33-38

[55] Li H-T et al. Diagnosis of fertilization and nutrition of *Cunninghamia lanceolata* (Lamb.) Hook seedlings based on secondary general rotation design. Chinese Soil and Fertilizer. 2017;**1**:73-79

[56] Chen H. Nutrient compensation experiment and formula optimization of *Castanea henryi* (Skan) Rehd. et Wils. plantation—Formula fertilization experiment of high yield type forest. Scientia Silvae Sinica. 2001;**37**(S1):60-67

[57] He Y et al. Study on N, P, K uptake and fertilization of 107 *Populus* L. young forest under drip fertilization. Forest Research. 2015;**28**(3):426-430

[58] Su M-Y et al. Study on the technology of TDS growth regulator to improve the bearing rate of *Castanea mollissima* BL. Forest Research. 1998;**11**(3):92-97

[59] Jia H-J et al. Study on the growth and nutrition of *Paulownia* Sieb.et Zucc. root cuttings. Research on Forestry Science. 1988;**1**(5):485-491

[60] Zhang W-Y et al. Effect of potassium application level on nutrient accumulation and oil production of *Camellia oleifera*. Journal of Plant Nutrition and Fertilizers. 2016;**22**(3):863-868

[61] Zhang W-Y et al. Effect of fertilization on aboveground biomass structure of *Phyllostachys edulis* forest. Journal of Northwest Forestry College. 2016;**31**(5):61-67

[62] Zhou G-X et al. Species diversity of undergrowth shrubs of *Eucalyptus robusta* Smith under different management measures. Journal of Jiangxi Agricultural University. 2012;**34**(1):59-65

[63] Zeng J et al. Effects of different fertilization types and dosage on the growth and resistance physiology of *Cinnamomum camphora*. Journal of Central South University of Forestry and Technology. 2018;**38**(6):50-55

[64] Hu X-K et al. Study on the effect of formula fertilization on the growth characteristics of *Evodia rutaecarpa* plantation. Nonwood Forest Research. 2009;**27**(2):40-43

[65] Hu D-N et al. Effects of nitrogen, phosphorus, potassium and irrigation on spring shoot growth of *Camellia oleifera*. Scientia Silvae Sinica. 2015;**51**(4):148-155

[66] Guo X-M et al. Bottleneck analysis and countermeasures for the development of Jiangxi *Camellia oleifera* industry. Nonwood Forest Research. 2013;**31**(2):1-7

[67] Tu S-P et al. Soil erosion resistance evaluation of *Eucalyptus robusta* Smith forest land in Ganxian rare earth mining area. Forest Research. 2013;**26**(6):752-758

[68] Jiang L et al. Alpine meadow restorations by non-dominant species increased soil nitrogen transformation rates but decreased their sensitivity to warming. Journal of Soils and Sediments. 2017;**17**(9):2329-2337

[69] Zhi L et al. Response of soil sulfur availability to elevation and degradation in the Wugong Mountain meadow, China. Plant, Soil and Environment. 2017;**63**(6):250-256

[70] Li Z et al. Distribution characteristics of soil available nutrients in subtropical mountain meadow: A case study of Wugong Mountain, Jiangxi Province. Journal of Southwest Agriculture. 2017;**30**(10):2308-2314

[71] Deng B et al. Increases in soil CO_2 and N_2O emissions with warming depend on plant species in restored alpine meadows of Wugong Mountain, China. Journal of Soils and Sediments. 2016;**16**(3):777-784

[72] Li Z et al. Soil microbial community responses to soil chemistry modifications in alpine meadows following human trampling. Catena. 2020;**194**:104717

[73] Li Z et al. Effects of altitude and tourism disturbance on soil permeability of mountain meadow in Wugong mountain. Acta Ecologica Sinica. 2018;**38**(2):635-645

[74] Zhang X-L et al. Temporal and spatial change of vegetation coverage of Wugong Mountain meadow based on tmndvi. Acta Ecologica Sinica. 2018;**38**(7):2414-2424

[75] Li Z et al. Effect of different disturbance on soil organic matter and acidity of mountain meadow. Jiangsu Agricultural Sciences. 2018;**46**(9):285-288

[76] Li Z et al. Study on the growth effect and adaptability of different vegetation restoration measures in Wugongshan degraded meadow. Journal of Central South University of Forestry & Technology. 2018;**38**(2):90-96

[77] Hou X-J et al. Effect of nitrogen application on soil nitrogen content, root growth and nitrogen absorption of meadow in Wugong mountain. Pratacultural Science. 2018;**35**(6):1343-1351

[78] Li Z. Variation and influencing factors of soil microbiological characteristics in Wugong mountain meadow [PhD thesis]. Nanchang of China: Jiangxi Agricultural University; 2017. pp. 75-98

[79] Li H-T et al. Soil fertility analysis of *Cunninghamia lanceolata* (Lamb.) Hook plantation in different development stages. Forest Research. 2017;**30**(2):322-328

[80] Pi B. Characteristics of forestry fertilization and problems in fertilization. Hunan Forestry Science and Technology. 2006;**33**(6):81-83

[81] Zhou F-Y et al. Discussion on the development stage and the third generation product characteristics of microbial fertilizer in China. Chinese Soil and Fertilizer. 2015;**1**:12-17

[82] Wang Q et al. N and P fertilization reduced soil autotrophic and heterotrophic respiration in a young *Cunninghamia lanceolata* (Lamb.) Hook forest. Agricultural and Forest Meteorology. 2017;**232**(15):66-73

[83] Gao W et al. Nutritional diagnosis of DRIs in early spring sprouting stage of Jiangxi *Camellia oleifera* Abel. Slice. Economic Forest Research. 2017;**35**(4):192-196

[84] Jiang Y et al. Effects of long-term fertilization and water increase on soil properties and plant properties of semi-arid grassland. Journal of Applied Ecology. 2019;**30**(7):2470-2480

[85] Gong Q-L et al. Effects of different fertilizer combinations on soil nutrients and enzyme activities in the northern area of Weihe river dry land apple orchard covered with grass. Journal of Applied Ecology. 2018;**29**(01):205-212

[86] Wu J-W et al. Dynamic changes of leaf development of *Catalpa bungei* C. A. Mey. Clones under different nitrogen index fertilization. Journal of Beijing Forestry University. 2015;**37**(7):19-28

[87] Yang J-S et al. Study on the comprehensive evaluation of soil quality in the coastal reclamation area of northern Jiangsu Province. Chinese Journal of Eco-Agriculture. 2009;**17**(3):410-415

[88] Wang W-G et al. Application status and development strategy of water and fertilizer integration technology. Chinese Fruits and Vegetables. 2019;**39**(10):68-70

[89] Yang Y et al. Formula fertilization of soil testing and its correlation with tree nutrients in *Poplar* plantation around Dongting Lake. Journal of Central South University of Forestry and Technology. 2018;**38**(12):103-107

[90] Shen D-L et al. Current situation and development direction of microbial fertilizer industry in China. Journal of Microbiology. 2013;**33**(3):1-4

[91] Jing D-W et al. Water retaining agent urea gel on fine root growth and nitrogen use efficiency of bare roots seedlings of *Platycladus orientalis*. Acta Sinica Sinica. 2016;**27**(4):1046-1052

[92] Sun Y et al. Effects of advanced anaerobic digestion sludge organic fertilizer on growth and nutrient accumulation of *Pinus tabulaeformis* and *Ulmus pumila* trees. Journal of Central South University of Forestry and Technology. 2019;**39**(10):55-63

[93] Deng B et al. Effects of nitrogen deposition and UV-B radiation on seedling performance of Chinese tallow tree (*Triadica sebifera*): A photosynthesis perspective. Forest Ecology and Management. 2019;**433**:453-458

[94] Zhang L et al. Interactive effects of elevated CO_2 and nitrogen deposition accelerate litter decomposition cycles of invasive tree (*Triadica sebifera*). Forest Ecology and Management. 2017;**385**:189-197

[95] Li Z et al. Effects of moso bamboo (*Phyllostachys edulis*) invasions on soil nitrogen cycles depend on invasion stage and warming. Environmental Science and Pollution Research. 2017;**24**(32):24989-24999

[96] Pan J et al. Root litter mixing with that of Japanese cedar altered CO_2 emissions from Moso Bamboo Forest soil. Forests. 2020;**11**(3):356

[97] Zheng X et al. Litter removal enhances soil N_2O emissions: Implications for management of leaf-harvesting Cinnamomum camphora plantations. Forest Ecology and Management. 2020;**466**:118121

[98] Liu X et al. Moso bamboo (*Phyllostachys edulis*) invasion effects on litter, soil and microbial PLFA characteristics depend on sites and invaded forests. Plant and Soil. 2019;**438**(1):85-99

[99] Xie J et al. Understory plant functional types Alter stoichiometry correlations between litter and soil in Chinese Fir plantations with N and P addition. Forests. 2019;**10**(9):742

[100] Pan P et al. Impact of understory vegetation on soil carbon and nitrogen dynamic in aerially seeded *Pinus massoniana* plantations. PLOS One. 2018;**13**:e01919521

[101] Deng B et al. Biochar is comparable to dicyandiamide in the mitigation of nitrous oxide emissions from *Camellia oleifera* Abel. Fields. Forests. 2019;**10**(12):1076

[102] Deng B et al. Effects of biochar and dicyandiamide combination on nitrous oxide emissions from *Camellia oleifera* field soil. Environmental Science and Pollution Research. 2019;**26**(4):4070-4077

[103] Xu X et al. Rice straw biochar mitigated more N_2O emissions from fertilized paddy soil with higher water content than that derived from ex situ bio-waste. Environmental Pollution. 2020;**263**:114477

[104] Deng B et al. Effects of spent mushroom substrate-derived biochar on soil CO_2 and N_2O emissions depend on pyrolysis temperature. Chemosphere. 2020;**246**:125608

Chapter 3

Plant Invasion and N_2O Emission in Forest Ecosystems

Nasir Shad, Ling Zhang, Ghulam Mujtaba Shah, Fang Haifu, Muhammad Ilyas, Abbas Ali and Salman Ali Khan

Abstract

Nitrogen (N) is a key factor for any ecosystem and has been found limited for biomass production. More N in forest ecosystem and their efficient utilization will contribute to the maximization in their growth, competition, and reproduction. Invasive plants capture and utilize more N than native plants and accelerate N cycles through altering the structure and community of soil microbes and the litter decomposition rates, under microclimate conditions, resulting in an increase of N availability. All these factors are promoting the invasiveness of plants and cause further ecological and economic damage and decline in native biodiversity. Plant invasions affect soil microbial community, soil physiochemical properties, and litter decomposition rates, promoting N cycle and releasing more nitrous oxide (N_2O) into the atmosphere, further facilitating global warming, causing changes in the geographic ranges of some invasive species. Also, a better understanding of the mechanism, affecting factors, impacts, and control of the invasive species will lead to proper forest management. Proper and effective management will ensure the control of invasive species which includes invasive plant inventory, early deduction and rapid response, management plan and implication, and government support.

Keywords: global warming, plant invasions, greenhouse gases, nitrogen, forest management

1. Introduction

Biological invasion and global climate change pose threats to the loss of biodiversity, genetic diversity, agriculture output, and ecosystem service change worldwide, thus causing huge economic loss [1–5]. Furthermore, global warming causes global climate change in the present era. Various exotic components including water vapor, ozone, and greenhouse gases (GHGs) play a role in the atmosphere absorbing an amount of the emitted radiation from Earth's surface and then re-emitting it back to Earth, further increasing the surface temperature and resulting to disasters like floods, hurricanes, and drought [6–8]. N_2O, CO_2, and CH_4 are mostly produced naturally as a biological process and by anthropogenic activity. These GHGs amounted about 80% of total the GHGs [8, 9]. N_2O is a major long-lived GHG with a global warming potential of about 310 times greater than of CO_2 over a lifetime of 100 years [10] and is also involved in the atmospheric ozone depletion [11, 12], and >80% of global N_2O emissions are projected to be linked to soil microbial activity [13]. A reorientation of multidimensional problems between forest and climate changes is a complex issue. Climate change affects forest composition, and in addition, forest disturbances such as destruction and degradation further facilitate plant invasion which results to acceleration of the global GHG emissions [14–16]. Disturbances in the forest ecosystem lead to a loss of biodiversity, loss of biomass, and decreased forest regeneration potential [17]. The modification of abiotic and biotic factors will affect the exchange rate of GHG emission released into the atmosphere by forest soil, primarily through changes in microbial-mediated process and plant-derived process (e.g., photosynthesis) [18–20]. Therefore, adopting effective forestry and sustainable management practices will ensure productivity, N_2O mitigation, and biodiversity [21]. Soil N_2O production has been widely linked to soil microbial activity [12], which can be affected by litter and rhizosphere inputs of invasive plants [22], land-use legacy, and many other factors which are still unknown [23]. These changes to forest ecosystems can accelerate nutrient cycling and increase soil N_2O production to the atmosphere [24]. The world's forests are likely to face an increasing number of invasions in the future. It is necessary to identify the existing invasions and their potential for expansion and then set up invasive species management plan [25]. Managing forest invasion involves avoiding entry, eradicating nascent species, biological control, choosing host trees for resistance, and using cultural practices (silviculture and restoration) to mitigate invader impacts.

The problem on biological invasion is highlighted. It poses a threat to any ecosystem which includes forest ecosystems, causing economic and ecological damages worldwide. The factors contributing to plant invasion include microbial facilitation, global warming, and nutrients availability which make it more complex and still unknown. Based on the previous literature, we tried to understand and discuss the following issues: plant invasion in forest ecosystems, factors contributing to plant invasions, and soil N process and N_2O emission in the context of forest plant invasion. The aim of our study is to highlight the mechanism of plant invasion and its control and management in the context of sustainable forest management.

2. Effects of global warming on plant invasion

The rising GHGs in the atmosphere such as N_2O emission and other global change components affecting temperature can help hinder or promote plant invasions [26, 27]. For example, species may increase in size with warming and decline of canopy transpiration [28, 29]. Furthermore, previous studies and models indicate that invasive plant often responds unpredictably to global change components [26]. The response of plant species to elevated temperature depends on the features of their ecological and physiological characteristics. The previous study demonstrated that invasive species (*Lantana camara)* respond significantly to elevated temperature with increasing allopathic effects and high growth rate, suggesting that global warming may increase the invasions of plant species [30]. The world's climate with rising temperature can change the interaction, physiology, phenology, and dispersal pattern of plant species, and the introduced species may have an advantage over the native species in terms of responding more to this climate change [29]. The introduction of alien plant species is considered to survive if the introduced range is likely to their native range, temperature being a key factor for their further expansion, reproduction, and growth [31, 32]. Global warming provides opportunity for invasive species to expand into regions where they could not previously survive and reproduce [4]. In addition, drought resulting from the climate change can affect biodiversity which further results in a warmer climate region, therefore damaging soil properties and affecting the plant nutrient uptake ability. These changes can threaten important biodiversity and foods for local populations. Drought and warm climate are likely due to an expansion of invasive species and can also lead to biodiversity loss and changes in frequency and intensity, which can affect seed germination, potential growth of young plants, and ecosystem services [33]. To date, global warming has been related to the rapid expansion of native plant populations [34, 35] and colonization of newly exposed land on local scale, although natural colonization of the region would occur. Consequently, under climate change, non-native species are likely to interfere with native biodiversity [36]. Climate change has also effects on plant-soil feedback such as the interaction among soil microbes and plants. Global warming as one of the components of climate change greatly affects input to the soil by litter production from decomposition [37, 38]. Warming affects seed germination of plants, for which invasive species show positive response specially in the summer season. Also, the total biomass of invasive species can be affected by global warming and they show high response in winter season compared to native species [39].

3. Forest plant invasions

The plant species in forest ecosystems can successfully grow when the introduced range is likely in their native habitat and can further expand and become invasive with unlimited soil resources, rising temperature, and soil microbial facilitation with a positive interaction to species [31, 32]. The success of plant invasion in forest ecosystems can be affected by many factors: rising temperature [30], landscape structure [40], and disturbance, especially harvest-induced disturbance which increased the abundance of invasive plant species [41–43]. The overstory harvest increases the microclimate temperature. Such factors and resources availability at the proper time can help the introduced species invade in forest ecosystems [44]. Such types of impact change in forest succession alter nutrients, carbon and water cycle, and the competition between native and invasive plant species is a much more threat to changes in ecosystem services. Plantation and regeneration forests are also at risk due to rapid plant invasions [45]. In order to impose an impact on ecological systems, invasive species not only required high-relative biomass, but they should also have characteristics that differ from those already present in the native species, which are necessary to drive ecosystem process [46]. The traits between invasive and native plants in forests can differ due to invasive species being assigned with higher resource utilization, fast-decaying leaf, more decomposition, high photosynthetic rate, relative growth rate, and higher specific leaf area [47–51]. Higher forest canopy cover can lessen the plant invasion, and it may limit the light source for invaded species when it is demanding for more light [52].

4. Forest management with plant invasions

Plant invasion in forest ecosystem is causing economic and ecological damage and threatens biodiversity conservation [52]. Forest management is required to identify the invasive species and its invasion stages and possible expansion and then set up a plan for its control [25], The inventory of invasive plants will help on proper management and planning. It is based on the invasive species status, distribution, and effects and threats to forest ecosystem [53]. Early deduction of invasive species and their identification, based on to confirm whether it is new to the area and measure its establishment, expansion to other areas as well as predict its impact on the forest ecosystem and loss will lead to effective management plan. The rapid response with effective management/plan can lessen the further invasion with daily basis monitoring [53].

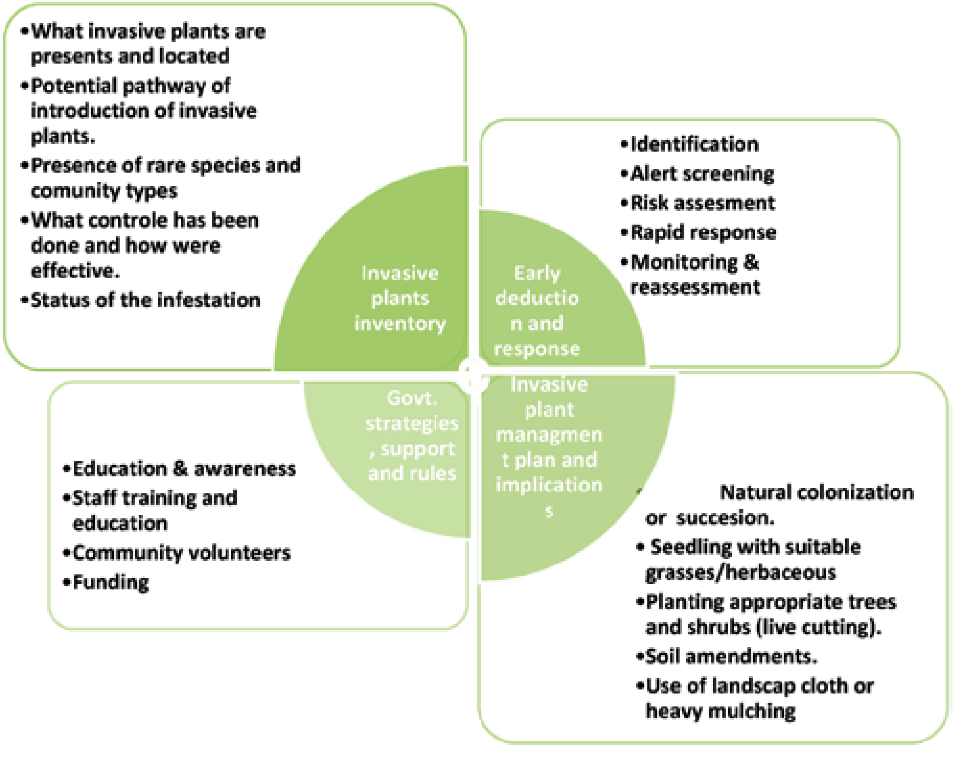

Figure 1.
A stepwise model is leading an effective forest management of invasive species (adapted from [53]).

Forest management includes prevention of arrival and dispersal of invasive species and their biological control as well as silviculture and restoration practices to lessen invasion impacts [45]. Restoration should be based on choosing plant species which suit to the condition of the target area [53]. For example, to increase the forests canopy cover may resist those invading species which demanding for more light, thus, invasive species with high resource demanding can be managed by proper way to minimize its further effects [54]. Also, a better understanding of the mechanism, affecting factors, impacts, and control of the invasive species will lead to a proper forest management. The (**Figure 1**) model is based on invasive species management, a stepwise model leading an effective management of species.

5. Forest plant invasions and soil N cycling

N is a key factor determining the outcome of interspecific competition in many ecosystems [55–57]. Previous literature found invasive plants dominant over the native plants because of they have more nutrient utilization, high photosynthetic rate, increased biomass production, more N availability from litter, high decomposition rate [58]. In addition invasive species produce fast-decaying litter [48]. Such characteristics of plant invasions can accelerate/increase soil N cycling by altering soil microbial community which further affects N_2O emission and forest ecosystem services in the invaded site [59, 60]. It may vary the types of plant invasion, such as woody plant invasion and N-fixing plants which have more significant impacts on N cycling than their alternatives. There is no difference between the responses of forests, wetlands, and grasslands to plant invasions [49].

N is a key nutrient, limiting factor for biomass production in forest ecosystems [57, 61]. No plant is suitable for all habitat to grow potentially [47, 62, 63]. However, invasive plants efficiently utilize resources showing maximization in growth, competition, and reproduction and improving their invasiveness characteristics [57, 62, 64, 65]. The N use efficiency of invasive plants is enhanced by many ways such as N fixation, photosynthetic N use efficiency, and N mineralization, allowing invasive species to have an advantage over native plant population [47, 56, 57, 66].

Rapid nutrient cycles especially N cycle may promote the invasiveness of plants [49, 59, 67, 68]. Also, increased N availability may affect the activity of soil microbial community with invasive plants and contribute to further invasion and provide a favorable environment for soil microbes [46, 59, 69]. Plant invasion changed (a) soil microbial community, (b) physiochemical properties, and (c) litter decomposition rate, which can affect the soil N cycle.

a. Plant invasion helps in the succession of soil microbes and promotes their functions, further facilitating plant invasions [70–72]. Some finding suggests that invasive plants in the invaded site may cause positive structural change in microbial community, which results in negative effects on native plant community, establishment, growth, and the whole ecosystem [56, 73]. Increasing the availability of N by invasive plants through changed in soil microorganism structure and community in result rapid decomposition, or through N_2 symbiotic fixation can further accelerate the N cycles [49, 58, 59, 74, 75]. These changes of plant invasion and especially the symbiotic N fixers have large effects on N cycles [58].

b. There is considerable evidence that plant invasion may alter physiochemical properties of soil. For example, invasive plants may cause soil moisture reduction with rapid evapotranspiration because of the long survival and rapid growth of invasive plants [75–77]. Some studies also observed a positive association between plant invasion and soil moisture [78]. Invasion of plants results in high pH value in soil, such as more ammonium and nitrate absorption result in acidification and alkalinization [78–80]. Si et al. [81] findings show that low-degree plant invasion increased soil pH value, but high-degree plant invasion did not. A decrease in soil pH values caused by invasive plants could improve the solubility of P in soil, which contributes to further plant invasion [82]. Such factors, soil pH, soil moisture, and temperature are regulating soil microbes, soil N availability, litter decomposition rate, and community structure, thus also affecting the physiochemical properties effects on plant invasions [83, 84].

c. Fast-decaying litter of invasive species increases soil nutrients, especially N [83]. Thus, invasive plants obtain more nutrients especially N, and fast decomposition might also impact N cycle and further promote plant invasions [83, 85, 86]. Leaf litter quality and remarkable condition in the surrounding environment created by plants such as an increase in soil temperature and moisture can affect litter decomposition rate [87]. Invasive plants are often found with higher leaf N concentration affecting litter decomposition rates [51].

Soil N availability and transformation (mineralization, nitrification and denitrification) process from unusable form to usable form for plants is a key factor for primary net production. The involved microbes in nitrification and denitrification process are associated with N_2O emission [12, 88]. More N_2O emissions from the forest soil further accelerate global warming, thus greatly affecting N inputs to the soil by litter production through rapid decomposition by invasive plants [37, 51].

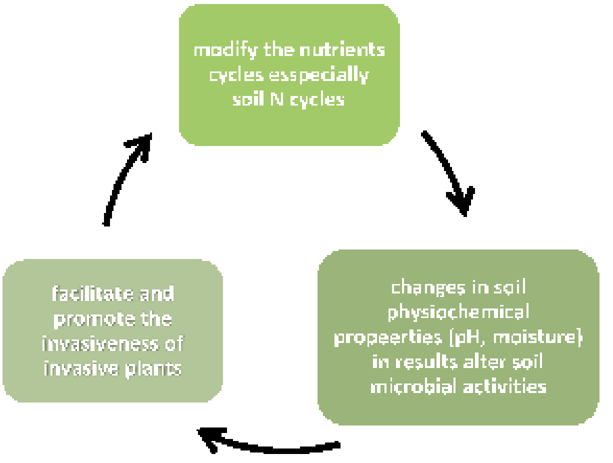

Figure 2.
The dynamic feedback diagram between invasive plants, soil properties, and soil N cycles (modified from [89]).

Invasive plants are often found with high soil N content because of the fast-decaying litter production [48], which may affect the activity of soil microbial community, providing favorable environment to them [59, 69], such as increase in soil temperature [87], which may not be the same case for native species (**Figure 2**).

6. Forest plant invasions and soil N_2O emissions

Nitrous oxide is a major GHG which contributes to the depletion of ozone layer and is released from soils [90]. It has been widely linked to soil microbial activity [12]. Soil biota can be affected through litter and rhizosphere inputs of invasive plant species and may stimulate nutrient release via litter effect. Furthermore, invasive plants support more decomposers [22] and can modify soil enzyme activity [91], as well as fast-decaying litter from the invasive species [48], land-use legacy and many other factors alter soil microbial communities [23], further accelerate N cycling and increasing N_2O emissions altering the atmosphere composition [24]. The emission of N_2O to the atmosphere further facilitating global warming is expected to change the geographic ranges of some invasive species [26, 92], creating new opportunity for the establishment and development of introduced species, and can also affect the phenology of invasive species [93]. We define that more N concentration causes more N_2O emission. Hall et al. [16] show that canopy N concentration has effects on N_2O emission where the canopy concentration of invasive species was higher than that of native plants, especially in the summer season, and vary between forest types. By comparison remote estimates of canopy N in either season did not properly predict N_2O emission in the dry forest ecosystems. However invasive *Morella faya* increased N_2O emission in dry and wet forest ecosystem but the effects was most significant when the forest canopy dominated by Morella faya individual and with few other plant species in the overstory or understory. In addition, an increase in the soil pH and abundance of nosZ and nirK genes results in decreasing N_2O emission [94].

7. Conclusion

Plant invasion alters ecosystem service which results to huge economic loss and ecological loss worldwide. There are many factors behind the invasive plant success.

Some of these factors, such as climate change, underline the microbial mechanism of invasive species, micro-climate that created by invasive plant, more nutrients capturing by invasive plants and more N availability make more complexity which may not be experienced by native species. Previous literature of invasive plants demonstrated their impact complexity and changed the structure and function of ecosystem permanently. Thus, effective control of invasive species needs more attention nationally and internationally to lessen its further damage, leading to sustainable forest management. As well a better understanding of the mechanism, affecting factors, impacts, and control of the invasive species will lead to proper forest management, which include invasive plant inventory, early deduction and response, management and its implication, education and awareness, and indeed government support. Forest managers must pay special attention to species and regional wildlife at risk due to plant invasions. Future studies on the underlying microbial mechanism of invasive plants under the context of global climate change are still necessary to determine the role of the microbial community on plant invasion success.

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Conflict of interest

The authors declare no conflict of interest.

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References

[1] Vilà M, Hulme PE. Non-native species, ecosystem services, and human well-being. In: Impact of Biological Invasions on Ecosystem Services. Springer; 2017. pp. 1-14

[2] Urban MC. Accelerating extinction risk from climate change. Science. 2015;**348**(6234):571-573

[3] Dogra KS et al. Alien plant invasion and their impact on indigenous species diversity at global scale: A review. Journal of Ecology and The Natural Environment. 2010;**2**(9):175-186

[4] Walther G-R et al. Alien species in a warmer world: Risks and opportunities. Trends in Ecology & Evolution. 2009;**24**(12):686-693

[5] Li Z, Xie Y. Invasive Alien Species in China (in Chinese). Vol. 2002. Beijing: China Forestry Press;

[6] Smith P, Martino Z, Cai D. Agriculture. In: Climate Change 2007: Mitigation. 2007

[7] Stocker T. Climate Change 2013: The Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press; 2014

[8] Thomas R et al. What is meant by 'balancing sources and sinks of greenhouse gases' to limit global temperature rise. Briefing Note. 2016;**3**:1-5

[9] Ciais P et al. Carbon and other biogeochemical cycles. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press; 2014. pp. 465-570

[10] He J-Z, Zhang L-M. Key processes and microbial mechanisms of soil nitrogen transformation. Microbiology/Weishengwuxue Tongbao. 2013;**40**(1):98-108

[11] Gao G-F et al. Spartina alterniflora invasion alters soil bacterial communities and enhances soil N_2O emissions by stimulating soil denitrification in mangrove wetland. Science of the Total Environment. 2019;**653**:231-240

[12] Stocker TF et al. Climate change 2013: The physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change. 2013. p. 1535

[13] IWG. Climate Change 2013-The Physical Science Basis: Summary for Policymakers. Intergovernmental Panel on Climate Change; 2013

[14] Thuiller W, Richardson DM, Midgley GF. Will climate change promote alien plant invasions? In: Biological Invasions. Springer; 2008. pp. 197-211

[15] Tian X et al. Global climate change impacts on forests and markets. Environmental Research Letters. 2016;**11**(3):035011

[16] Hall SJ, Asner GP. Biological invasion alters regional nitrogen-oxide emissions from tropical rainforests. Global Change Biology. 2007;**13**(10):2143-2160

[17] Raj A, Jhariya M, Bargali S. Climate smart agriculture and carbon sequestration. In: Climate Change and Agroforestry: Adaptation Mitigation and Livelihood Security. New Delhi: New India Publishing Agency (NIPA); 2018. pp. 1-19

[18] Gathany MA, Burke IC. The effects of forest thinning practices and altered nutrient supply on soil trace gas fluxes in Colorado. Open Journal of Forestry. 2014;**4**(3):278

[19] Wang H et al. The effects of elevated ozone and CO_2 on growth and defense of native, exotic and invader trees. Journal of Plant Ecology. 2018;**11**(2):266-272

[20] Wang H et al. UV-B has larger negative impacts on invasive populations of Triadica sebifera but ozone impacts do not vary. Journal of Plant Ecology. 2016;**9**(1):61-68

[21] Torras O, Saura S. Effects of silvicultural treatments on forest biodiversity indicators in the Mediterranean. Forest Ecology and Management. 2008;**255**(8-9):3322-3330

[22] Zhang P et al. Invasive plants differentially affect soil biota through litter and rhizosphere pathways: A meta-analysis. Ecology Letters. 2019;**22**(1):200-210

[23] Chen W-B, Peng S-L. Land-use legacy effects shape microbial contribution to N_2O production in three tropical forests. Geoderma. 2020;**358**:113979

[24] Shen F et al. Soil N/P and C/P ratio regulate the responses of soil microbial community composition and enzyme activities in a long-term nitrogen loaded Chinese fir forest. Plant and Soil. 2019;**436**(1-2):91-107

[25] Adhikari P et al. Potential impact of climate change on plant invasion in the Republic of Korea. Journal of Ecology and Environment. 2019;**43**(1):36

[26] Bradley BA et al. Predicting plant invasions in an era of global change. Trends in Ecology & Evolution. 2010;**25**(5):310-318

[27] Zhang L et al. Perennial forb invasions alter greenhouse gas balance between ecosystem and atmosphere in an annual grassland in China. Science of the Total Environment. 2018;**642**:781-788

[28] Clausnitzer F et al. Relationships between canopy transpiration, atmospheric conditions and soil water availability—Analyses of long-term sap-flow measurements in an old Norway spruce forest at the Ore Mountains/Germany. Agricultural and Forest Meteorology. 2011;**151**(8):1023-1034

[29] Walther G-R. Plants in a warmer world. Perspectives in Plant Ecology, Evolution and Systematics. 2003;**6**(3):169-185

[30] Zhang Q et al. Climate warming may facilitate invasion of the exotic shrub Lantana camara. PLoS One. 2014;**9**(9):e105500

[31] Woodward FI, Woodward F. Climate and Plant Distribution. Cambridge University Press; 1987

[32] Charnov EL, Gillooly JF. Thermal time: Body size, food quality and the 10 C rule. Evolutionary Ecology Research. 2003;**5**(1):43-51

[33] Lawal S, Lennard C, Hewitson B. Response of southern African vegetation to climate change at 1.5 and 2.0° global warming above the pre-industrial level. Climate Services. 2019;**16**:100134

[34] Cannone N et al. Ecology of moss banks on Signy Island (maritime Antarctic). Botanical Journal of the Linnean Society. 2017;**184**(4):518-533

[35] Cannone N et al. Vascular plant changes in extreme environments: Effects of multiple drivers. Climatic Change. 2016;**134**(4):651-665

[36] Siegert MJ et al. The Antarctic Peninsula under a 1.5° C global warming

scenario. Frontiers in Environmental Science. 2019;**7**:102

[37] Davidson EA, Janssens IA. Temperature sensitivity of soil carbon decomposition and feedbacks to climate change. Nature. 2006;**440**(7081):165-173

[38] Zhang L, Zou J, Siemann E. Interactive effects of elevated CO_2 and nitrogen deposition accelerate litter decomposition cycles of invasive tree (Triadica sebifera). Forest Ecology and Management. 2017;**385**:189-197

[39] Chen B-M et al. Differential responses of invasive and native plants to warming with simulated changes in diurnal temperature ranges. AoB Plants. 2017;**9**(4):plx028

[40] With KA. The landscape ecology of invasive spread. Conservation Biology. 2002;**16**(5):1192-1203

[41] Kotanen PM. Effects of experimental soil disturbance on revegetation by natives and exotics in coastal California meadows. Journal of Applied Ecology. 1997;**34**:631-644

[42] Mack MC, D'Antonio CM. Impacts of biological invasions on disturbance regimes. Trends in Ecology & Evolution. 1998;**13**(5):195-198

[43] Mooney HA, Hobbs RJ. Global change and invasive species: Where do we go from here. In: Invasive species in a changing world. Washington, DC: Island Press; 2000. pp. 425-434

[44] Jose S et al. Invasive plants: A threat to the integrity and sustainability of forest ecosystems. In: Invasive plants and forest ecosystems. 2009. pp. 3-10

[45] Liebhold AM et al. Biological invasions in forest ecosystems. Biological Invasions. 2017;**19**(11):3437-3458

[46] Wardle DA et al. Terrestrial ecosystem responses to species gains and losses. Science. 2011;**332**(6035):1273-1277

[47] Funk JL, Vitousek PM. Resource-use efficiency and plant invasion in low-resource systems. Nature. 2007;**446**(7139):1079-1081

[48] Jo I, Fridley JD, Frank DA. Invasive plants accelerate nitrogen cycling: Evidence from experimental woody monocultures. Journal of Ecology. 2017;**105**(4):1105-1110

[49] Liao C et al. Altered ecosystem carbon and nitrogen cycles by plant invasion: A meta-analysis. New Phytologist. 2008;**177**(3):706-714

[50] Peltzer DA, Kurokawa H, Wardle DA. Soil fertility and disturbance interact to drive contrasting responses of co-occurring native and nonnative species. Ecology. 2016;**97**(2):515-529

[51] Zhang L et al. Decomposition of Phragmites australis litter retarded by invasive Solidago canadensis in mixtures: An antagonistic non-additive effect. Scientific Reports. 2014;**4**:5488

[52] Sharma L, Adhikari B, Watson M, et al. Forest canopy resists plant invasions: A case study of Chromolaena odorata in sub-tropical Sal (Shorea robusta) forests of Nepal. bioRxiv. 2019. DOI: 10.1101/747287

[53] Sherman K. Creating an Invasive Plant Management Strategy: A Framework for Ontario Municipalities. Peterborough, ON: Ontario Invasive Plant Council; 2015

[54] Dyderski MK, Jagodziński AM. Drivers of invasive tree and shrub natural regeneration in temperate forests. Biological Invasions. 2018;**20**(9):2363-2379

[55] Theoharides KA. Plant invasions across space and time: Factors affecting non-indigenous plant species success during four stages of invasion [thesis]. Boston: University of Massachusetts; 2007

[56] Sanon A et al. Differences in nutrient availability and mycorrhizal infectivity in soils invaded by an exotic plant negatively influence the development of indigenous Acacia species. Journal of Environmental Management. 2012;**95**:S275-S279

[57] Laungani R, Knops JM. Species-driven changes in nitrogen cycling can provide a mechanism for plant invasions. Proceedings of the National Academy of Sciences. 2009;**106**(30):12400-12405

[58] Ehrenfeld JG. Effects of exotic plant invasions on soil nutrient cycling processes. Ecosystems. 2003;**6**(6):503-523

[59] Hawkes CV et al. Plant invasion alters nitrogen cycling by modifying the soil nitrifying community. Ecology Letters. 2005;**8**(9):976-985

[60] Liu X et al. Moso bamboo (Phyllostachys edulis) invasion effects on litter, soil and microbial PLFA characteristics depend on sites and invaded forests. Plant and Soil. 2019;**438**(1):85-99

[61] Chen B-M, Peng S-L, Ni G-Y. Effects of the invasive plant Mikania micrantha HBK on soil nitrogen availability through allelopathy in South China. Biological Invasions. 2009;**11**(6):1291-1299

[62] Matzek V. Superior performance and nutrient-use efficiency of invasive plants over non-invasive congeners in a resource-limited environment. Biological Invasions. 2011;**13**(12):3005

[63] Wang X-Y et al. Genotypic diversity of an invasive plant species promotes litter decomposition and associated processes. Oecologia. 2014;**174**(3):993-1005

[64] Ochoa-Hueso R et al. Nitrogen deposition effects on Mediterranean-type ecosystems: An ecological assessment. Environmental Pollution. 2011;**159**(10):2265-2279

[65] Heberling JM, Fridley JD. Resource-use strategies of native and invasive plants in Eastern North American forests. New Phytologist. 2013;**200**(2):523-533

[66] Deng B et al. Effects of nitrogen deposition and UV-B radiation on seedling performance of Chinese tallow tree (Triadica sebifera): A photosynthesis perspective. Forest Ecology and Management. 2019;**433**:453-458

[67] Elgersma KJ et al. Legacy effects overwhelm the short-term effects of exotic plant invasion and restoration on soil microbial community structure, enzyme activities, and nitrogen cycling. Oecologia. 2011;**167**(3):733-745

[68] Zhang L et al. Soil respiration and litter decomposition increased following perennial forb invasion into an annual grassland. Pedosphere. 2016;**26**(4):567-576

[69] Mitchell CE et al. Biotic interactions and plant invasions. Ecology Letters. 2006;**9**(6):726-740

[70] Kiers ET et al. Reciprocal rewards stabilize cooperation in the mycorrhizal symbiosis. Science. 2011;**333**(6044):880-882

[71] Hautier Y, Niklaus PA, Hector A. Competition for light causes plant biodiversity loss after eutrophication. Science. 2009;**324**(5927):636-638

[72] Svensson JR et al. Novel chemical weapon of an exotic macroalga inhibits recruitment of native competitors in the invaded range. Journal of Ecology. 2013;**101**(1):140-148

[73] Li Z et al. Effects of moso bamboo (Phyllostachys edulis) invasions on soil nitrogen cycles depend on invasion stage and warming. Environmental Science and Pollution Research. 2017;**24**(32):24989-24999

[74] Dassonville N et al. Niche construction by the invasive Asian knotweeds (species complex Fallopia): Impact on activity, abundance and community structure of denitrifiers and nitrifiers. Biological Invasions. 2011;**13**(5):1115-1133

[75] Rout ME, Chrzanowski TH. The invasive Sorghum halepense harbors endophytic N 2-fixing bacteria and alters soil biogeochemistry. Plant and Soil. 2009;**315**(1-2):163-172

[76] Novoa A et al. Soil quality: A key factor in understanding plant invasion? The case of Carpobrotus edulis (L.) NE Br. Biological Invasions. 2014;**16**(2):429-443

[77] Wolf J, Beatty S, Seastedt T. Soil characteristics of Rocky Mountain National Park grasslands invaded by Melilotus officinalis and M. alba. Journal of Biogeography. 2004;**31**(3):415-424

[78] Kuebbing SE, Classen AT, Simberloff D. Two co-occurring invasive woody shrubs alter soil properties and promote subdominant invasive species. Journal of Applied Ecology. 2014;**51**(1):124-133

[79] Kourtev P, Ehrenfeld J, Huang W. Effects of exotic plant species on soil properties in hardwood forests of New Jersey. Water, Air, and Soil Pollution. 1998;**105**(1-2):493-501

[80] Fan L et al. The effect of Lantana camara Linn. invasion on soil chemical and microbiological properties and plant biomass accumulation in southern China. Geoderma. 2010;**154**(3-4):370-378

[81] Si C et al. Different degrees of plant invasion significantly affect the richness of the soil fungal community. PLoS One. 2013;**8**(12):e85490

[82] Herr C et al. Seasonal effect of the exotic invasive plant Solidago gigantea on soil pH and P fractions. Journal of Plant Nutrition and Soil Science. 2007;**170**(6):729-738

[83] Wang C et al. Response of litter decomposition and related soil enzyme activities to different forms of nitrogen fertilization in a subtropical forest. Ecological Research. 2011;**26**(3):505-513

[84] Zhang X et al. Response of the abundance of key soil microbial nitrogen-cycling genes to multi-factorial global changes. PLoS One. 2013;**8**(10):e76500

[85] Zhang L et al. Non-native plant litter enhances soil carbon dioxide emissions in an invaded annual grassland. PLoS One. 2014;**9**(3):e92301

[86] Zhang L et al. Chinese tallow trees (Triadica sebifera) from the invasive range outperform those from the native range with an active soil community or phosphorus fertilization. PLoS One. 2013;**8**(9):e74233

[87] Vivanco L, Austin AT. Tree species identity alters forest litter decomposition through long-term plant and soil interactions in Patagonia, Argentina. Journal of Ecology. 2008;**96**(4):727-736

[88] Zhang L, Liu X. Nitrogen Transformations Associated with N_2O Emissions in Agricultural Soils, in Nitrogen in Agriculture-Updates. London: IntechOpen; 2017

[89] Wang C et al. Insights into ecological effects of invasive plants on soil nitrogen cycles. American Journal of Plant Sciences. 2015;**6**(01):34

[90] Piñeiro-Guerra JM et al. Nitrous oxide emissions decrease with plant diversity but increase with grassland primary productivity. Oecologia. 2019;**190**(2):497-507

[91] Zhou Y, Staver AC. Enhanced activity of soil nutrient-releasing enzymes after plant invasion: A meta-analysis. Ecology. 2019;**100**(11):201

[92] Allen JM, Bradley BA. Out of the weeds? Reduced plant invasion risk with climate change in the continental United States. Biological Conservation. 2016;**203**:306-312

[93] Wolkovich EM, Cleland EE. The phenology of plant invasions: A community ecology perspective. Frontiers in Ecology and the Environment. 2011;**9**(5):287-294

[94] Aamer M et al. Biochar mitigates the N_2O emissions from acidic soil by increasing the nosZ and nirK gene abundance and soil pH. Journal of Environmental Management. 2020;**255**:109891

Section 2

Forest Management and Biodiversity Conservation

Chapter 4

Increasing Biodiversity of Russian Taiga Forests by Creating Mixed Forest Cultures of Scots Pine and Siberian Larch

Elena Runova

Abstract

Studies were conducted in the Padunsky forest area of the Bratsk district of the Irkutsk region in order to identify the influence of self-sowing that appears in the young growth of Scots pine, created by sowing or planting due to the self-seeding of Scots pine, which can be proved by the age of test trees that are less than 1–3 years old than the forest cultures. Birch and aspen appear in the composition, Siberian larch and Siberian pine appear in a small amount, and at some test plots, silver birch takes up to six units. Such forest cultures require thinning to avoid changing to soft-leaved species. The parameters of the macroscopic structure of Scots pine wood and the thickness of the bark at the base of the trunks, depending on the age of forest cultures, have been determined. To solve the choice of the most effective method of reforestation and increase the economic value of the young stands formed in various types of forest-growing conditions, the effectiveness of various methods and technologies of reforestation has been evaluated. As a result of the work performed, it was established that regardless of the year when the forest cultures are created, self-seeding always appears in the plantations. The smallest amount of self-sowing appeared on relatively poor fresh soils in the cowberry-grass type of forest. The greatest amount of self-seeding can be seen in the motley grass type forests with relatively rich wet soils.

Keywords: biodiversity, taiga ecosystems, mixed stands, scots pine, Siberian larch

1. Introduction

In the context of modern global climate change, forest ecosystems play an important part in stabilizing the ecological state. According to international standards, mixed, complex forests that have a large biological diversity are of particular importance. In this regard, the forests of the Irkutsk region are mostly of natural origin, often based on pyrogenic factors. Many forests are classified as high conservation value forests according to FSC standards. Basically, the forests of the Irkutsk region belong to light-coniferous taiga. Recently, the content of larch in the total composition of the forests of the Irkutsk region has been decreasing both in percentage terms by area and by age groups. In this regard, a special task is to preserve and multiply mixed pine and larch plantations of natural and artificial origin in the

Angara region on the example of the Irkutsk region. The relevance of the topic lies in the study of the state of mixed pine-larch stands on the example of forests in the Irkutsk region and recommendations for the creation of pine-larch forest crops.

The features of growth of mixed and complex pine stands were studied by many authors: Buzykin and Pshenichnikov [1]; Varaksin et al. [2]; Gvozdev [3]; Klyuchnikov [4]; and Plaksiva et al. [5]. However, the regularities of the composition and growth, formation, and structure of mixed stands of the East Siberian taiga are not fully studied, especially for the Irkutsk region. The author [6–9] studied the growth and formation of pine and larch plantations in the conditions of the Angara taiga region (on the example of the Irkutsk region).

The scientific novelty of the research is that on the basis of the conducted research and generalization of information about the regularities of formation, growth and structure of mixed forest cultures, the dynamics of formation of the main inventory indices, and the quality of the stem wood of artificially grown mixed crops were studied. For the first time, forest management and inventory indices of mixed pine and larch plantations in the Angara region of the Irkutsk region, various age classes, and forest cultures were observed for the study areas. The features of the formation of annual rings of pine and larch in mixed forest cultures were studied.

2. Research methodology and methods

The research methodology was based on a systematic approach to the studied natural objects. The methods of establishing sample plots, which are generally accepted in forest research, were used. Processing of inventory indices was carried out according to generally accepted methods [6, 10–12].

One of the main tasks of the modern development of forest science is to study the dynamics of mixed stands in order to grow more productive and biologically more stable productive stands, which should contribute to a more rational use of natural resources, the preservation of biological diversity. Mixed pine-larch stands often have higher productivity than pure stands. However, in recent years, the area and stocks of Siberian larch are decreasing, and this tree species is losing its predominant function as the main forest-forming species of the taiga forests of Eastern Siberia. The scientific novelty of the work and its significance lies in the study of the growth and development of mixed pine-larch stands and the study of the possibility of creating artificial forest stands of mixed composition, characterized by higher productivity and stability. For proper forest management, it is necessary to study the regularities of changes in inventory indices that take into account the co-growth of light-loving species of Scots pine (*Pinus sylvestris* L.) and Siberian larch (*Larix sibirica* Ldb.) and their silvicultural and biological characteristics.

To achieve this goal, the following tasks are set:

- To study the processes of formation, growth, and productivity of mixed pine-larch stands under the age of 40.

- To study the dynamics of individual inventory indices of mixed stands.

The main method of collecting experimental data was a field survey of plantings at permanent and temporary sample plots. The main method of collecting experimental data was a field survey of plantings at permanent and temporary sample plots. For each sample plot, a forest geobotanical description was made, indicating the features of the stand, young growth, undergrowth, ground cover, and terrain.

Then a continuous list of trees of Scots pine (*Pinus sylvestris* L.) and Siberian larch (*Larix sibirica* Ldb) was carried out at the age of 40 years using conventional measuring devices: altimeters-eclimeters, measuring fork for 1-cm stem diameter. Data of inventory indices was processed using statistical methods. The research program consisted of a comparative assessment of the growth and development of young pine (*Pinus sylvestris* L.) and Siberian larch (*Larix sibirica* Ldb.) in the most widespread types of forest at the sample plots in the Irkutsk region. The areas with 200–250 pine and larch trees were selected, which ensured the determination of the average diameter and other inventory indices with an accuracy of ±2–3%.

The Resistograph 4450 device by RINNTECH, Germany, was used to assess the quality of the wood of test trees. The cuttings of the studied trees were drilled with a thin drill needle. The device allows measuring the relative density of wood and fixing dense (healthy) wood and internal damage rot in the initial stage of development, highly developed rot, and cavities, without causing harm to growing trees or samples. According to the obtained resistogram graphs, the percentage of healthy wood or wood rot damage was determined.

When processing test results, the following characteristics were calculated: a sample arithmetic average, sample square mean deviation, average error S of the sample average, and sample coefficient of variation V as a percentage relative accuracy of determining the sample average.

3. Research result

While processing the collected experimental materials, the following results were obtained, which characterize the average morphometric indicators of the sample plots of Scots pine and Siberian larch at the age of 5 up to 40 years in the cowberry-grass and motley grass type of forest that are the most common ones in the studied region.

In **Figure 1**, the dynamics of the average height of young pine trees of different age groups is presented.

The figure shows the height of trees in meters (axis of ordinates) for age periods up to 5 years, from 6 up to 10 years, from 11 up to 20 years, from 21 up to 30 years, and from 31 up to 40 years. The equation describing the relationship between the height and age periods is also presented. The graphs shown in **Figures 1**–**8** characterize the average dendrometric indicators of increasing dendrometric indicators for age groups, generalized according to the data from 12 permanent and 45 temporary

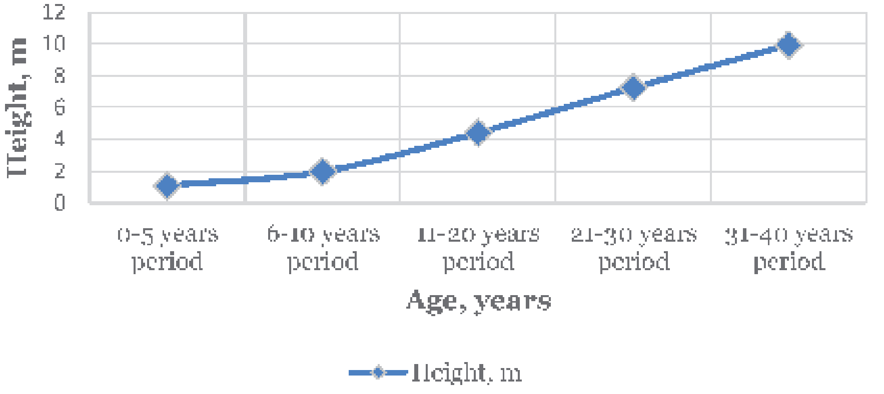

Figure 1.
Dynamics of the average height of young pine trees of different age periods.

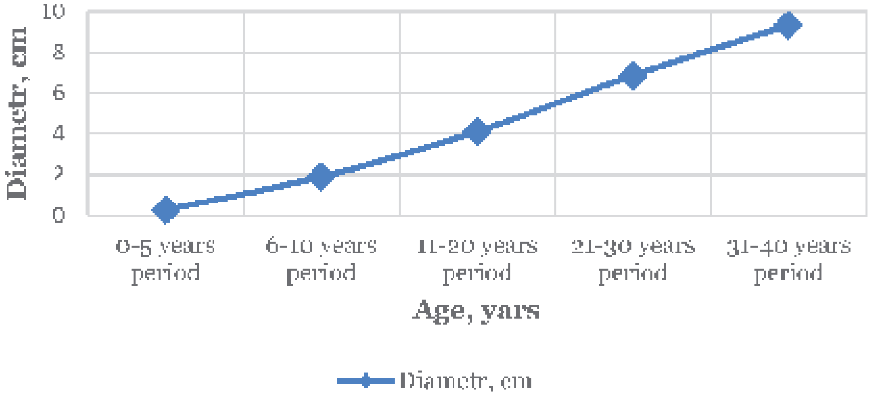

Figure 2.
Dynamics of changes in the average diameter of young pine trees by age periods. The figure shows the diameter of trees in centimeters (axis of ordinates) for age periods up to 5 years, from 6 up to 10 years, from 11 up to 20 years, from 21 up to 30 years, and from 31 up to 40 years. The equation describing the relationship between the diameter and age periods is also presented. As it can be seen from the graph in **Figure 2***, at the age of 40 years, the average diameter of the studied plantings reaches 9.8 cm at the height of 1.3 m.*

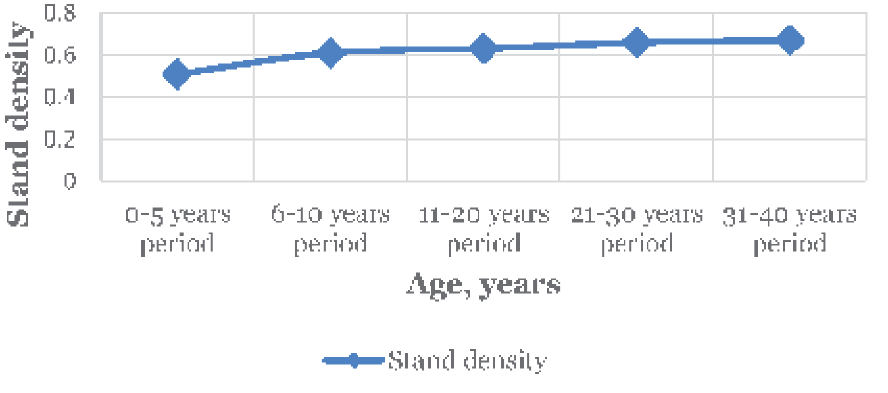

Figure 3.
Dynamics of changes in the relative basal area of young pine growth by age periods. The figure shows the relative basal area of trees (axis of ordinates) by age period up to 5 years, from 6 up to 10 years, from 11 up to 20 years, from 21up to 30 years, and from 31 up to 40 years. The equation describing the relationship between the basal area and age periods is also presented. The density of plantings allows forming quite productive stands.

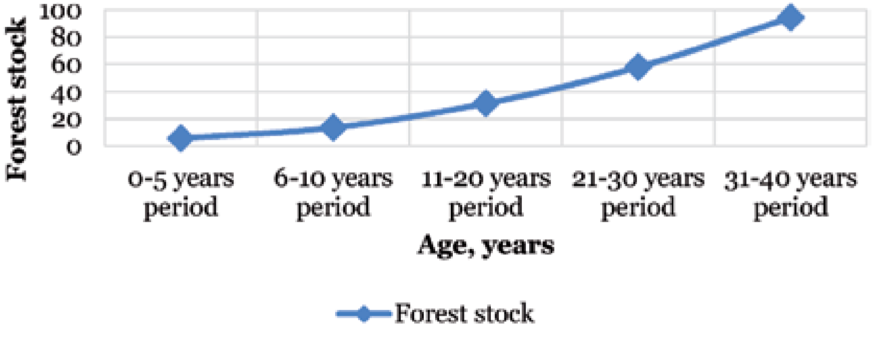

Figure 4.
Dynamics of changes in the growing stock of young pine growth per 1 hectare by age periods. The figure shows the growing stock of stands per 1 hectare in cubic meters (axis of ordinates) for age periods up to 5 years, from 6 up to 10 years, from 11 up to 20 years, from 21 up to 30 years, and from 31 up to 40 years. The equation describing the relationship of the growing stock by age periods is also presented. According to **Figure 4***, it can be assumed that by the age of logging, the stand can form a fairly good operational reserve.*

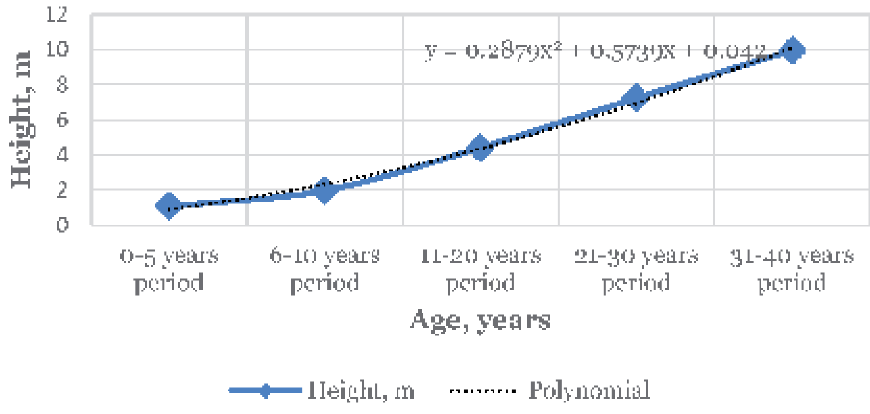

Figure 5.
Dynamics of changes in the height of young larch plants by age periods.

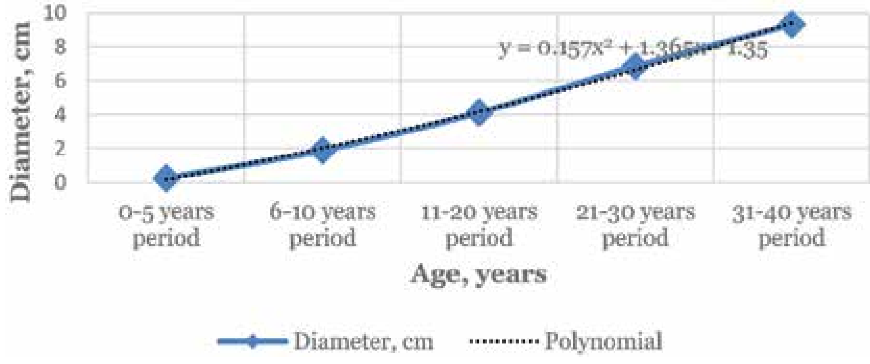

Figure 6.
Dynamics of changes in the average diameter of young larch plants by age periods. The figure shows the diameter of trees in centimeters (axis of ordinates) for age periods up to 5 years, from 6 up to 10 years, from 11 up to 20 years, from 21 up to 30 years, and from 31 up to 40 years. The equation describing the relationship of diameter by age periods is also presented.

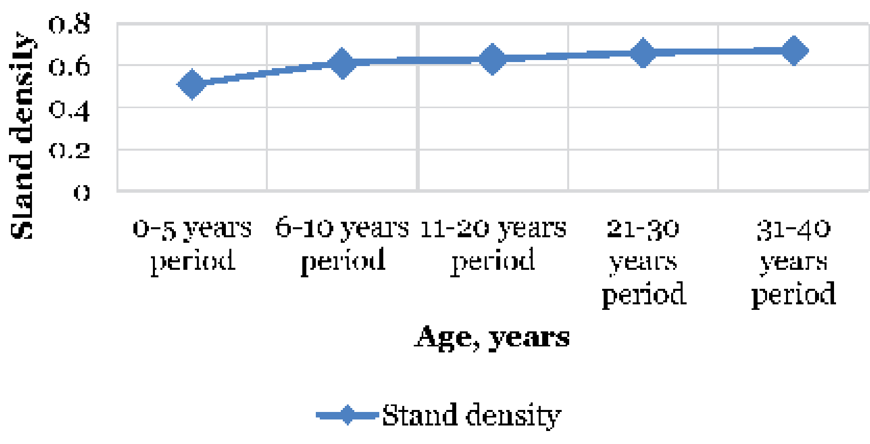

Figure 7.
Dynamics of changes in the relative basal area of young larch growth by age periods. The figure shows the relative basal area of trees (axis of ordinates) by age period up to 5 years, from 6 up to 10 years, from 11 up to 20 years, from 21 up to 30 years, and from 31 up to 40 years. The equation describing the relationship of basal area by age periods is also presented.

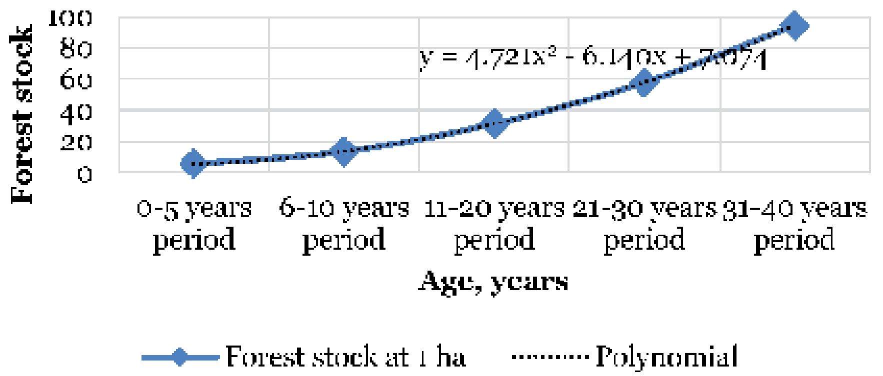

Figure 8.
Dynamics of changes in the growing stock per 1 hectare of young larch growth by age periods. The figure shows the growing stock of stands per 1 hectare in cubic meters (axis of ordinates) for age periods up to 5 years, from 6 up to 10 years, from 11 up to 20 years, from 21 up to 30 years, and from 31 up to 40 years. The equation describing the relationship of the growing stock by age periods is also presented.

plots with a total area of 14.25 hectares, as well as statistical processing of the taxation description at the plot of 128 hectares, while young growth of natural and artificial origin were studied.

As we can see from **Figure 1**, the height of young growth increases with age, while the most intensive increase in height occurs at the age period from 21 up to 40 years. The maximum height of a pine tree at the age of 40 is approximately 10 m, which corresponds to bonitet class III.

Figure 2 shows the dynamics of changes in the average diameter of young growth of trees by age periods. From the graph in **Figure 2**, it is possible to trace the dynamics of increasing the average diameter from 0.37 to 9.5 cm at the age of 40.

Figure 3 shows the dynamics of relative density and basal area of young pine growth by age periods. It is interesting that the average density of the stand at the age of 1–10 years is relatively small (0.5–0.55), and by the age of 40 years, the basal area reaches a value of 0.76. Such young plants can already be referred to high-density plantings.

Figure 4 shows the dynamics of changes in the growing stock of young pine growth per 1 hectare by age periods. At the age up to 10, it was impossible to determine the growing stock because there are no volume tables for such thin-sized stems. The period from 21 up to 40 years is characterized by a significant increase in the average stock per 1 hectare and reaches a value of up to 115.9 cubic meters per 1 hectare.

Figures 5–8 show generalized results of studies of young larch growth for different age periods. The materials obtained at the sample plots and as a result of processing the taxational descriptions of the Padunsky forest area of the Irkutsk region are statistically processed and generalized. As it can be seen from the figures, the inventory indices differ somewhat from the inventory indices of young pine growth.

The figure shows the height of trees in meters (axis of ordinates) for age periods up to 5 years, from 6 up to 10 years, from 11 up to 20 years, from 21 up to 30 years, and from 31 up to 40 years. The equation describing the relationship of height and age periods is also presented.

Figure 5 shows the dynamics of changes in the height of young plants by age periods. The change in height can be described by a logarithmic curve with sufficient accuracy (correlation coefficient 0.99). The maximum height at the age of 31–40 years is 10 m, which exactly corresponds to the height of pine trees of the same area. These results prove the successful co-growth of Scots pine and Siberian larch as light-loving tree species that are biologically well compatible throughout pathogenesis.

Figure 6 shows the change in the average diameter of young larch trees by age periods. The relationship of the dynamics is also described by a polynomial curve, with a maximum diameter of 9.5 m, which also corresponds to the data on pine trees. This coincidence indicates a good compatibility of pine and larch as light-loving and fast-growing tree species.

Figure 7 shows the dynamics of changes in the relative basal area of young larch growth by age periods. The stand density is relatively low and ranges from 0.5 to 0.67, which is lower than that of the Scots pine. This is due to the more powerful root system of the larch which requires more space to accommodate.

Figure 8 shows the dynamics of changes in the growing stock of 1 hectare of young larch growth by age periods. This relationship is relatively well described by a polynomial curve with a high degree of accuracy. The growing stock per 1 hectare is small and reaches 95–100 cubic meters per 1 hectare which is lower than that of young pine trees which can also be explained by the relatively small stand density. However, larch at the age of maturity can reach a large stock (up to 500 m^3), which is higher than that of pure stands of Scots pine at the same age.

A sample plot in the Kuitun forest area of the Irkutsk region was selected as an example of creating mixed forest cultures of Siberian larch and Scots pine. Forest cultures were created at the site of the fire. The area of forest cultures is 214 hectares; forest cultures were created by sowing in 1997. Currently, the age of forest crops is 21 years. When creating forest crops, a partial pre-sowing preparation of the soil was carried out with PLP-135 plow. The distance between the furrows is 2 m, and the width of the plowed furrow is 1.3 m. The scheme for creating forest crops is shown in **Figure 9**.

The plot has the type of forest vegetation conditions B2 with fresh sandy loam soil, the forest is of the cowberry-grass type. The seeds were purchased in the Republic of Tuva (Kyzyl). Pine and larch seeds have the 1 class of quality. Sowing was carried out in spring, when sowing the seeds were evenly mixed in the proportion of 70% larch and 30% pine. Seeding was carried out manually in rows. The seedlings sprouted perfectly, and now we have an excellent example of creating mixed larch-pine forest crops.

Figures 10 and **11** show photos of experienced larch and pine forest crops. The photo shows that the larch is taller than the pine. The trunks are flat and fully wooded. Thinning in rows is required, as overgrown forest crops are too dense in the rows (**Figure 11**).

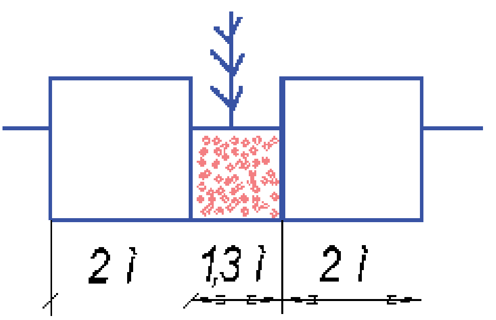

Figure 9.
Diagram of the creation of mixed forest crops.

Figure 10.
Experimental mixed forest cultures of larch and pine (the current composition of 7L3S).

Figure 11.
The state of forest crops in a row.

For a detailed study, four sample plots of 0.5 ha were established in forest crops. The number of trees in the test areas was 1300–1400, which is enough for statistical processing of materials. Processing of materials was carried out separately for the elements of the forest—larch and pine. The general characteristics of forest crops at sample plots are presented in **Table 1**.

Age and composition	Type of forest and type of vegetation conditions	Average height, m	Average diameter, cm	Average site index (bonitet), class	The average relative basal area	Average stock per 1 ha	Area, ha
21 year 7Л3С	Cowberry /B_2	10.1 ± 0.30	8.7 ± 0.32	1.5	0.77 ± 0.22	73.6 ± 3.22	.0.4
Larch	Cowberry /B_2	11.3 ± 0.50	9.3 ± 0.41	1.0	0.56 ± 0.17	51.7 ± 2.11	0.4
Pine	Cowberry /B_2	8.9 ± 0.25	8.1 ± 0.34	3.0	0.21 + 0.05	21.9 ± 0.95	0.4

Table 1.
Average taxation indicators of mixed forest crops of larch and pine.

D1,3	The number of trees, pieces/%	Average height, m	Cross-sectional area of one trunk, m^2	Sum of cross-sectional areas of stem diameter, m^2	Volume of one trunk, m^3	Volume of stem diameter, m^3
4	337/7.9	5.2 ± 0.2	0.0013	0.4381	0.0037	1.2469
6	1283/30.5	6.8 ± 0.3	0.0028	3.5924	0.0101	12.9583
8	1206/28.5	8.5 ± 0.4	0.0050	6.0300	0.0261	31.4766
10	874/20.7	10.7 ± 0.5	0.0078	6.8172	0.0261	22.8114
12	302/7.2	11.5 ± 0.5	0.0113	3.4126	0.0672	20.2944
14	218/5.2	12.0 ± 0.7	0.0154	3.3572	0.0672	14.2464
Total per 2.0 ha	4220/100.0			23.6475		103.034
Total per 1 ha	2110			11.8275		51.51

Table 2.
The results of the inventory of larch trees at the sample plots.

For more detailed information on the tax indicators, the total data for four sample areas is given. The total area of the inventory was 2.0 hectares. **Table 2** shows the inventory indices of larch.

The average cross-sectional area of one tree is 0.0068 m^2, the average diameter is 9.3 cm, the average height is 11.3 m, and the relative basal area is 0.56; the bonitet class is first, the growing stock per 1 ha is 51.5 m^3, and the average volume of the tree is 0.0245 cubic meters.

Figure 12 shows the relationship between the height and diameter for larch at the sample plots.

As we can see from **Figure 12** and **Table 2**, the height and diameter are interrelated. The height ranges from 5.2 to 12.0 m. As an example, **Figure 13** shows the distribution of the number of trees by stem diameter at sample plot 2.

On the ordinate axis, you can see the percentage of the total number of trees and on the abscissa axis, the diameter at the height of 1.3 m in centimeters.

As we can see from **Figure 13**, the distribution does not follow the normal distribution curve, and the trees with a diameter of 6–10 cm prevail. However, it should be noted that there are trees with a diameter of 12 and even 14 cm.

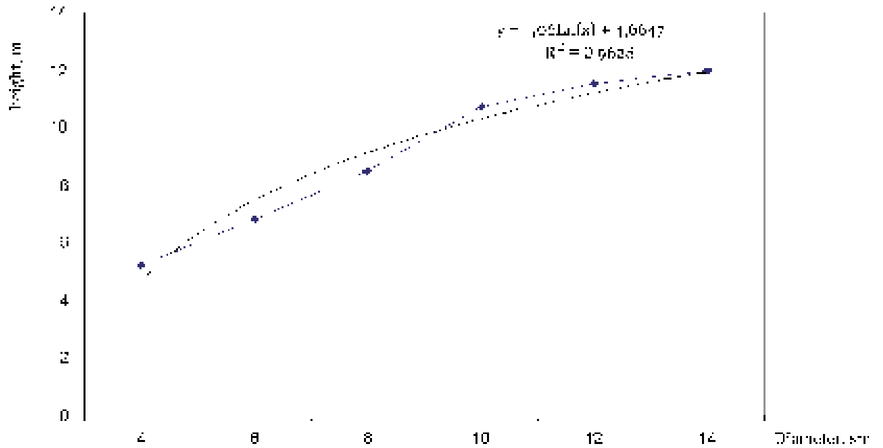

Figure 12.
Relationship of height and diameter in experimental larch forest cultures. On the ordinate axis, the height is in meters; on the abscissa axis, the diameters are in centimeters.

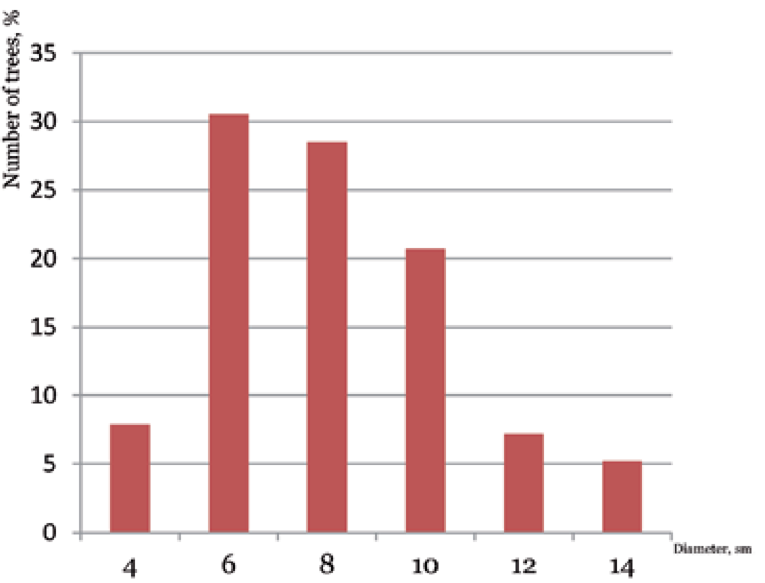

Figure 13.
Distribution of the number of larch trees by stem diameter.

Table 3 shows the total data for four sample plots of pine trees.

The average cross-sectional area of one pine tree is 0.006 m^2, the average diameter is 8.1 cm, the average height is 8.7 m, the relative basal area is 0.21, the bonitet class is third, and the growing stock of pine for 1 hectare is 18.5 m^3. The total growing stock of larch and pine per 1 hectare is 70.02.

Figure 14 shows the relationship between the height and diameter for pine trees at the sample plot.

As it can be seen from **Figure 14** and **Table 3**, the relationship between the height and diameter has a fairly high degree of correlation R2 = 0.9323, and the height of the pine tree ranges from 5.8 to 11.7 m. As an example, **Figure 15** shows the distribution of the number of pine trees by stem diameter at sample plot No 2.

As it can be seen from **Figure 15**, the distribution of pine by stem diameter approximates the normal distribution curve. Most pine trees are from 6 up to 10 cm in

D1,3	The number of trees, pieces%	Average height, m	Cross-sectional area of one trunk, m^2	Sum of cross-sectional areas of stem diameter, m^2	Volume of one trunk, m^3	Volume of stem diameter, m^3
4	141/7.9	5.8 ± 0.2	0.0013	0.1833	0.0010	0.1410
6	539/30.1	7.0 ± 0.3	0.0028	1.5092	0.0107	5.7673
8	527/29.6	8.1 ± 0.4	0.0050	2.6350	0.0225	11.8575
10	438/24.5	10.9 ± 0.54	0.0078	3.4164	0.0225	9.8550
12	143/7.9	11.7 ± 0.58	0.0113	1.6159	0.0657	9.3951
Total per 2.0 ha	1788			9.3598		37.0159
Total per 1 ha	894	8.7 ± 0.4	0.006	4.6799	0.00244	18.5079

Table 3.
The results of the inventory indices of pine at the sample plots.

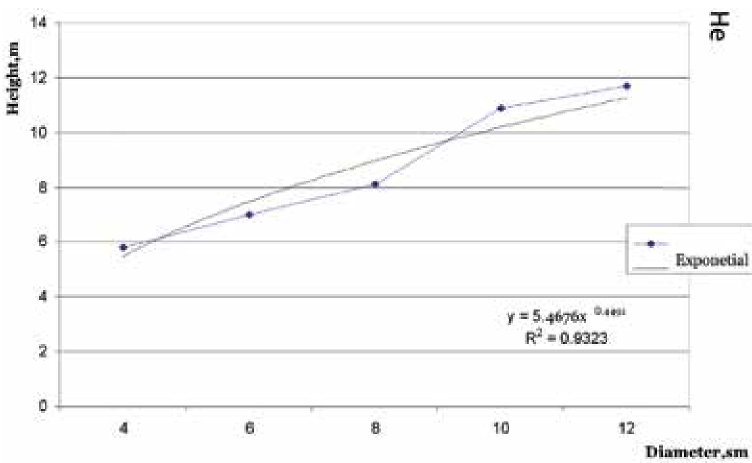

Figure 14.
Relationship of height and diameter of experimental pine forest crops. On the ordinate axis, we can see height in meters and on the abscissa axis, diameter at the height of 1.3 m in centimeters.

diameter. It is important to track the dynamics of growth in height for pine and larch. In **Table 4** data on the annual growth of larch and pine for the last 2 years are given.

As it can be seen from **Table 4**, larch has the highest annual growth in height, and for 2016 and 2017, the increase is higher than the average total growth which is 0.42 m on average, and the increase in height over the past 2 years for some trees reaches 0.61 m. The average total increase for 21 years is 0.42 (column 4). Let us consider the growth in height of pine trees.

The average total increase for 21 years is 0.33 (column 4). As it can be seen from **Table 5**, the pine tree also has a good annual growth in height, and for 2015 and 2016, the growth is higher than the average total growth, which on average is 0.033 m, and the growth in height over the past 2 years for some stem diameter reaches 0.60. On average, the growth of pine is lower than that of larch.

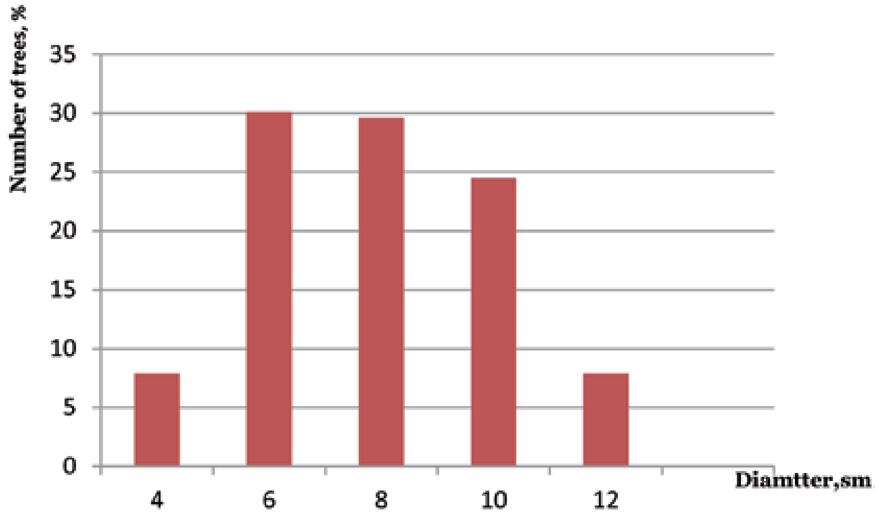

Figure 15.
Distribution of the number of pine trees by stem diameter. On the ordinate axis, we can see the percentage of the total number of trees and on the abscissa axis, the diameter at the height of 1.3 m in centimeters.

Tree view	D1,3	Growth in height, 2015, m	Growth in height, 2016, m	Average total height increase, m
1	2	3	4	5
Larch	4	0.28 ± 0.05	0.21 ± 0.05	0.19 ± 0.05
	6	0.38 ± 0.05	0.23 ± 0.05	0.25 ± 0.05
	8	0.38 ± 0.05	0.36 ± 0.05	0.31 ± 0.05
	10	0.61 ± 0.05	0.60 ± 0.05	0.40 ± 0.05
	12	0.63 ± 0.05	0.61 ± 0.05	0.43 ± 0.05
	14	0.63 ± 0.05	0.60 ± 0.05	0.44 ± 0.05
Average result		0.48 ± 0.5	0.44 ± 0.05	0.42 ± 0.05

Table 4.
Annual growth of the larch in height according to the materials of sample plots.

Tree view	D1,3	Growth in height, 2015, m	Growth in height, 2016, m	Average total height increase, m
1	2	3	4	5
Pine tree	4	0.23 ± 0.03	0.21 ± 0.03	0.21 ± 0.03
	6	0.28 ± 0.05	0.20 ± 0.04	0.26 ± 0.05
	8	0.34 ± 0.08	0.34 ± 0.07	0.30 ± 0.06
	10	0.56 ± 0.07	0.56 ± 0.09	0.40 ± 0.07
	12	0.58 ± 0.08	0.60 ± 0.09	0.43 ± 0.09
Average result		0.38 ± 0.062	0.38 ± 0.064	0.33 ± 0.06

Table 5.
Annual growth of pine trees by height based on the materials of sample plots.

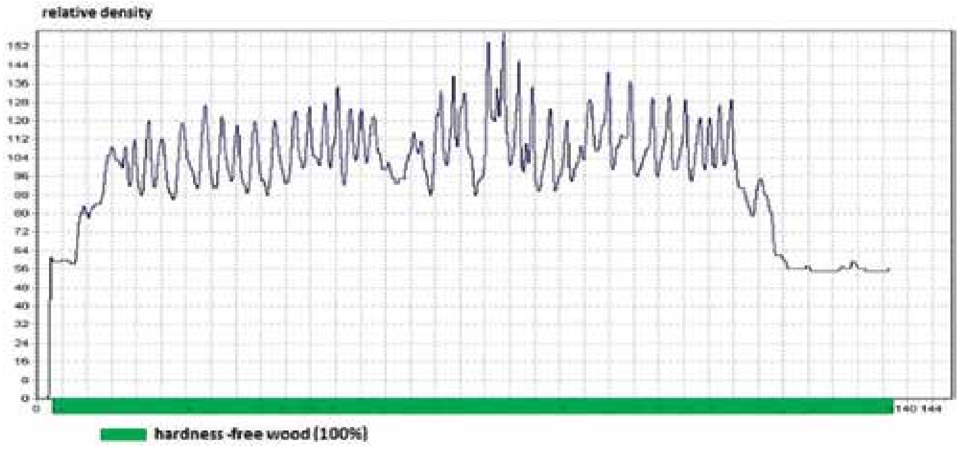

Figure 16.
Resistograms of Siberian larch. On the ordinate axis, we can see the relative density of Siberian larch wood according to the Resistograph 4450 device and on the ordinate axis, the diameter at the base of the tree in centimeters.

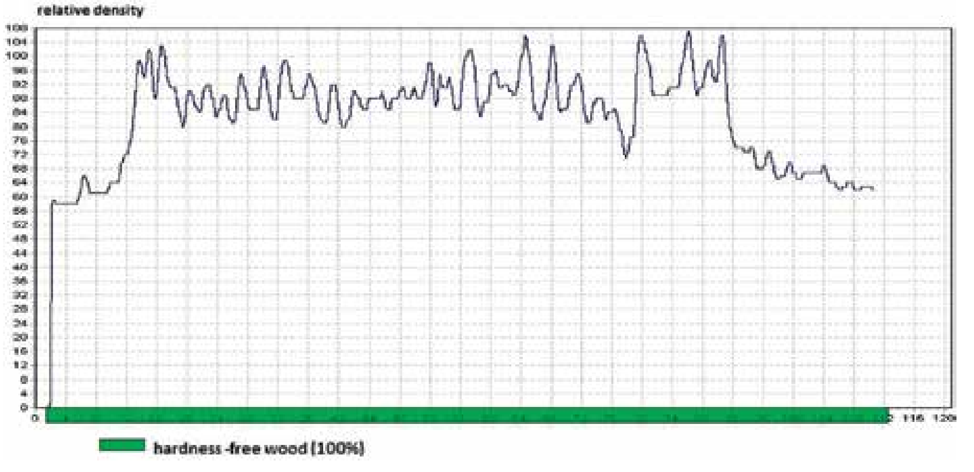

Figure 17.
Resistograms of scots pine. On the ordinate axis, we can see the relative density of Siberian larch wood according to the Resistograph 4450 device and on the ordinate axis, the diameter at the base of the tree in centimeters.

Additionally, using the Resistograph 4450 device, the quality of the wood was evaluated by examining the cross section of test pine and larch trees (40 trees in total). Resistograms showed high strength indicators of the cross section of a tree in the butt part without signs of a decrease in the hardness of the wood (**Figure 16**).

From the resistogram (**Figure 16**), it can be concluded that the Siberian larch wood is healthy, there are no pathologies, and there is a significant decrease in the strength; the presence of rot is not observed. The difference between the relative density of early wood (60 for early wood) and late wood (162 for late wood) is particularly clear. The drop in the relative density values at the beginning and at the end of the resistogram shows the passing through the bark of the studied cross sections of the tree.

From **Figure 17** it can be seen that the wood is healthy and there are no any pathologies. The difference in the relative density of early and late wood is less than that of larch and ranges from 60 for early wood to 108 for late wood. On the basis of comparison of the resistograms, we can conclude that the relative density of late wood of Siberian larch is about 50% higher than that of Scots pine.

4. Chapter conclusions

The studies conducted to identify the growth and structure of wood of experimental mixed forest crops allow us to draw the following conclusions:

1. The main inventory indices of mixed pine-larch stands, including the composition of stands, are formed in the cowberry and cowberry-mixed grass and mixed types of forest at the young age.

2. Young trees in these types of forests have an average productivity that is approximately equal to bonitet class III; mixed young trees of pine and larch represent stable stands with high biological diversity.

3. Experimental mixed forest crops of pine and larch with the total area of 214 hectares, established in the Irkutsk region, indicate that pine and larch by the age of 21 have good growth and development. At the same time larch is higher than pine and can grow up to bonitet class 1.

4. The closure in the rows is high; in general, per 1 hectare the stand density is 0.77 which means that in the rows the density is more than 1.0. In these forest crops, thinning is required to provide additional opportunities for growth and development of forest crops [12, 13]. It is recommended to expand the creation of mixed pine-larch and larch-pine forest crops both by sowing and planting.

5. In forest cultures, slender full-wood trees are formed with good physical and mechanical properties of wood. Thinning young plants (a sufficiently high degree of thinning 35–50%) can achieve more uniform placement of trees in rows, which will increase diameter and height, reduce the severity of intra- and interspecific competition, and increase the productivity of experimental forest crops. It is also recommended to practice creating mixed forest crops of pine and larch by sowing or planting in appropriate forest-growing conditions, thereby preserving larch as the predominant tree species of Russian forests and increasing the biological diversity of light taiga forests in Eastern Siberia [7–9].

6. The prospects for further development of research should be seen in a further study of the growth and development of light-coniferous mixed stands in the Irkutsk region of the Angara region in the design and construction of a mathematical model for the dynamics of light-coniferous taiga plantations with the aim of increasing their biological stability and productivity, as well as improvement of the quality of the trunk and tree canopy and physicomechanical properties of wood of pine and larch, silvicultural measures in particular to optimize the quantity of sowing and planting, and commercial thinning in young stands improving the composition and quality characteristics of pine and larch stands.

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References

[1] Buzykin AI, Pshenichnikova LS. Formation of Pine-Deciduous Young Plants. Novosibirsk: Nauka; 1980. p. 168

[2] Varaksin GS, Polyakov VI, Inyushkin SV. Assessment of the state and growth of experimental pine and larch crops in the southern taiga subzone of Central Siberia. Forestry Information. 2002;**9**:23-28

[3] Gvozdev VK, Grigoriev VP, Chisty VI. Forestry and Reforestation. Minsk: The Design PRO; 2003. p. 236c

[4] Klyuchnikov MV. Forest characteristics of larch forests in the south of Western Siberia. Coniferous of the Boreal Zone. 2008;**XXV**(l-2):51-58

[5] Plaksiva IV, Sudachkova NE, Buzykin AI. Influence of planting density on xylogenesis and metabolism of common pine and Siberian larch. 2003;**4**:47-53

[6] Runova EM, Serkov DV. Forest management and taxation assessment of pine-leaf stands in the Irkutsk region. Current Problems of the Forest Complex. 2014;**39**:33-35

[7] Runova EM, Markatyuk AA, Gavrilin II, Vedernikov IB. Current state of boreal forests in eastern Siberia in the aspect of natural renewal of scots pine. Systems Methods Technologies. 2013;**1**(17):163-169

[8] Runova EM, Vedernikov IB. Factors of stability of coniferous boreal forests of the Angara region to successional processes. Forest Bulletin. 2012;**1**(84):127-131

[9] Zhang SA. Current state of the pine forests of the Angara region /CA Zhang, OA Puzanova, EM Runova// Successes of Modern Natural Science. No. 7. 2013. pp. 52-53

[10] Anuchin NP. Forest Taxation: Textbook. 6th ed. Moscow: VNIILM; 2004. p. 552

[11] Buzykin AI, Pshenichnikova TA. Thinning and productivity of diverse young Siberian larch. Forest Economy. 2011;**3**:33-39

[12] Lavrenov MA, Vasiliev SB, Nikitin VF, Savchenkova VA. Individual variability of morphological features of polish larch in conditions of introduction. Forest Engineering Journal. 2019;**4**(36):33-41. DOI: 10.34220/issn/2222-7962|2019.4/4

[13] Maudlin IV, Sudachkova NE, Buzykin IA. Influence of planting density on xylogenesis and metabolism of scots pine and Siberian larch. Forest Science. 2003;**4**:47-53

Chapter 5

Sustainable Management of National Parks and Protected Areas for Conserving Biodiversity in India

Abhishek Kumar, Rajni Yadav, Meenu Patil, Pardeep Kumar, Ling Zhang, Amandeep Kaur, Sheenu Sharma, Sabir Hussain, Diksha Tokas and Anand Narain Singh

Abstract

Habitat loss due to human activities and climate change is synergistically posing serious threats to the global biodiversity leading to irreversible extinction of several species. In wake of recent extinction, several forests are declared as protected areas where no more human activities are allowed. However, the scope of these protected areas got broadened from mere conservation to poverty alleviation and sustainable development during the past decades. Though these protected areas seem to be supportive of the biodiversity conservation, several challenges and gaps have emerged that need to be addressed for effective conservation and sustainable management in these protected areas. Therefore, the present chapter aims to address the roles, challenges, and approaches for conservation, and sustainable management in protected areas of India. Based on the published literature, we have found that protected areas proved to be a successful strategy for the conservation of wild animals and plants. However, management of poaching, man-wildlife conflicts, funding, extensive resource use, and tourism is still a challenge for some national parks of the country. Although governmental policies have addressed some of these challenges, only limited success has been achieved so far. Therefore, further studies need to assess the efficiency of protected areas for biodiversity conservation and devise the mechanisms for effective sustainable management of these protected areas.

Keywords: biodiversity conservation, national parks, protected areas, sustainable management

1. Introduction

The variability in all life forms at different scales on the earth is collectively termed as biodiversity. Further, biodiversity is not evenly distributed on the globe as tropical regions are relatively more diverse than other geographical regions. It is an integral component that ensures and sustains our own life by providing necessary services from oxygen to clean water and from food to clothing. Despite their central role in sustaining life, species are disappearing at alarming rates, and it has been estimated that about 27% of the total species are facing threats to extinction [1]. Much of today's large-sized vertebrate animals represent less than 5% of their historical ranges. Many species such as the greater one-horned rhino (*Rhinoceros unicornis*), Asiatic lion (*Panthera leo persica*), and the hard-ground barasingha (*Rucervus duvaucelii branderi*) are restricted to microscopic remnants of their historical range. The biggest threats are posed by habitat destruction by human activities together with changing climatic conditions. Therefore, there is an urgent need to take measures to protect biodiversity in order to sustain life on earth.

Several strategies and measures have been proposed for biodiversity conservation that varies with the type of habitat and their requirement. Protected areas are one of the prominent strategies for the in situ conservation of species and their habitats. However, this concept is not recent to India, and provisions for the establishment of reserved forests and laws such as the death penalty for killing elephants date back to the third century B.C. as mentioned in Kautilya's *Arthashastra* [2]. Many of today's existing national parks once served as a hunting preserve for the local Maharajas and Emperors during the colonial and precolonial era [3]. It was in 1936 when the Hailey (now Jim Corbett) National Park was formally notified as to the first national park of the country, and there were only four national parks till the 1970s (**Figure 1**). However, the continued hunting and habitat destruction resulted in a dramatic decrease in the population of tigers in the country. In the wake of this alarming decline of tigers, the then prime minister of India, Late Smt. Indira Gandhi, launched the "Project Tiger" in 1973, which still stands as the world's most comprehensive tiger conservation initiative. She established nine tiger reserves, hired guards to patrol them, and forcibly moved whole villages outside their perimeters. These efforts proved to be fruitful as the tiger numbers topped to 4,000 along with an increase in their prey, and thus, India had put forward a global model for wildlife conservation. Since then, the protected area network of the country increased exponentially after the 1980s, and presently there are about 104

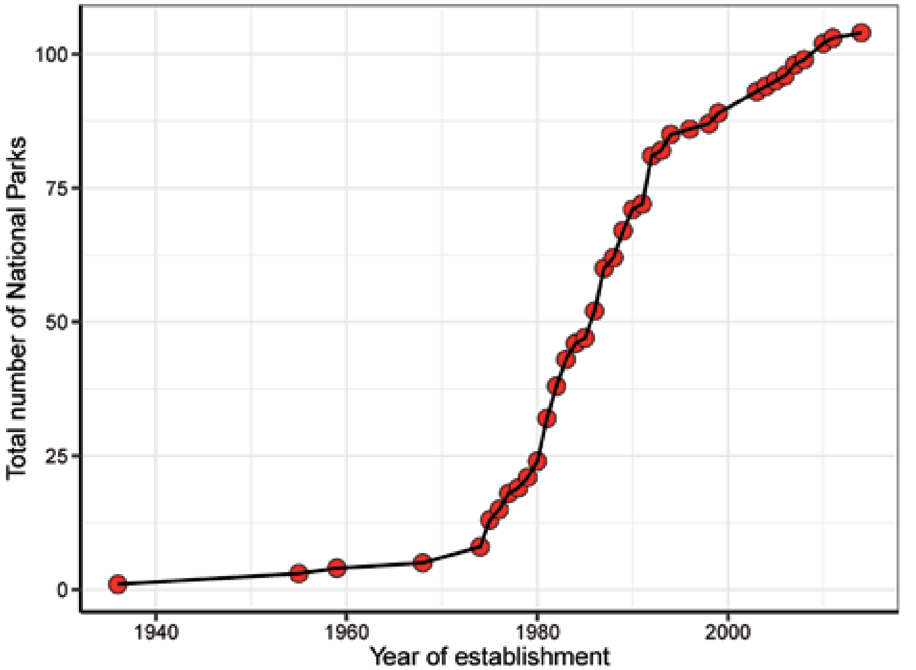

Figure 1.
An exponential increase in the total number of national parks in the country India after the 1970s [4].

IUCN Category II national parks covering an area of 40,501 km^2, which is 1.23% of the geographical area of the country [4]. Currently, there are about 870 protected areas in 2019 including 104 national parks, 551 wildlife sanctuaries, 88 conservation reserves, and 127 community reserves.

Although these protected areas were initially established for biodiversity conservation, their objectives have now expanded to also include human-centered socioeconomic development. Besides being critical to preserving global biodiversity and stemming from the extinction crisis, these protected areas bring tremendous cultural, ecological, spiritual, and scientific benefits to society. Now, a new paradigm of conservation incorporates the socioeconomic development of local people and encourages the sustainable use of resources within the protected areas. This approach promotes the utilizing of various benefits from protected areas for the socioeconomic development of the local residents. Thus, the scope of national parks has been broadened to poverty alleviation and the development of the nation. Although this paradigm shift has been widely accepted and appreciated, there are some challenges to the effective management of these protected areas.

Therefore, the present chapter aims to assess the roles and challenges of national parks for biodiversity conservation and sustainable development in India using published case studies. To accomplish this, we have searched the available literature databases, viz., Web of Science, Scopus, Google Scholar, ScienceDirect, and NCBI, using keyword combinations such as "National parks AND India," "Sustainable development AND India," "Wildlife sanctuary AND India," and "protected areas AND India" from the year 1985 to recent. Additionally, gray literature from other additional sources including books, unpublished theses, governmental reports, and newsletters was also consulted. After removing the duplicate, insignificant, and inappropriate studies, in total, 50 more relevant studies were included for the preparation of this chapter. Here, we have first discussed the major roles of national parks in conservation, tourism, and ecosystem services. Then various challenges faced by national parks such as conservation, tourism, resource

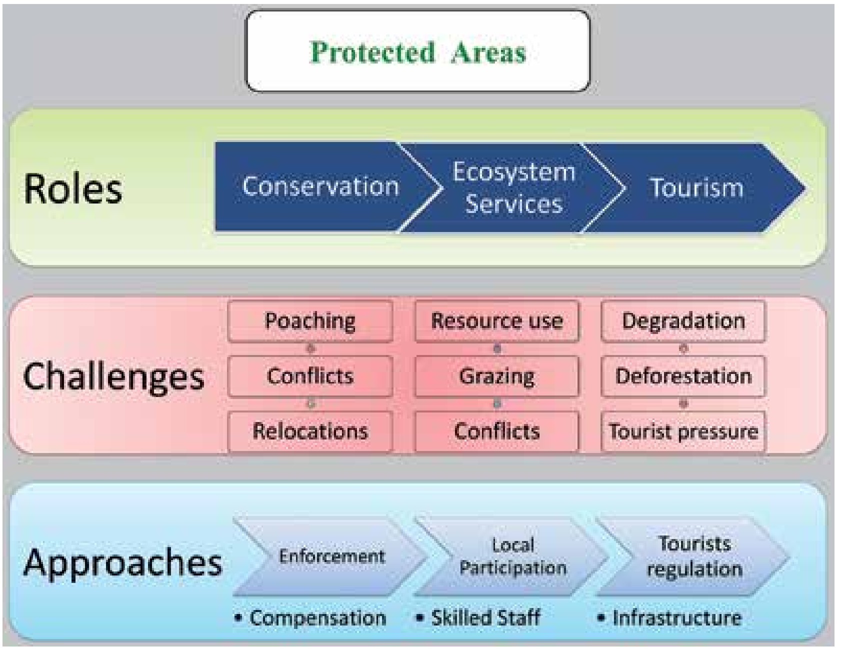

Figure 2.
Major roles, challenges, and approaches for sustainable development of protected areas in India.

use, human relocation, and conflicts have been discussed. In the next section, two major conservation paradigms, i.e., preservationism and sustainable use, their merits, and demerits are discussed. Furthermore, major challenges to conservation and management of national parks are highlighted with suitable examples from Indian case studies (**Figure 2**).

2. Role of national parks

National parks including tiger reserves not only conserve biodiversity but also play an important role in local people's livelihoods by providing several direct and indirect benefits and services [5]. These areas are important components of tourism, agro-biodiversity, spirituality, capacity building, poverty reduction, and sustainable development. The ecological, economic, social, and cultural benefits provided by protected areas both conserve biodiversity and support human well-being. Apart from providing economic benefits through sustainable use of bioresources, these areas also serve as important sites for documenting and quantifying biodiversity and various services provided by them. In addition, protected areas act as a buffer to mitigate the impacts of environmental disturbances and climate change.

2.1 Biodiversity conservation

National parks are the critical tool to conserve biodiversity in the face of the global crisis of species extinction and the loss of the world's natural capacity to support all life and human existence. This can be evidenced by the fact that a large proportion of biological diversity exists only in protected areas. Many national parks of the country harbor important wild relative of cultivated crops and thus serving as a reservoir of agro-biodiversity. Furthermore, some species like brow-antlered deer (*Rucervus eldii eldii*), the Indian rhinoceros (*Rhinoceros unicornis*), the Asiatic lion (*Panthera leo persica*), and other large vertebrates can be found only in some national parks, and their populations outside are almost diminished. According to the report of the country-wide assessment of the status of tigers, co-predators, and their prey in India, there are about 1,706 tigers occupying 81,881 km^2 of the area in 2010. This 20% increase in tiger numbers is due to the good management of tiger reserves and protected areas. Thus, national parks in India proved to be an effective strategy for species conservation. While conserving species, these areas also protect habitat, and therefore these are effective for checking land use pressures throughout the world as most of the national parks have maintained their borders against human-based encroachment [6]. Furthermore, healthier ecosystems with high biodiversity tend to resist erosion, soil loss, or water quality loss. According to a study conducted by the Indian Institute of Forest Management (IIFM) Bhopal, it has been estimated that the stock value of tiger reserves to protect and conserve tigers vary from INR 22 to 656 billion [7].

2.2 Ecosystem services

Protected areas provide a range of associated economic, social, cultural, and spiritual benefits, which are together called ecosystem services. Clean water, clean air, access to food sources, buffers of weather events, cultural and spiritual values, and raw materials for consumers are some of the ecosystem services that ensure the well-being of humanity. Many cities and villages directly rely on these natural reserves for essential resources such as clean drinking and irrigation water. For example, the metropolitan city of Mumbai receives its drinking water from the

Sanjay Gandhi National Park [8]. About 70% of protected areas of the country are inhabited by local communities and also partly grazed by local livestock. Almost 60% of protected areas are subjected to the collection of non-timber forest products [9]. For example, forest products like fuelwood, fodder, and green leaves are consumed and sold by the local people living close to Kalakad Mundanthurai Tiger Reserve [10] and Kumbhalgarh Wildlife Sanctuary [3]. Furthermore, natural and cultural resources in tiger reserves are important drivers of tourism, supporting local earnings, and employment [7]. A study conducted by the Indian Institute of Forest Management, Bhopal, provided quantitative and qualitative estimates for as many as 25 ecosystem services from selected tiger reserves of the country. It revealed that the benefits originating from selected tiger reserves had a monetary value ranging from INR 8.3 to 17.6 billion annually. In terms of unit area, this translates into INR 50,000–190,000 per hectare per year. While creating a new tiger reserve in the Pilibhit-Dudhwa landscape, covering an area of approximately 1000 km^2 would cost approximately INR 500 billion [7].

2.3 Wildlife tourism

Although tourism in India is dominated by its cultural heritage, wildlife also acts as a significant component of tourism in the country. Since India is now hosting more than 50% of world tigers, therefore it is a center of attraction for a large number of domestic and foreign tourists every year. Further, national parks represent the beauty of undisturbed nature, and thus, it significantly attracts tourists, enthusiasts, and nature lovers, though the number of tourists has fallen in some national parks such as Keoladeo of Rajasthan [11]. Therefore, wildlife and nature tourism can potentially benefit local communities economically by creating opportunities for jobs and businesses. For example, some of the local *Adivasis* of Sanjay Gandhi National Park are employed within the park as caretakers of the animals, security guards, cleaners, casual labor, and workers in the lion and tiger safari [12]. Similarly, local people associated with ecotourism in Kaziranga National Park of Assam not only became economically well-equipped and enjoys better living conditions, but they also feel more politically empowered [13]. Furthermore, the Gonda people of Pench National Park earn livelihoods for their unique traditional arts and dance activities, which can alleviate poverty and improve the quality of life among these people. Thus, national parks are an important source of earning money for both local people and the government. For example, the park authorities of Sariska National Park collect and deposit to the state government about INR 28–53 lakh per year, while the Pench National Park has collected a revenue of about INR 28,808,123 during 2016–2017 [14]. Furthermore, it can also potentially promote the participation of local stakeholders for the effective conservation of biodiversity. Though the number of visitors in national parks and wildlife sanctuaries are increasing in the country, it still contributes less than 10% of all tourism in India. The park offers unusually large numbers of local employment opportunities for non-park staff [11].

3. Challenges to national parks

Although protected areas provide opportunities for biodiversity conservation and sustainable development, numerous challenges related to the effective management of national parks also emerge which need to be addressed. It has been acknowledged that many of the national parks in the country are under pressure from the clearing, hunting, logging and, to a lesser extent, fire and grazing. Also, the majority of eco-development projects have not effectively addressed the importance of local concerns [15, 16]. These issues and conflicts have developed a confidence crisis and negative attitude in local people's perceptions. Furthermore, linking economic benefits to conservation is difficult where wildlife is highly endangered, pressure on biomass resources is high, and stakeholders are many. This could be more serious if the economic benefits from the parks are few and the number of beneficiaries is large.

3.1 Conservation

India takes pride in tiger conservation worldwide through the establishment of tiger reserves under its Project Tiger. However, it turned a matter of shame, when the news of the disappearance of all the tigers from the Sariska National Park haunted all the conservationists, nature lovers, and the whole country in December 2004. Investigations revealed that poachers along with local villagers and trading middlemen had been killing the tigers since July 2002 [14]. This local extinction of tigers from the Sariska was the first confirmed tiger extinction in a Tiger Reserve, though Kailadevi Wildlife Sanctuary was also speculated for the local extinction of tigers. Not only in Sariska but more recently in 2010, the Panna Tiger Reserve has also become "tigerless," and even Sanjay Gandhi National Park may face the same in upcoming years [17]. Thus, wildlife conservation is not ensured against human pressures even under the well-controlled mechanisms of protection [18].

Apart from poaching, habitat degradation and destruction by various human-mediated activities possess serious threats to the wildlife even in the protected areas. For example, developmental works cause habitat degradation and fragmentation as happened in the Raja Ji National Park and Corbett National Park [19]. Also, the expansion of pastoralists creates pressure on wildlife, which results in increased human-wildlife conflicts [19].

Wild animals including tigers and elephants are frequently killed by surrounding villagers citing various reasons such as damage to crops, preying of livestock, and killing of local people. A series of such incidents can be cited in different protected areas such as poisoning and killing of elephants in Bandipur National Park and Palamau Tiger Reserve, poisoning of wild dogs in Kanha Tiger Reserve, and killing of tigers in Dudhwa Tiger Reserve, Kanha Tiger Reserve, Nagarjunasagar-Srisailam Tiger Reserve, and Pench National Park. Thus, human-wildlife conflicts pose a major constraint for the conservation and sustainable development of protected areas. The nature and intensity of these conflicts vary with bio-geographical distribution and social characteristics [20].

Many protected areas in Chhattisgarh and Jharkhand are under the control of Naxalites (a group of people following the legacy of Marxism-Leninism), and these people often poison wild animals citing that they kill people. For example, as many as 20 cases of tiger poisoning were reported from the Nagarjunasagar-Srisailam reserve of Andhra Pradesh. The control of Naxalites is so prominent in some areas that no forest guard had even courage to enter in the Indravati reserve of Chhattisgarh since 2002.

3.2 Resource use

Regulating and managing resource use and extraction has always been a major challenge for protected area management. However, increased intensity of conservation efforts has introduced a complex bribery system, which opened another window to local people for accessing forest resources [3]. Further, activities of smugglers and poachers such as Veerappan continue to extract a substantial amount of forest resources, kill wildlife, and even murder government officials in some protected areas. This access eventually increased extensive pressure from the local communities in the form of illicit tree felling, grazing, and extraction of various forest products leading to the degradation of the forest [21]. Such reports of forest degradation also echoed from the Bhadra Tiger Reserve, Biligiri Rangan Hills Temple Sanctuary, and Sariska National Park. These activities lead to poaching, jhum cultivation, construction, and developmental activities, which resulted in the extinction of some primates and other wildlife animals [22]. All these activities and resource use intensity lead to altered vegetation through time [23] resulting from reduced richness, regeneration, and density of forest trees [24]. Thus, man-made activities become more serious threats than natural fire and grazing in protected areas [6]. This is why the rate of forest loss is still high in some protected areas, not only in India but across the world [25]. Therefore, it becomes essential to protect natural areas from human impacts in such severe cases.

Local people are severely restricted or relocated from protected areas such as Sariska Wildlife Sanctuary, the Gir Forests, and Dachigam National Park for the sake of conservation during the 1970s, and thus, another important challenge has emerged for the sustainability of protected areas. The Baigas were displaced from the Banjar Valley Reserved Forest (now the Kanha National Park) because their slash and burn agriculture was interfering with the regeneration of the Sal (*Shorea robusta* C. F. Gaertn.). After the launch of Project Tiger in 1973, several relocations including Bandipur, Kanha, Nagarhole, and Ranthambhore National Park were carried and funded by the government [26], and recently the Adivasis and slum dwellers have been isolated from the Sanjay Gandhi National Park in Mumbai [12]. Whenever such a relocation takes place, there are great chances of compromise of livelihoods and rights of the local communities and forest dwellers. For example, the livelihoods of local communities were severely affected after displacement from Kuno Wildlife Sanctuary and Tadoba Andhari Tiger Reserve. The Sariska rehabilitation was ineffective because many spaces to which villagers were relocated lacked basic facilities and many residents returned to their original village in the sanctuary [14]. Such memories develop a negative attitude of local communities toward subsequent relocation programs. This eventually leads to the conflicts which again hinder the conservation and sustainable management of protected areas. The Indian Institute of Public Administration, New Delhi, in 1989 reported that most of the forest managers have communicated about the cases of illegal grazing, hunting, and poaching in wildlife reserves. Furthermore, the forest guards have faced offenses such as setting reserves on fire, and while opposing such offenses, they often get attacked and assaulted by local communities [9]. Thus, the growing conflict between forest staff and local people perceived as an emerging threat to conservation.

3.3 Wildlife tourism

Wildlife tourism works both ways; if it provides economic benefits on the one hand, it can also prove to be detrimental for biodiversity on the other hand. Tourism often causes environmental degradation and threat for biodiversity leading to a compromise in ecological services. For instance, in Kashmir, tourism has caused increased extraction of forest resources such as firewood and other raw materials. The construction of hotels and guesthouses in forests causes forest degradation and deforestation, and after construction, they pollute the environment due to unscientific disposal of solid and liquid waste. This results in ecological disturbance by soil erosion and forest destruction [27]. The increasing number of tourists and their management has appeared as another challenge for the sustainability of protected areas. The number of visitors in protected areas of India has increased several folds only during the past few years. However, the levels of sustainability and carrying capacity are not estimated for many protected areas. Although the increased number of tourist visitors is often blamed for the negative impacts and environmental degradation, the lack of resources for effective visitor management technologies is also the real gap that one should blame for. This is because all the money collected locally needs to be submitted to the central government in most national parks in the country [8]. Nevertheless, tourism is not considered a major problem in some national parks such as Keoladeo National Park of Rajasthan [11]. Similarly, increased pilgrimage tended to degrade the biodiversity and habitat in some protected areas such as Periyar Tiger Reserve and Sariska National Park. Further, the economic benefits generated from tourism are not shared with local inhabitants, which causes a conflict between local communities and park authorities [5]. A recent study found that lack of coordination among various stakeholders and lack of government incentives are the most significant barriers to sustainable development in protected areas of the country [28].

4. Conservation models

"Preservationism" and "sustainable use" are perhaps the two conservation models among the conservationists of India. Although both conservation models aim to conserve bioresources and landscapes, "preservationism" restricts any human-mediated activities, whereas the "sustainable use" approach advocates the involvement of local people [29]. The sustainable use approach involves local communities for conservation of biodiversity with extractive human use, while preservationists argue that some species especially large vertebrates, habitat specialists, and other sensitive species cannot be conserved with high human densities and extractive use of forests. Both the paradigms have their own strengths and weaknesses, and therefore, none of the models can be explicitly applied to all the cases.

4.1 Preservationism

The preservationist paradigm of conservation is based on its biological, ecological, and ethical values of each species. It considers that mere maintaining ecosystem services and sustainable use do not go to preserve all the forms of biodiversity. Thus, it advocates strictly protecting natural ecosystems from human activity and ensuring that they are minimally altered [29]. Successful implementation of this approach has resulted in fruitful results, which are evident from the fact that most of the threatened wildlife is now only restricted to protected areas. For example, the Asiatic lions and the wild Ass can only be spotted in Wildlife Sanctuaries of Gujarat. Similarly, Kaziranga National Park of Assam has now become home to the single highest population (more than 60% individuals) of one-horned rhino and the Asian water buffaloes in the world. Further, the number of tigers has increased significantly from 268 in 1972 to more than 2900 in 2018 through the establishment of tiger reserves.

Although this approach is most common and successful for the conservation of large vertebrate animals and another organism including plants, it too has some demerits. The restriction of human activities and resource use usually gives rise to conflicts with local communities and administration. It emphasizes more on law and order problems, protection, poaching, and illicit resource use. Resettlements carried out in this approach often considered overly bureaucratic, authoritarian, and expensive. Furthermore, civil engineering works such as the construction of roads, waterholes, and watchtowers are taken more into consideration rather than conservation aspects such as implementation and effective management of wildlife. Therefore, preservationists must prove with examples that they can compensate the costs of local communities for their extractive use and livelihoods along with conservation of endangered species and ecosystems.

4.2 Sustainable use

It has been observed that several local communities use resources in a much judicious way rather than exploiting the resources. These traditional resource use practices involve temporal shifts in resource use such as food preference, hunting, spatial limitations for some forest areas (such as sacred groves), and shifting agriculture. Such resource use patterns of indigenous communities are considered sustainable which forms the basis of "sustainable use" paradigm of conservation in India [29]. This paradigm assumes that the upkeep and survival of biodiversity can be enhanced by providing control to local communities for traditional management as their livelihoods depend on biological resources. For example, nomadic Changpas of Ladakh have sustained their pastoralist lifestyles for centuries and coexisted with endangered wild species like the Snow leopard [8]. Similarly, the Indian state Kerala has attained social sustainability through their mutualistic equitable resource use rather than unequal competitive resource consumption [30]. Thus, when local communities are provided with the complete access and management of land use like shifting cultivation and pastoralism, local sustainability is maintained, and biodiversity is conserved in a more effective way [29]. However, this is not the case in every protected area and these traditional practices are not being followed in some reserved areas. For example, Kailadevi Wildlife Sanctuary, which was considered as a successful model of participatory conservation, has too suffered from the local extinction of tigers. Similarly, intensive jhum cultivation in a locally managed forest has not only reduced forest cover but also caused a decline in biological diversity [31]. Further, many local people such as Tibetan refugees, Gujjar, and other pastoralists do not follow the traditional practices of pastoralism that were maintained for centuries [8, 19]. Similarly, selling of community-owned reserves and growing of cash crops in northeast India have increased during the past decades [32]. Thus, traditional sustainable practices no longer seem to exist in reality, and they are being faded away even in sacred groves [33]. Therefore, this approach needs to put forward as examples for the successful conservation of large vertebrate species such as the tiger and elephant compatible with extractive use and high-density human populations. Before adopting any sustainable use models, the impact of uncontrolled human pressures on wildlife should be evaluated carefully [18].

5. Approaches for sustainable management

India followed the "preservationism" model for biodiversity conservation during the initial establishment of protected areas, but it resulted in increased conflicts with local people. In order to buffer conflicts of the local people, India was the first country to introduce the concept of "Joint Forest Management" in its National Forest Policy, 1988, which has the provision of involving the local communities for sustainable conservation and management of forests. Thus, there is a shifting paradigm from "preservationism" to "sustainable use" approach during the recent times. This approach is managing forest resources with varying degrees of success by taking care of community needs and aspirations for the past 30 years. Although rural communities and forest officers are developing a positive attitude toward forest conservation, there are still some concerns like the functioning of forest committee, the role of women, freedom of working, and participatory approach in forest conservation and management [34].

5.1 Conservation

The human-wildlife conflict was one of the major challenges for the conservation of species within protected areas. The government of India launched the eco-development project in the 1990s, to minimize such conflicts and effective conservation. In order to promote human security and protecting biodiversity simultaneously, the government of India introduced financial compensation as a policy against human-wildlife conflicts around the protected areas of the country. Similarly, some compensation incentives are instituted in Wildlife Trust of India (WTI) in response to crop damage, livestock, or human injuries caused by wildlife in protected areas. For example, crop loss due to wildlife is compensated by providing equivalent incentives under the "grain-for-grain" scheme in Pakke Tiger Reserve and northeast states of India [35]. Similarly, active bio-fences consisting of beehives or defensive crops (with pungent smell and thorns) were used to keep away elephants and other wild animals in Kaziranga National Park of Assam. Several services are implemented by WTI to help the cases of human-wildlife conflicts such as Mobile Veterinary Service, Guardians of the Wild, Primary Response Teams (PRTs), Rapid Response Teams (RRTs), and Sociologist-Biologist-Veterinarian expert teams that have been constituted to respond and handle human-wildlife conflict cases in Dudhwa National Park of Uttar Pradesh. Further, the safety of wildlife was ensured by developing canopy bridges in Chakrashila Wildlife Sanctuary of Assam, regular removal of snares from Bandipur Tiger Reserve of Karnataka, and installation of low voltage solar-powered fences in parts of Wayanad Wildlife Sanctuary, Aralam Wildlife Sanctuary, and Kaziranga National Park.

5.2 Resource use

Often resource use in many protected areas of the country is banned or restricted. According to the Supreme Court orders (dated 14.02.2000 and 21.02.2000 in I.A. No. 548 in WP No. 202/1995), the removal of dead, diseased, dying, or wind-fallen trees, driftwood, and grasses, etc. is restrained from any national park or game sanctuary [36]. This develops conflicts among the local people and forest officials, which is one of the major challenges for sustainability in protected areas. Later, the Government of India enacted the Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006, with provisions to acknowledge rights within forests including within protected areas. Until recently, bamboo has been considered as a "tree" in the country under the Indian Forest Act, 1927, and its felling and transit required prior permission from the forest department. However, a recent amendment has taken out bamboo from the category of "trees," and now local farmers can freely cultivate and harvest bamboo. This major step by the Indian government has economically empowered almost 20 million people including farmers, forest dwellers, and poor sections of society. Moreover, it has not only enhanced the income of farmers but also created job opportunities through boosting bamboo-dependent industries like handicraft industries in the country. Furthermore, the local people especially poorer sections, support conserving wildlife as it did not affect their livelihood as far as their primary needs are met [16].

5.3 Eco-development

Several eco-development projects have been launched in the country to reduce the dependency of local people from forest products, enhancing their livelihoods. Currently, such eco-development projects are running in more than 80 protected areas of the country, most of them are centrally funded, while few heritage sites have received grants from international organizations such as Global Environment Facility and the World Bank.

In order to conserve large mammals and sensitive species that are threatened by human-wildlife conflicts, village relocations are often carried out. Many villagers are happy after relocation outside the protected areas, as they were provided with better facilities such as land for cultivation, drinking water, electricity, jobs, etc. Such happy relocations have been carried out satisfactorily in Nagarhole National Park of Karnataka and Sariska National Park of Rajasthan. In Bhadra wildlife sanctuary of India, the resettled families are satisfied with the relocated sites as they are now living a better life with all necessary facilities such as electricity, drinking water, transport, market, etc. [37].

Under these projects, the cooperation of local communities has been awarded in terms of economic incentives and legal support as evidenced by the Periyar National Park. Further, the money collected by tourism is used to pay for salaries of members and park management and to build up a community development fund. However, these developmental activities are only promoted as long as the biodiversity and wildlife are not exploited. Despite enormous funding from India Eco-Development Project, the people-initiated natural management could no longer be managed to sustain the tigers and their prey [18].

6. Recommendations for sustaining national parks

Government policies for conservation and sustainable development of protected areas must respect the social and cultural traditions of the community while preparing rules and regulations. The management and action plans of the government should consider the improved development of both local people and protected area. Also, the state rules must consider the local adaptation and cultural traditions of a specific community. Thus, the selection of a conservation approach must be chosen wisely based upon the needs and requirements of the protected area. For example, the "sustainable use" approach may not be effective for species that are highly sensitive to human interference. Similarly, "preservationism" will not be effective in protected areas with a high density of local people that are highly dependent on forests for their livelihoods. Further, the governmental policies like compensation policy are governed by the bureaucratic style that is quite different from the environmental governance at local levels. Therefore, such policies are needed to be designed in such a manner that it considers the ecological and social dimension of human-wildlife conflicts so as to achieve better conservation and development priorities [38].

The governmental action plans must be clear enough and transparent in order to avoid conflicts and disputes. For example, the agreements for resource use and conservation between park officials and local communities must be very clear and transparent. Similarly, the rights and duties of local communities and forest should be undoubtedly defined, so as to avoid any disputes later on. Also, there should not be any incompatibility or inconsistency between state rules and local institutions. Further, the boundaries and zones of any protected area should be clearly demarcated for the effective implementation of action plans. The governance and legislation must be conveyed effectively to the forest officials and local people in order to develop confidence and local participation. Thus, increasing awareness about their rights will be effective for sustainable forest management in India [23].

Enforcement and implementation of governmental policies have remained a great challenge for the effective management and sustainability of protected areas in the country. This can be overcome by employing a sufficient number of local people as forest staff and forest guards. This forest staff should be trained well and equipped with modern facilities and good communication skills. In cases where human resettlements are necessary for conservation, newer sites must provide a better quality of life for the local population in order to achieve effective and voluntary human relocations. The government must put forward examples of providing improved necessary facilities (such as education, medical, household, etc.), good infrastructure (such as water supply, sewerage, transportation, and electricity, etc.), income sources, and other cultural-, religious- and ritual-oriented requirements with the relocated sites. This will develop a positive attitude and respect for rules associated with conservation.

India has scope for both collaboratively managed and community conserved protected areas because many of the protected areas in the country are distinguished by human settlements and resource use [8, 39]. Thus, the participation of local people becomes necessary for achieving sustainability in such areas because these people will be directly involved in any intervention to be implemented. These people including women should be encouraged to get involved in management plans by providing incentives in the form of social and economic benefits. The economic benefits generated from the developmental activities like tourism should be shared and rewarded for effective conservation activities of the local people. However, in many cases, wildlife conservation became a second priority for villagers. Therefore, national parks should not be always projected for economic benefits; rather we must highlight the roles of wildlife and forests for essential services and ecological balance. Local communities should be encouraged to protect the environment and bioresources for future use.

If any conflicts or disputes arise during implementation, they must be minimized through communication and respecting the local cultural rules in order to develop confidence in governmental policies and good relations with forest officials. Therefore, the formation of some local conservation councils that chiefly include local people and associated NGOs will be effective for moderating disputes and management of the protected area. Further, the efficiency of any protected area depends on basic management practices such as enforcement, local participation, boundary demarcation, and direct compensation to local communities. Therefore, effective management of national parks demands increase and moderation in funding [6]. Thus, businessmen, industrialists, private organizations, and international bodies should provide financial assistance to the protected area development.

Tourism activities that operate within ecological capacities and also contribute to the economic prosperity of local communities can be referred to as sustainable tourism. This approach can generate economic benefits to local communities, which might be more supportive of conservation as well as development. Further, tourism also makes people aware from corporate and other external agencies about the beauty of charismatic animals and undisturbed forest landscapes. Thus, tourism helps to raise funding for biodiversity conservation which would be more effective for keeping conservation programs longer. However, the sustainability of each protected area must be ensured before promoting any tourism-related activities. To accomplish this, the number of tourists needs to be regulated depending upon the carrying capacity of each protected area. Further, impacts of tourism need to be evaluated periodically, and infrastructural facilities should be developed by promoting low-impact activities such as walking trails and other nonconsumptive wildlife utilization. Local communities participate actively and support conservation when they see direct economic benefits from activities such as tourism. Tourism that involves local communities can further result in fruitful development of these protected areas.

7. Conclusions

Protected areas were initially established to conserve biodiversity in the face of inevitable human-centered development. However, they have emerged as a critical tool for not only safeguarding species but also for poverty alleviation, improving human livelihoods, and overall development of a nation. This broadened scope of protected areas has posed several challenges for effective conservation and sustainable management. Among major challenges, human activities such as extractive resource use, grazing, development, and tourism are disproportionately degrading and compromising the sustainability of the forests in such protected areas. The lack of baseline data and research is exaggerating the issue, and therefore, further studies need to carefully assess these impacts in order to develop effective management strategies.

The conservation paradigm in the country has been shifted from "preservationism" to "sustainable use" approach during the past decades. Now, local resource use and socioeconomic development are advocated, which often compromise the long-term ecological balance and biodiversity conservation. Therefore, a sustainable future demands a balanced approach including both preservationism and sustainable use depending on the needs of target species to be conserved and local inhabitants. The diverse ecosystems and ethnic groups of India do not allow a single conservation approach to be implemented successfully across the country. Therefore, a feasible approach based on primary field data should be promoted for the successful conservation of the species and ecosystems. Further, the success and failure of any protected areas should be judged on the basis of conservation of species and ecosystems rather than planning whether to restrict or allow local communities and other such factors.

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Conflict of interest

The authors declare no conflict of interest.

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References

[1] IUCN. The IUCN Red List of Threatened Species 2020. Available from: https://www.iucnredlist.org/ [Accessed: 11 February 2020]

[2] Gadgil M, Guha R. This Fissured Land: An Ecological History of India. New Delhi: Oxford University Press; 2013. p. 274. DOI: 10.1093/acprof:oso/9780198077442.001.0001

[3] Robbins P, McSweeney K, Chhangani AK, Rice JL. Conservation as it is: Illicit resource use in a wildlife reserve in India. Human Ecology. 2009;**37**:559-575. DOI: 10.1007/s10745-009-9233-6

[4] Wildlife Institute of India. National Wildlife Database 2019. Available from: http://wiienvis.nic.in/Database/Protected_Area_854.aspx [Accessed: 11 February 2020]

[5] Sekhar NU. Local people's attitudes towards conservation and wildlife tourism around Sariska Tiger Reserve, India. Journal of Environmental Management. 2003;**69**:339-347. DOI: 10.1016/j.jenvman.2003.09.002

[6] Bruner AG, Gullison RE, Rice RE, Da Fonseca GAB. Effectiveness of parks in protecting tropical biodiversity. Science. 2001;**291**:125-128. DOI: 10.1126/science.291.5501.125

[7] Verma M, Negandhi D, Khanna C, Edgaonkar A, David A, Kadekodi G, et al. Economic Valuation of Tiger Reserves in India: A Value + Approach. Indian Institute of Forest Management: Bhopal, India; 2015. p. 284

[8] Secretariat of the Convention on Biological Diversity. Protected Areas in Today's World: Their Values and Benefits for the Welfare of the Planet. Technical Series No. 36. Montreal: 2008. p. 96

[9] Kothari A, Pande P, Singh S, Dilnavaz R. Management of National Parks and Sanctuaries in India: A Status Report. New Delhi: Indian Institute of Public Administration; 1989. p. 298

[10] Davidar P, Arjunan M, Puyravaud JP. Why do local households harvest forest products? A case study from the southern Western Ghats, India. Biological Conservation. 2008;**141**:1876-1884. DOI: 10.1016/j.biocon.2008.05.004

[11] Goodwin H, Kent I, Parker K, Walpole M. Tourism, Conservation & Sustainable Development: Case Studies from Asia and Africa. Wildlife and Development Series No. 11. London: International Institute for Environment and Development; 1998. p. 98

[12] Sen A, Pattanaik S. Alienation, conflict, and conservation in the protected areas of urban metropolis: A case study of Sanjay Gandhi National Park, Mumbai. Sociological Bulletin. 2015;**64**:375-395. DOI: 10.1177/0038022920150306

[13] Das D, Hussain I. Does ecotourism affect economic welfare? Evidence from Kaziranga National Park, India. Journal of Ecotourism. 2016;**15**:241-260. DOI: 10.1080/14724049.2016.1192180

[14] Tiger Task Force. The Report of the Tiger Task Force: Joining the Dots. New Delhi: Project Tiger, Union Ministry of Environment and Forests; 2005. p. 206

[15] Singh B, Borthakur SKS. Forest issues and challenges in protected area management: A case study from Himalayan Nokrek national park and biosphere reserve, India. International Journal of Conservation Science. 2015;**6**:233-252

[16] Arjunan M, Holmes C, Puyravaud JP, Davidar P. Do developmental initiatives influence local attitudes toward conservation?

A case study from the Kalakad-Mundanthurai Tiger Reserve, India. Journal of Environmental Management. 2006;**79**:188-197. DOI: 10.1016/j.jenvman.2005.06.007

[17] Wuerthner G, Crist E, Butler T. Protecting the Wild: Parks and Wilderness the Foundation for Conservation. Washington, DC: Island Press/Center for Resource Economics; 2015. p. 362. DOI: 10.5822/978-1-61091-551-9

[18] Reddy GV. Lessons from two local extinctions: Sariska and Kailadevi (Ranthambhore) in Rajasthan, India. Conservation and Society. 2008;**6**:256-262. DOI: 10.4103/0972-4923.49218

[19] Johnsingh AJT, Joshua J. Conserving Rajaji and Corbett National Parks—The elephant as a flagship species. Oryx. 1994;**28**:135-140. DOI: 10.1017/s0030605300028453

[20] Anand S, Radhakrishna S. Investigating trends in human-wildlife conflict: Is conflict escalation real or imagined? Journal of Asia-Pacific Biodiversity. 2017;**10**:154-161. DOI: 10.1016/j.japb.2017.02.003

[21] De UK, Chauhan K. Degradation of forest and biodiversity in Sariska National Park, India and the responsible factors. International Journal of Environment and Sustainable Development. 2015;**14**:398-426. DOI: 10.1504/ijesd.2015.072104

[22] Mazumder MK. Diversity, habitat preferences, and conservation of the primates of Southern Assam, India: The story of a primate paradise. Journal of Asia-Pacific Biodiversity. 2014;**7**:347-354. DOI: 10.1016/j.japb.2014.10.001

[23] Macura B, Zorondo-Rodríguez F, Grau-Satorras M, Demps K, Laval M, Garcia CA, et al. Local community attitudes toward forests outside protected areas in India. Impact of legal awareness, trust, and participation. Ecology and Society. 2011;**16**:10. DOI: 10.5751/es-04242-160310

[24] Sapkota RP, Stahl PD, Norton U. Anthropogenic disturbances shift diameter distribution of woody plant species in *Shorea robusta* Gaertn. (Sal) mixed forests of Nepal. Journal of Asia-Pacific Biodiversity. 2019;**12**:115-128. DOI: 10.1016/j.japb.2018.08.004

[25] Heino M, Kummu M, Makkonen M, Mulligan M, Verburg PH, Jalava M, et al. Forest loss in protected areas and intact forest landscapes: A global analysis. PLoS One. 2015;**10**:e0138918. DOI: 10.1371/journal.pone.0138918

[26] Rangarajan M, Vihar M, Shahabuddin G, Programme WCS, Group S, Estate L. Displacement and relocation from protected areas: Towards a biological and historical synthesis. Conservation and Society. 2009;**4**:359-378. DOI: 10.1117/12.601161

[27] Malik MI, Bhat MS. Sustainability of tourism development in Kashmir—Is paradise lost? Tourism Management Perspectives. 2015;**16**:11-21. DOI: 10.1016/j.tmp.2015.05.006

[28] Yadav N, Sahu NC, Sahoo D, Yadav DK. Analysis of barriers to sustainable tourism management in a protected area: A case from India. Benchmarking: An International Journal. 2018;**25**:1956-1976. DOI: 10.1108/bij-09-2016-0149

[29] Madhusudan MD, Shankar Raman TR. Conservation as if biological diversity matters: Preservation versus sustainable use in India. Conservation and Society. 2003;**1**:49-59

[30] Basiago AD. Economic, social, and environmental sustainability in development theory and urban planning practice. Environmentalist. 1999;**19**:145-161. DOI: 10.1023/a:1006697118620

[31] Shankar Raman TR. Effect of slash-and-burn shifting cultivation on rainforest birds in Mizoram, Northeast India. Conservation Biology. 2001;**15**:685-698. DOI: 10.1046/j.1523-1739.2001.015003685.x

[32] Kothari A, Suri S, Singh N. Conservation in India: A new direction. Economic and Political Weekly. 1995;**30**:2755-2766

[33] Tiwari BK, Barik SK, Tripathi RS. Biodiversity value, status, and strategies for conservation of sacred groves of Meghalaya, India. Ecosystem Health. 1998;**4**:20-32. DOI: 10.1046/j.1526-0992.1998.00068.x

[34] Rishi P. Joint forest management in India: An attitudinal analysis of stakeholders. Resources, Conservation and Recycling. 2007;**51**:345-354. DOI: 10.1016/j.resconrec.2006.10.009

[35] Menon V, Chaudhary RG. Conflict to Co-Existence: A Dozen Cost Effective Human Interventions for Co-Existence with Wildlife. Wildlife Trust of India: Noida, India; 2017. p. 23

[36] MoEFCC. Handbook of Forest (Conservation) Act, 1980 (With Amendments Made in 1988); Forest (Conservation) Rules, 2003 (With Amendments Made in 2004); Guidelines & Amp; Clarifications (Up to June, 2004). New Delhi: Government of India, Ministry of Environment & Forest; 2004. p. 131

[37] Karanth KK. Making resettlement work: The case of India's Bhadra Wildlife Sanctuary. Biological Conservation. 2007;**139**:315-324. DOI: 10.1016/j.biocon.2007.07.004

[38] Johnson M, Karanth K, Weinthal E. Compensation as a Policy for Mitigating Human-wildlife Conflict Around Four Protected Areas in Rajasthan, India. Conservation and Society. 2018;**16**:305. DOI: 10.4103/cs.cs_17_1

[39] Kanagavel A, Pandya R, Sinclair C, Prithvi A, Raghavan R. Community and conservation reserves in southern India: status, challenges and opportunities. Journal of Threatened Taxa. 2013;**5**:5256-5265. DOI: 10.11609/jott.o3541.5256-65

Section 3

Forest Protection and Fire Prevention

Chapter 6

Gypsum/Desulfurization Fly Ash/Activated Shale Char/Claystone of Şırnak with Popped Biochar Composite Granules as Fire Inhibitor for Fire Hazard Risk in Forest Management

Yıldırım Ismail Tosun

Abstract

Chemical hydrate analysis using gypsum and lime solution was carried out for dehydration of ashes in heavy heat and fire conditions. The 20–50 g pasted popped char samples soaked at higher temperatures of 750 and 500°C showed higher dehydration and heat sorption capacities and became increasingly nonlinear isotherm due to loss of ash surface on granule sites and dehydrogenation. However, this sorption of popped char was slower than other materials such as expanded clay, because microwave permittivity was attributed to their pore differences in solute molarities and sorption mechanisms. Inhibition of hydrate and CO_2 source cooling flame was tested in our research to avoid the spread of forest fires into live bushes and forest areas due to distribution of hot flame of wind. The prospects were designed for construction of materials, such as bubbled gas, for arresting house fires. The similar materials can be produced using bio-waste materials and by-products of construction wastes or forest soil filling. In this study, porous limestone and porous anhydrite metalized stone absorbed the bubbled balls with microwave melted recycling anhydrite metalized powders covering the surface to avoid combustion. In this investigation, the recrystallized gypsum and powdered limestone were reroasted in microwave to melt anhydrite with the porous cores and basalt granules and even the bubbling of anhydrite metalized granules. The fillers finished was used for fire arrestor powder and soil, absorbing heat of fire which were determined as metalized coal carbon-rich forest soil were investigated for arrestor on floor test and deterioration of soil and heat sorption were calculated, respectively. For this purpose, heat resistance, heat sorption, and soil combustion experiments were conducted. As defined, the test results were conducted by comparing metal powders with high heat. The production flow sheet and advantageous process parameters using recycling coal shale and anhydrite gypsum microwave processing parameters were defined. To recrystallize anhydrite metalized carbon limestone, the composite balls of marls having the relation between composite rock formation and discontinuity at production have been established.

Keywords: microwave, metalized anhydrite-porous rock, composite balls, earthquake wave sorption, bulk elastic behavior

1. Introduction

In order to protect the environment with rich bioresources for life, the nature needs to take real precautions and humans should reduce the source of greenhouse gases. The wild bushes, forests, and nature are highly needed for human life with increasing population. The energy consumption needs alternative clean and renewable energy sources. The bushes and forest fires have become important research topics in order to take precautions on time in this century. This mobile production of the fire inhibitor unit project was critical in forest soil mixture of biomass-based waste and garbage and clean, renewable, and sustainable alternative inhibitor source.

The consumption of natural resources in inhibitor production is increasing parallel to the construction materials for inhibiting fire at house needs today. The production of low-thermal-value waste bio carbon resources is limited in terms of quantities. It enables the evaluation of biotechnological byproducts related to waste management over food processing technology with advanced technological incineration systems. Environmental norms allow the production of the necessary waste fuels such as waste oil as fuel, that is, compatible with biogas production, biopyrolysis or gasification became the high-cost benefaction. In Turkey, the forest fire and the filler production form bioresources rather attracted so critical significance on even less intensive areas of Eastern Anatolia and Southeastern Anatolia region, especially in the low populated steep mountains and high plateaus such as the provinces of Şırnak, Hakkari, and the surrounding steep mountains forest areas, the production of bio resources for production forest fire inhibitor soils and humus soils from waste bio resources for cleaner nature and renewable bio energy production by means of mobile units using incineration or pyrolysis method will provide the development of the South-East Anatolian region and also the industrial development and diversification will increase [1–5].

Flexible and regional targets for a mobile solid waste incineration from an environmental and economic perspective are:

- The 3 ton/hour mobile plant where the waste sorting process is performed for inhibitor soil, and material production resources were processed to acquire secondary materials to be evaluated.

Waste type	Waste statistics		
	Heat value, kJ/kg	Country, actual million ton/year	Eastern Anatolian region, actual 1000 tons/year
Textile, rubber, plastics	18,200	0.6	2.1
Wood, cardboard, paper	17,600	2.4	1.6
Organic municipal waste	13,500	2.2	29
Animal waste	13,500	1.9	21
Forestry and agricultural biomass	18,500	2.8	63
Total	18,000	9.9	116.7

Table 1.
Total amount of municipal waste divided into actual values in Turkey and Eastern Anatolian Region in 2012.

- Biological treatment or carbonization units of biomass and conversion to compost, which are a market value or energy production by producing inhibitors by mixing and treatment.

- Reduction of the amount of waste to be sent to regular storage by thermal treatment systems, making it inert and obtaining energy.

- Reduction of landfill and use of forest fills for inhibiting reclamation and at least the reduction of forest fire as given in **Table 1** [5], and **Figure 2** shows the forest management methods in the elimination of forest fires in the country.

2. Forest fire management

2.1 Forest fires

The rainforests in Amazon still burned many years at a record rate: Brazil experienced more than 76,000 fires in 2019, whereas the total was about 40,000 in 2018. About 10,000 of this year's fires shown in **Figure 1** resulted in catastrophic devastation of fire smoke caused by harsh weather conditions. **Figure 1** shows every fire that unwillingly flamed in central South America since August 2019.

In Amazon, most of the fires were started by farmers and loggers and caused by human facts for industrial or agricultural purposes. However, forest fire caused harsh climate change, which increased flaming and widening fire devastation.

There were more than 76,000 fires in Brazil so far this year, but the issue has not changed any human urbanization, and other parts of South America were burning too.

Global Forest Watch, an organization sponsored by the World Resources Institute, monitors forests and tracks fires using satellite data. The group reported more than 109,000 fire alerts in Brazil between August 13, 2019, but the map of current blazes shows fires in many other regions as well, as shown in **Figure 1**. So far this year, Brazil's neighbor, Bolivia, has experienced more than 17,400 fires. Paraguay, to the south, has had just fewer than 10,000, and Colombia, to the north, 14,000. Venezuela had experienced the second-highest number of fires of 26,500 in 2019: that was one-third of Brazil's forest fire totally.

Australia had one of the most fires on earth, and bushfires form part of the natural cycle of its landscapes. However, the dry weather and high summer

Figure 1.
Part of the Amazon jungle burning near the city of Novo Progresso, Brazil, on 23 August. Nacho Doce/Reuters.

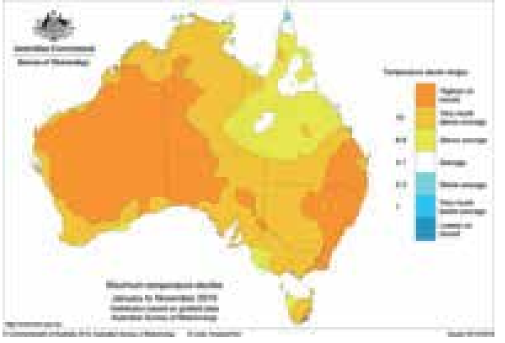

Figure 2.
Maximum temperature deciles.

temperature factors such as high climate risk trends, weather patterns, and vegetation management by humans may not contribute to the intensity of hard seasons as seen in **Figure 2**, and the most destructive fires in Australian history preceded by extreme high temperatures, low relative humidity, and strong winds on last November 2019, which combine to create ideal conditions for the rapid spread of fire. Forest experts and land management accepted that severely below average fuel moisture attributed to record-breaking temperatures and drought, accompanied by severe fire weather, is the primary cause of the 2019 Australian bushfire. The devastating flames were likely to have been exacerbated by long-term trends of warmer and dryer weather over the Australian land mass. Nonetheless, the political nature of many of the crisis and its associated issues has also resulted in the circulation of large amounts of disinformation regarding the causes of the fire activity, to the neglect of credible scientific research, expert opinion, and previous government inquiries, as shown in **Figures 3–5**. The precautious methods were prepared regarding forest land urban interface mapping, showing fire fuel risk and temperature risk on mapping as in **Figure 5**.

2.2 Fuel management

The spatial distribution of tree and bush was considered in the fire management models. The forest plantation characteristics such as land, thermal, physical, and chemical properties of tree elements were constructed. Fuel data of forest were a powerful source of knowledge used for software enabling representation of any

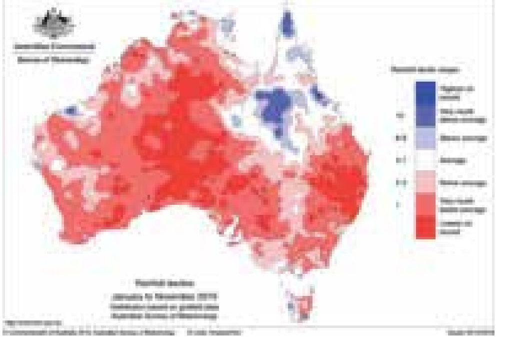

Figure 3.
Rainfall deciles, from January to November 2019.

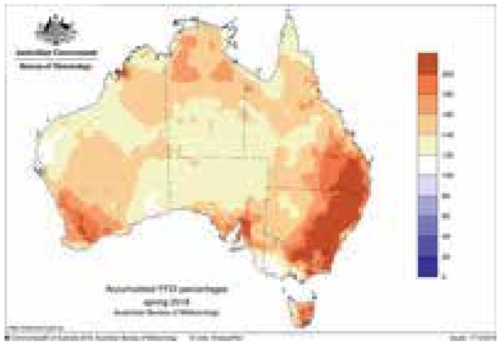

Figure 4.
Forest Fire Danger Index (FFDI), Spring 2019.

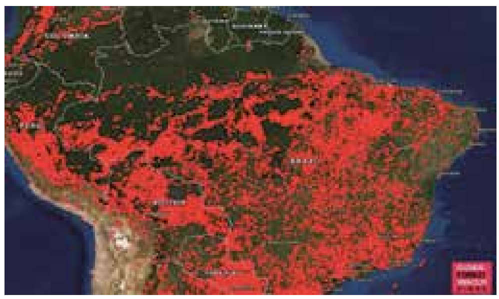

Figure 5.
Forest fires on the Amazon region in Global Forest Watch map.

vegetation community in the landscape, simultaneously integrating the required attributes for running complex fire simulation in the background.

GPS and phone to phone was always provided safe control on internet connection, a touch-screen, and a camera remote control improved extinguishing period following the stages shown in **Figure 6**.

Fire fight commander and team led by the fire extinguishing method following discussion with expert field operators reported a major concern about the visibility on the screen of such weather tools emergency station stage for an observation cam device and available in a field operating car.

Figure 6.
Fire fight commander and team over the fire reports and weather conditions.

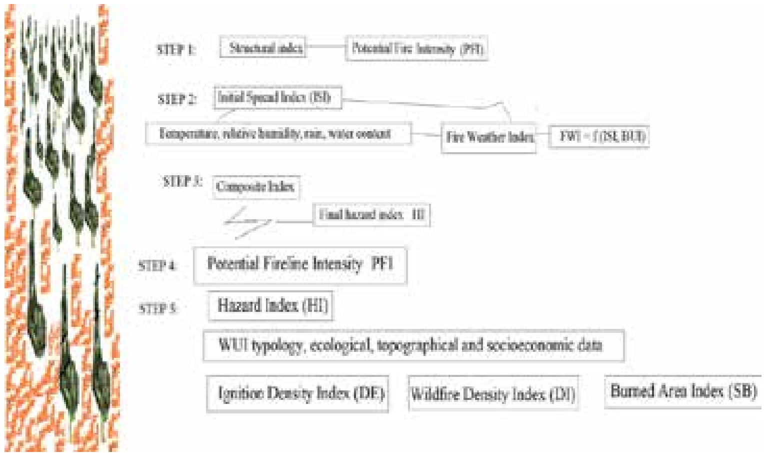

Figure 7.
The organized fire team work that included the extinguishing plan and method is followed by team on risk mapping and data logging.

The data entailing simulation of vegetation growth with and without fire was also shown from risk factors, and the assessment of the wild-land fire risk was calculated on map. It is organized on five step risk parameters as shown in **Figure 7**:

The fire management software made a map over fuel risk and extinguishing system and put the information related to weather and climate conditions together. The forest fire showed risk parameters made available outstanding feedback from forest fire managers within the fire as shown in **Figures 8** and **9**.

2.3 Main tools for fire management

The forest plantation and dry matter characteristics regarding wet land, thermal, and climate risks, physical and chemical properties of tree elements covered the reporting previously in order to eliminate the fuel potential risks. The reported high risk areas contained the parameters such as fire ecology and wet land; fire risk distribution; forest ecology of local plant species; fire land management risk; monitoring and assessment of fire areas; fire weather conditions; wind; and extinguishing plan.

The methods were practiced at the following stages:

- Fire ignition patterns for control flame of forest fire.
- Case studies: detailed assessments on selected management risks.
- Prescribed burning practice (extensive training): at least 5 days of burning.

2.4 Extinguishing by slurry mud or foam

The flame of fire on sites could be inhibited by foaming agent mixed water pouring or muddy water pouring by plane carriers that used effectively on extinguishing work and fire management in urban interface or forest urbanization intercontact area, mainly found in various regions all over the world. In Şırnak, the lightweight materials may be evaluated and investigated for fire flame inhibitor in this study such as: Altered Limestone (Şırnak Center), Marly Limestone (Şırnak Center), Marl (Şırnak Center), Cizre White Porous Limestone (Şırnak Cizre),

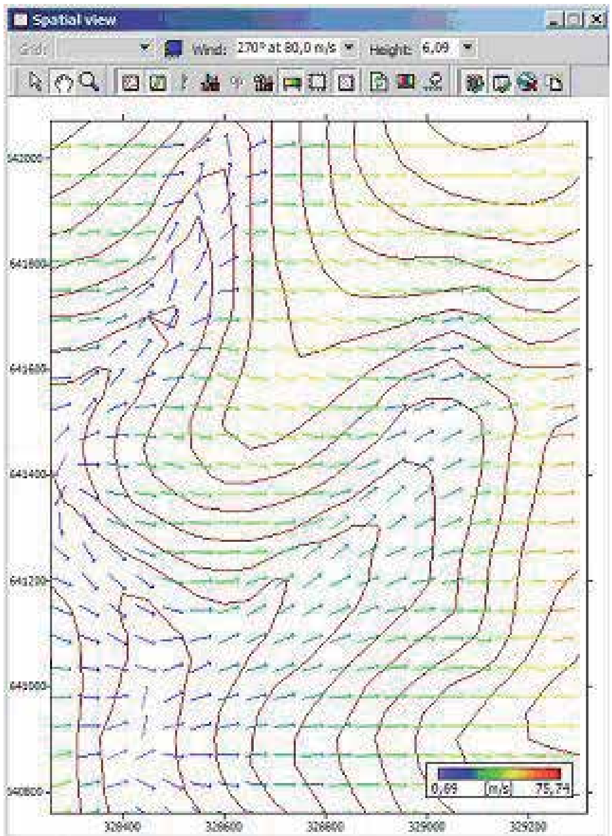

Figure 8.
Forest Fire Flame Danger Index, 2019.

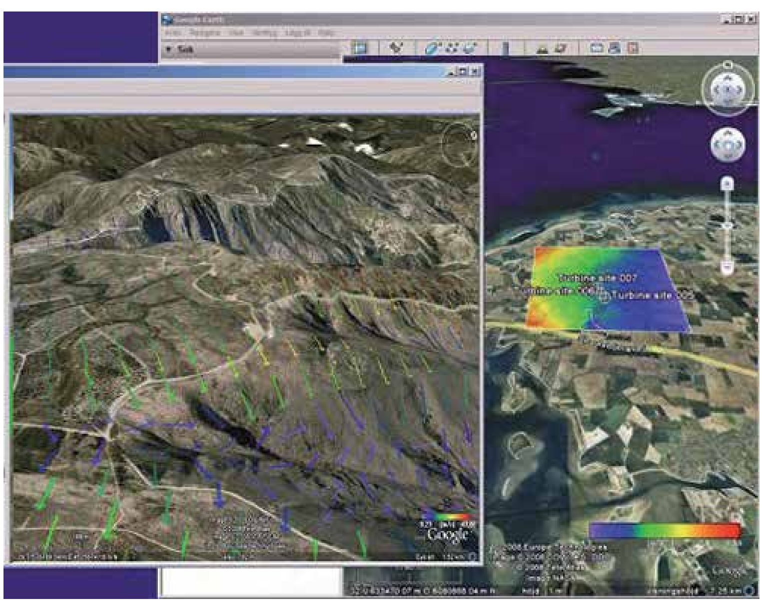

Figure 9.
Forest Fire Urbanization Wind Danger Index, 2019.

Porous Limestone (Cizre Stream), Volcanic Cinder, Midyat Limestone, and Şırnak Coal Mine Waste Marly Shale.

The light porous limestone and marl of Şırnak province can be used as concrete aggregates due to lightweight strength. However, this region consisted of brownish-yellow limestone formations, heterogeneous and carbonates containing 30–45% weight decrease and carbon dioxide dissociation at flame temperature of fire at 800°C regarding dissociation kinetics as extinguisher water slurries.

The various local industrial wastes were used as extinguishing work of fly ash materials [1–3]. Fly ashes of desulfurization units like gypsum are defined as extinguishing slurry materials that inhibiting flaming properties of forest fire but have binding hydrate properties that are finely ground and dissociated chemically with alkali hydrates at flame temperature and providing moisture flame environments [6]. Fly ash provided rain water hydrated soil, low permeability capturing rain water, controlling the lightweight material, dust easily inhibiting dry leafs and woods, and the sulfate effect on soil for humus [5]. It is estimated that there are 600 million tons of fly ash in the world today, but only 10% of it is evaluated in concrete and as filler in road pavement covering technology [7]. Fly ash has a wide range of uses in concrete because of lowering cost of concrete, saving energy, and reducing environmental problems [8]. Use of fly ash in extinguisher fire inhibitor slurry mixtures; decreasing the combustion of wood and light weight flying matters in certain proportions, the use of fly ash instead of granule decreasing the oxygen take up or transfer into high heat flame [9]. The effects of fly ash on the mechanical properties of pavement were studied extensively. In this study, the effects of Silopi fly ash as filler additive on hot combustion chamber for decreasing combustion heat of coal were determined. In this study, the effect of amount of ash replaced to fine gypsum amount, change on flame inhibition ability, oxygen take-up ability, and lightweight slurry density of water mixture at 10–20% weight was determined.

The weight ratio of lightweight limestone, shale, marly shale, and fly ash greatly affected the water content in inhibiting filler material significantly. Bottom aerated combustion of fuel matter in the forest peat and flaming radiated fire development could be inhibited by the stone matters of the fuel flaming styles as shown in **Figures 10** and **11**.

This fire extinguishing work prepared model risk patterns as shown in **Figure 10** by fire hazard maps, on a daily basis, by combining fuel models, forest area topography, soil conditions, and dynamic factors such as wind direction, air wind speed, air temperature, relative humidity, and fuel moisture content, as shown in **Figures 12** and **13**.

The parameters regarding fire features improved the control implemented recently as follows:

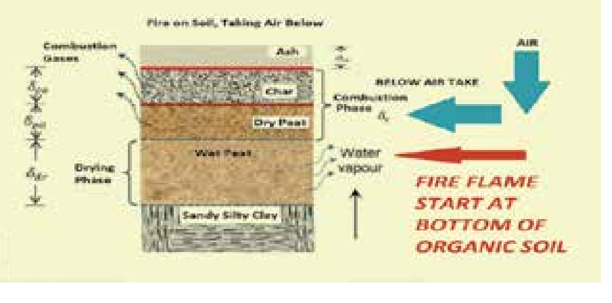

Figure 10.
Forest fire movement with below fired peat with high planted organic soil.

DOI: http://dx.doi.org/10.5772/intechopen.92592

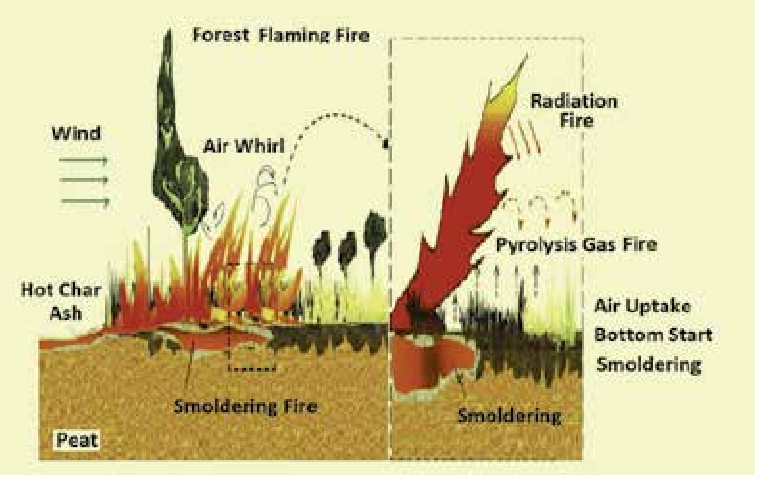

Figure 11.
Forest fire movement with below ignited forest fire, peat with high planted organic soil as happening in Amazon and Indonesian Rain Forests.

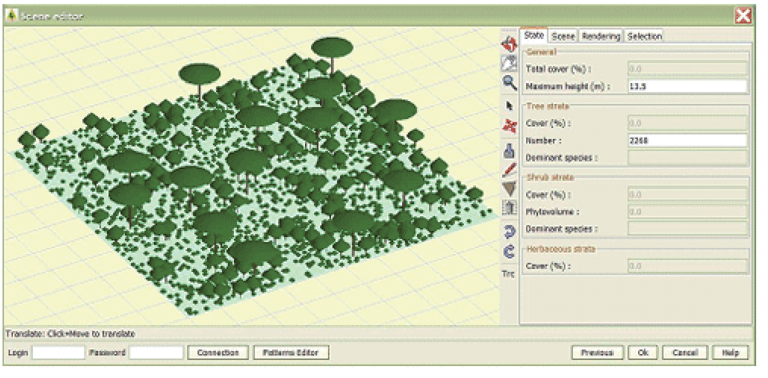

Figure 12.
Software used in forest fire risk management with dry peat or aggregated banning soil, fuel management, and fire risks.

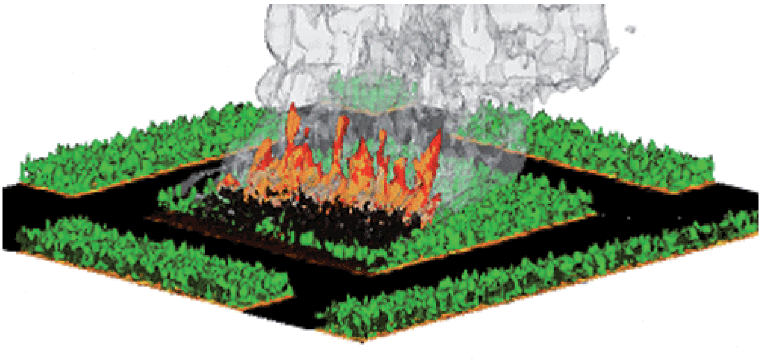

Figure 13.
Forest fire movement with below fired peat with high planted organic soil, fire fuel model.

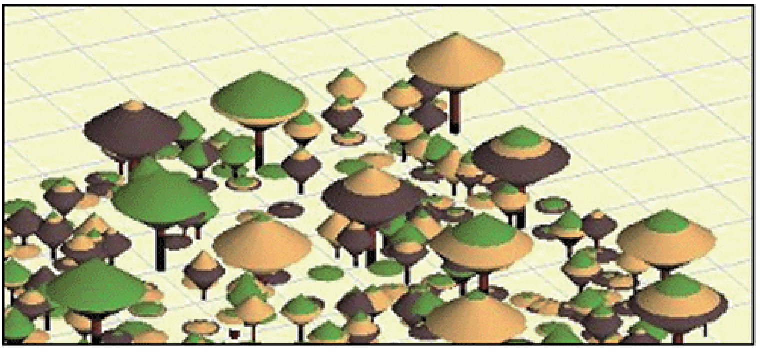

Figure 14.
Dry fuel source, forest fire movement risk with below fired peat soil, and visualization of fire risks on dry fuel matters.

- fuel matter balance dry matter and decayed matters over wet matter forest fuel data (**Figure 14**);
- the dry matter removal and manipulating a vegetation matter;
- the fuel source data for fire model simulations; and
- the environmental risk mapping and mapping over the base of urbanization and impacts at fire as shown in **Figures 10** and **12**.

2.5 Inhibitors as activated clays and hydrated clay matters

There are hydrated layers mainly in clay minerals and lattice layers associated with the inner layer hydrates and the metal oxide with clay lateral surfaces. The water molecules in the spheres surrounding the exchangeable cations are exchange degree of polarization of the alkali metal cation and the surface silanol groups (Si-OH) resulting from the breakage of the Si-O-Si bonds in the tetrahedral layer, in the exchange of the Al^{3+} and Mg^{2+} cations in the octahedral layer, and the Si^{4+} and Al^{3+} and Fe^{3+} cations in the tetrahedral layer as shown in **Figure 5**, associated with metal atoms on the crystal edges. The oxygen planes in the space between the plates act as a pair of electrons [9].

The increasing demand of clay utilization for advanced material technology and the limited reserves of high quality bentonites push the researchers and the operators/producers to evaluate the lower quality calcium and mixed shales for the of hydrates in fire inhibition use. The technological properties of fly ashes, however, can be upgraded by the application of hydrating and activating acids. Mostly, wet concentration methods such as decantation, cycloning, and centrifuging have been applying and water quality and ion type/amount which the water carries becomes more important to control the further activation process since clays carry the releasable and exchangeable cations on interlayers which interact with ions in water. **Table 2** comprised the inhibiting values over extinguishing manner of flame.

In this study, the effect of water quality (ion type and amount in water) was subjected to the concentration and further alkali activation tests with mixed type shale, asphaltite deposits in Şırnak. The water slurries including different salts namely $CaCl_2.2H_2O$ foaming and $AlCl_3.6H_2O$ foaming were used as fire inhibition media in concentration by mixing and agitation. The effect of water quality on concentration and alkali activation was declared based on pH, viscosity, solid ratio, and size.

Inhibitor type	Waste inhibitors			
	25-T_d heat calcination value, kJ/kg	T_d temperature, °C	Hydrate weight, %	Carbonate weight, %
Talc	38,200	613	10.6	2.1
Montmorillonite	27,600	456	12.4	1.6
Zeolite	33,500	565	12.2	2.9
Bentonite	23,500	430	11.9	2.1
Fly ash	18,500	425	12.8	6.3
Gypsum	18,000	250	19.9	0.7
Limestone	59,900	815		42
Marly shale	45,400	845	11	22

Table 2.
Total inhibiting values in Eastern Anatolian region in Turkey.

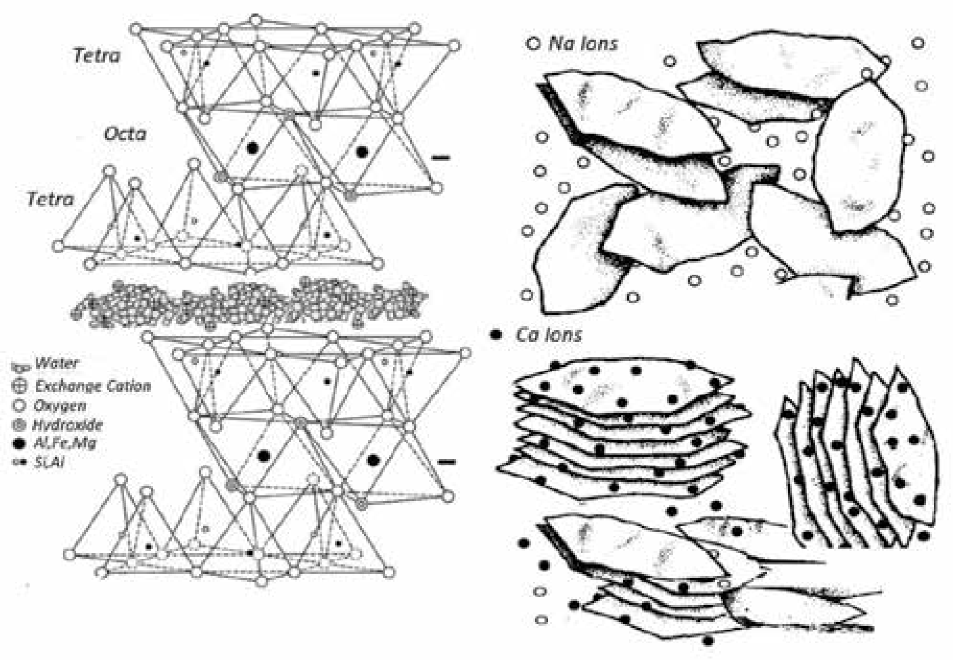

Figure 15.
Shale clay structure, Şırnak resource in Turkey regarding hydrate.

Şırnak shale contained marly carbonates over 45% providing carbonates with the clay minerals of the smectite group, shows colloidal properties when mixed with water, and its properties such as water are due to the three-layered crystal structure (**Figure 15**) [9].

2.6 The methods used ın forest fire management

The investigation of water resources and logging in the Şırnak, Mardin, and Batman provinces was effectively carried out, and construction debris is widely distributed in the forest area to protect urbanization from fire near village location.

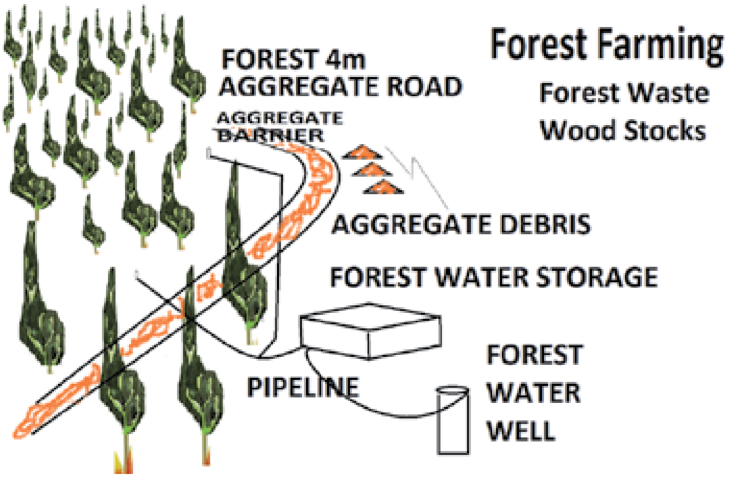

Figure 16.
Total amount of municipal waste for forest management in Turkey and Eastern Anatolian Region in fly ash use of Şırnak Asphaltite.

Figure 16 shows the methods used mainly in construction of water pools for both farming and extinguishing of local forest areas. Inhibitor aggregates roads and high amount of fly ash as municipal waste for forest fire management in Turkey. In Eastern Anatolian Region, high amount of inhibitor waste was used for forest fire inhibition over 120,000 tons fine aggregate as gypsum and ash material with Şırnak Asphaltite wastes and construction debris.

2.6.1 Hydrate sorption matter

The large specific surface area inhibiting fire flame could be water content and evaporation heat of used in industrial foamed water extinguishing purposes as natural materials. Hydrated liquid absorbents and solid adsorbents generally used fly ash matters of desulfurization unit contained mainly gypsum hydrates. It can be classified as waste *group is one of fly ash minerals or* inhibiting filler for flame and more with foamed matter base with sponged stones and hydrated minerals such as containing 85% montmorillonite, is an aluminum hydrosilicate with a colloidal property. When mixed with water, density of a few solid swelling bentonite is about 2.6 g/cm^3.

Shale clay is calcium in many countries clay is a general name of Al Mg silicate hydrates and the main hydrate content of which montmorillonite can change mainly cation and be defined as clay with Ca;. Attapulgite, 2MgSi8O20 (OH2) 4 (OH) The palygorskite expressed by the formula 4H_2O an aqueous magnesium, aluminum Silicate. Sepiolite is 6 Mg 9 Si 12 O 30 (OH) 4 6H 2 O group is aqueous Mg silicate. In these minerals channel-shaped pores water bound to crystal structure with molecules. The shale clays contained in this group is micropore and channels and large surface area over 11% due to the possession of various substances inhibitors and high adsorbing capacities.

3. Materials and methods

Wood straw and oak wood char composite type fuel was used as combustion flame test. The fly ash used in the experiments was put into 30 cm dish plate half at half wit fuel content obtained from the Şırnak inhibitor lightweight filler at fine size at 0.1 mm and the chemical composition of the fly ash and inhibitors are given in **Tables 3** and **4** regarding flaming combustion and adsorption matter [10–13].

Reaction heat adsorption:

$$E = kA \log Kp^{RT} \tag{1}$$

$$\text{Cellulose } C + O_2 \rightarrow CO_2 \tag{2}$$

$$\text{Cellulose } 2C + O_2 \rightarrow 2CO \tag{3}$$

The materials of fly ash as inhibitor and popped carbon as shale of Şırnak asphaltite from waste material of Şırnak evaluated in forest fire control as shown in **Table 5**.

In this study, the specific unit weights are given in **Table 6**. Degree of hydrate or carbonate inhibiting ability rates of the filler was determined by evaluating the 3-ton briquetting compression test results (**Table 5**). Combustion weight TGA tests showed higher burning inhibition ability for the Şırnak fly ash and gypsum mixture at 30/70 weight rate so that they gave higher advantageous effect on compaction of road pavement.

In ASTM standards [5], the amount of mixing pine wood and lightweight inhibiting filler rates was taken, however at the amount of wood and porous aggre-

Reaction	log A[log (s)]	E [kJ/mol]	[kJ/kg]
(1) Hemicellulose	16.32	186	0
(1) Cellulose	19.44	242	0
(1) Lignin	8.98	107	0
(2) Hemicellulose	11.42	145	−20
(3) Hemicellulose	15.93	202.4	255
(2) Cellulose	10.11	150.5	−20
(3) Cellulose	14.52	196.5	255
(2) Lignin	6.89	111.4	−20
(3) Lignin	9.18	143.8	255

Table 3.
Kinetic constants used in a-priori modeling, following Bellan's kinetic scheme [6, 10].

Property	Units	Value
Thermal conductivity k	W/m K	0.13
Density ρ	kg/m^3	490
Specific heat capacity c_p	J/kg K	2300
Surface emissivity ϵ	—	0.95
Thermal conductivity of char k_{char}	W/m K	0.08
Density of char ρ_{char}	kg/m^3	330
Specific heat capacity of char	J/kg K	1100

Table 4.
A-priori modeling parameters for wood, taken from Ref. [6].

Components	Şırnak fly ash	Şırnak mid ash
SiO_2	39.71	20.71
Al_2O_3	10.53	10.53
Fe_2O_3	6.62	4.62
S + A + F	68.6	68.6
CaO	16.56	26.56
MgO	3.41	12.41
SO_4	3.02	11.02
K_2O	2.44	2.44
Na_2O	0.55	0.55
Ignition loss	5.74	14.74
Free CaO	4.13	12.13
React. SiO_2	21.12	14.12
React. CaO	8.72	2.72

Table 5.
Seyitömer and Şırnak Silopi fly ash chemical compositions and aggregate compliance with standard values ASTM C616.

Inhibitor Type	Size, mm	25 min	40 min	50 min	60 min	Density	1.1	1.2	1.3
Şırnak shale	−0.15	88	87	85	80	1.55	36	47	52
	−0.5 + 0.15	88	87	85	80	1.55	36	47	52
	−1 + 0.5	88	87	85	80	1.55	36	47	52
Sırnak marly shale	−0.15	78	77	75	80	1.65	36	47	52
	−0.5 + 0.15	78	77	75	70	1.65	36	47	52
	−1 + 0.5	78	77	75	70	165	36	47	52
Şırnak porous limestone	−0.15	75	74	85	70	1.45	36	47	52
	−0.5 + 0.15	75	74	72	66	1.45	36	47	52
	−1 + 0.5	75	74	72	66	1.45	36	47	52
Şırnak gypsum	−0.15	48	47	72	66	1.55	36	47	52
	−0.5 + 0.15	48	47	85	80	1.55	36	47	52
	−1 + 0.5	48	47	85	80	1.55	36	47	52
Şırnak shale 50%+	−0.15	58	57	85	80	1.55	36	47	52
Şırnak gypsum 50%	−0.5 + 0.15	58	57	85	80	1.55	36	47	52
	−1 + 0.5	58	57	85	80	1.55	36	47	52
Sırnak marly shale 50%+	−0.15	68	67	85	80	1.55	36	47	52
Şırnak gypsum 50%	−0.5 + 0.15	68	67	85	80	1.55	36	47	52
	−1 + 0.5	68	67	85	80	1.55	36	47	52
Şırnak porous limestone 50%+	−0.15	68	67	85	80	1.55	36	47	52
Şırnak gypsum 50%	−0.5 + 0.15	68	67	85	80	1.55	36	47	52
	−1 + 0.5	68	67	85	80	1.55	36	47	52
Şırnak shale 30%+	−0.15	59	57	85	80	1.55	36	47	52
Şırnak gypsum 70%	−0.5 + 0.15	59	57	85	80	1.55	36	47	52

Inhibitor Type	Size, mm	25 min	40 min	50 min	60 min	Density	1.1	1.2	1.3
	−1 + 0.5	59	57	85	80	1.55	36	47	52
Şırnak shale 70%+	−0.15	73	74	85	80	1.55	36	47	52
Şırnak gypsum 30%	−0.5 + 0.15	73	74	85	80	1.55	36	47	52
	−1 + 0.5	73	74	85	80	1.55	36	47	52

Table 6.
Şırnak inhibitor material properties and slurries and aggregate time 50% fuel flame weight with standard values ASTM C6167.

Inhibitor with fly ash type	Size, mm	25 min	40 min	50 min	60 min	Density	1.1	1.2	1.3
Şırnak shale + fly ash	−0.15	73	74	85	80	1.55	36	47	52
	−0.5 + 0.15	73	74	85	80	1.55	36	47	52
	−1 + 0.5	73	74	85	80	1.55	36	47	52
Sırnak marly shale + fly ash	−0.15	73	74	85	80	1.55	36	47	52
	−0.5 + 0.15	73	74	85	80	1.55	36	47	52
	−1 + 0.5	73	74	85	80	1.55	36	47	52
Şırnak porous limestone + fly ash	−0.15	73	74	85	80	1.55	36	47	52
	−0.5 + 0.15	73	74	85	80	1.55	36	47	52
	−1 + 0.5	73	74	85	80	1.55	36	47	52
Şırnak gypsum + fly ash	−0.15	73	74	85	80	1.55	36	47	52
	−0.5 + 0.15	73	74	85	80	1.55	36	47	52
	−1 + 0.5	73	74	85	80	1.55	36	47	52
Şırnak shale 50%+	−0.15	73	74	85	80	1.55	36	47	52
Şırnak gypsum 50% + fly ash	−0.5 + 0.15	73	74	85	80	1.55	36	47	52
	−1 + 0.5	73	74	85	80	1.55	36	47	52
Sırnak marly shale 50%+	−0.15	73	74	85	80	1.55	36	47	52
Şırnak gypsum 50% + fly ash	−0.5 + 0.15	73	74	85	80	1.55	36	47	52
	−1 + 0,5	73	74	85	80	1.55	36	47	52
Şırnak porous limestone 50%+	−0.15	73	74	85	80	1.55	36	47	52
Şırnak gypsum 50%	−0.5 + 0.15	73	74	85	80	1.55	36	47	52
	−1 + 0.5	96	1						
Şırnak shale 30%+	−0.15	73	74	85	80	1.55	36	47	52
Şırnak gypsum 70% + fly ash	−0.5 + 0.15	73	74	85	80	1.55	36	47	52
	−1 + 0.5	94	0.2						
Şırnak shale 70%+	−0.15	73	74	85	80	1.55	36	47	52
Şırnak gypsum 30% + fly ash	−0.5 + 0.15	73	74	85	80	1.55	36	47	52
	−1 + 0.5	94	0.2						

Table 7.
Seyitömer and Sirnak Silopi fly ash chemical compositions and aggregate compliance with standard values ASTM C616.

gate content, amounts of mixture components used in forest fire extinguishing mixture covers used for this experimentation are given in **Tables 6** and 7.

3.1 Gypsum/desulfurization fly ash

Gypsum is generally used as construction material: manufacture of wallboard, cement, plaster of Paris, soil conditioning, and a hardening retarder in portland cement. Varieties of gypsum known as "satin spar" and "alabaster" are used for a variety of ornamental purposes; however, their softening and impurity limit their durability (**Table 8**).

The inhibitor compositions of Şırnak location were determined by means of standard methods. The inhibitor materials were ground by vibration milling to −0.1 mm. Inhibitor samples of the Şırnak aggregate rocks from masonary plants

Chemical classification	**Hydrous sulfate, $CaSO_4.2H_2O$, 98.3%**
Color	Clear, colorless, white
Streak	White
Luster	Vitreous, sugary
Diaphaneity	Transparent to translucent
Cleavage	Perfect
Mohs hardness	2
Specific gravity	2.3
Diagnostic properties	Cleavage, specific gravity, low hardness
Chemical composition	Hydrous calcium sulfate, $CaSO_4.2H_2O$
Crystal system	Monoclinic
Uses	Used to manufacture dry wall, plaster, and joint compound. An agricultural soil treatment and fire inhibitor.

Table 8.
Physical properties of gypsum of Şırnak.

Component	**Siirt Limestone**	**Hasankeyf Limestone**	**Mardin Limestone**	**Şırnak Porous Limestone**	**Marly Shale**
SiO_2	3.53	5.42	14.14	2.12	38.53
Al_2O_3	2.23	5.43	4.61	1.71	14.61
Fe_2O_3	1.59	2.48	334	0.58	7.59
CaO	41.48	34.23	39.18	45.22	19.48
MgO	2.20	12.28	4.68	7.41	3.28
K_2O	0.1	1.83	3.12	0.40	2.51
Na_2O	0.3	1.24	1.71	0.21	0.35
Ignition Loss	36.19	24.11	25.43	48.04	13.09
SO_3	0.22	0.31	0.20	0.02	0.32

Table 9.
The chemical analysis of lightweight inhibiting slurry fillers of Şırnak Province, lightweight limestone, marl, and shale.

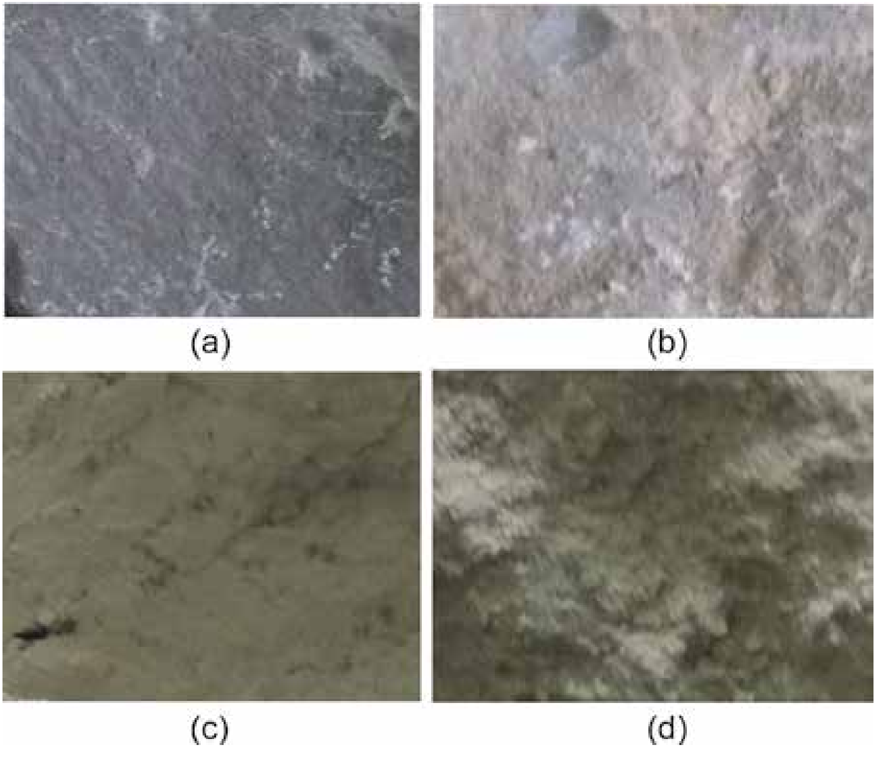

Figure 17.
(a) Marly shale, (b) Mardin limestone, (c) porous Hasankeyf limestone, and (d) the Siirt limestone.

provided in the Mardin, Batman, and Şırnak province in the experiments were given in **Table 9**. The amount of marly shale and porous silty limestone was efficient in fire inhibition reducing flame.

Prior to the preparation of the bright section, a liquid yellow epoxy resin was impregnated with the samples in a medium vacuum. This resin penetrates into the pores and makes the pores appear easier under the microscope (**Figure 17**).

4. Results and discussions

4.1 Flame inhibitor/extinguisher source: gypsum/fly ash/light shale

Mobile solid waste management included incineration of municipal wastes for thermal energy need and following landfill. However, the fire inhibitor soil production technologies from recycling, composting of waste became one method with other feasible mobile units of humus and agro soil production. In this studied case, the classified waste products were tested for inhibitor construction material, and fire inhibitor soil must be able to be developed for forest management and fire control and be aware that the inhibitor materials and composite products to be obtained from them must be processed by the gypsum or fly ash. These plaster sources widely used in construction and markets are also likely to be sensitive to the quality and quantity of the supply. The distribution of fly ash and biomass wastes in Şırnak province is shown in **Table 10**.

Mobile waste management is flexible in terms of design, compliance, and operation, and it needs to be able to adapt to existing social, economic, and

Component%	Şırnak Gypsum	Şırnak fly ash
SiO_2	1.44	21.48
Al_2O_3	1.12	13.10
Fe_2O_3	0.51	7.52
CaO	34.41	18.48
MgO	0.08	4.20
K_2O	0.10	2.61
Na_2O	0.05	1.95
Ignition loss	21.9	1.92
SO_3	26.22	0.32

Table 10.
Chemical compositions of the studied inhibiting fillers for forest fire extinguishing.

environmental conditions in the best way possible. Mobile/integrated systems including such waste inhibitor production and solid waste management units provide the flexibility to direct waste to other treatment systems as much feasible and waste sources of inhibitor soils provided even humus source of forest soil by protection natural conditions change (**Figure 1**).

The mobile solid waste inhibitor system should also be planned on a large scale in the regional base. The need for a range of waste disposal options can be envisaged as a reason for the large-scale plan to benefit from the demand and scale economics of recycled materials, compost, or energy at a certain quality and quantity [7–9, 14–17].

Mobile solid waste incineration can be successfully applied in areas with populations less than 500,000, depending on their work in various applications. The combustion system to be applied in this measure is also the amount of waste that depends on the nature and characteristics. The basic operations are mainly as follows:

4.1.1 Şırnak asphaltite: activated shale char/claystone

The scope of this fire inhibiting material production was filling material based porous solid heat absorption matter, for which the study was aimed metallization Şırnak asphaltite char as soil, fire arrestor source. In order to evaluate Şırnak asphaltite fine and other local limestones and gypsum for fire arrestor instead of construction material. The common burning of matter and metalized resources within the special fire arms is designed and proposed by providing legal and institutional, economic and environmental impact assessment. However, the use of Şırnak asphaltite and biomass source to develop materials against fire and tests of combustion weight change with standard flame and burning tests in laboratory ASTM D1373.

This situation of fire extinguishing matter was considered as metalized char instead of energy sources for better competitive. The fire management materials and safety market was caused additional policy tools needing to emphasize that EU and safety policy and law by environmental concerns drawn from Turkey. According to the potential policy instruments included the country determined the specified safety deviation from the materials fire inhibiting methods and guarantees to domestic targets including sustainable energy sources. The domestic forest potential and fire management regarding gross wood consumption had a certain share on concern to forest fire target (below 10%) should be management on high risk policy and legislation. The fire legislations reported from bio resources in renewable energy production and electric power for heating comprised separate but integrated objectives. These policies and laws only for biomass separate, but can also include an integrated target. All use of renewable sources in the EU target of achieving 12% market share for the biomass should be increased up to 300%. Regarding forest management at high risk fields in Turkey, appropriate potential control instruments and methods included forest fuel control and distribution to public-private sector and fire extinguishing lorry rods, construction ways, observation stations, aggregate road used in easy transport to high fuel risk zones, flexible loans, low interest loans, property first operating subsidies and/or grants and related service for consumers willing to use discounts as well as other financial support mechanisms. A potential wood market instrument of state was not required to support loans on forest management forever.

4.2 Inhibitor soil source as Şırnak asphaltite in Şırnak Province

The fluidized bed combusting of Şırnak asphaltite is producing 415 MW thermal power plant of CİNER in Silopi for electricity in compliance with the addition of limestone at the weight rate of 25% to the fluidized bed boiler on environmental norms to cut SO_x of low quality coal with 46% ash and 7% total sulfur combustion. The high ash of low quality types of coals was unfeasible in combustion systems and energy production facilities. The low quality coals are needed in inhibitor construction material production and mortar materials or pavement in road, and material technology provided also enables the production of liquid and gaseous mixing byproducts of fly ash and flue gas as fire inhibitor [15]. However, agricultural waste materials and humus chemical nature of them require a variety of mixing methods for soil amendments. For this purpose, alternative renewable energy resources need to process them to provide the basic information required in the laboratory and on pilot scale. The methods use feasible process in fire inhibitor materials, waste biomass, and metalized derivative shale chars as fly ash in the local area. So, significant design works for Shale char need to obtain as the char derivatives from the wastes as available fire inhibitor resources (**Figure 18**).

Figure 18.
Emission control with ESF, combustion with Şırnak chalk, limestone, and fly ash at weight rate of 25%, in Şırnak thermal station.

4.3 Fire inhibitor granule/sand/soil: mobile unit for waste carbonization-metalized char carbonization in Şirnak

In this study, porous limestone and porous anhydrite metalized stone absorbed the bubbled balls with microwave melted recycling anhydrite metalized powders covering the surface to avoid combustion. In this investigation, the recrystallized gypsum and powdered limestone were reroasted in microwave to melt anhydrite with the porous cores and basalt granules and even the bubbling of anhydrite metalized granules. The products finished was used for fire arrestor powder and soil, absorbing heat of fire which were determined as metalized coal carbon rich forest soil were investigated for arrestor on floor test and deterioration of soil and heat sorption were calculated, respectively. For this purpose, heat resistance, heat sorption, and soil combustion experiments were conducted. As defined, the test results were conducted by comparing metal powders with high heat. The production flow sheet and process advantageous parameters using recycling coal shale and anhydrite gypsum microwave processing parameters were defined. To recrystallize anhydrite metalized carbon limestone, the composite balls of marls having the relation between composite rock formation and discontinuity at production have been established.

In the tests, the Şırnak asphaltite sample was used as shown in **Figure 19**, and the reduction of the coal samples was shown in melt anhydrite fractions. The chemical melt anhydrite temperature was continuously weighed, and the metalized carbonization analysis was carried out in the bath microwave oven. The test results are shown in **Figure 3** for biomass pellets and coal sample. As shown in the figure, the effect of addition is determined in combustion experiments, the heat absorption as hydrated/dehydrated gypsum, the reactor temperature was 500°C and metalized

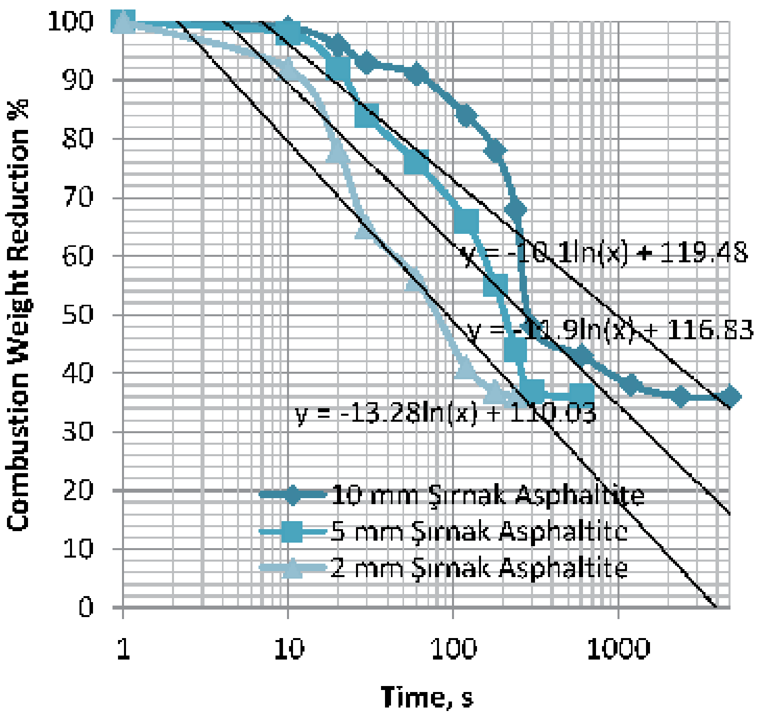

Figure 19.
TGA weight decrease during experimental flame combustion.

anhydrite only 10% metalized coal carbon soil pellet and slaked pores expanded in microwave treatment. The metalized carbonization weight ratio was varied to 750°C, and waste carbon samples were analyzed for heat hold-up by burning.

4.4 Microwave radiated metallized sponge char production

Porous compost production by char was managed in pilot systems using retort combustion systems that are adaptable to flexible and variable fuels in need of low quality fuel. In real applications, char waste fuel qualities were not be fully metalized in a variety of fluid and grate combustion systems. However, environmental effects were reduced due to semi-burning. Burning biowaste or Şırnak asphaltite slime in the fluidized bed manufactured by ALFA Company, combustion and energy production were developed within the scope of char and combustion wastes to char [6, 18, 19]. Char production systems in the integrated solid waste management can provide energetic energy production with biogas plant. The combustion inhibition or flame inhibitor porous char granules occurred on the coarse sized material is shown in **Figure 16** and flame model in **Figures 20** and **21**.

Mobile plant carbonization system with the following design produces integrated energy with the biogas plant (**Figure 2**):

- separation of metal waste and pet wastes;
- classification of biological wastes and drying and storage in pools;
- biogas anaerobic conversion of bio wastes;
- mobile combustion; and
- energy production.

Integrated solid waste incineration is evaluated as more advantageous in some countries. Mobile systems, however, provide economic benefits in the areas of low population density in our country and in cities. The separation of metals from scrap or recycling from household waste has often been an expensive cost step. However,

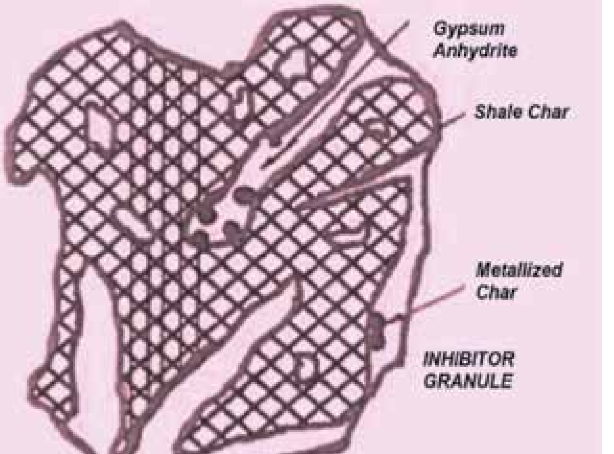

Figure 20.
Integrated fluidized bed biogas and solid waste incineration.

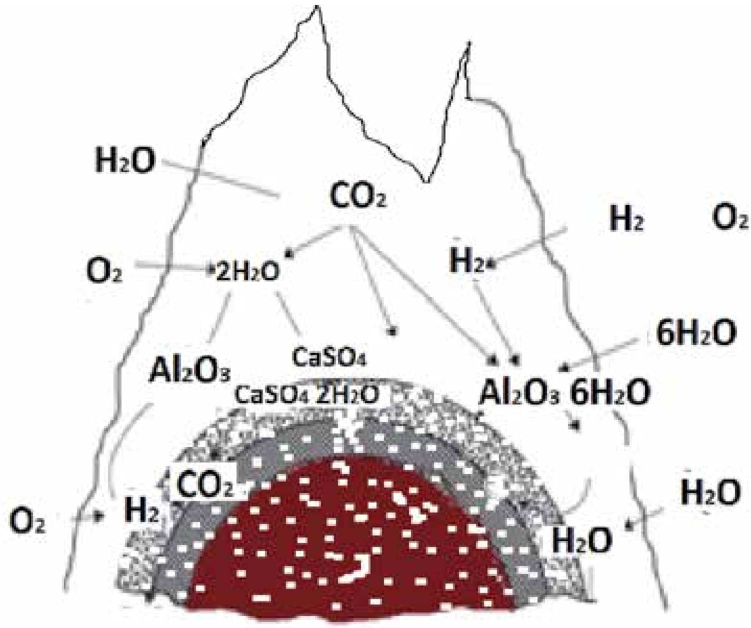

Figure 21.
Inhibitor flame solid waste incineration model on fire.

with the acquisition of biosolid wastes from the domestic source of the waste, the incineration system has been made feasible.

The conductive heat values could be determined by calorimetric studies regarding equations below:

4.5 Porosity and matrix content

The microwave metalized char led to relatively low heat conductivity of mass heat conduction of 53%. After application of recycling of waste asphaltite slime, the pyrolysis char extraction increased to about 11.7%. The char extraction from the waste samples in the conventional furnace at 600 and 700°C yielded values of 15 and 17% low heat conductive char products, respectively.

Microwave metalized char work could be integrated into such a system in order to make pretreatment faster and more economical. The proposed process that includes even microwave pyrolysis circuit was retorted for conducting heat by microwave oven. The test results in this study were given by TGA burning weight decrease of oak and fire inhibitor addition at half weight rate in the dish pot in TGA are shown in **Figures 22** and **23**. The granule composting was obtained by briquetting method under microwave radiation as permittivity loss and heat absorbance as temperature change are shown in **Figures 24** and **25**.

TGA weight decrease during experimental flame combustion results is shown in **Figure 5**.

4.6 Stone type

The problems of water collection in dry climates and hard hot conditions of the water storage pools became advantageous for the production of muddy slurry preparations. The inhibiting slime coal matter such as coal ash particles had a property of noncombusting and low-heat conducting rate than fines; thus, temperature control during fire combustion could be avoided. Additionally, there will be

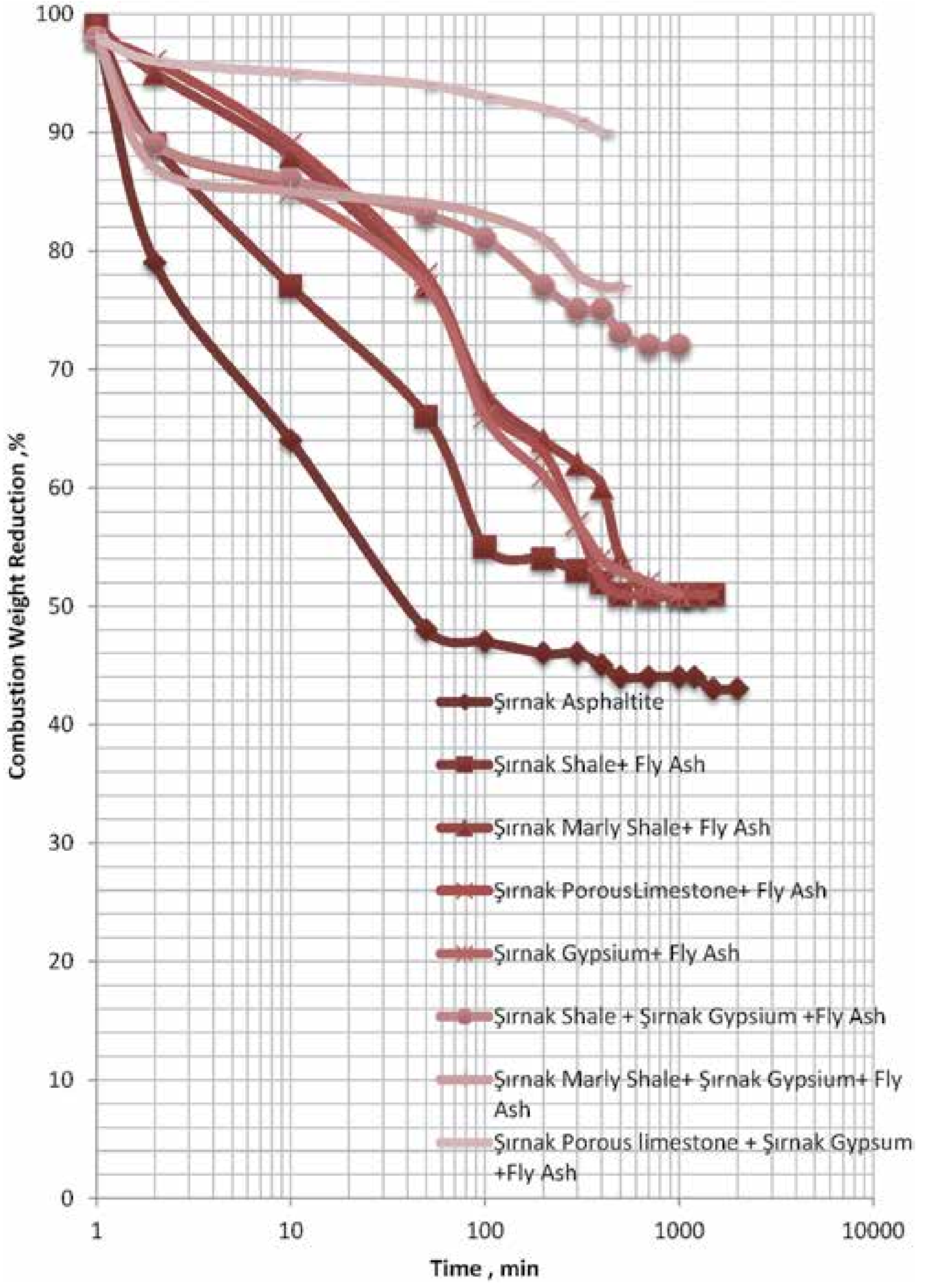

Figure 22.
TGA weight decrease during experimental flame combustion by fly ash, Şırnak shale, limestone and Şırnak gypsum.

fly ash dust that may control during flaming by the high-specific surface area over 12–22 m^2/g and low heat conduction for complete combustion by microwave metalizing char. The carbonaceous matter in the gypsum compost adsorbed much flame heat. The most important matter was the metalized char carbon and waste slime carbon. The constituents of the inhibiting source carbon were amorphous metalized inertia.

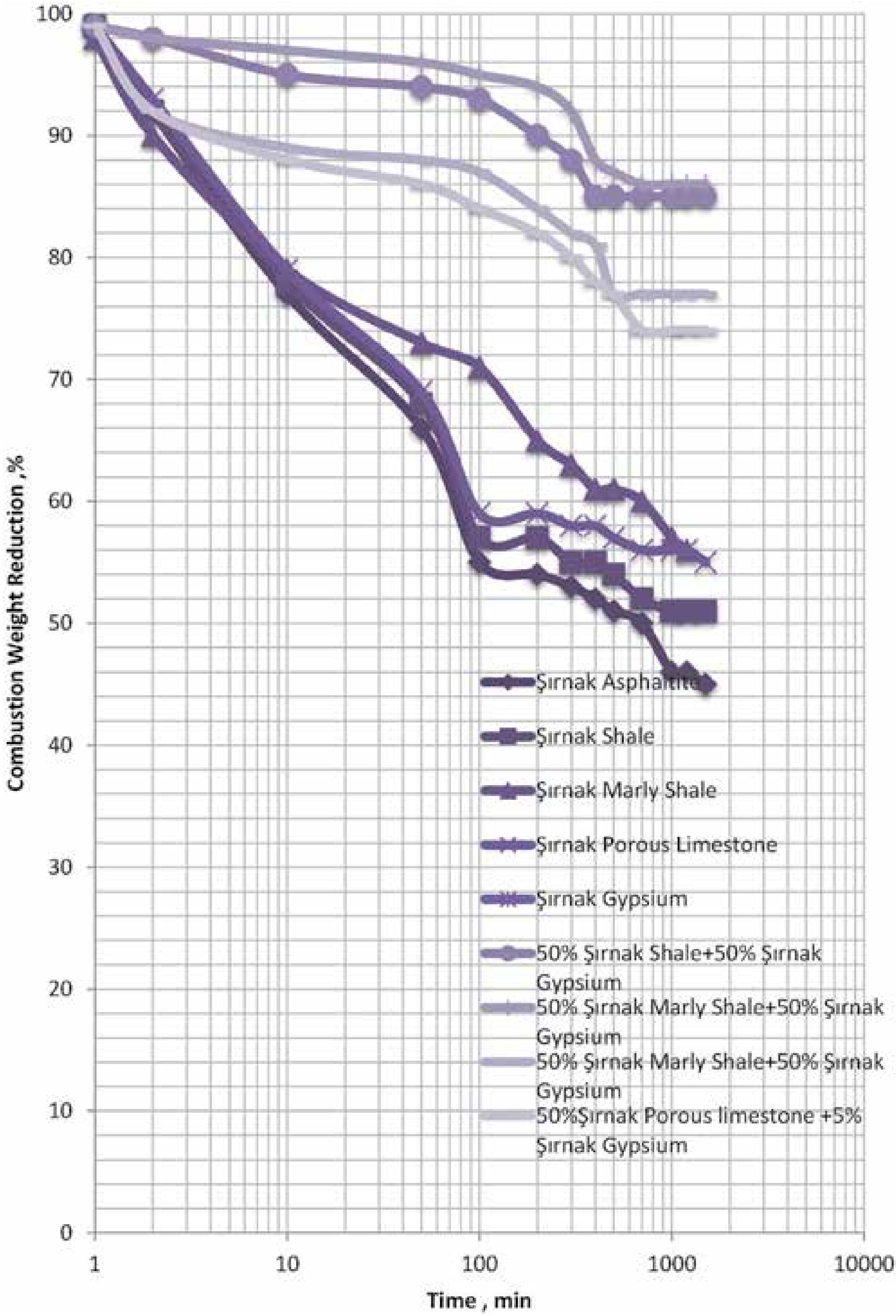

Figure 23.
TGA weight decrease during experimental flame combustion by Şırnak shale, porous limestone and Şırnak gypsum.

Such limestones containing limonite and iron hydroxides provided the inhibitor hydrate in flame extinguishing with microwave pretreatment to break down the matrix of the oxides and metal hydrated matters or passivity the carbonaceous matter before calcinations by heat absorption. The methods included hydrating, pressure hydration, metalized char lining, and flame inhibiting gaseous matter

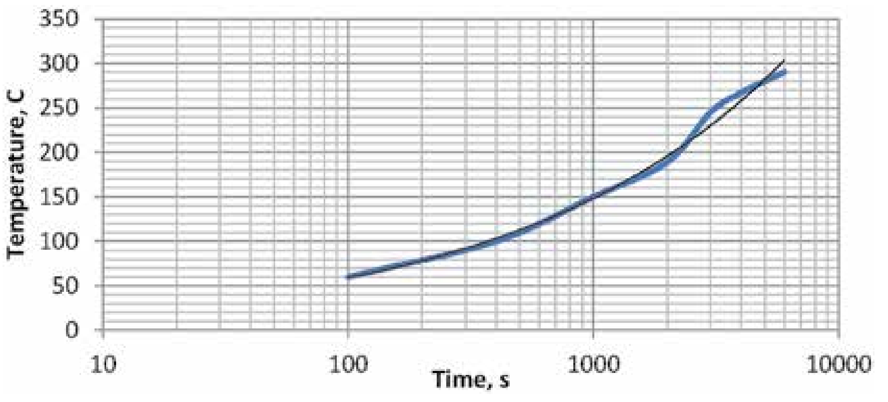

Figure 24.
Time effect of metalized char processing time on briquetted matter by temperature in microwave char metallization.

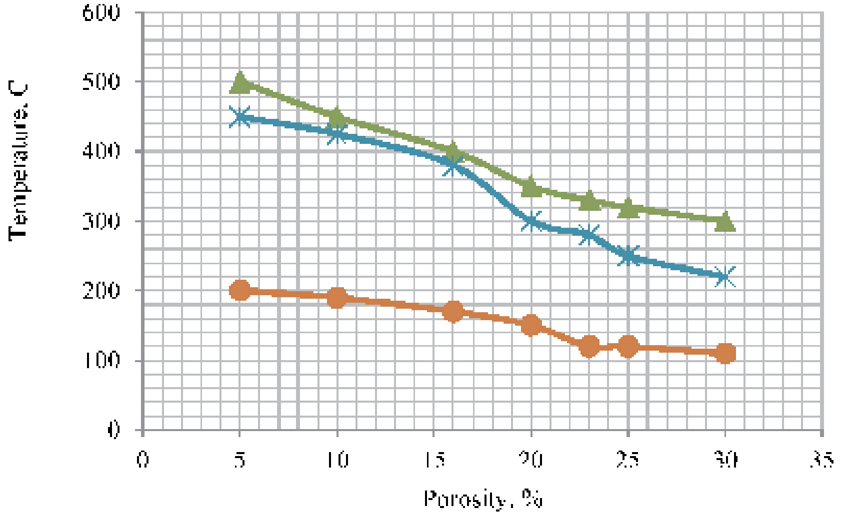

Figure 25.
Porosity effect on temperature in microwave char metalizing.

output of waste. Microwaves could be utilized as an alternative source of energy for hydrate treatment of composts in some of the unit operations such as porous metalized carbon and metal oxides known to be very good microwave absorbers, and they rapidly and selectively inhibited heated flame matters. In the present study, the microwave pyrolysis of a coal sample with coal pyrite and copper pyrite was investigated. The porous limestone was very responsive to microwave heating, and this resulted in almost semi-reactive porous matter for calcination and in some cases active porous compost of the material as shown in **Figure 20**.

The changes in the heat absorbing behavior of the limestone were monitored, and the optimum conditions for metalized char pyrolysis rate were established as shown in **Figure 24**.

Eight hundred powered microwave radiation over the 10 g powder samples reached a temperature of about 500°C in metalized calcination of compost, while the 10 g sample reached temperature long time to about 500°C. Generally, in laboratory scale microwave metalizing, the sample temperature increases with sample mass. In contrast to conventional heating, in microwave systems, the heat is generated internally, and thus, the metalized product porous mass covered heat loss from the sample. There were porosity and density factor that controlled the flame inhibiting weight decrease by fire heating behavior. For samples with a relatively low mass, the high surface area to volume ratio restricted the flame power. The rate of temperature rises, and the maximum attainable temperature could be inhibited by slurry composts. As a result, the conductivity at soil peat values was relatively low, and the soil sample was effectively coupled with inhibition of the fire dish. On the other hand, for the same cross-sectional area of the clay pot, as the sample mass depth was increased, there was a reduction in the surface area to inhibition volume ratio, and this reduced the inhibition matter in fire loss from the bottom, leading to a higher flame and fire temperature. Additionally, as Pot dish depth mass decreased, there was more efficient inhibition on fuel material to reduce interaction with the fire field.

5. Conclusions

The inhibitor granules and water granule slurries at lightweight matter resulted in successive heat absorption in the flame plasma, and the composite granules of gypsum in the bubble composite form were so effective. The shale hydrated was also effective with metalized carbon content and hydrate content.

The microwave radiation metallization of char showed heat absorption in the flame increasing process time and sample mass in the flame. Due to the heat decrease response of the composite gypsum to carbon, low slurry densities of 1.2 and 1.3 kg/lt were found to be suitable for inhibition flaming as higher densities resulted in bubbling and foaming of the metalized char/anhydrite. The waste metalized char/shale/anhydrite weight rates after radiation route in microwave were over 25%, and the bubbling route was continued in the flaming fire period of wood to those obtained by conventional heating. The main advantages of microwave melting were that both the total flaming heat rates conducted to metalized char gypsum surface equally disseminated pores, and the cooled bubbling over cooling rates was higher, and the specific energy area of solid matters in flame was lower than in fly ash composite granule.

Şırnak porous limestones containing 20% porosity and the high gypsum content discarded as sponge stone from aggregate stocks swept to waste products. Şırnak produces the porous gypsum stones by construction stone product about 50,000 tons per annum for swept to waste broken stone wall matter to dispose, Siirt and Şırnak porous limestone was not also evaluated. Those waste stone products both should mainly be evaluated as fire inhibitor material as sponge isolator stone. Those must be evaluated in terms of high valuable metal contents emitting heat conduction and radiation. In this study, samples were subjected to microwave melting of metalized anhydrite shale tailings, fly ash, and subsequently pelletized and subjected to microwave bubbling briquetting over stone surface blocking to clusters. Porous limestone sand, fine waste of porous limestone were wide advantageous in filer raw material sequence in the region containing disseminated distribution of low and high quality cementing limestones. The porous limestones over 50–70% were produced by filler construction or isolation stones processed at least 100,000 tons waste. Every year about a few million tons of limestones could be used as waste fire inhibitor or extinguishing material. The granule in a particle size of these wastes usually occurs below 10 mm in size, which may be advantageous for the evaluation of shock wave şolator composite stone production. The evaluation of those waste sources in sponge composite iron stone block production was prompted as chemical properties in the microwave process, and feasible production of sponge composite iron stone was managed in this study.

Abbreviations

A	*pre-exponential factor* $[s^{-1}]$
c_p	*specific heat capacity* [J/kg K]
E	*activation energy* [kJ/mol]
heat of pyrolysis	[J/kg]
h_c	convective heat transfer coefficient $[W/m^2\ K]$
k	thermal conductivity [W/m K]
L	depth of the sample [mm]
heat flux	$[kW/m^2]$
R	*universal gas constant* [J/mol K]
T	temperature [°C]
t	time [s]
Y	mass fraction
z	depth into the sample [m]
ε	*emissivity*
κ	radiative absorption coefficient $[m^{-1}]$
reaction rate per unit volume	$[kg/m^3\ s]$
ρ	density $[kg/m^3]$
σ	*Stefan-Boltzmann constant* [J/K]
0	initial
e	external
d	destruction
g	gas
i	condensed-phase species index
ig	at ignition
r	in-depth radiation
s	solid

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References

[1] Babrauskas V. Common solids. In: Ignition Handbook, Chapter 7. Fire Science Publishers; 2003. pp. 234-251

[2] Didomizio MJ, Mulherin P, Weckman EJ. Ignition of wood under time-varying radiant exposures. Fire Safety Journal. 2016;**82**:131-144

[3] Flores-Garnica JG, Omi P. Mapping forest fuels for spatial fire behavior simula-tions using geomatic strategies. Agrociencia. 2003;**37**:65-72

[4] Flores-Garnica JG, Moreno-González DA. Spatial modeling of the influence of forest fires on natural regeneration of a disturbed forest. Agrociencia. 2005;**39**:339-349

[5] Mouillot F, Rambal S, Joffre R. Simulating climate change impacts on fire frequency and vegetation dynamics in a Mediterranean-type ecosystem. Global Change Biology. 2002;**8**:423-437

[6] Bell DA, Towler BF, Fan M. Coal Gasification and Applications. Oxford: Elsevier Inc; 2011. ISBN: 978-0-8155-2049-8

[7] Hoffmann WA, Schroeder W, Jackson RB. Regional feedbacks among fire, climate, and tropical deforestation. Journal of Geophysical Research. 2003; **108**:4721. DOI: 10.1029/2003JD003494

[8] Torero JL. Flaming ignition of solids fuels. In: SFPE Handbook of Fire Protection Engineering, Chapter 2–11. 4th ed. National Fire Protection Association; 2008. pp. 2-260-2-277

[9] Tewarson A. Flammability parameters of materials: Ignition, combustion, and fire propagation. Journal of Fire Sciences. 1994;**12**:329-356

[10] ASTM D6413 Standard composite burning ability test of solids

[11] ASTM D4809 Standard Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter (Precision Method)

[12] ASTM D3841 Standard flammability test of burning material

[13] ASTM D 1230 Standard flammability test of textile

[14] Mouillot F, Field CB. Fire history and the global carbon budget: A 1° x 1° fire history reconstruction for the 20th century. Global Change Biology. 2005; **11**:398-420

[15] Wesson HR, Welker JR, Sliepcevich CM. The piloted ignition of wood by thermal radiation. Combustion and Flame. 1971;**16**:303-310

[16] ASTM. D-3173, D-3174 and D-3175. 2013

[17] ASTM. Standard Test Method for Ash in Biomass E1755-10. PA (USA): ASTM; 2010

[18] ASTM. Standard Test Method for Water Using Volumetric Karl Fischer Titration E203-11. PA (USA): ASTM; 2011

[19] ASTM. Standard Test Method for Ash from Petroleum Products D482-13. PA (USA): ASTM; 2013

Section 4

Advanced Technologies and Policies in Forest Management

Chapter 7

Use of Fractal Analysis in the Evaluation of Deforested Areas in Romania

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Abstract

Spectacular spatial dynamics of forest areas is one of the biggest challenges for the scientific world, concerned with completing the methodologies devoted to new methodological approaches, to provide new information that is indispensable in assessing the impact of deforestation within the ecosystem. In this study, we analyzed the evolution of the deforested areas, using the fractal fragmentation index (FFI). The research is based on high-resolution satellite images of forest areas between 2000 and 2017. The use of fractal algorithms allowed the modeling of the grinding patterns, identifying obvious differences between compact and fragmented cuts. Information is needed especially in the evaluation of the areas cleared because of illegal actions. Research has shown spectacular increases in deforestation in the mountain area, the northern and central groups of the Eastern Carpathians being the most fragmented geographical regions in Romania. The study showed that deforestation led to the fragmentation of forests, which generates major natural changes. The results obtained can contribute to the identification of new approaches in national forest fund management policies by establishing a critical fragmentation threshold.

Keywords: fractal analysis, deforestation, forest fund, ecosystem, fragmentation of the forest

1. Introduction

Forests represent perhaps the most complex terrestrial ecosystem, given their ecosystem role, as well as habitat and socioeconomic development. The increasing pressure exerted by the global economy and climate change leads to the degradation and shrinking of global forest areas [1–4]. The reduction of the forest area and its degradation have negative repercussions on the environment, in general, but especially on the quality of the air, the soil, and the security of the water resources [5–12]. Thus, a series of programs and researches were initiated aimed at evaluating, monitoring, and reporting the physical and biological states of the forest (Convention on Long-Range Transboundary Air Pollution (CLRTAP) [13];

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UN Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation (REDD) [14]; International Long Term Ecological Research Network (ILTER) [15]; NASA's Carbon Monitoring System (CMS) [16]; Climate Change Initiative (CCI) [17]).

The reduction of forest areas as well as the process of fragmentation of the forest is a ubiquitous problem worldwide. Haddad et al. estimated that half of the planet's forests are less than 500 m from an inhabited area and most of the forested areas have an area of less than 10 hectares [18].

The satellite images offer an unprecedented perspective on the spatial evolution of the cover surfaces with forest vegetation, allowing the mapping of the compactness of the surfaces as well as their degree of fragmentation over time [19–22].

Forest fragmentation assessments have been completed for many countries, such as Canada, China, the Democratic Republic of Congo, India, the UK, or the USA [23–26]. Many of the researchers who developed these studies point out that fragmentation of forest areas has negative effects on the natural ecosystems by increasing the isolation, creating artificial margins, and reducing the basic areas of habitats.

In Romania, forests are under pressure due to climate changes (extreme temperatures, low rainfall, strong winds, and even tornadoes) and natural disturbances (insect outbreaks), but mainly due to anthropogenic causes (various forms of property, poor pest control, illegal logging, large demands on wood for export, etc.). Although Romania's forest area is estimated at about 29% of the country's total area, well below the EU average level of 40%, logging is still at a high rate [27].

A continuous, accurate, and reliable monitoring of the territorial evolution of forests as well as their state of sanogenesis is required both locally, in Romania, and regionally, Europe or worldwide. Such monitoring systems can be based on the information provided by the satellite monitoring networks correlated with on-site measurements and with accurate methods of quantification [28–32].

Establishing methods of continuous observation and accurate determination of long-term environmental changes is necessary to ensure the sustainability of the forest ecosystem and the efficiency of the planned ecological restoration [33].

The method proposed in this study wants to perform a fractal analysis regarding the deforestation of forests at the level of Romania.

2. Methodology

In order to start the analyses for GIS and fractal methods used, we downloaded layer (a raster image in tiff format) corresponding to the granule with the top-left corner at 50°N, 20E (in which Romania is situated), containing the forest loss (loss year) data, for the 2001–2018 [34].

The images prepared for the fractal analyses followed a step-by-step algorithm, consisted on the extraction by mask procedure. The input feature mask was the vector limit of each relief unit of Romania, in our case 11 vector limits (the Carpathians, the Subcarpathians, the West Hills, the Danube Delta, Transylvania Depression, Dobrogea Plateau, Mehedinți Plateau, Getic Plateau, Moldova Plateau, Romania Plain, and West Plain). For each of the 11 input limits, 21 images in tiff format were exported providing pixels with useful informations. The first image exported contains the geographical limit for the relief unit, the other 18 images contain the yearly forest loss, from 2001 to 2018, and another image contains the cumulated forest loss for the entire period (2001–2018) and the last image the tree-cover information. We have to mention that for the best results, all the images exported were in black-and-white tones (the pixels corresponding to limits, to the forest loss, and to the tree cover were in white, while the background was in black color). Other important aspects were the scale and the image position: in order to avoid the information errors that might have appeared during the export processes, for each input feature mask (relief unit), the same scale and the same unmoved image position were kept.

The exported images provided useful informations that were extracted by using some specific softwares for the fractal and nonfractal analyses. We mentioned that, depending on the surfaces of the relief units, the images were exported to different scales and analyzed later fractal objects. Thus, for the Carpathians, the exported images kept the scale 1:1,750,000; for Subcarpathians, 1:1,300,000; the Transylvanian Depression, 1:1000,000; Moldova Plateau, 1:1,500,000; Dobrogea Plateau, 1:800,000; Getic Plateau, 1:650,000; Mehedinți Plateau, 1:200,000; the West Hills, 1:1,500,000; Romania Plain, 1:1,350,000; West Plain, 1:1,500,000; and the Danube Delta, 1:600,000. Even if the exported images were analyzed at different scales, the pixel sizes being the same for each exported image, there were no distortions or errors in their subsequent processing.

The applicability of fractal geometry is limited not only to static phenomena but also to the study of dynamic phenomena, in evolution, such as the phenomena of growth in biology or of development of urban populations [35].

A versatile possibility to determine the deforestation patterns but also their impact on forest compaction is the fractal fragmentation index (FFI). FFI is a recent indicator and describes fractal fragmentation and can also be interpreted as an index of compaction of the analyzed surfaces, being a dimensionless indicator [36].

The FFI is calculated using the equation (Eq. (1)):

$$FFI = D_A - D_P = \lim_{\varepsilon \to 0}\left(\frac{\log N(\varepsilon)}{\log\frac{1}{\varepsilon}}\right) - \lim_{\varepsilon \to 0}\left(\frac{\log N'(\varepsilon)}{\log\frac{1}{\varepsilon}}\right) \tag{1}$$

where FFI is the fragmentation fractal index, D_A is the fractal dimension of the summed areas, and D_P is the fractal dimension of the summed perimeters; ε represents the size of the box; $\log N(\varepsilon)$ represents the number of contiguous and non-overlapping boxes needed to cover the object area; and $\log N'(\varepsilon)$ represents the number of contiguous and non-overlapping boxes needed to cover only the object's perimeter.

When the value of the indicator has $FFI = 0$, it means that the analyzed fractal objects (in our case the deforested areas or forests) are very small, of the order of 1–4 pixels, so that their outline cannot be extracted, D_AD = D_P =0. When the FFI value tends to be 1, the occupied areas are large and compact. $FFI = 1$, when analyzing a Euclidean object, 100% compact, without any discontinuity ($D_P = 1$ and $D_A = 2$). When the areas occupied by the fractal are smaller, more dispersed, and more fragmented, the value of the FFI approaches more than 0. The FFI was calculated using IQM-plugin-FFI, available online at https://sourceforge.net/projects/iqmplugin-ffi/, for open source software IQM 3.5 [37].

The analysis of the evolution of the analyzed parameter is carried out through a series of steps. In advance, IQM 3.50 software is downloaded from https://sourceforge.net/projects/iqm/files/latest/download; then, IQM-plugin-FFI is downloaded from the address https://sourceforge.net/projects/iqm-plugin-ffi/files/latest/download. The downloaded plug-in is inserted in the plug-in folder of the IQM program, and a series of steps are taken.

Step 1: Import the images into the information quality metric (IQM - An Extensible and Portable Open Source Application for Image and Signal Analysis in Java) [File—Open Image(s)] (**Figure 1**).

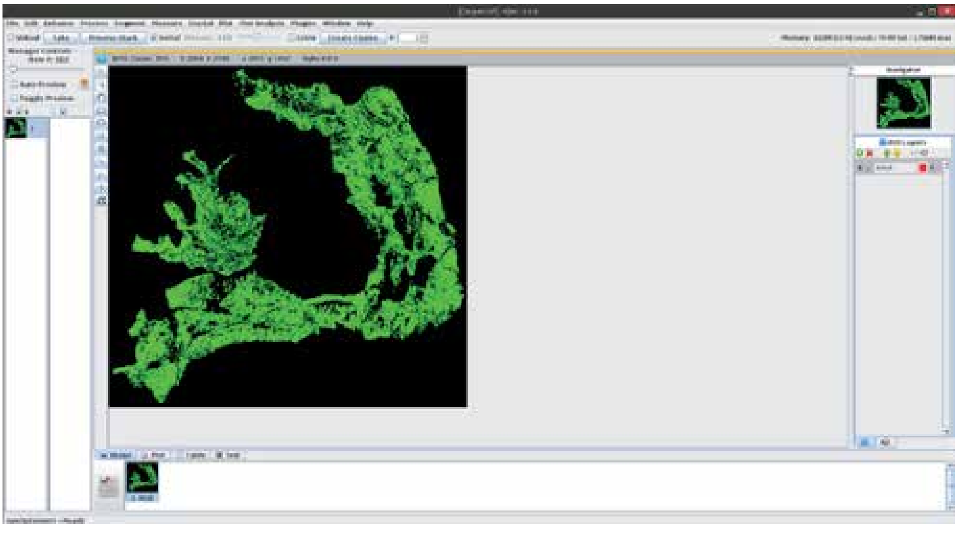

Figure 1.
Importing images to analyze.

Step 2: Convert RGB images into 8 bits [Process—Convert Image–extract G] (**Figure 2**).

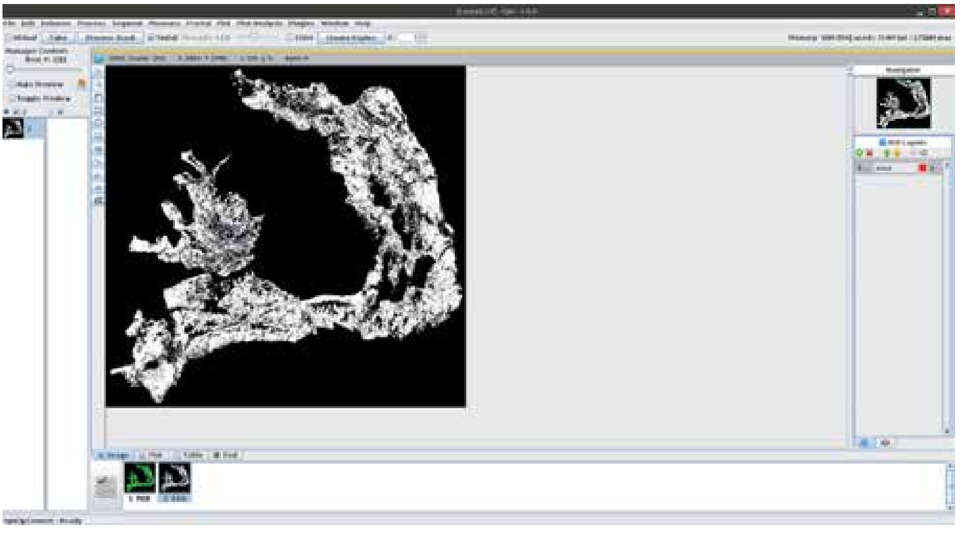

Figure 2.
Convert RGB images to 8 bits.

Step 3: Open the FFI plug-in [Plug-in—Image—FFI v2.0].

Method P-Dimension (Pyramid Dimension) is selected (because it is much faster than box counting and the results are similar), and the number of boxes is 9; then press Preview and the fractal analysis is done (**Figure 3**).

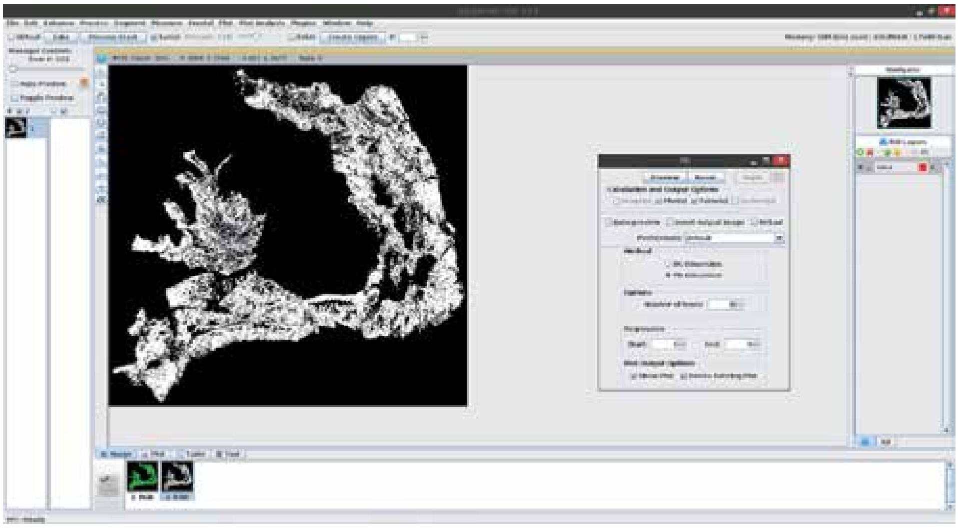

Figure 3.
Using the FFI plug-in.

Step 4: This gives the FFI value on the last column of the displayed table (**Figure 4**).

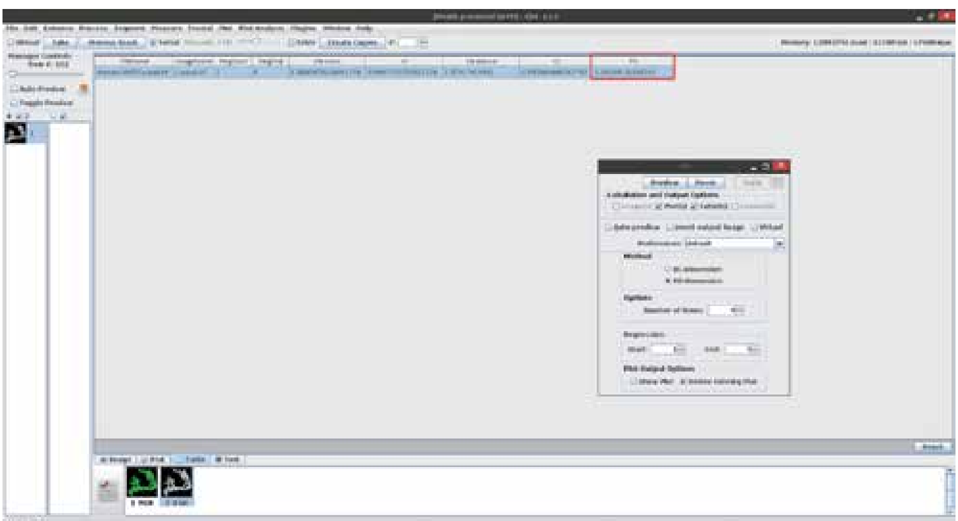

Figure 4.
Obtaining the results of the FFI index.

3. Study area

Romania is a state located in the Southeast of Central Europe, on the lower Danube, north of the Balkan Peninsula, and on the northwestern shore of the Black Sea. The population, at the level of 2019, is estimated at 19.4 million citizens. On its territory are the southern and central parts of the Carpathian Mountains and the lower Danube basin. It borders Bulgaria to the south, Serbia to the southwest, Hungary to the northwest, Ukraine to the northeast, the Republic of Moldova to the east, and the Black Sea to the southeast (**Figure 5**).

Figure 5.
Romania—Study area.

According to the National Institute of Statistics, Romania's forest fund covers an area of 6,529,000 hectares, representing 27.3% of the country's territory. The total volume of forest stands is estimated at over 1340 million m^3.

The multifunctional character of forests is given by their multiple roles: ecological, economic, and social. From a socioeconomic point of view, forest exploitation generates resources, especially wood, but it also plays an important role in the regeneration of water resources and air quality. Their use is multiple starting from the energy role (about half of the renewable energy consumed in the EU is produced from wood mass), for timber, paper industry, wood fiber panels, etc. The relationship between man and the forest is complex, and the dependence is obviously mutual.

The territory of Romania represents a point of intersection between different biogeographic regions: Arctic, Alpine, Western and Central European, Pannonian, Pontic, Balkan, sub-Mediterranean, and even Colchian and Turanic-Iranian. This high level of diversity of ecological conditions/systems also determines a great diversity of flora and fauna, estimated at 3700 species of plants and over 33,000 species of animals. A large number of these species (over 220 plants and over 1000 animals) are endemic species, adapted to local conditions and are found only in Romania.

Important areas of natural, virgin, and quasi-virgin forests are preserved in Romania. However, these areas are rapidly narrowing, currently occupying only about 280,000 hectares, that is, less than half of the existing area 20–25 years ago. These forests are located in a proportion of 99% in mountain regions (in karst areas, in hard-to-reach regions, on steep slopes and screes) and only in a proportion of 1% in the hill and plain regions (hard-to-reach areas of the Danube Delta or compact forest massifs located at a considerable distance from localities). Most of them are located in the area of beech and spruce and mixtures of spruce, fir, and beech. Currently, parts of the virgin and quasi-virgin forests of unique value, including for the biodiversity of natural ecosystems, are included in officially protected areas.

The division of the property regime of the national forestry fund after the 1990s, the great dynamics of the laws in the forestry field, the lack of a coherent policy in this field, and the desire for quick financial gains generated significant deforestation of the forests at the national level. The lack of precise statistics of the deforested surfaces and the quantities of wood exploited has generated at the level of some groups of researchers or environmental organizations of solutions for the prevention and quantification of the deforested areas.

4. Results

Economic pressure and extreme environmental factors have led to the reduction of forest areas worldwide. Romania has also registered a marked dynamics of the national forestry fund in the last decades.

The division of forest fund ownership, inadequate or poorly applied legislation, poor monitoring of the way the wood is exploited, and the occurrence of natural phenomena that have affected the forest (wind blows, biological attacks, etc.) led to the reduction of forest areas and especially to a strong fragmentation of them.

Finding methods that determine the most precisely deforested areas, the density of the existing forest, and its territorial fragmentation is of great importance for sustainable management of the national forestry fund but also within a sustainable development of the environment (protection against landslides, floods, air quality, groundwater resources, etc.).

The analysis was performed according to the types of relief units and their degree of forest cover. Thus, it is found that socioeconomic and natural factors of the last decades have generated a decrease of the compaction of the forest areas (**Figure 6**). The most affected unit of relief is that of the Carpathian Mountains and of the Mehedinți Plateau. All the relief units have suffered over time decreases of the compaction of the forest surface following the deforestation.

The tested and analyzed method may also indicate the technical way of extracting the wood from the logging. A selective extraction of valuable and mature trees or a

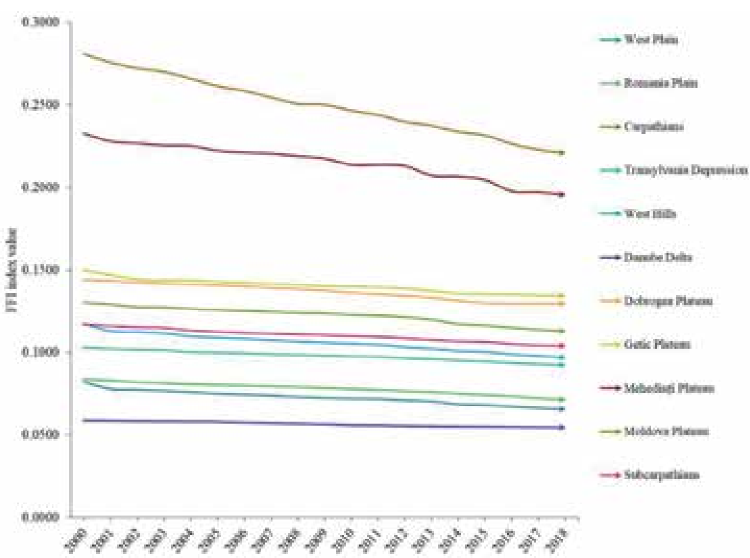

Figure 6.
Evolution of the compaction of the areas occupied by the forest, at the level of relief units, between 2001 and 2018, in Romania.

"shaved" exploitation, regardless of the size and nature of the successive species within those plots. This can be determined by comparing the obtained values of the FFI at the level of any reference year in the analyzed period.

By performing the value difference of the FFI obtained at the level of 2018 and the one from 2001, it can be seen which relief unit was more intense and more fragmented and deforested (**Figure 7**).

The area of the Carpathian Mountains, by the nature of the relief, leads to the clearing of surfaces arranged on different slopes and positions. This is also due to the access to the exploited plots and the shelving of the species. Instead, in the Romanian Plain or in the Danube Delta where the forest surfaces are composed of

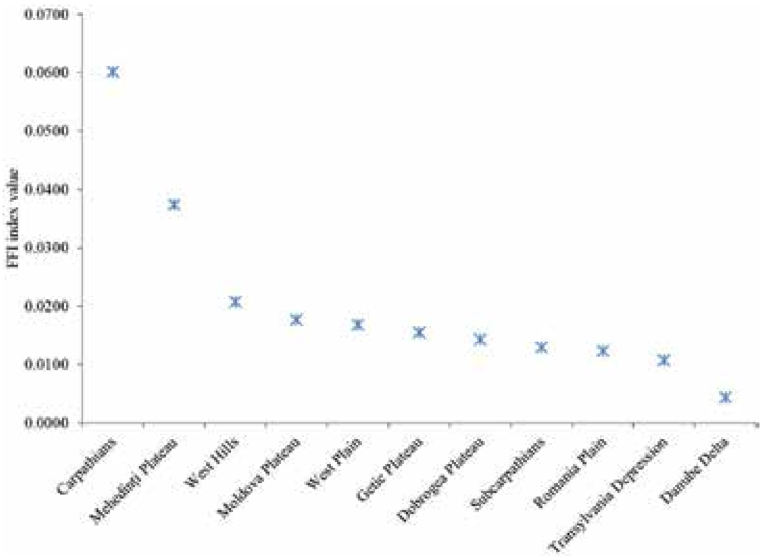

Figure 7.
The degree of fragmentation of forests, obtained by comparing the value of the FFI 2018–FFI 2000.

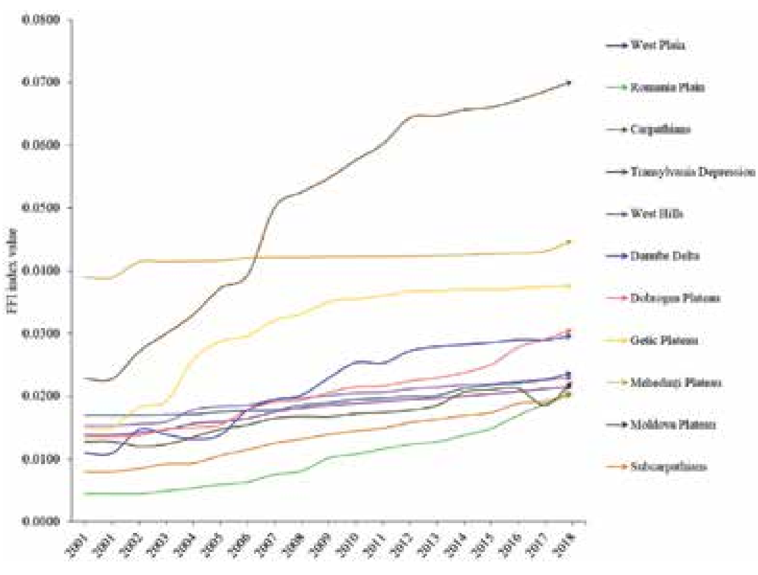

Figure 8.
Dynamics of cumulative deforestation.

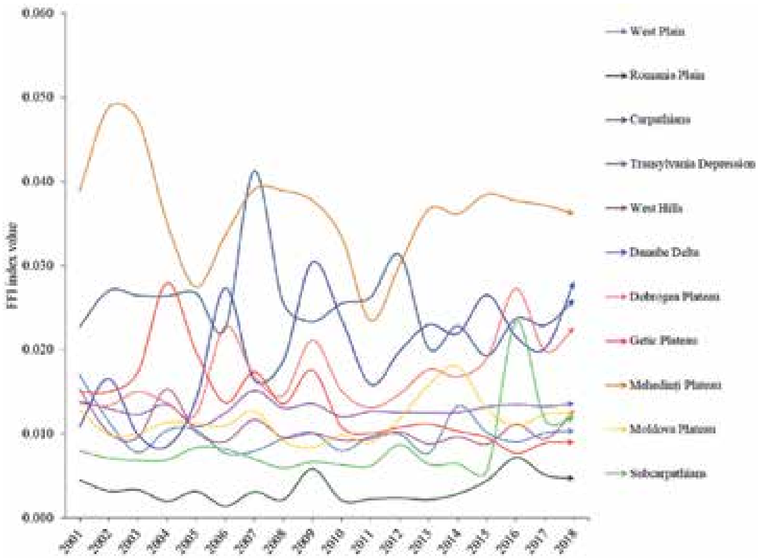

Figure 9.
Annual dynamics of deforestation, by relief units, between 2001 and 2018.

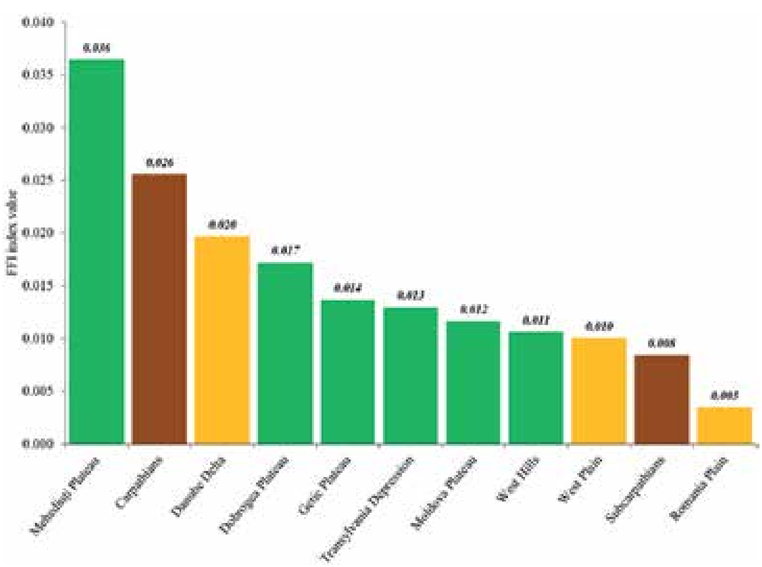

Figure 10.
The average of the FFI deforestation index, between 2001 and 2018 (plateau, green color; plain, yellow color; mountain and premontane units, brown color).

the same species, the exploitations are generally made from the marginal areas of the forest fund; thus, a decrease of the forested surface is recorded, but maintaining its degree of fragmentation, in general.

If the deforestation is done on small and isolated surfaces from year to year, the values of the FFI will be zero or very close to zero. The more the deforestation is done in continuation of the previous deforestation, expanding some deforested areas spatially, the more the value of the FFI will increase.

The Carpathian Mountains have reduced accessibility to the forest fund. In the absence of adequate exploitation technologies (funiculars, helicopters, etc.), the arrangements in the immediate vicinity of the roads are overexploited [38].

In the relief units where the forest fund is naturally fragmented and the access is much easier, we have forest exploitations on various locations (**Figure 8**).

It can be seen that the deforestation carried out within all the relief units varied from year to year. They are highlighted by the values of the annual FFI for each relief unit separately (**Figure 9**).

Figure 10 shows the average FFI for all 18 years of analysis. The most compact deforestation, on average, took place in the Mehedinți Plateau, in the Carpathian Mountains, and in the Danube Delta. Instead, they were more fragmented in the plains and hills (Subcarpathians).

5. Conclusion

Today, logging is one of the most important pressures on the natural environment, which causes major imbalances on all systemic components, the most important being the modification of microclimates [39, 40], floods, and landslides [41, 42]. In many specialized works, the need to develop methodologies for obtaining data on deforested surfaces and patterns in which they are made, especially for illegal cutting, is highlighted [43–46]. Fractal analysis offers a considerable amount of information, regarding the spatial characteristics of some fractal objects, whether or not they are in dynamics. The proposed index quantifies these characteristics, being very useful in establishing patterns.

Fractal analysis has proven to be a versatile method for evaluating the dynamics of deforestation, as well as identifying deforestation patterns; thus, it can be used complementary to the classical analyses by which data are obtained. FFI is useful in quantifying the degree of fragmentation and implicitly fractal compaction of forest areas and also provides important information on the effect of deforestation on forests, identifying also the moments of agglutination (clustering) of cumulative deforestation.

Being a fractal index, the FFI analyses are invariant at scale, bringing a significant addition to the classical analyses, thus being relevant in the realization of strategies for forest management. The FFI was used in the analysis of deforestation in Romania and the effect of deforestation at the county level [19, 36], indicating in all cases that fragmentation of forests increases following deforestation, having negative consequences on the stability of the hydrographic network and on the habitats. Like any fractal analysis, FFI analysis has limitations. For a correct analysis, but also to be able to make comparisons, all images, which are analyzed, must be at the same resolution, scale, and position and equally binarized.

In this study, FFI analysis allowed a clear differentiation of some patterns regarding the degree of fragmentation of the forests, but also of the compaction of the cumulative deforestation from the relief units in Romania, highlighting different dynamics. Thus, we have shown that the fragmentation of the forest is also relevant for the complex methodologies for calculating the flood risk and offers new perspectives for understanding the way in which the economic pressure on the forests is manifested.

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Conflict of interest

The authors declare no conflict of interest.

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References

[1] Chen CR, Condron LM, Davis MR, Sherlock RR. Effects of afforestation on phosphorus dynamics and biological properties in a New Zealand grassland soil. Plant and Soil. 2000;**220**:151-163. DOI: 10.1023/A:1004712401721

[2] DeFries RS, Rudel T, Uriarte M, Hansen M. Deforestation driven by urban population growth and agricultural trade in the twenty-first century. Nature Geoscience. 2010;**3**:178

[3] Steffen W, Richardson K, Rockstrom J, Cornell SE, Fetzer I, Bennett EM, et al. Planetary boundaries: Guiding human development on a changing planet. Science. 2015;**80**:347

[4] Stoy PC. Deforestation intensifies hot days. Nature Climate Change. 2018;**8**:366-368. DOI: 10.1038/s41558-018-0153-6

[5] Allen CD, Macalady AK, Chenchouni H, Bachelet D, McDowell N, Vennetier M, et al. A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. Forest Ecology and Management. 2010;**259**:660-684

[6] Zhou G, Wei X, Chen X, Zhou P, Liu X, Xiao Y, et al. Global pattern for the effect of climate and land cover on water yield. Nature Communications. 2015;**6**:5918

[7] Pravalie R, Piticar A, Rosca B, Sfica L, Bandoc G, Tiscovschi A, et al. Spatio-temporal changes of the climatic water balance in Romania as a response to precipitation and reference evapotranspiration trends during 1961-2013. Catena. 2019;**172**:295-312. DOI: 10.1016/j.catena.2018.08.028

[8] Andronache I, Fensholt R, Ahammer H, Ciobotaru AM, Pintilii RD, Peptenatu D, et al. Assessment of textural differentiations in forest resources in Romania using fractal analysis. Forests. 2017;**8**:54

[9] Gholoubi A, Emami H, Alizadeh A, Azadi R. Long term effects of deforestation on soil attributes: Case study, Northern Iran. Caspian Journal of Environmental Sciences. 2019;**17**:73-81. DOI: 10.22124/cjes.2019.3346

[10] Draghici CC, Peptenatu D, Simion AG, Pintilii RD, Diaconu DC, Teodorescu C, et al. Assessing economic pressure on the forest fund of Maramures County Romania. Journal of Forest Science. 2016;**62**:175-185. DOI: 10.17221/72/2015-JFS

[11] Petrisor AI, Andronache IC, Petrisor LE, Ciobotaru AM, Peptenatu D. Assessing the fragmentation of the green infrastructure in Romanian cities using fractal models and numerical taxonomy. Ecosmart - Environment at crossroads: Smart approaches for a sustainable development. Procedia Environmental Sciences. 2016;**32**:110-123. DOI: 10.1016/j.proenv.2016.03.016

[12] Draghici CC, Andronache I, Ahammer H, Peptenatu D, Pintilii RD, Ciobotaru AM, et al. Spatial evolution of forest areas in the Northern Carpathian Mountains of Romania. Acta Montanistica Slovaca. 2017;**22**:95-106

[13] Available from: http://www.unece.org/fileadmin//DAM/env/lrtap/welcome.html [Accessed: 29 December 2019]

[14] Available from: https://www.un-redd.org/ [Accessed: 29 December 2019]

[15] Available from: https://www.ilter.network/ [Accessed: 29 December 2019]

[16] Available from: https://carbon.nasa.gov/ [Accessed: 29 December 2019]

[17] UN. SEEA experimental ecosystem accounting: Technical recommendations

consultation draft. New York, USA: United Nations; 2017

[18] Haddad NM, Brudvig LA, Clobert J, Davies KF, Gonzalez A, Holt RD, et al. Habitat fragmentation and its lasting impact on Earth's ecosystems. Science Advances. 2015;**1**(2):e1500052

[19] Pintilii RD, Andronache I, Diaconu DC, Dobrea RC, Zeleňáková M, Fensholt R, et al. Using fractal analysis in modeling the dynamics of Forest areas and economic impact assessment: Maramureș County, Romania, as a case study. Forests. 2017;**8**:25

[20] Taubert F, Fischer R, Groeneveld J, Lehmann S, Muller MS, Rodig E, et al. Global patterns of tropical forest fragmentation. Nature. 2018;**554**: 519-522

[21] Andronache I, Marin M, Fischer R, Ahammer H, Radulovic M, Ciobotaru AM, et al. Dynamics of forest fragmentation and connectivity using particle and fractal analysis. Scientific Reports. 2019;**9**(1):1-9. DOI: 10.1038/s41598-019-48277-z

[22] Diaconu DC, Andronache I, Pintilii RD, Brețcan P, Simion AG, Drăghici CC, et al. Using fractal fragmentation and compaction index in analysis of the deforestation process in Bucegi Mountains Group, Romania. Carpathian Journal of Earth and Environmental Sciences. 2019;**14**:431-438. DOI: 10.26471/Cjees/2019/014/092

[23] Kang S, Choi W. Forest cover changes in North Korea since the 1980s. Regional Environmental Change. 2013;**14**:347-354

[24] Reddy CS, Sreelekshmi S, Jha CS, Dadhwal VK. National assessment of forest fragmentation in India: Landscape indices as measures of the effects of fragmentation and forest cover change. Ecological Engineering. 2013;**60**:453-464

[25] Shapiro AC, Aguilar-Amuchastegui N, Hostert P, Bastin JF. Using fragmentation to assess degradation of forest edges in Democratic Republic of Congo. Carbon Balance and Management. 2016;**11**:11

[26] Li Y, Xiao X, Li X, Ma J, Chen B, Qin Y, et al. Multi-scale assessments of forest fragmentation in China. Biodiversity Science. 2017;**25**:372-381

[27] Available from: http://ec.europa.eu/agriculture/fore/publi/2007_2011/brochure_en.pdf [Accessed: 29 December 2019]

[28] Simard M, Pinto N, Fisher JB, Baccini A. Mapping forest canopy height globally with spaceborne lidar. Journal of Geophysical Research. 2011;**116**:1-12

[29] Rullan-Silva CD, Olthoff AE, de la Mata JAD, Pajares-Alonso JA. Remote monitoring of forest insect defoliation. A review. Forest Systems. 2013;**22**: 377-391

[30] Tanase M, Ismail I, Lowell K, Karyanto O, Santoro M. Detecting and quantifying forest change: The potential of existing C- and X-band radar dataset. PLOS One. 2015;**10**:1-14

[31] Reiche J, Hamunyela E, Verbesselt J, Hoekman D, Herold M. Improving near real time deforestation monitoring in tropical dry forests by combining dense Sentinel-1 time series with Landsat and ALOS-2 PALSAR-2. Remote Sensing of Environment. 2018;**204**:147-161

[32] Zhao Y, Zeng Y, Zhen Z, Dong W, Zhao D, Wu B, et al. Forest species diversity mapping using airborne LiDAR and hyperspectral data in a subtropical forest in China. Remote Sensing of Environment. 2018;**213**:104-114

[33] Bryan BA, Lei G, Ye Y, Sun X, Connor JD, Crossman ND, et al. China's response to a national land-system sustainability emergency. Nature. 2018;**559**:193-204

[34] Hansen MC, Potapov PV, Moore R, Hancher M, Turubanova SA, Tyukavina A, et al. High-resolution global maps of 21st-century forest cover change. Science. 2013;**342**:850-853. DOI: 10.1126/science.1244693

[35] Mandelbrot BB. The Fractal Geometry of Nature. San Francisco: W.H. Freeman and Company; 1982. p. 460

[36] Andronache I, Ahammer H, Jelinek HF, Peptenatu D, Ciobotaru AM, Draghici CC, et al. Fractal analysis for studying the evolution of forests. Chaos, Solitons and Fractals. 2016;**91**:310-318. DOI: 10.1016/j.chaos.2016.06.013

[37] Kainz P, Mayrhofer-Reinhartshuber M, Ahammer H. IQM: An extensible and portable open source application for image and signal analysis. PLOS One. 2015;**10**(1):e0116329. DOI: 10.1371/journal.pone.0116329

[38] Ciobotaru AM, Andronache I, Ahammer H, Jelinek HF, Radulovic M, Pintilii RD, et al. Recent deforestation pattern changes (2000-2017) in the Central Carpathians: A gray-level Co-occurrence matrix and fractal analysis approach. Forests. 2019;**10**:308

[39] Pravalie R, Sirodoev I, Patriche CV, Bandoc G, Peptenatu D. The analysis of the relationship between climatic water deficit and corn agricultural productivity in the Dobrogea plateau. Carpathian Journal of the Earth and Environmental Science. 2014;**9**:201-214

[40] Pravalie R, Patriche CV, Sirodoev I, Bandoc G, Dumitrescu M, Peptenatu D. Water deficit and corn productivity during the post-socialist period. Case study: Southern Oltenia drylands, Romania. Arid Land Research and Management. 2016;**30**:239-257. DOI: 10.1080/15324982.2015.1091399

[41] Andronache I, Pintilii RD, Grecu A, Diaconu DC. Quantification method of the cumulative loss of the forests. In: Public Recreation and Landscape Protection—With Sense Hand in Hand... Czech Soc Landscape Engineers, Krtiny, Czech Republic; Date: 13-15 May 2019. Public Recreation and Landscape Protection. 2019:297-302

[42] Diaconu DC. Particularities of drain liquid in the small wetland of Braila Natural Park, Romania. In: Negm A, Romanescu G, Zeleňáková M, editors. Water Resources Management in Romania. Springer Water. Cham: Springer. 2020:437-464. DOI: 10.1007/978-3-030-22320-5_13

[43] Diaconu DC, Peptenatu D, Simion AG, Pintilii RD, Draghici CC, Teodorescu C, et al. The restrictions imposed upon the urban development by the piezometric level. Case study: Otopeni-Tunari, Corbeanca. Urbanism Architecture Constructions. 2017;**8**:27-36

[44] Ciobotaru AM, Peptenatu D, Andronache I, Simion AG. Fractal characteristics of the afforested, deforested and regenerated areas in Suceava County, Romania. In: Proceedings of International Scientific Conferences on Earth & Geo Sciences-Sgem Vienna Green Sessions 2016; 2-5 November 2016; Vienna, Austria: Technology Ltd.; Sofia, Bulgaria; Vol. 3. 2016. pp. 445-452

[45] Braghină C, Peptenatu D, Draghici CC, Pintilii RD, Schvab A. Territorial management within the systems affected by mining. Case study the South-Western development region in Romania. Iranian Journal of Environmental Health Science and Engineering. 2011;**8**:343-352

[46] Diaconu DC, Andronache I, Ahammer H, Ciobotaru AM, Zelenakova M, Dinescu R, et al. Fractal drainage model—A new approach to determinate the complexity of watershed. Acta Montanistica Slovaca. 2017;**22**:12-21

Chapter 8

Automatic Recognition of Tea Diseases Based on Deep Learning

Jing Chen and Junying Jia

Abstract

With the rapid development of intelligent agriculture and precision agriculture, computer image processing technology has been widely used to solve various problems in the agricultural field. In particular, the advantages of convolutional neural networks (CNNs) in image classification have also been widely used in the automatic recognition and classification of plant diseases. In this paper, a deep convolutional neural network named LeafNet capable of recognizing the seven types of diseases from tea leaf disease images was established, with an accuracy of up to 90.23%, aiming to provide timely and accurate diagnostic services in the remote and topographic tea plantation in China. At the same time, the traditional machine learning algorithm is applied for comparative analysis, which extracts the dense scale-invariant feature transform (DSIFT) of the image and constructs the bag of visual word (BOVW) model to express the image based on the DSIFT descriptor. The support vector machines (SVMs) and multilayer perceptron (MLP) were used to identify tea leaf diseases, with an accuracy of 60.91 and 70.94%, respectively.

Keywords: tea leaf disease, deep learning, convolutional neural network, dense SIFT, bag of visual word

1. Introduction

Tea has a long history of cultivation in China, and the tea planting area and yield rank first in the world. According to statistical data, in 2016 China's 17 provinces had a total of 2.87 million hectares of tea plantation and production, and the total output of tea reached 2.4 billion tons [1]. As the main tea-producing areas in China are mainly distributed in subtropical regions, the natural environment differs due to geographical latitude and topographical conditions. The tea tree is a perennial evergreen woody plant, which grows in warm and humid growth environment. However, these regions are conducive to the breeding and reproduction of diseases. In recent years, the tea planting area has increased year by year, and the tea leaf diseases have risen continuously, which has seriously threatened the quality and yield of tea. Because the distribution of tea areas in China is mostly in high mountain areas, the infrastructure construction in these areas is relatively lagging behind, and the occurrence of tea leaf diseases is often not controlled in a timely and effective manner, resulting in huge economic losses. Therefore, being able to detect and identify diseases early in the field is an important task to ensure the sustainable development of the tea industry.

The diagnosis of plant diseases is usually based on the appearance of the disease. When the leaves of a plant are infected by a disease, the appearance of the leaves will change significantly. Each disease usually has a discernible leaf color and texture symptom, and plant diseases can be diagnosed based on these characteristics. However, farmers mainly rely on their own experience to diagnose plant diseases with their own senses. Due to the limitation of knowledge background, there are ambiguities in the diagnosis. Most tea trees in China are planted in mountainous areas, which are large, difficult to investigate in the field, and inefficient. Relying on agricultural experts to diagnose tea leaf diseases is not only time-consuming but also costly. The transportation and infrastructure conditions in these places are limited. Finally, the expert must have experience and knowledge in various disciplines and need to understand all the symptoms of the disease and the causes of the diversity of the disease. At the same time, because China's agricultural population is relatively large and the number of experts engaged in agricultural services is extremely limited, it is necessary to establish a system that can diagnose tea leaf diseases in a timely and accurate manner.

The current diagnostic methods of plant diseases mainly include microscope identification, molecular biology technology, and spectroscopic technology, but the first method is time-consuming and subjective. Even experienced plant pathologists may have wrong judgments, leading to inaccurate conclusion. The latter two methods are currently considered more accurate, and their main disadvantages are the high labor intensity and the requirement of specific instruments.

With the rapid development of intelligent agriculture and precision agriculture, machine learning methods and computer image processing technologies have been applied to the identification of plant diseases [2, 3], providing a new method for detecting plant diseases, which can help farmers and researchers quickly and accurately identify the types of plant diseases. The general approach based on machine learning and computer image processing technology is first to manually design and extract disease image features, namely, global features, such as color features [4], shape features [5], texture features [6], or two or more than three features [7–11], and local features, using scale-invariant feature transform (SIFT), speeded-up robust features (SURF), dense scale-invariant feature transform (dense SIFT), and pyramid histograms of visual words (PHOW) [12–14]. After extracting the features, they are identified and classified using different classifiers, such as artificial neural networks [15, 16] and support vector machines [17, 18]. Because traditional machine learning relies on features extracted manually, the resulting recognition system is not fully automated.

At present, most of the researches on tea using computer vision technology focus on tea quality detection [19], tea species identification [20], and tea leaf disease information query and management based on expert systems [21]. Because the expert system has limited knowledge and needs to be updated and maintained on a regular basis, it is also limited for noncomputer professional technicians. For some literatures, the identification of tea diseases is based on hyperspectral [22] or infrared thermal images [1]. These methods are easy to operate and have high accuracy, but the cost of the instrument is not suitable for widespread promotion.

In recent years, the popularity of the Internet has led to the explosive growth of Internet data, and the technical performance of computers and smartphones has continued to improve. These factors are the main reasons that have led to widespread attention for deep learning. Deep learning refers to the process of learning sample data through a certain training method to obtain a deep network structure containing multiple levels [23]. Deep learning is a branch of machine learning. Its essence is also a neural network, but the number of hidden layers is more than one layer, which is an extension of artificial neural networks. "Neural network" is a component of deep learning.

The concept of deep learning was first mentioned by Professor Geoffrey Hinton of the University of Toronto in a paper on back-propagation algorithms. The concept of "depth" was used to represent large artificial neural networks. With the introduction of deep learning, more and more researchers have begun to develop large-scale neural network systems. These deep neural network systems can take the characteristics from the original data, can work alone without human manipulation, and then can use what humans have learned to learn new things.

The advantage of the deep learning is that it does not require artificial feature extraction but this is obtained automatically by the network. It can solve nonlinear separable problems and has strong generalization ability and robustness. Among them, the most widely used is the convolutional neural network, which is a deep neural network. Images can be directly used as input data, eliminating the complicated process of feature extraction and data reconstruction in traditional machine learning algorithms. At the same time, the multilayer network structure of the convolutional neural network maintains a high degree of invariance to image translation, scaling, or lighting changes [18]. At present, convolutional neural networks have been applied to the identification and diagnosis of plant diseases [24–26].

In recent years, many researchers in the world have used machine learning algorithms to build many disease recognition systems, but because the characteristics of each plant disease are different, the different machine learning methods will have different recognition effects. Hence, based on previous studies, this paper uses deep convolutional neural networks to identify and classify tea leaf diseases. At the same time, the traditional machine learning algorithm is compared with the proposed convolutional neural network, and a recognition system suitable for the tea leaf disease is found through comparative analysis.

2. Date acquisition

The existing databases on the network such as ImageNet, PlantVillage, and CIFAR-1 datasets do not have sufficient tea leaf disease images and some studies

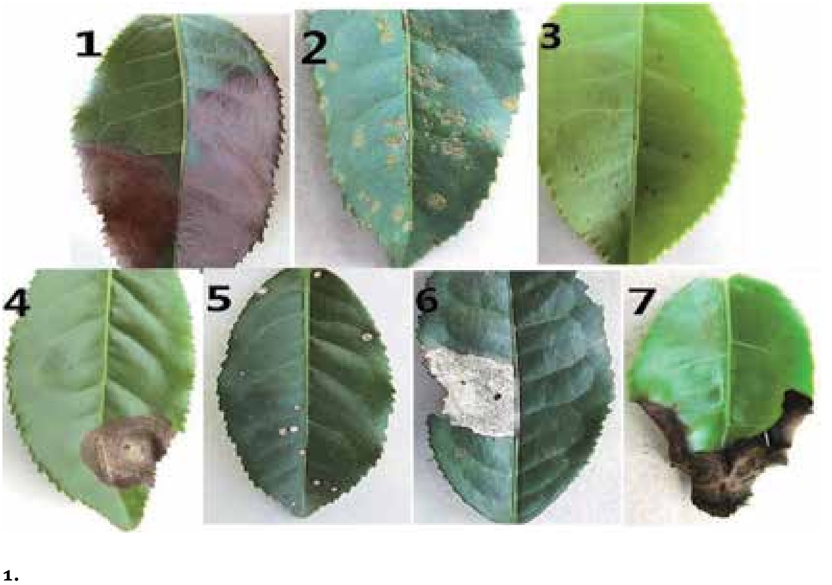

Figure 1.
*Typical example images of tea leaf diseases used in this manuscript. (1) Red leaf spot (*Phyllosticta theicola Petch*). (2) Algal leaf spot (*Cephaleuros virescens Kunze*). (3) Bird's-eye spot (*Cercospora theae Bredde Haan*). (4) Gray blight (*Pestalotiopsis theae Steyaert*). (5) White spot (*Phyllosticta theaefolia Hara*). (6) Anthracnose (*Gloeosporium theae-sinensis Miyake*). (7) Brown blight (*Colletotrichum camelliae Massee*).*

have collected disease photos in indoor or controlled environments. These factors have made the recognition system designed to identify diseases under natural light conditions to have certain limitations, so a new disease data set is constructed in this paper.

Tea leaf disease images were all captured using the Canon PowerShot G12 camera in the natural light environment of the tea garden in Chibi and Yichang within Hubei Province. The images were taken about 20 cm directly above the leaves with autofocus mode at resolution of 4000 × 3000 pixels. A total of 3810 disease images were collected, which contained 7 diseases, and all disease images have been identified by plant pathologists. The identification criteria used for the tea leaf diseases were based on the previously described identification schemes [27, 28]. In order to meet the requirements of the model algorithm and reduce the computational complexity of the network, all disease images are resized to 256 × 256 pixels and 750 × 750 pixels, respectively. **Figure 1** shows the types of tea leaf diseases used in this experiment. Data amplification processing is performed on a smaller number of disease images so that the number of the seven diseases image is balanced. Data amplification processing improves the generalization ability of the classifier, which is more conducive to network training. Three different methods were used to alter the image input and improve classification (**Figure 2**). A total of

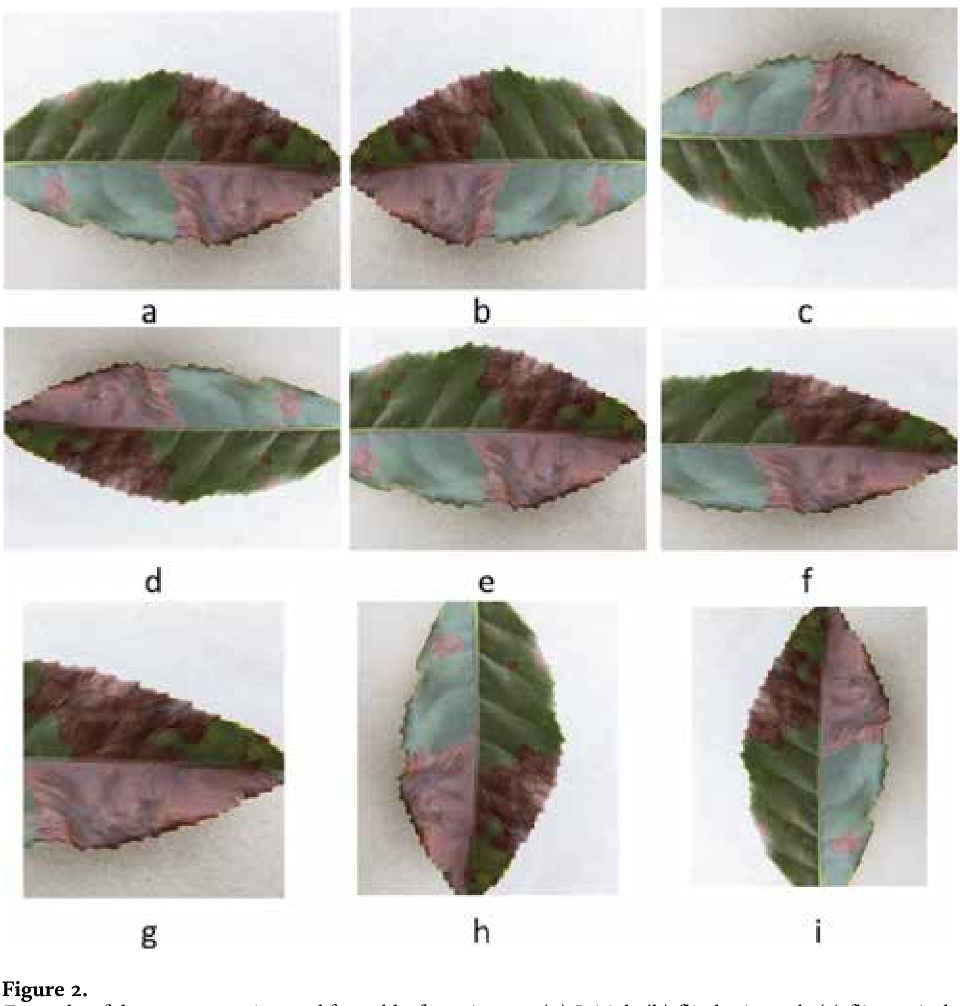

Figure 2.
Examples of data augmentation used for red leaf spot images. (a) Initial; (b) flip horizontal; (c) flip vertical; (d) rotated 180°; (e–g) randomly cropped; (h) right-rotate 90°; (i) left-rotate 90°.

Class	Training	Validation	Testing
(1) White spot	941	118	117
(2) Bird's-eye spot	955	120	119
(3) Red leaf spot	890	111	111
(4) Gray blight	893	112	111
(5) Anthracnose	880	110	110
(6) Brown blight	920	115	115
(7) Algal leaf spot	846	106	105
Total	6325	792	788

Table 1.
Tea leaf disease dataset in this manuscript.

7905 tea leaf disease images were obtained after the amplification treatment (**Table 1**). The 80/20 ratio of training/test data is the most commonly used ratio in neural network applications. In addition, a 10% subset of the test dataset was used to validate the dataset [29].

3. Tea leaf disease identification based on BOVW model

Traditional machine learning algorithm is a shallow architecture that contains one or two nonlinear transformation layers. It can automatically learn the underlying laws in the data and use the learned rules to make predictions. In the field of computer vision, many models can be realized by manually designing and extracting the visual characteristics of the image in advance, and the image content is converted into a quantitatively calculated information description form, after being processed by the shallow structure model.

3.1 Image visual feature

The extraction and selection of image visual features is an important means to transform the image content into a quantitatively calculated information description form, which mainly include global features and local features. Global features refer to the overall attributes of the entire image, mainly including color features, texture features, and shape features. These features are features that can be directly observed by the eyes. Global features are pixel-level shallow features with good stability, real-time performance, and simple and easy-to-implement algorithms. However, their shortcomings are high feature dimensions, large amount of calculations, and changes in image scale, lighting, and perspective. Local features are features extracted from local areas of the image, including corners, lines, edges, and areas with special attributes. Local features are distinguishable and robust to changes in lighting, rotation, perspective, and scale, as well as low dimensions and easy implementation.

The scale-invariant feature transform (SIFT) is local feature descriptor proposed by David G. Lowe in 1999 [30]. The SIFT descriptor maintains invariance to image rotation, translation, scaling, affine transformation, perspective and brightness changes, and noise and also maintains stability. And it can be combined with other algorithms to form a new optimization algorithm, thereby increasing the operation speed.

The traditional SIFT descriptor mainly extracts stable feature points in the image, which will lead to loss of some information in the image and long calculation time. And the number of feature points extracted from each image is different, which will inevitably lead to different dimensions. Lazebnik et al. improved the number and distribution of SIFT descriptors to obtain dense SIFT [31]. The main difference between the dense SIFT descriptor and the traditional SIFT descriptor is that the sampling method is different. The SIFT descriptor constructs a scale space to detect and filter feature points. The dense SIFT algorithm applies a fixed-size rectangular window for sampling from the left to the right of the image and from the top to the bottom according to the specified step size. The center of the window is used as a key point, and an image block composed of 16 pixels around the center is divided into 4×4 pixel-sized units. Within each pixel, the SIFT algorithm is used to calculate the gradient histogram in 8 directions and obtain $4 \times 4 \times 8 = 128$ dimensional feature vectors to form a DSIFT descriptor. The feature points extracted by this method are uniformly distributed, and the specifications are the same; they maintain good stability to illumination, changes in perspective, and affine transformation, scaling, and rotation.

3.2 Bag of visual word-based feature representation

Bag of visual word (BOVW) model was mainly applied to text classification and retrieval technology. The core idea of the bag of visual word model is to treat text as a collection of different words, ignoring the word order, grammar, and syntax of the text, and these words are discrete and independent of each other or do not depend on the presence of other words. The frequency of each word in the text is counted and is represented with histogram so that each text is represented as a vector.

Due to the successful application of the BOVW model in text retrieval, Csurka et al. introduced the BOVW model to the field of computer vision [32]. Think of an image as a document and the features of the image (usually referred to as local features) as the words that make up the image. Unlike the words in the text, there are no ready-made words in the image. We need to extract independent features from the image, which are called visual word. Similar features can be regarded as a visual word. In this way, the image can be described as an unordered set of visual words (local features). Although local features (such as SIFT) also can describe an image, each SIFT is a 128-dimensional vector, and an image contains hundreds or thousands of SIFT descriptor. The calculation amount is very large, so these vectors are clustered, and the cluster center was used to represent a visual word.

The image classification using BOVW model mainly includes the following steps:

1. Image feature extraction and description: Local feature vectors of the entire training set image are obtained through methods such as point-of-interest detection, dense sampling, or random sampling. Commonly used local features include SIFT descriptor and SURF descriptor.

2. Construct a visual vocabulary: After obtaining the local feature vectors of all sample images, use the k-means algorithm to cluster the local feature vectors. The k-means algorithm is an unsupervised learning algorithm. It divides the data into different categories through an iterative process and then calculates the Euclidean distance between each data and various types of centers [33]. The smaller the distance, the higher the similarity. k represents the number of clusters, and means represents the mean of the data in the clusters. If there are

k cluster centers (i.e., visual words), then the size of the visual vocabulary is also k. This manuscript selects 1000 visual words, and the size of the visual vocabulary is 1000.

3. Representing images by word frequency: using the vocabulary as a standard, count the number of occurrences of each visual word in the image, and each image becomes a word frequency vector corresponding to the visual word sequence in the vocabulary, that is, each image is represented by a 1000-dimensional numerical vector.

4. Select classifier to classify the 1000-dimensional numerical vector generated in the previous step as the input of the classification.

3.3 Classifiers

3.3.1 Support vector machines

Support vector machines (SVMs) were proposed by Corinna Cortes and Vapnik in 1995 [34]. It is a learning method based on VC statistical theory and structural risk minimization criteria. It has advantage in solving small sample, nonlinear, and high-dimensional pattern recognition problems. The basic idea of the SVMs is to map the low-dimensional space vector to the high-dimensional space through the nonlinear transformation defined by the inner product. In this high-dimensional space, the optimal classification hyperplane is determined according to the maximum geometric distance between the support vector and the classification plane. SVMs were initially used to classify two-class problems in the analysis of linear separable cases and require smaller sample sizes and an appropriate train rule, which have led to widespread use in image classification and recognition.

With the deepening of research on support vector machines, many scholars have carried out various toolkits in order to make them suitable for specific fields. In this manuscript a linear classifier LIBLINEAR designed by Professor Lin Zhiren of the National Taiwan University is used, mainly for processing large-scale data and features [35]. LIBLINEAR can be used in the following three cases: when the number of features is much larger than the number of samples; when the number of features and samples is large; and when the number of features is much smaller than the number of samples. Because the complexity of the linear classifier is lower than the nonlinear classifier, the training operation time is greatly reduced, and the training performance of the linear and nonlinear classifiers is also comparable under a large amount of data.

3.3.2 Multi-layer perceptron

The perceptron was proposed by Rosenblatt in 1958 [36]. It is an artificial neural network structure and the earliest feed-forward neural network. A single-layer perceptron contains only two layers, namely, the input layer and the output layer. Due to its limited mapping capability, it can only achieve linearly separable classification problems. A multi-layer perceptron has one or more hidden layers between the input layer and the output layer, which is mainly used for nonlinear classification and regression. The training algorithm is consistent with the traditional multi-layer neural network and also uses a back-propagation algorithm.

Perceptron in this manuscript uses a three-layer structure. Because the extracted features are 1000-dimensional vectors, the input layer contains 1000 nodes, the hidden layer contains 100 nodes, and the output layer contains 7 nodes, which refer to the number of types of tea leaf disease.

4. Deep learning network construction

The network architecture designed in this manuscript was improved based on the classic model AlexNet model, named as LeafNet. The total number of parameters (weights and deviations) of the classic AlexNet network reaches more than 60 million, the parameters of the convolution layer comprises 3.8% of the total network parameters, and the parameters of the fully connected layer comprises 96.2% of the total. Therefore, by reducing the number of LeafNet's convolutional layer filters and the number of fully connected layer nodes, the total number of network parameters is reduced, and the computational complexity is reduced. The recognition model has a relatively simple structure and a small amount of calculation, which effectively reduces the problem of overfitting.

4.1 Network structure

LeafNet consists of five convolutional layers, two fully connected layers, and a classification layer. The number of filters for the first, second, and fifth convolutional layers is half of those used in AlexNet's filters. In addition, the number of neurons in the fully connected layer is set to 500, 100, and 7, respectively. The entire network structure is shown in in **Table 2**.

In this experiment, except for the last layer, the rectified linear unit (ReLU) activation function is selected instead of the traditional sigmoid and tanh functions. The main disadvantages of the sigmoid and tanh functions are the large amount of calculations, and when the input is large or small, the output is relatively smooth, the gradient is small, and it is not conducive to the weight update, which ultimately cause the network to fail to complete the training. ReLU is more in line with the

Layer	Parameters	Activity function
Input	227 × 227 × 3	–
Convolution1(Conv1)	24 convolution filters (11 × 11) 4 stride	ReLU
Pooling1(Pool1)	Max pooling (3 × 3) 2 stride	–
Convolution2(Conv2)	64 convolution filters (5 × 5) 1 stride	ReLU
Pooling2(Pool2)	Max pooling (3 × 3) 2 stride	–
Convolution3(Conv3)	96 convolution filters (3 × 3) 1 stride	ReLU
Convolution4(Conv4)	96 convolution filters (3 × 3) 1 stride	ReLU
Convolution5(Conv5)	64 convolution filters (3 × 3) 1stride	ReLU
Pooling5(Pool5)	Max pooling (3 × 3) 2 stride	–
Full Connect 6(fc6)	500 nodes 1 stride	ReLU
Full Connect 7(fc7)	100 nodes 1 stride	ReLU
Full Connect8(fc8)	7 nodes 1 stride	ReLU
Output	1 node	Softmax

Table 2.
Layer parameters for the LeafNet.

principle of neuron signal excitation. It will make some neurons' output 0, making the network sparse and reducing the interdependence of parameters, effectively alleviating overfitting. At the same time, ReLU has better transmission error characteristics and solves the problem of gradient disappearance, so it makes the training network converge faster.

After the nonlinear neuron output of the first two convolutional layers, a local response normalization operation is introduced. It is a normalization operation and mimics the lateral inhibition phenomenon of neurobiology. Local response normalization creates a competition mechanism for the output of local neurons. Local response normalization creates a competition mechanism for the output of local neurons, making the neurons with large responses larger, thereby enhancing the generalization ability of the model.

The first two fully connected layers have introduced the dropout operation. The dropout technique is an effective solution to overfitting via the training of only some of the randomly selected nodes rather than the entire network [37]. In this article, the dropout ratio is set to 0.5.

Softmax is the activation function of the last fully connected layer, which is mainly used in the output layer of multi-classification problems. It can make the sum of all output values equal to 1. That is, the output value of multiple classifications is converted into a relative probability, in which the category which has a high relative probability is the predicted value.

4.2 Training network

LeafNet's training uses stochastic gradient descent (SGD) technique. The weight values of all convolutional layers and fully connected layers are initialized with a Gaussian distribution, and the bias is initialized with a constant of 1. This setting guarantees that the input of the ReLU activation function is a positive number and can also speed up the training speed of the network [25]. Because the number of samples is small, the batch size is set to 16. Batch training can improve the convergence speed of the network and keep the memory usage at a low level. The initial learning rate of all layers of the network is set to 0.1. The learning rate is reduced according to the decline of the error, and each time it is reduced to 0.1 times the original learning rate in subsequent iterations, with the minimum threshold of the learning rate set to 0.0001. The number of epochs was set as 100, while the weight of decay was set to 0.0005 and the momentum was set to 0.9 [38]. LeafNet is implemented using Matlab's MatConvNet toolbox. The network training is performed on a Windows system, configured with a Core i7-3770K CPU, 8 GB of RAM, and accelerated training via two NVIDIA GeForce GTX 980 GPUs.

5. Performance measurements

As mentioned in [39], the classification accuracy and mean class accuracy (MCA) are used to evaluate the performance of the algorithm. CCR_k is first defined as the correct classification rate for class k, as shown in Eq. (1):

$$CCR_k = \frac{C_k}{N_k} \tag{1}$$

Where C_k is the number of correctly identified for class k and N_k is the total number of elements in class k. Classification accuracy is then defined by Eq. (2):

$$\text{Accuracy} = \frac{\sum_k \text{CCR}_k \cdot \text{N}_k}{\sum_k \text{N}_k} \tag{2}$$

Lastly, MCA is determined using Eq. (3):

$$\text{MCA} = \frac{1}{k}\sum_k \text{CCR}_k \tag{3}$$

6. Results and analysis

In this study, the accuracy of the SVM, MLP, and CNN classifiers in determining disease states for tea leaves from images was evaluated. The results of these analyses are shown in **Figure 3**. Error matrices were used to evaluate the accuracy of tea leaf disease recognition classifiers (**Tables 3–5**). From these data, although LeafNet algorithms are significantly better than SVM and MLP algorithms, three recognition algorithms can usually correctly identify most tea leaf diseases. Traditional machine learning algorithms extract the surface features of images, and the number is limited. The ability to represent image features is not strong, resulting in a low accuracy rate for identifying diseases. However, the CNN can automatically extract the deep features of the image, which can more accurately express the features of the disease image, so its recognition accuracy is higher.

It can be seen from the error matrix that the recognition accuracy of MLP and SVM for the seven tea leaf diseases is 70.94% and 60.91%, respectively, and the MCA is 70.77% and 60.62%, respectively. In the two algorithms, the correct rate of the bird's-eye spot is the highest, but there is no obvious regularity for the rest of diseases. The bird's-eye spot is clearly distinguishable, characterized by small and dense red-brown dots, which are significantly different from other disease characteristics, so its accuracy of identification is high.

The recognition accuracy of tea leaf disease by SVM and MLP algorithm is not high, which is caused by artificial selection of features. The recognition effect of SVM and MLP algorithm largely depends on whether the artificially selected features are reasonable, and researchers usually rely on personal experience when selecting features. Although better results can be obtained using artificial feature

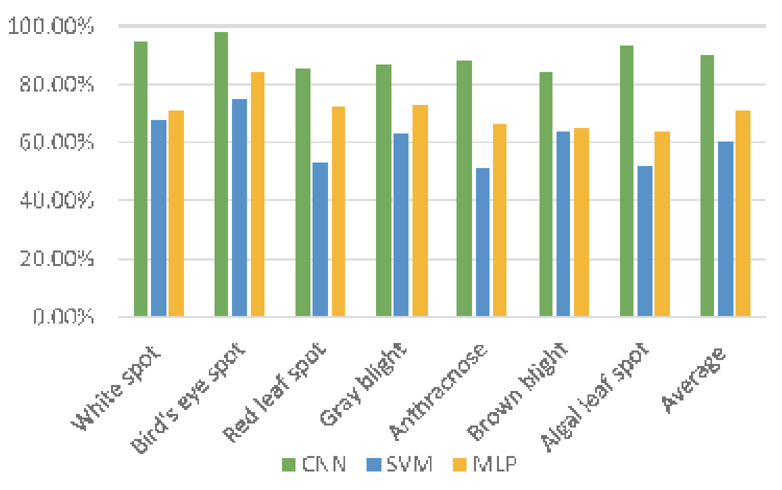

Figure 3.
Accuracy (%) of disease classification for each of the three classification models in recognizing the seven candidate tea diseases.

	White spot	Bird's-eye spot	Red leaf spot	Gray blight	Anthracnose	Brown blight	Algal leaf spot	Sensitivity	Accuracy	MCA
White spot	111	3	0	0	3	0	0	94.87%	90.23%	90.16%
Bird's-eye spot	1	117	0	0	0	0	1	98.32%		
Red leaf spot	0	0	95	7	0	8	1	85.59%		
Gray blight	0	0	4	96	3	7	1	86.49%		
Anthracnose	5	0	1	6	97	1	0	88.18%		
Brown blight	0	1	15	2	0	97	0	84.35%		
Algal leaf spot	1	1	2	2	1	0	98	93.33%		

Table 3.
Error matrix showing the classification accuracy of the LeafNet algorithm.

	White spot	Bird's-eye spot	Red leaf spot	Gray blight	Anthracnose	Brown blight	Algal leaf spot	Sensitivity	Accuracy	MCA
White spot	79	11	0	2	19	1	5	67.52%	60.91%	60.62%
Bird's-eye spot	12	89	0	4	1	10	3	74.79%		
Red leaf spot	2	4	59	23	2	19	2	53.15%		
Gray blight	0	0	13	70	8	17	3	63.06%		
Anthracnose	19	0	5	13	56	11	6	50.91%		
Brown blight	0	2	19	17	3	73	1	63.48%		
Algal leaf spot	9	10	12	13	3	4	54	51.43%		

Table 4.
Error matrix showing the classification accuracy of the SVM algorithm.

	White spot	Bird's-eye spot	Red leaf spot	Gray blight	Anthracnose	Brown blight	Algal leaf Spot	Sensitivity	Accuracy	MCA
White spot	83	13	0	3	15	1	2	70.94%	70.94%	70.77%
Bird's-eye spot	6	100	0	6	1	5	1	84.03%		
Red leaf spot	1	1	80	17	0	11	1	72.07%		
Gray blight	0	0	9	81	6	14	1	72.97%		
Anthracnose	13	0	4	10	73	8	2	66.36%		
Brown blight	0	5	16	15	3	75	1	65.22%		
Algal leaf spot	6	5	9	10	4	4	67	63.81%		

Table 5.
Error matrix showing the classification accuracy of the MLP algorithm.

classification, these features are specific to certain datasets. If you use the same features to analyze different data sets, the results may be very different, which is a problem inherent in these technologies.

LeafNet has the best recognition effect on the bird's-eye spot, which may be due to the obvious plant pathological symptoms and the strong recognition ability of the LeafNet algorithm. The white spot disease was the second, while the other diseases range from 84 to 93%. Because of the similar pathological characteristics of the gray blight, red leaf spot, and brown blight, the classification accuracy of the three diseases is lowest. The symptoms of gray blight and brown blight diseases are too similar, which both exhibit annulations in their late stage and cannot be distinguished. In addition, the symptoms of white spot and bird's-eye spot diseases both include reddish brown spots at early stages. In addition, both anthracnose and brown blight diseases are typified by waterlogged leaves during early disease stages, while symptoms are different in the later stages. Some diseases can occur in tea plants throughout the year, although some diseases occur at distinct times. Consequently, diseases diagnosed at different times may affect the accuracy of disease identification. Another factor that affects the accuracy may be that the tea leaf can be infected with two or more diseases at the same time. This is because when the tea leaf is infected by one pathogen, the leaves are suffering from physiological weakness, and the second pathogen can easily infect. Therefore, the above factors explain the main reasons for the low accuracy of the test model in some diseases.

In addition, the performance of LeafNet is compared with the method of Reference [40], which contains 10 diseases of 3 crops with a maximum accuracy of 97.3%. Therefore, the performance of LeafNet is slightly lower than Reference [40], which used currently popular transfer learning algorithm. The main advantages of this algorithm are as follows: the network can converge quickly when the data set is small; easy to implement; and shorter training time. Therefore, in the future we will continue to research on and apply transfer learning algorithms to identify more plant diseases.

7. Conclusion

CNNs have developed into mature techniques that have been increasingly applied in image recognition. The computational complexity needed for neural network analyses is considerably reduced compared to other algorithms, and it also significantly improves computing precision. Concomitantly, the high fault tolerance of CNNs allows the use of incomplete or fuzzy background images, thereby effectively enhancing the precision of image recognition.

Feature extraction is an important step in image classification and directly affects classification accuracies. Thus, two feature extraction methods and three classifiers were compared in their abilities to identify seven tea leaf diseases in the present manuscript. These analyses revealed that LeafNet yielded the highest accuracies among SVM and MLP classification algorithms. CNNs thus have obvious advantages for identifying tea leaf diseases. Importantly, the results from the present study highlight the feasibility of applying CNNs in the identification of tea leaf diseases, which would significantly improve disease recognition for tea plant agriculture. Although the disease classification accuracy of the LeafNet was not 100%, improvements upon the present method can be implemented in future studies to improve the method and provide more efficient and accurate guidance for the control of tea leaf diseases.

In this manuscript, the expansion process of sample data is a time-consuming process, but with the continuous growth of network information resources, the number of tea tree disease images will continue to increase, so we must collect images of different morphological features in the early, middle, and late stages of each disease and continuously expand the tea tree disease data set to make the data set more detailed and comprehensive.

At present, disease recognition is based on computer system operations. However, as the performance of smartphones continues to improve, the recognition model of deep convolutional neural networks is migrated to android-based mobile applications. It can timely and accurately obtain relevant information about diseases and can provide help for the control of tea tree diseases.

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Conflict of interest

The authors declare no conflict of interest.

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References

[1] Yang N, Yuan M, Wang P, Zhang R, Sun J, Mao H. Tea diseases detection based on fast infrared thermal image processing technology. Journal of the Science of Food and Agriculture. 2019; **99**(7):3459-3466. DOI: 10.1002/jsfa.9564

[2] Rumpf T, Mahlein AK, Steiner U, Oerke EC, Dehne HW, Plümer L. Early detection and classification of plant diseases with support vector machines based on hyperspectral reflectance. Computers and Electronics in Agriculture. 2010;**74**(1):91-99. DOI: 10.1016/j.compag.2010.06.009

[3] Sladojevic S, Arsenovic M, Anderla A, Culibrk D, Stefanovic D. Deep neural networks based recognition of plant diseases by leaf image classification. Computational Intelligence and Neuroscience. 2016;**6**:1-11. DOI: 10.1155/2016/3289801

[4] Chaudhary P, Chaudhari AK, Cheeran AN. Color transform based approach for disease spot detection on plant leaf. International Journal of Computer Science and Telecommunications. 2012;**3**(6):65-70 DOI: 10.1.1.679.8915

[5] Chung CL, Huang KJ, Chen SY, Lai M, Chen Y, Kuo Y. Detecting bakanae disease in rice seedlings by machine vision. Computers and Electronics in Agriculture. 2016;**121**: 404-411. DOI: 10.1016/j.compag.2016.01.008

[6] Hossain E, Hossain MF, Rahaman MA. A color and texture based approach for the detection and classification of plant leaf disease using KNN classifier. In: 2019 International Conference on Electrical, Computer and Communication Engineering (ECCE). IEEE. Vol. 2019. 2019. pp. 1-6. DOI: 10.1109/ecace.2019.8679247

[7] Shrivastava S, Singh SK, Hooda DS. Soybean plant foliar disease detection using image retrieval approaches. Multimedia Tools and Applications. 2017;**76**(24):26647-26674. DOI: 10.1007/s11042-016-4191-7

[8] Pydipati R, Burks TF, Lee WS. Identification of citrus disease using color texture features and discriminant analysis. Computers and Electronics in Agriculture. 2006;**52**(1–2):49-59. DOI: 10.1016/j.compag.2006.01.004

[9] Zhang S, Wu X, You Z, Zhang L. Leaf image based cucumber disease recognition using sparse representation classification. Computers and Electronics in Agriculture. 2017;**134**: 135-141. DOI: 10.1016/j.compag.2017.01.014

[10] Diao ZH, Song YM, Wang YP, et al. Feature extraction of leaf images for mite disease in cotton fields. Advanced Materials Research. 2013;**605**:919-922. DOI: 10.4028/www.scientific.net/amr.605-607.919

[11] Ali H, Lali MI, Nawaz MZ, et al. Symptom based automated detection of citrus diseases using color histogram and textural descriptors. Computers and Electronics in agriculture. 2017;**138**: 92-104. DOI: 10.1016/j.compag.2017.04.008

[12] Pires RDL, Goncalves DN, Orue JPM. Local descriptors for soybean disease recognition. Computers and Electronics in Agriculture. 2016;**125**: 48-55. DOI: 10.1016/j.compag.2016.04.032

[13] Zhang S, Zhu Y, You Z, Wu X. Fusion of super pixel, expectation maximization and PHOG for recognizing cucumber diseases. Computers and Electronics in Agriculture. 2017;**140**:338-347. DOI: 10.1016/j.compag.2017.06.016

[14] Zhang J, Marszalek M, Lazebnik S, Schmid C. Local features and kernels for classification of texture and object categories: A comprehensive study. International Journal of Computer Vision. 2007;**73**(2):213-238. DOI: 10.1109/cvprw.2006.121

[15] Wang H, Li G, Ma ZH, Li X. Image recognition of plant diseases based on principal component analysis and neural networks. In: Proceedings of the 2012 8th International Conference on Natural Computation. Chongqing, China, 29–31 May. 2012. pp. 246-251. DOI: 10.1109/icnc.2012.6234701

[16] Karmokar BC, Ullah MS, Siddiquee MK. Tea leaf diseases recognition using neural network ensemble. International Journal of Computer Applications. 2015;**114**(17): 1-9. DOI: 10.5120/20071-1993

[17] Yao Q, Guan Z, Zhou Y, Tang J, Hu Y, Yang B. Application of support vector machine for detecting rice diseases using shape and color texture features. In: Proceedings of the International Conference on Engineering Computation. Hong Kong, China, 2–3 May. 2009. pp. 79-83. DOI: 10.1109/icec.2009.73

[18] Hossain MS, Mou RM, Hasan MM, et al. Recognition and detection of tea leaf's diseases using support vector machine. In: 2018 IEEE 14th International Colloquium on Signal Processing & Its Applications (CSPA). IEEE. 2018. pp. 150-154. DOI: 10.1109/cspa.2018.8368703

[19] Xu M, Wang J, Gu S. Rapid identification of tea quality by E-nose and computer vision combining with a synergetic data fusion strategy. Journal of Food Engineering. 2019;**241**:10-17. DOI: 10.1016/j.jfoodeng.2018.07.020

[20] Zhang Y, Yang X, Cattani C, Rao R, Wang S, Phillips P. Tea category identification using a novel fractional Fourier Entropy and java algorithm. Entropy. 2016;**18**(3):77. DOI: 10.3390/e18030077

[21] Xu Y, Mei H, Lin L, Shi X, Zhou H. The study and exploitation of diagnosed and controled of tea disease's expert system. System Sciences and Comprehensive Studies in Agriculture. 2003;**19**(2):93-96. DOI: 10.3969/j.issn.1001-0068.2003.02.004

[22] Zhang S, Wang Z, Zou X, et al. Recognition of tea disease spot based on hyperspectral image and genetic optimization neural network. Transactions of the Chinese Society of Agricultural Engineering. 2017;**33**(22): 200-207. DOI: 10.11975/j.issn.1002-6819.2017.22.026

[23] Yosinski J, Clune J, Bengio Y. How transferable are features in deep neural networks? Advances in Neural Information Processing Systems. 2014; **2014**:3320-3328. Available from: http://yosinski.com/media/papers/Yosinski__2014__NIPS__How_Transferable_with_Supp.pdf

[24] Ouppaphan P. Corn disease identification from leaf images using convolutional neural networks. In: 21st International Computer Science and Engineering Conference. 2017. pp. 233-238. DOI: 10.1109/icsec.2017.8443919

[25] Liu B, Zhang Y, He D, Li Y. Identification of apple leaf diseases based on deep convolutional neural networks. Symmetry-Basel. 2018;**10**(1): 11. DOI: 10.3390/sym10010011

[26] Zhang X, Qiao Y, Meng F, Fan C, Zhang M. Identification of maize leaf diseases using improved deep convolutional neural networks. IEEE Access. 2018;**6**:30370-30377. DOI: 10.1109/access.2018.2844405

[27] Lehmann-Danzinger H. Diseases and pests of tea: Overview and

possibilities of integrated pest and disease management. Journal of Agriculture in the Tropics and Subtropics. 2000;**101**(1):13-38. Available from: https://www.jarts.info/index.php/jats/article/viewFile/1383/567

[28] Keith L, Ko WH, Sato DM. Identification guide for diseases of tea (*Camellia sinensis*). Plant Disease. 2006: 1-4. Available from: https://scholarspace.manoa.hawaii.edu/bitstream/10125/12400/PD-33.pdf

[29] Chen J, Liu Q, Gao L. Visual tea leaf disease recognition using a convolutional neural network model. Symmetry. 2019;**11**(3):343. DOI: 10.3390/sym11030343

[30] Lowe DG. Object recognition from local scale-invariant features. IEEE. 1999:1150-1157. DOI: 10.1109/iccv.1999.790410

[31] Lazebnik S, Schmid C, Ponce J. Beyond bags of features spatial pyramid matching for recognizing natural scene categorie. IEEE. 2006:2169-2178. DOI: 10.1109/cvpr.2006.68

[32] Csurka G, Dance C, Fan L, et al. Visual categorization with bags of keypoints. In: International Workshop on Statistical Learning in Computer Vision (Prague). 2004. pp. 1-22. Available from: https://people.eecs.berkeley.edu/~efros/courses/AP06/Papers/csurka-eccv-04.pdf

[33] Hartigan JA, Wong MA. A k-means clustering algorithm. Journal of the Royal Statistical Society. Series C (Applied Statistics). 1979;**28**(1):100-108

[34] Vapnik V. Statistical Learning Theory. New York, NY, USA: John Wiley and Sons; 1998. DOI: 10.1002/9780470140529.ch4

[35] Fan R-E, Chang K-W, Hsieh C-J. LIBLINEAR: A library for large linear classification. Journal of Machine Learning Research. 2008;**9**(9): 1871-1874. Available from: http://140.112.114.62/bitstream/246246/155266/1/37.pdf

[36] Rosenblatt F. The perceptron: A probabilistic model for information storage and organization in the brain. Psychological Review. 1958;**65**:386-408. DOI: 10.1037/h0042519

[37] Kim P. MATLAB Deep Learning with Machine Learning, Neural Networks and Artificial Intelligence. Berkeley, CA, USA: Apress; 2017. pp. 114-116. DOI: 10.1007/978-1-4842-2845-61

[38] Sutskever I, Martens J, Dahl G, et al. On the importance of initialization and momentum in deep learning. International Conference on Machine Learning. 2013;**28**:1139-1147. Available from: http://www.jmlr.org/proceedings/papers/v28/sutskever13.pdf

[39] Benammar EA, Cascio D, Bruno S, Ciaccio MC, Cipolla M, Fauci A, et al. Computer-assisted classification patterns in autoimmune diagnostics: The AIDA project. BioMed Research International. 2016;**2016**:1-9. DOI: 10.1155/2016/2073076

[40] Rangarajan Aravind K, Raja P. Automated disease classification in (selected) agricultural crops using transfer learning. Automatika. 2020; **61**(2):260-272. DOI: 10.1080/00051144.2020.1728911

Chapter 9

Forest Conservation Management Using SWOT Analysis and QSPM Matrix (Case Study in the Baluran National Park, East Java, Indonesia)

Adil Siswanto

Abstract

The Quantitative Strategic Planning Matrix (QSPM) has been succeeded and implemented by the Baluran National Park (BNP) managers as an institution strategy. This study wants to discuss the internal and external factor evaluation and the priority strategy analysis of forest conservation management using a survey method with collection of data by a questionnaire with a proportional random of 170 respondents of households. They are 120 as a member of Forestry Community. Training Center and 50 respondents of local government and staff of BNP. Priority strategy analysis consists of (1) optimizing the public participation to save the natural tourism, (2) the transparency and accountably to maximize the conservation effort and the implementation of sustainable tourism, and (3) optimization the resources as a tourist attraction. The practical implications are provided information to a manager or related parties of the importance of internal and external factors that affect the success of management strategy plan. Originalities of this research are the internal and external factors, performing plotting on a matrix internal-external, as well as considering and comparing the external and internal factors in the SWOT matrix. The results can be taken by a decision in the formulation of priority strategies by using analysis of QSPM.

Keywords: forest, conservation, management, quantitative strategic planning matrix

1. Introduction

According to [1], National Park is a conservation area that has different types of flora and fauna that can be relied upon to ensure the survival of human beings in the present and in the future. Refs. [1, 2] indicated that almost of the protected areas face threats and interference in the form of encroachment and illegal cultivation is increasing from time to time. Refs. [1, 3] also stated that the reason of threats and disturbances in the conservation area: (1) because of the institutional role of National Park are still weak in increasing the public participation; (2) the level of public awareness is still low against the values of environmental conservation; (3) the level of education or knowledge are still low; (4) the lack of agricultural land; and (5) isolated villages around the conservation areas.

Darusman [4] says there are at least four reasons why the public participation is very important in the national park management paradigm: (1) the public participation is an integral part of the National Park ecosystem; (2) public participation is a very large part of the subject and object of development in Indonesia; (3) public participation is a party and has been marginalized by development; and (4) public participation is an enormous strength and significantly either positively or negatively to the presence of the National Park conservation area.

Baluran National Park can be developed: (1) as a tourism activities based on natural resources, organized with following the principles of ecotourism to minimize the impact of tourism activities, (2) encourage the conservation of National Park, (3) stimulate economic growth of local people, and (4) provide experiences and conservation education for tourists.

Forest Conservation Management Benefits are able to (1) improve quality and quantity of timber; (2) reduce soil erosion; (3) improve water quality; (4) provide wildlife habitat; (5) sequester carbon in the soil; (6) increase energy source of biomass; and (7) reduce forest health risk of pests and invasive species [5, 6].

Refs. [5, 6], also gives some recommendations of forest management plan, include the need for a supporting institutional, legal, and policy framework that is not just different but more dynamic, to facilitate resource management adaptation and preparedness in a period of accelerating environmental change.

According to the State of The World's Forests [7], "Sustainable forest management", "ecologically sustainable forest management", "forest ecosystem management", the "ecosystem approach" to forest management and "systemic forest management" are among the many terms used to describe concepts and practices that incorporate the three pillars of sustainable forest management – economic, environmental and socio-cultural aspects – to varying degrees.

Singh et al. [8] state that "strategy intent and strategic mission influenced by external environment consisting of opportunities, threat or constraint, and internal environment such as strengths and weakness. The external environment was developed by external conditions such as economic trends, political or legal environment, socio-culture environment, and global environment, which is affect to the company's performance. "Singh advises to do this study by using the value chain analysis".

Some research conducted by Fries [9] stated that the strategy is influenced by variables organization are consisting of: (1) goals and values; (2) resources and capabilities; (3) structure and system; and (4) environment variable such as (i) competitors; (ii) communities; (iii) customers; (iv) government; (v) industry; (vi) institutions; (vii) interest group; and (viii) media and public.

The research of Singh et al. and Fries [8, 9] that provide a gap to be studied by using a variable internal to the organization concerning with the analysis of the value chain by Michael E Porter [10] and the external variable organization based on a research by Jochen [9].

Feurer [11] stated that there are five stages in the preparation of the strategic plan an institution, such as (1) identification and classification of the organization's resources by identifying strengths and weaknesses; (2) identifying the organizational capabilities regarding what can be done organization for more effective and efficient in the face of competitors; (3) utilize the potential resources and it is ability to manage and achieve an competitive advantage in a sustainable manner and immediately get some results; (4) choose a strategy that using the organization's resources very well and skills, also related to external opportunities; and (5) identify

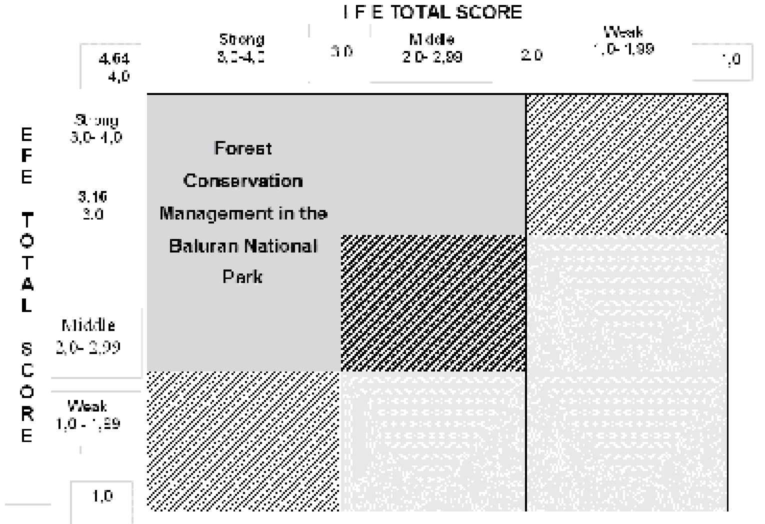

Figure 1.
Internal-external/I-E matrix Forest conservation management in the Baluran National Park Using SWOT Analysis and QSPM Matrix.

gaps of resources that need to be filled by additional investment, expand and upgrade the resource-based organization.

Koontz and Weihrich [12] state that the design stage is the establishment so many strategic plans of the mission, objectives, policies, procedures, rules, programs, and budgets, where this stage is tiered and hierarchical. The study objectives are analyze and explained by the formulation of priorities strategic of the Baluran National Park (BNP) through Quantitative Strategic Planning Matrix (QSPM).

According to Ref. [13], it is said that the Quantitative Strategic Planning Matrix (QSPM) has become widely used among strategic management professors and students for two decades. However, the Quantitative Strategic Planning Matrix (QSPM) has not been widely adopted by strategic planning consultants and organizations. Kazem Zare and Sepideh Karimi [14] also said that the Strength-Weakness-Opportunity-Threat (SWOT) analysis is a powerful strategic tool for evaluating an organization according to internal and external key factors. David and David [13] stated that analytical tools are used by the Strength-Weakness--Opportuniy-Threat (SWOT) Matrix and Boston Consulting Group (BCG) Matrix that generate strategies and it can be evaluated by a Quantitative Strategic Planning Matrix (QSPM).

According to Ref. [15] the management system in Baluran National Park separated by three zones (see **Figure 1**). Based on Director general of forest Conservation and Nature Number SK.228/IV- SET/2012 and the date in December, 26, 2012 stated that some zone in Baluran National Park has include for: (1) Zone around 6920.18 Ha (27.68%); (2) Rimba Zone around 12,604.14 Ha; (3) Advantages Zone around 1856.51 Ha (7.43%); (4) Traditional Zone around 1349,21 Ha (5.36%); (5) Zone around 738.19 Ha (2.95%); (6) Security Zone around 1174.96 Ha (4.70%); and also (7) Rehabilitation Zone around 365.81 Ha (1.46%).

2. Materials and methods

Quantitative Strategic Planning Matrix (QSPM) are (1) one of approach for strategic management at the top level to evaluate strategic opportunities; (2) a method of analysis that compare the activity of suitable alternative strategies; (3) a method of analysis can provide for three (3) stages of strategy formulation framework analysis; (4) is an analytical tool that is able to select the best strategy objectively by using inputs and management techniques with easy computational [16].

To implement strategy forest conservation management by using Quantitative Strategic Planning Matrix (QSPM) analysis, within three stages as follows: (1) The first stage for preparing an external factors evaluation matrix (EFEM), and internal factor evaluation matrix (IFEM), (2) arrange external or internal matrix, then determines the strategy to be taken.

The sampling method is proportional random sampling and unit analysis is the heads-of-household who are members of the forestry community training center (120 people) and local government and staff of Baluran National Park with 50 people (see **Table 1**).

Quantitative Strategic Planning Matrix (QSPM) are (1) one of approach for strategic management at the top level to evaluate strategic opportunities; (2) a method of analysis that compare the activity of suitable alternative strategies; (3) a method of analysis can provide for three stages of strategy formulation framework analysis; (4) is an analytical tool that is able to select the best strategy objectively by using inputs and management techniques with easy computational.

No	Key external factors	Weight	Value rating	Score
Opportunities				
1	Global support to conservation of natural resources in developing			
	countries with tremendous natural wealth	0.05	3.88	0.19
2	Communication is getting better and coordinated between the parties	0.09	3.40	0.31
3	Policy budget resource management and transparency	0.12	2.84	0.34
4	BNP located in geographical zones that are growing rapidly	0.07	3.28	0.23
5	The Minister of forestry policies are encouraging management programs and development	0.07	3.32	0.23
Threats				
1	Population growth around buffer village of BNP with the space requirements and ever increasing economic	0.14	3.04	0.43
2	The global economic downturn and the availability of jobs	0.09	3.28	0.30
3	Growth objects and attractions around BNP	0.12	2.76	0.33
4	The behavior of tourists and residents in the area of BNP uncontrolled, potentially causing damage to forests	0.09	2.96	0.27
5	The rise of rare flora and fauna trade that affect the extraction of natural resources	0.03	3.68	0.11
6	Local government policies that are inconsistent as influenced by economic and political dynamics	0.13	3.32	0.43
7	Growth objects and attractions around BNP	0.12	2.76	0.33
	Total	1.00	—	3.16

Table 1.
The external factor evaluation (EFE) matrix.

3. Results and discussions

3.1 The External Factor Evaluation Matrix (EFEM)

The steps must be carried out by other agencies or managers to implement the strategy of forest management using by analysis Quantitative Strategic Planning Matrix (QSPM) within three stages as follows: (1) The first stage for preparing an evaluation matrix external factors (EFE), and internal factor evaluation matrix (EFI), (2) arrange external or internal matrix form (EI), then determines the strategy to be taken. External factors are outside the organization that affect to the successful of forest management, and may be divided into opportunities as the external factors that it can encourage a successful management of BNP, and threats from outside the organization as a factor, it has also been increase the risk of failure to achieve management goals. The matrix evaluation of external factors is influence to the management strategy of Baluran National Park (BNP) is presented in **Table 1**.

Note that there are five opportunities and six threats facing by Baluran National Park (BNP). Fifth opportunities include (1) the existence of global support to conservation of natural resources in developing countries with a wealth of outstanding natural, (2) the communication is getting better and coordinated between the parties, (3) Policies institutional accountable and transparent in the management of budget and resources, (4) Baluran National Park (BNP) lies in the geographical zone that is growing rapidly, (5) the policy of the Ministry of Forestry are encouraging management programs and development.

While the six threats faced by manager of Baluran National Park (BNP) are: (1) the population growth around Baluran National Park (BNP) with space requirements and economic growth (2) the global economic downturn and job availability, (3) Growth of object and tourist attractions around Baluran National Park (BNP) not able to provide incentives and to improve a welfare of the surrounding community, (4) behavior of tourists and residents in the area of BNP uncontrolled, potentially causing damage to forests, (5) the trade of flora and fauna that affect extraction of natural resources of Baluran National Park (BNP), and (6) local government policies that are inconsistent as influenced by economic and political dynamics. The weight and value given to each of the external factor is based on the same criteria as is done in EFE. EFE matrix analysis results showed that the total value is multiplied by the weight to the overall external factor is 3.16.

The analysis of the internal factors that influence the forest management indicates that there are seven strengths and nine weaknesses that affect the performance of forest management. Seventh strengths are: (1) biological and non-biological diversity; (2) sustainability empowerment program with potential ownership of social assets that have the support of various parties; (3) Buffer zone (Bitakol) entrance area as a Baluran National jungle zone; (4) the relationship between Baluran National Park (BNP) with local people are good enough; (5) the relationship and coordination with the local government runs well; (6) training to improve quality of human resources of Baluran National Park (BNP) good, this is indicated partly by the success of the staff who pass the competency of performance; and (7) the wealth of biodiversity is able to attract the attention of the academics to conduct a study and research.

Internal weaknesses are internal factors in forest management that affect forest management organization to reach a destination that has been set. The results of the analysis of internal factors indicate nine weakness in forest management, namely: (1) the amount of the area has been disturbed habitat for the invasion of exotic species; (2) disturbance forests increasingly high due to the lack of participation and awareness; (3) resource management wizard which has not been optimal so it is not able to provide benefits in improving the welfare of the surrounding community; (4) enforcement of tourist activity that has not been done properly; (5) law enforcement is not optimal and transparent; (6) the conservation efforts Bull have not shown optimal results; (7) the interaction of people still harm the BNP based on characteristic of the socio-demographic aspects; (8) many memorandum of understanding (MOU) has not been implemented optimally; and (9) unavailable the road map of research, so the research focused on the needs of researchers and research objects.

The weight of each internal factor indicates the importance of each factor in forest management. Figures weights between 0.0 indicate that these factors are not important up to 1.0 indicating that the weights are very important and affect the success of forest management. Grades or rankings indicate how effective the strategy of forest management set will increase the internal strength or overcome internal weaknesses that exist. Based on the analysis of EFI is known that the total amount is 4.64. It means Baluran National Park has good potential internal factors (**Table 2**).

No	Key Internal Factors	Value		
		Weight	Rating	Score
Strengths				
1	Biodiversity complex	0.09	4	0.34
2	Sustainability programs related to community empowerment which received support from various parties	0.15	3	0.46
3	Ex buffer zone (Bitakol) sign BNP area as jungle zone	0.09	3	0.28
4	Good relations with community institutions	0.07	3	0.23
5	Liaison and coordination with the local government goes well	0.06	3	0.20
6	BNP good in human resources, who pass the competency performance	0.14	3	0.40
7	The biological wealth to attract the attention of academics to conduct a study and research	0.10	3	0.30
Weaknesses				
1	Many areas have been impaired due to the invasion of exotic species habitat	0.07	3	0.24
2	Major anthropogenic disturbances	0.13	3	0.33
3	Resource management wizard that is not optimal	0.07	3	0.22
4	Enforcement of the rules of tourism activities that have not enforced properly	0.08	3	0.26
5	Law enforcement is not optimal	0.05	4	0.18
6	Bull conservation efforts have not shown optimal results	0.14	3	0.40
7	Community interaction (people) still hurt BNP	0.10	3	0.30
8	The amount of the memorandum of understanding (MOU) has not been implemented to the fullest	0.07	3	0.23
9	Road map research activities unavailable, so the research focused on the needs of researchers and research objects	0.09	3	0.28
	Total	1	-	4.64

Table 2.
The Internal Factor Evaluation (IFE) Matrix.

3.2 The Strength-Weakness-Opportunity-Threat (SWOT) Matrix

Based on the strengths and weaknesses found in Baluran National Park (BNP), which has been described above, it will be found through a StrengthWeakness-Opportunity-Threat (SWOT) analysis of forest management strategy to support the vision and mission. The use of Strength-Weakness-Opportunity-Threat (SWOT) analysis in this study aims to look at the feasibility of the potential of the region to be managed with public participation as the key to a successful program to create a sustainable forest management that is capable of providing independence and prosperity of society.

Strength-Weakness-Opportunity-Threat (SWOT) Matrix used is to find development options besides the main strategy that has been determined. Strength-Weakness-Opportunity-Threat (SWOT) Matrix is built based on the results of the analysis of strategic factors both internal and external factors which consist of strengths, weaknesses, opportunities and threats. Here is a Strength-Weakness-Opportunity-Threat (SWOT) analysis matrix of Baluran National Park (BNP) (**Table 3**).

IFAS		
	Strengths	**Weakness**
	1. Biodiversity	1. A large area of habitat has been disturbed
	2. Sustainability programs related to community empowerment which receives support	2. Natural tourism is not optimal.
	3. Bitakol area as an entrance area in Baluran National jungle zone Good relationships with community institutions	3. Regulation of tourist activities not enforced properly
	4. Well—run and coordinated relationships with local government	4. Law enforcement has not been optimal.
	5. High—quality human resources	5. Bull conservation has not shown optimal results
	6. Biodiversity attracting academics to do research	6. Interactions of people still hurt BNP
		7. MOU has not been implemented
		8. No road map for researchers
EFAS		
Opportunities	**Strategy SO**	**Strategy WO**
1. Global support for conservation	Strategies that use strengths to take advantage of opportunities.	Strategies that minimize weakness in order to exploit opportuninties.
2. Improving communication	BNP forest management strategies (S 1,2,3,4,5,6,7; O 1,2,3,4,5)	The strategy of exploiting global support for the restoration of degraded areas. (W 1,2,4; O 1,2,3,4,5,6,7,8,9)
3. Resource management transparency		
4. BNP as a main corridor of the Java—Bali		
5. Encouraging management programs strategy		Utilizing the global support strategy and communication efficiency coordination to enhance tourism competitiveness BNP. (W 3,4,5,6,7,8,9; O 1,2,3,4,5)
Threats	**Strategy ST**	**Strategy WT**
1. Population growth	Strategies that use strengths to overcome threats.	Strategies that minimize weakness and avoid threats.
2. The global economic downtown	Draw up strategies for optimizing the preservation around BNP	The strategy of exploiting the objects and attractions of natural resources in transparency and accountability of management policies to maximize conservation efforts, including implementation of sustainable tourism in TN Baluran

3. The growth of tourism	BNP for the welfare of the local community	
4. The behavior of tourists and the residents.	(village buffer)	
5. The rise of the rare flora and fauna trade	(S 1,2,3,4,5,6,7; T 1,2,3,4,5,6)	(W 1,2,3,4,5,6,7,8,9; T 1,2,3,4,5,6)
6. Local government policies		

Table 3.
A SWOT matrix.

3.3 Quantitative Strategic Planning Matrix (QSPM)

The last stage prioritization strategy that should be taken in the management of Baluran National Park (BNP) which is capable of improving the sustainability of economic, ecological and social is the analysis of Quantitative Strategic Planning Matrix (QSPM). Each strategy was analyzed to determine its ability to improve the internal strength to take advantage of existing opportunities, as well as to overcome

Key Factors	Weight	Alternative					
		Strategy 1		Strategy 2		Strategy 3	
		AS	TAS	AS	TAS	AS	TAS
Opportunities							
Global support to conservation	0.05	4	0.55	4	0.56	4	0.52
Communication is getting better	0.09	3	0.45	3	0.45	3	0.45
Resource management transparency.	0.12	3	0.34	3	0.35	3	0.35
BNP as a main corridor of the Java-Bali.	0.07	3	0.10	3	0.32	3	0.31
Encouraging management programs	0.07	3	0.30	3	0.30	3	0.10
Threats							
Population growth	0.14	3	0.10	3	0.09	3	0.29
The global economic	0.09	3	0.23	3	0.20	3	0.25
Growth objects and attractions around BNP.	0.12	3	0.32	3	0.40	3	0.24
Behavior of tourists and residents	0.09	3	0.40	3	0.40	3	0.23
The rise of rare flora and fauna trade	0.03	4	0.05	4	0.05	4	0.15
Local government policies	0.13	3	0.10	3	0.10	3	0.10
	1.00						
Strengths							
Biodiversity complex	0.09	4	0.40	4	0.20	4	0.50
Sustainability programs received support	0.16	3	0.35	3	0.30	3	0.35
Bitakol area sign BNP area as jungle zone.	0.09	3	0.09	3	0.06	3	0.20
Relationships with community institutions well	0.08	3	0.08	3	0.03	3	0.15
Relationship and coordination running properly.	0.06	3	0.12	3	0.08	3	0.10
Human Resources very well	0.06	3	0.28	3	0.28	3	0.08
Biodiversity attract academics to do research	0.03	3	0.10	3	0.10	3	0.05
Weaknesses							
A large area of habitat has been disturbed	0.07	3	0.28	3	0.34	3	0.40
Natural tourism is not optimal.	0.03	3	0.45	3	0.40	3	0.18
Tourist activities not enforced properly.	0.07	3	0.06	3	0.06	3	0.06
Law enforcement has not been optimal.	0.08	3	0.04	3	0.04	3	0.04
Bull conservation not shown optimal results	0.02	4	0.12	4	0.12	4	0.12
Interaction people still hurt BNP	0.04	3	0.04	3	0.05	3	0.03
MOU has not been implemented	0.01	3	0.31	3	0.32	3	0.33
No road map for researchers	0.02	3	0.10	3	0.06	3	0.06
	1.00		5.79		5.82		5.80

Table 4.
Quantitative Strategic Planning Matrix Applied to Forest Conservation in Baluran National Park.

internal weaknesses by controlling the threat to be faced. In the analysis of Quantitative Strategic Planning Matrix (QSPM), that this capability is also called the appeal. Rated appeal is 1–4, where 1 = not attractive, 2 = somewhat attractive, 3 = quite interesting, and 4 = very interesting.

Research results indicate by optimizing resource of destinations and tourist attractions is 5.79 (**Table 4**). Strategies to increase public participation in the management of natural tourism is 5.82, the value strategy utilizing management policies are transparent and accountable to maximize conservation efforts, including the implementation of sustainable tourism is 5.80.

Priority strategies based on the analysis Quantitative Strategic Planning Matrix (QSPM) specified three priorities that have a total value attractiveness score (TAS) is highest include (1) increasing public participation in the management of natural tourism, (2) utilizing the management policy that is transparent and accountable to maximize efforts conservation, including the implementation of sustainable tourism, and (3) optimizing resources destinations and attractions Baluran National Park (BNP).

4. Conclusions

Developing a Quantitative Strategic Planning Matrix (QSPM) makes it less likely that key external/internal factors will be overlooked or weighted inappropriately in deciding which alternative strategies to pursue. Although developing a Quantitative Strategic Planning Matrix (QSPM) requires a number of subjective decisions, making small decisions along the way enhances the probability that the final strategic decisions will be best for the firm.

As evidence for the Baluran National Park (BNP) examined in this paper, the Quantitative Strategic Planning Matrix (QSPM) can be a useful strategic planning tool even for small firms. Priority strategies based on the analysis Quantitative Strategic Planning Matrix (QSPM) which include (1) increasing public participation in the management of natural tourism with a value of 5.82; (2) utilizing forest management policies are transparent and accountable to maximize conservation efforts, including the implementation of sustainable tourism in TN Baluran with a value of 5.80; and (3) optimizing resources destinations and attractions with a value of 5.79.

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References

[1] PHKA. Pengelolaan Pemberdayaan Masyarakat Di Daerah Penyangga. Jakarta: SATKER Direktorat Pemanfaatan Jasa Lingkungan dan Wisata Alam Direktorat Jenderal Perlindungan Hutan dan Konservasi Alam; 2008

[2] Tahajuddin U. Pengelolaan Sumber Daya Hutan: Suatu Tantangan. In: Pengelolaan Hutan Lestari: Partisipasi, Kolaborasi, dan Konflik. Jakarta: Yayasan Pustaka Obor Indonesia; 2015

[3] Muntasib EKSH. Hutan dan Lingkungan. Bogor: Pusat Penyuluhan Kehutanan dan Perkebunan Kerjasama dengan Fakultas Kehutanan IPB. Fakultas Kehutanan IPB, Institut Pertanian Bogor; 1999

[4] Darusman D. Pembenahan Kehutanan Indonesia. Penerbit: Laboratorium Politik Ekonomi dan Sosial Kehutanan, Fakultas Kehutanan, IPB, Bogor. Halaman 37-52; 2002

[5] Sustainable Timber Tasmania. Forest Management Plan. Sustainable Timber Tasmania, Level 1, 99 Bathurst Street, Hobart, Tasmania. ISBN: 978-0-9806456-1-3; 2018

[6] Forest Conservation and Management in the Anthropocene: Adaptation of Science, Policy, and Practices. 2014. Forest Service Department of Agriculture, United States Department of Agriculture. Rocky Mountain Research Station Publishing Services. Available from: http://www.fs.fed.us/rm/pubs/rmrs_p071.html

[7] Management, Conservation and Sustainable Development of Forests. 2005. State of The World's Forests: Part 1 Situation and Developments in the Forest Sector. pp. 1-22

[8] Singh K, Pangarkar N, Heracleous L. Business Strategy in Asia: A Casebook. Singapore: Thompson; 2004

[9] Fries J. The Contribution of Business Intelligence to Strategic Management. Disertation. Brussel, Vrije Universitait, Brussel. 2006

[10] Hitt M, Ireland RD, Hoskisson RE. Strategic Management: Competitiveness and Globalization. Ohio: Thomson-South Western; 2005

[11] Feurer R. Analysis of strategy formulation and implementation at Hewlett Packard. Management Decision Journal. 1995;**33**(10):4-16

[12] Koontz H, Weihrich H. Management. New York: Mc Graw_Hill Book Co; 1998

[13] David ME, David FR. The QSPM applied to retail computer store. The Coastal Business Journal. 2009;**8**(1)

[14] Kazem Zare JM-T, Karimi S. A SWOT framework for analyzing the electricity supply chain using an integrated AHP methodology combined with fuzzy-TOPSIS. Journal of International Strategic Management Review. 2015;**3**(2015):66-80

[15] Baluran TN. Rencana Pengelolaan Jangka Panjang Taman Nasional Baluran Tahun 2014–2023. Situbondo: Direktorat Jenderal Kehutanan dan Konservasi Alam, Kementerian Kehutanan. Situbondo Indonesia, Taman Nasional Baluran; 2014

[16] Quantitative Strategic Planning Matrix (QSPM). Retrieved 14 of January 2017; 2017. Available from: www.mexi-pedia.com/

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Advances in forest management will enhance the sustainable development of human society, and should be focused on. Under the context of global change, soil nutrients, especially nitrogen, should be carefully managed and monitored in plantations experiencing intensive nitrogen input, and forests with exotic plant invasion disturbance, considering its substantial contribution to global nitrous oxide. One negative effect of global change could be loss of biodiversity, which could be maintained by forest management. In addition, advanced technologies should also be developed to prevent fire in forests considering its increased frequency. Importantly, policies and technologies should also be developed for advanced forest management, such as deep learning in plant disease prevention, and quantitative strategic planning matrix in management of forest conservation.

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