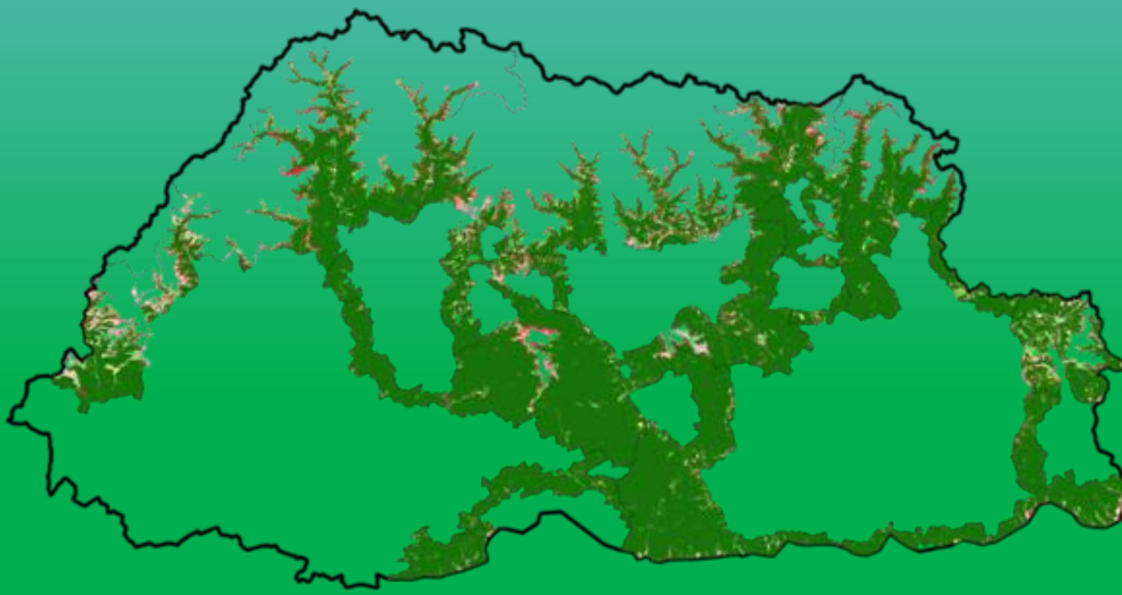
# Forest Carbon Accounting for Protected Areas in Bhutan 2022



**Forest Monitoring and Information Division**

**Department of Forests ad Park Services**

**Ministry of Energy and Natural Resources**

**2024**

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ROYAL GOVERNMENT OF BHUTAN
MINISTRY OF ENERGY AND NATURAL RESOURCES
DEPARTMENT OF FORESTS AND PARK SERVICES
THIMPHU

# Foreword

The Kingdom of Bhutan has one of the highest areas under a network of Protected Areas (PA), encompassing 52% of its surface area. PA serves as a critical strategy for addressing climate change and biodiversity loss. Therefore, the integrity of these PA, their forests, and their biodiversity is of crucial importance for the country's climate change mitigation strategy and for its climate adaptation strategy.

While the effectiveness of PA as tools for climate change mitigation and adaptation is highly discussed at national and international levels, the climate change mitigation potential of Bhutan's PA has not been properly studied. Therefore, this report on "*Forest Carbon Accounting for Protected Areas in Bhutan 2022"*, represents a significant step in our understanding of the environmental assets of Bhutan's PA. By providing a detailed analysis of carbon dynamics within these regions, it offers valuable insights that will aid policymakers, conservationists, and researchers in making informed decisions. It also emphasizes the need for ongoing research and adaptive management to ensure the continued effectiveness of PA in combating climate change.

The findings of this report will serve as a foundational resource for advancing Bhutan's climate and conservation objectives. It provides a roadmap for leveraging the carbon sequestration potential of protected areas and emphasizes the urgent need for effective management practices. As we move forward, let us be guided by the knowledge and insights gained from this study, fostering a deeper commitment to environmental protection and sustainable development.

Further, I applaud Forest Monitoring and Information Division, Department of Forests and Park Services for coming up with this report and express my gratitude to those who contributed to the report and offer the Department's support in similar studies.

(Lobzang Dorji)
**Director**

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Contents

## Abstract/Executive Summary

**Background:** Bhutan is a carbon-negative country with 52% of its land area designated as Protected Area Networks (PAN). While PANs are advocated as cost-effective nature-based climate solutions, their specific contribution to carbon storage and sequestration has remained relatively unexplored in Bhutan. This study provides a comprehensive carbon accounting for all 20 PANs in Bhutan.

**Methods:** We analysed data from the National Forest Inventory (NFI) 2021-2022, which includes 1,255 cluster plots inside PAs. Carbon stocks were estimated for five pools: aboveground biomass (AGB), belowground biomass (BGB), dead organic matter (litter and coarse woody debris), and soil organic carbon (SOC). Sequestration was calculated using five-year tree core increment data, and emissions were estimated from deforestation, timber/firewood removal, and forest fires using the gain-loss method (IPCC 2006).

**Results:** The PAs store a total of 317.98 ± 15.87 million tonnes of carbon (t C). Forest carbon density averaged 216.95 t C $ha^{-1}$, with biomass carbon (141.82 t C $ha^{-1}$) exceeding SOC (75.13 t C $ha^{-1}$). Jigme Khesar Strict Nature Reserve (JKSNR) had the highest carbon density (290.83 t C $ha^{-1}$). Gross annual carbon sequestration from tree growth was 1.6 million tonnes C (5.88 million tonnes $CO_2$ equivalent, t $CO_2e$). However, total annual emissions were 1.95 million t $CO_2e$, primarily from deforestation (1.84 million t $CO_2e$). The net annual carbon sink of the PA network is 3.93 million t $CO_2e$. The annual deforestation rate inside PAs (0.4%) was double the national rate (0.2%), with 94.7% of forest loss converting to grassland.

**Conclusion:** Bhutan's PAs are a significant net carbon sink but face considerable pressure from land-use change. The actual carbon stock is substantially higher than previous estimates (e.g., Bhutan for Life project). We recommend urgent identification of deforestation drivers, improved monitoring, and strengthened land-use management to mitigate reputational risks and enhance climate mitigation outcomes.



***Keywords:*** *Carbon stock, Carbon sequestration, Protected areas, Deforestation, Bhutan, Climate change mitigation, National Forest Inventory*

# 1 Introduction

Bhutan's commitment to environmental conservation is exemplified by its vast forest cover, which accounts for 69.71% (FMID, 2023) of the country's surface area. Over 50% of Bhutan's territory is managed within a network of protected areas (PA), including five national parks (NP), four wildlife sanctuaries (WS), one strict nature reserve (SNR), one botanical park (BP), and nine biological corridors (BC) (FMID, 2024). This network forms the foundation of Bhutan's conservation efforts, preserving diverse ecosystems and playing a crucial role in safeguarding the nation's biodiversity, ecological balance, and climate resilience.

Bhutan's pioneering status as the world's first carbon-negative country and its pledge to maintain carbon neutrality at the 15th Conference of Parties to the UNFCCC in 2009, is reaffirmed in its first and second nationally determined contributions (NDC), which underscores its unwavering dedication to sustainable environmental practices.

Further, PAs are advocated as a cost-effective nature-based solution to mitigate the impacts of climate change, as they efficiently mitigate the risks of deforestation and forest degradation (Liang et al., 2023; MacKinnon, Dudley & Sandwith, 2011) while storing more carbon than unprotected area (Graham et al., 2021; Liang et al., 2023; Smith & Young, 2023; Duncanson et al. 2023). Studies have underscored the pivotal role of PAs in reducing the threat of deforestation (Andam et al., 2008; Fragoso-Lopez et al., 2017; Geldmann et al., 2013; Maxwell et al., 2020; McNicol et al., 2023; Mekela et al., 2023; Scharlemann et al., 2010) and forest degradation (McNicol et al., 2023), thereby addressing concerns about the impermanence of forest carbon credits with reduced threat as well as the virtue of being located in remote and inaccessible areas (Pulido-Chadid, Virtanen & Geldmann, 2023). Moreover, research indicates that forest management practices significantly influence the carbon sequestration capacity of forest ecosystems (Makela et al., 2023; Hwang et al., 2021). Generally, PA generally exhibit higher carbon stocks and sequestration rates compared to non-protected areas. For example, Duncanson et al. (2023) discovered that PAs in Brazil harbour 3.540 million tonnes more aboveground biomass (AGB) carbon than unprotected forests; Liang et al. (2023) observed 24.4% higher biomass densities in PA compared to unprotected areas in Tanzania and Graham et al (2021) demonstrated 2.5 times lower carbon emission in PAs than areas outside PA in southeast Asia.

Similarly, the Department of Forests and Park Services (DoFPS) in Bhutan has envisioned reserving 206 million tonnes of $CO_2$-equivalent stored in the country's PA in perpetuity (GCF, 2017). Additionally, DoFPS aims to sequester a net additional 35.1 million tonnes of $CO_2$ over the 14 years period from 2018 to 2031, with 34.8 million tonnes from natural forests, 0.3 million tonnes from restoration efforts, and 0.1 million tonnes through renewable energy initiatives (GCF, 2017). This is expected to result in a net annual carbon sequestration of 2.51 t $CO_2$ ha-1yr-1 in the form of AGB and below-ground biomass (BGB) growth, with financial support from the Bhutan for Life (BFL) Project.

However, the contribution of Bhutan's PAs in mitigating climate change through carbon storage and sequestration remains relatively unexplored, and a better understanding of the importance of these areas as carbon reserves is pertinent. Therefore, the objective of this study is to fill this knowledge gap by conducting a comprehensive assessment of carbon stocks, sequestration potential, and emissions accounting in Bhutan's PAs using the National Forest Inventory (NFI) data, Land Use and Land Cover (LULC) maps and annual forest statistics (AFS) published by the DoFPS. By quantifying the carbon stocks, sequestration rates and emissions, this study aims to provide valuable insights and enhance the understanding of the role of PAs in Bhutan’s climate change mitigation strategies, importance of PA as carbon reserves and basis for effective management of the PAs.

# 2 Methodology

## 2.1 Study Area

There are a total of 20 PAs in Bhutan (Figure 1) spread across the country under different ecosystems. These PAs vary in size, collectively covering 52% of Bhutan's total land area. Within these PAs, Forests cover 56.29% of the land, while 24% consists of grassland/shrubland, 0.32% is designated as cropland, 0.04% as settlement areas, 0.71% as wetlands, and 18.44% falls under other land categories, as per the LULC data for 2020 (DoSAM, 2023).

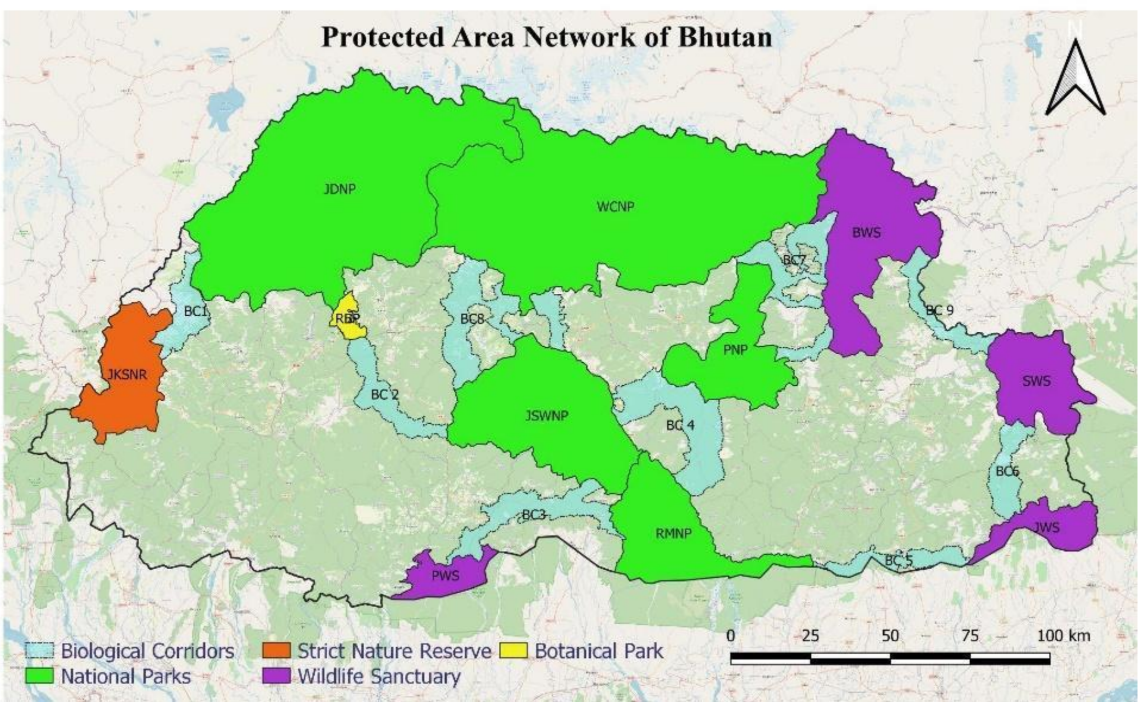


Figure 1: Study Area (Protected Area Network of Bhutan, 2023)

Unlike in many other countries, local communities were not relocated upon the establishment of PAs and settlements inside the PA continue to enjoy the forest ecosystem services for their domestic livelihood. Therefore, it provides a unique opportunity to study PA effectiveness in a wide range of ecosystems and for investigating relationships between PA effectiveness and management regimes, particularly as an effective climate change mitigation strategy.

## 2.2 Sampling Design and Data Collection

In this study, we use the NFI data (2021-2022) for assessment of carbon stock and sequestration in PAs. NFI of Bhutan adopted a systematic sampling design with a total of 2,424 sampling points laid throughout the country on a 4 km by 4 km grid (Figure 2). Each sampling point is called cluster plot and consists of three circular subplots of 12.62 m radius; which are laid in a "L" shaped transect of 50 m apart and are termed as elbow plot (L), north plot (N) and east plot (E). For this study, we have considered AGB, BGB, dead organic matter (DoM, litter & dead wood) and soil organic carbon (SOC) pools.

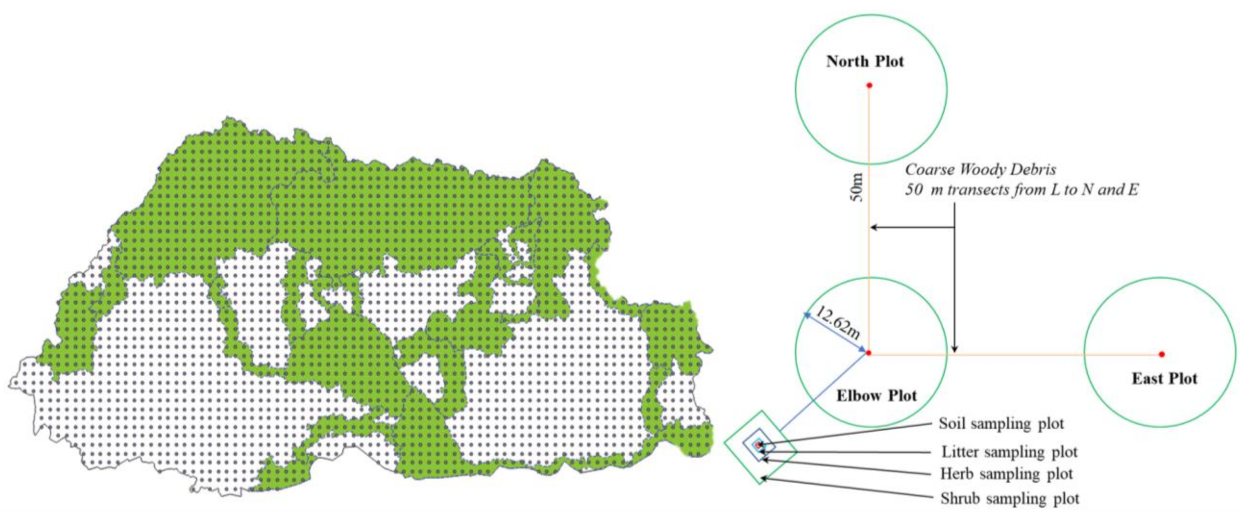


Figure 2: NFI sampling design and plot layout

Trees (diameter at breast height (DBH) greater than or equal to 10 cm) and saplings (DBH greater than or equal to 5 cm and less than 10 cm) are collected from all subplots of 12.62 m radius circular plot. Coarse woody debris (CWD) (dead wood) samples are collected from two 50 m transect lines perpendicular to each other; from the centre of L plot to N plot and L plot to E plot. In addition, Aboveground understory vegetation carbon samples (shrubs and herbs), litter and SOC are collected from the 20% of the total cluster plots in systematic fashion called *carbon plots.* The *"carbon plots"* are laid 20 m South-West from the "L" plot, at an azimuth of 225°, wherein a 5 m x 5 m square plot is laid out for destructive sampling of the shrubs. Herb samples are collected destructively from a 1 m x 1 m square plot laid within the shrub plot. Similarly, litter sample are collected from 30 cm x 30 cm plot laid inside the herb plot and soil sample are collected inside the litter sample plot using 10 cm x 10 cm soil sampling frame laid up to 30 cm depth in three different layers of 0-10 cm, 10-20 cm and 20-30 cm (DoFPS, 2021b; FRMD, 2020).

Of the 2424 cluster plots, 1255 cluster plots are located inside the PAs from which 868 cluster plots were accessible during the field work. Similarly, there are 219 understory aboveground vegetation, litter and soil carbon plots for destructive sampling inside PAs, of which only 168 plots were accessible. The NFI data is supplemented by the LULC Map of Bhutan 2016; LULC Map 2020; and Forest and Non- Forest map 2022 to examine the land use/land cover change in the PAs of Bhutan.

## 2.3 Data Analysis

The data analysis is performed in the R statistical package (version 4.0.3) and Microsoft Excel. No statistical tests are conducted as it is not within the scope of this assessment. The calculation methods and approaches are described below:

### 2.3.1 Calculation of Carbon Stock

The carbon stock in the PA is estimated using NFI Data collected from 2021-2022 for all carbon pools except harvested wood products. For estimation of AGB of trees and sapling, 35 species specific and two general allometric biomass equations employed (see Annexure I for list of equations). The BGB is estimated using Mokany *et al*. (2006) equation at plot level.

$$BGB_p = 0.489 \times AGB_p^{0.89}$$

Where,

$BGB_p$ = below ground biomass at plot level, (t $ha^{-1}$)

The biomass of shrubs, herbs and litter is estimated as oven dry weight of samples, which are dried for 3 to 10 days until constant weight is obtained in the laboratory at $70^o$ C.

CWD samples collected from two 50 m line transects sample in each cluster plots are converted into unit area volume using Smailian volume formula and DeVries'per unit formula described by Waddell (2002) in his paper titled "*Sampling coarse woody debris for multiple attributes in extensive resource inventories*". The biomass density of dead wood is obtained as a product of volume density, wood density and decay class reduction factor. The decay class reduction factor was adopted from Woodall & Monleon (2007) and average wood density of 0.483 t $m^{-3}$ and 0.623t $m^{-3}$ was applied respectively for softwood and hardwood based on UNIDO (1994). Biomass (dm) estimates are then converted into carbon (C) by multiplying the biomass with 0.47 (IPCC 2006). Table 1 shows the decay class reduction factor as adopted from Woodall & Monleon (2007)

*Table 1: Decay class reduction factor for softwood and hardwood*

| Decay class /Species group | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Softwood | 1 | 0.84 | 0.71 | 0.45 | 0.45 |
| Hardwood | 1 | 0.78 | 0.45 | 0.42 | 0.42 |

Percent of SOC content for different layers of 0-10 cm, 10-20 cm and 20-30 cm was determined by Walkley- Black method or CHN Analyzer (if OC is very high) wherever applicable. SOC per unit area is estimated using an equation based on FRMD (2018), Mandal *et al.* (2013) and Pearson *et al.* (2007).

$$SOC_{ha} = SOC\ \% \times S_{bd} \times S_d$$

Where,

$SOC_{ha}$ = Soil Organic Carbon, (t $ha^{-1}$);
$SOC\ \%$ = Soil Organic Carbon content (%);
$S_{bd}$ = bulk density of soil; and
$S_d$ = Thickness of horizon/ layer (cm)

### 2.3.2 Calculation of Carbon Sequestration

The carbon sequestration in the PA is estimated using the biomass increment/growth estimated using the tree cores collected as part of NFI fieldwork using *Haglof* increment borer. The radial increment for each core is measured in the laboratory for the last five years by species and multiplied by two to obtain the diameter increment (Young & Giese, 2003) for the 5-year growth period. This diameter increment data was used to reconstruct the DBH at the beginning of the growth period, which is five years prior to the current DBH measurement. The periodic annual biomass increment for 5 years is estimated based Assmann (1970) & Tenzin & Hasenauer (2016) for periodic basal area increment as follows:

$$B_g = \frac{B_2 - B_1}{5}$$

Where,

$B_g$,= 5-year periodic annual biomass increment, t d.m $ha^{-1}$ $yr^{-1}$;
$B_1$ = the biomass of the tree at the beginning of the growth period, t d.m $ha^{-1}$,
$B_2$ = the biomass of the tree at the end of the growth period, t d.m $ha^{-1}$

Biomass increment is converted into carbon by multiplying with 0.47 and subsequently into carbon dioxide by multiplying with 44/12 (3.67) (IPCC, 2006) per unit area. The total carbon sequestration is then obtained as a product of total forest area inside the PAs, carbon density and $CO_2$ conversion factor.

The dimensions and configuration of the designated area have influenced the number of NFI cluster plots surveyed within PA. Specifically, the number of cluster plots, notably those concerning understory vegetation, litter samples, and soil sample sizes, is significantly influenced by the size and configuration of the PA. No samples for shrubs, herbs, litter and SOC were collected from BC1 and BC7, while only one sample was obtained from BC4, BC5, BC6, BC9, and the Royal Botanical Park during the NFI field work. Under such a situation, the average carbon density of the districts where this PA is located serves as the representative carbon density for that PA.

### 2.3.3 Calculation of Carbon Emission

There are three sources of emission in PAs, i) conversion of forest land to non-forest land (deforestation); ii) harvesting of timber and firewood; and, iii) forest fire. The emission and removals on other land categories were not accounted for in this assessment. The emission/carbon stock loss is estimated using the gain loss method (IPCC 2006). The carbon loss is the sum of the losses due to deforestation, harvesting of timber and firewood and forest disturbance by forest fires.

The emission from the deforestation in PA is estimated as a product of activity data and emission factor. Activity data refers to an average forest land deforested from 2015 to 2023. On conversion of forest land to non-forest land, it is assumed that all of the biomass carbon is lost while differences between the SOC under forest land and non-forest land are assumed to be lost over 20 years.

The carbon loss due to wood removals for timber or firewood is estimated as a product of volume of wood removed, wood density, biomass expansion factor, carbon fraction and $CO_2$ conversion factor-based IPCC 2006 guidelines.

$$Biomass_{loss} = H \times WD \times BEF \times CF \times 44/12$$

Where,

$Biomass_{loss}$ is emission from conservation in $tCO_2$;
H is the volume of harvested timber ($m^3$);
WD is wood density ($t\ m^{-3}$);
CF is carbon fraction; and,
BEF is a biomass expansion factor.

Similarly, carbon loss due to forest disturbance such as forest fire and pest and diseases is estimated as product of area of forest disturbed, average biomass per ha, carbon fraction, fraction of biomass loss to disturbance and $CO_2$ conversion factor

$$Biomass_{loss\_disturbance} = A \times B_w \times CF \times fd \times 44/12$$

Where,

$Biomass_{loss\_disturbance}$ is emission from conservation in $tCO_2$;
$B_w$ is biomass per ha, t d.m $CO_2$;
A is area of forest affected by disturbance (ha) ;
CF is carbon fraction;
fd is fraction of biomass loss to disturbance; and
44/12 is $CO_2$ conversion fraction

The non-$CO_2$ greenhouse gas from forest fire is estimated as

$$Fire_{Emission} = A \times M_B \times C_f \times G_{ef} \times 10^{-3}$$

Where,

*A* is the area burnt in ha;
$M_B$ is the mass of fuel available for combustion in t/ha;
$C_f$ is the Combustion factor; and
$G_{ef}$ is the emission factor in (g/kg) dry matter burnt

However, the $CO_2$ emission resulting from forest fires is not estimated as forests are left to recover after fire and/or if extraction is required, volume of wood removed is either accounted for with volume of timber or firewood.

Time series data was developed using the LULC Map of Bhutan 2016 and 2022 and the Forest Type Map of Bhutan 2022, to understand the net land cover change in the PAs from 2015 to 2023. Further, forest land allotted from the PAs for national development activities and harvesting of timber and firewood were sourced from the Forestry Facts and Figures and AFS from 2015 to 2023 obtained from Forest Information Reporting and Management System, maintained by Forest Monitoring and Information Division (FMID), DoFPS including data on removal of forestry produce from the private registered land for the same period.

To determine the percentage of forest land converted into different land use from 2015-2020, a land use change analysis is conducted in QGIS using a semi-automatic classification plugin and only net gains or losses are accounted for land use changes.

### 2.3.4 Calculation of Net Removals

The net annual carbon removal in the PA of Bhutan is estimated as a difference between annual carbon sequestration and annual carbon emission described earlier.

# 3 Results

## 3.1 Carbon Stock in the PA of Bhutan in 2022

A total of 317.98 ± 15.87 million tonnes of carbon were stored in PAs comprising 246.45 ± 13.55 and 71.49 ± 8.26 million tonnes of carbon in Forest and Non- Forest land respectively. The average forest carbon stock of the 20 PA is estimated to be 216.95 t C $ha^{-1}$, where biomass carbon pools constituted about 141.82 t C $ha^{-1}$ and SOC constituted 75.13 t C $ha^{-1}$.

In the Forest land, the biomass carbon pool contributed 161.10 million tonnes of carbon and SOC contributed 85.35 million tonnes of carbon. Among the PAs, JKSNR has the highest carbon density of 290.83 t C $ha^{-1}$ while the least carbon density is estimated to be in BC5 with a carbon stock of 103.92 t C $ha^{-1}$. Table 2 shows the component wise carbon density and total carbon stock in PA in PA by carbon pools while Table 3 and 4 shows carbon density and total carbon stock by carbon pools in different PAs respectively.

Table 2: Forest and non-forest carbon density and carbon stock in protected area

| | | **Carbon Density (t C $ha^{-1}$)** | | | | **Carbon Stock (million t C)** | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Carbon pools** | **Carbon Pool parts** | **Forest** | **MoE %** | **Non-Forest** | **MoE %** | **Forest** | **MoE %** | **Non-Forest** | MoE % |
| **AGB** | Trees | 97.47 | 5.61 | 1.67 | 50.27 | 110.72 | 11.47 | 1.44 | 51.25 |
| | Sapling | 2.25 | 80.93 | 0.41 | 80.28 | 2.56 | 81.55 | 0.35 | 80.90 |
| | Shrubs | 0.6 | 43.77 | 1.48 | 73.16 | 0.68 | 44.9 | 1.27 | 73.84 |
| | Herbs | 0.19 | 29.09 | 0.21 | 35.18 | 0.22 | 30.76 | 0.18 | 36.57 |
| **BGB** | Tree Roots | 25.65 | 5.06 | 0.51 | 46.65 | 29.14 | 11.21 | 0.44 | 47.71 |
| | Sapling roots | 0.75 | 53.18 | 0.14 | 69.74 | 0.85 | 54.11 | 0.12 | 70.45 |
| **Litter** | Litter | 7.31 | 21.66 | 8.13 | 60.28 | 8.3 | 23.86 | 7.00 | 61.10 |
| **Dead wood** | Coarse woody Debris | 7.6 | 16.14 | 9.56 | 83.73 | 8.63 | 18.99 | 8.23 | 84.33 |
| **Soil** | Soil (0-30cm depth) | 75.13 | 12.35 | 60.97 | 17.15 | 85.35 | 15.89 | 52.47 | 19.85 |
| **Total** | | **216.95** | **2.89** | **83.08** | **11.44** | 246.45 | **5.5** | **71.5** | **11.55** |

Table 3: Forest carbon density in 20 PAs by carbon pool (t C $ha^{-1}$)

| PA Name | AGC | BGC | Litter-C | CWD-C | SOC | Total |
|---|---|---|---|---|---|---|
| **BC1** | 81.55 | 21.53 | 9.23 | 3.75 | 9.87 | 125.93 |
| **BC2** | 118.29 | 30.65 | 7.17 | 2.82 | 101.07 | 260 |
| **BC3** | 93.71 | 24.67 | 7.52 | 6.87 | 91.32 | 224.09 |
| **BC4** | 112.91 | 29.23 | 9.61 | 7.55 | 11.04 | 170.34 |
| **BC5** | 40.83 | 11.37 | 6.7 | 1.39 | 43.63 | 103.92 |
| **BC6** | 86.4 | 22.81 | 3 | 2.5 | 30.09 | 144.8 |
| **BC7** | 111.94 | 29.13 | 4.23 | 6.47 | 12.03 | 163.8 |
| **BC8** | 86.15 | 22.65 | 12.81 | 10.6 | 68.01 | 200.22 |
| **BC9** | 180.28 | 44.91 | 7.97 | 10.2 | 9.6 | 252.96 |
| **BWS** | 106.98 | 27.46 | 9.31 | 7.05 | 101.46 | 252.26 |
| **JDNP** | 99.21 | 22.63 | 8.61 | 6.49 | 94.96 | 231.9 |
| **JKSNR** | 108.43 | 27.64 | 9.48 | 3.19 | 142.09 | 290.83 |
| **JSWNP** | 134.63 | 34.12 | 5.5 | 7.81 | 60.43 | 242.49 |
| **JWS** | 64.93 | 17.56 | 4.21 | 3.52 | 32.09 | 122.31 |
| **PNP** | 128.27 | 33.2 | 1.21 | 7.6 | 108.99 | 279.27 |
| **PWS** | 54.55 | 15.12 | 3.55 | 3.72 | 28.31 | 105.25 |
| **RBP** | 95.25 | 25.08 | 5.06 | 10.25 | 6.64 | 142.28 |
| **RMNP** | 84.58 | 22.57 | 8.91 | 7.17 | 50 | 173.23 |
| **SWS** | 87.69 | 22.81 | 8.44 | 7.61 | 93.39 | 219.94 |
| **WCNP** | 116 | 29.46 | 8.42 | 10.72 | 65.16 | 229.76 |

Table 4: Forest carbon stock in 20 PAs by carbon pool (million tonnes C)

| PA_name | AGC | BGC | Litter-C | CWD-C | SOC | Total |
|---|---|---|---|---|---|---|
| **BC 1** | 0.88 | 0.23 | 0.1 | 0.04 | 0.11 | 1.37 |
| **BC 2** | 3.38 | 0.88 | 0.2 | 0.08 | 2.89 | 7.43 |
| **BC 3** | 3.72 | 0.98 | 0.3 | 0.27 | 3.62 | 8.89 |
| **BC 4** | 6.34 | 1.64 | 0.54 | 0.42 | 0.62 | 9.56 |
| **BC 5** | 0.8 | 0.22 | 0.13 | 0.03 | 0.86 | 2.04 |
| **BC 6** | 1.92 | 0.51 | 0.07 | 0.06 | 0.67 | 3.22 |
| **BC 7** | 4.39 | 1.14 | 0.17 | 0.25 | 0.47 | 6.42 |
| **BC 8** | 4.16 | 1.09 | 0.62 | 0.51 | 3.29 | 9.68 |
| **BC 9** | 3.56 | 0.89 | 0.16 | 0.2 | 0.19 | 4.99 |
| **BWS** | 9.49 | 2.44 | 0.83 | 0.63 | 9 | 22.38 |
| **JDNP** | 10.8 | 2.46 | 0.94 | 0.71 | 10.34 | 25.24 |
| **JKSNR** | 4.5 | 1.15 | 0.39 | 0.13 | 5.9 | 12.08 |
| **JSWNP** | 21.46 | 5.44 | 0.88 | 1.24 | 9.63 | 38.65 |
| **JWS** | 2.14 | 0.58 | 0.14 | 0.12 | 1.06 | 4.02 |
| **PWS** | 1.47 | 0.41 | 0.1 | 0.1 | 0.76 | 2.83 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **PNP** | 10.77 | 2.79 | 0.1 | 0.64 | 9.15 | 23.46 |
| **RBP** | 0.86 | 0.23 | 0.05 | 0.09 | 0.06 | 1.28 |
| **RMNP** | 8.65 | 2.31 | 0.91 | 0.73 | 5.12 | 17.73 |
| **SWS** | 4.53 | 1.18 | 0.44 | 0.39 | 4.83 | 11.37 |
| **WCNP** | 16.99 | 4.32 | 1.23 | 1.57 | 9.54 | 33.66 |

### 3.2 Biomass Growth and Carbon Sequestration

Table 5 and 6 shows annual biomass growth and carbon accumulation, and $CO_2$ sequestration respectively. Total gross carbon sequestration in the protected area in the form of tree aboveground and belowground biomass is 5.88 million tonnes per year. The average AGB and BGB carbon accumulation in forest inside PA in the form of tree biomass is estimated to be 0.98 ± 0.15 t C $ha^{-1}$ and 0.43 ± 0.06 t C $ha^{-1}$ respectively with corresponding annual gross $CO_2$ absorption of 3.59 ± 0.55 t $CO_2$ $ha^{-1}$ and 1.58 ± 0.22 t $CO_2$ $ha^{-1}$.

Table 5: Biomass growth and carbon accumulation

| Carbon pools | Biomass (tonnes per ha) | Carbon (tonnes per hectare) | Total Biomass (million tonnes) | Total carbon (million tonnes) |
|---|---|---|---|---|
| **Above ground biomass** | 2.1 | 0.98 | 2.39 | 1.11 |
| **Below ground biomass** | 0.92 | 0.43 | 1.05 | 0.49 |
| **Total** | 3.02 | 1.41 | 3.44 | 1.6 |

Table 6: Carbon sequestration

| Carbon pools | $CO_2$ (t $ha^{-1}$) | Total $CO_2$ sequestered (m t) |
|---|---|---|
| **Above ground biomass** | 3.59 | 4.08 |
| **Below ground biomass** | 1.58 | 1.8 |
| **Total** | 5.17 | 5.88 |

### 3.3 Land Use and Land Use Change

Change in forest area in the PA is significant based on the LULC statistics for the year 2016 and 2020 as well as Forest Cover Map 2022. The average net forest loss inside the PAs is *4,674.68* ha per annum from 2016 to 2022. Table 7 shows the forest area and average change in forest area in PA. The total surface area of PAs is 1,996,618.26 ha, of which 1,136,125.23 ha are forested while 860,493.03ha are non-forest land in 2022 (FMID, 2023).

Between 2016 to 2020, a total of 80,667.97 ha of forest was lost and gained 35,502.31 ha with a net loss of 45,165.65 ha of forest inside the PA (Figure 3). Similarly, from 2020 to

2022, 52,278.93 ha was lost and gained 64,721.80 ha with a net gain of 12,442.88 ha of forest (Figure 4). Overall, there is net loss of forest from 2016 to 2022 with 0.31%, 94.69%, 0.38%, 1.23% and 3.38% of forest land converted to Cropland, Grassland, Settlement, Wetland and Other land respectively.

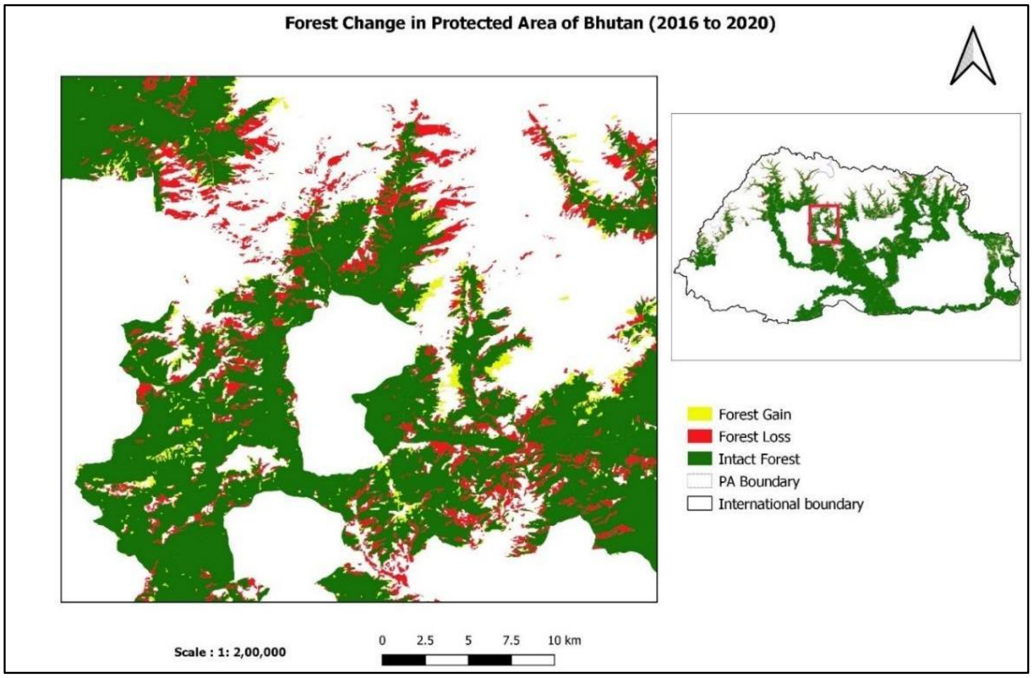


*Figure 2: Forest Cover Change in PA (2016-2020)*

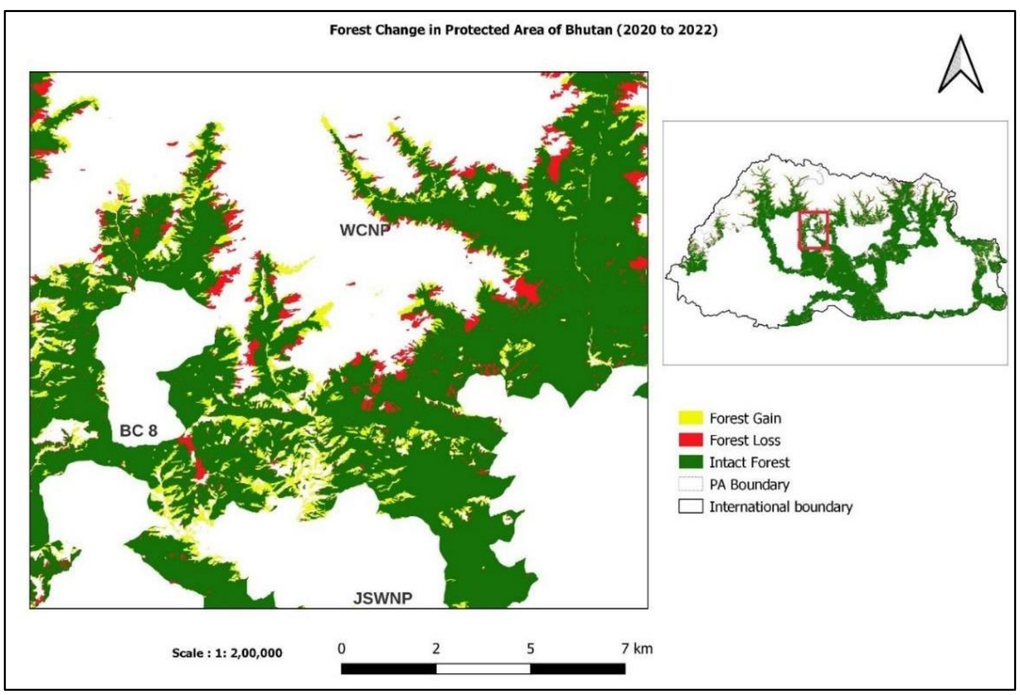


Figure 3: Forest Land Change in PA (2020-2022)

Table 7: Average annual forest loss in protected area

| Initial land category | Final land Category | Total forest loss (ha) | Annual forest loss (ha) |
|---|---|---|---|
| Forest Land | Cropland | 102.54 | 14.65 |
| Forest Land | Grassland | 30,985.42 | 4,426.49 |
| Forest Land | Settlement | 124.69 | 17.81 |
| Forest Land | Wetland | 402.89 | 57.56 |
| Forest Land | Other land | 1107.23 | 158.18 |
| | Total | 32,722.78 | 4,674.68 |

## 3.4 Timber and Firewood Removal and Damage by Forest Fire

Timber and firewood collection is one of the major disturbances in the PA. The average annual volume of timber and firewood removed from PAs from 2015 to 2023 is 25,101.39 $m^3$ and 18,617.79 $m^3$ respectively (Forestry Facts and Figures (FFF), 2016; 2017; 2018;2019; AFS, 2020, 2021; 2022; 2023). Table 8 and 9 show the volume of timber and firewood removed from national parks, wildlife sanctuaries and strict nature reserved. The volume of timber and firewood removed from BC and RBP is not available and are not included in the estimation of the emission.

Table 8: Volume of timber supplied ($m^3$)

| Office | 2022 | 2021 | 2020 | 2019 | 2018 | 2017 | 2016 | 2015 |
|---|---|---|---|---|---|---|---|---|
| **BWS** | 2,491.21 | 3534 | 4164.43 | 5916.24 | 1879 | 1322 | 295.1 | 2034.056 |
| **JDNP** | 2,890.92 | 2455.71 | 25302.2 | 16218.21 | 4412 | 2378 | 2232.3 | 1688.968 |
| **JKSNR** | 129.32 | 187.06 | 326.24 | 5393.61 | 0 | | | |
| **JSWNP** | 115.00 | 498.02 | 445.54 | 931.32 | 768 | 1600 | 1479.5 | 420.1192 |
| **JWS** | 4,127.16 | 268.79 | 2477.25 | 2455.85 | 3728 | 155 | | |
| **PWS** | 9.24 | 203.7 | 1203.46 | 359.5 | 816 | 166 | 111.5 | |
| **PNP** | 819.35 | 836.63 | 9423.46 | 7559.71 | 3537 | 3712 | 5635.1 | 3554.856 |
| **RMNP** | 1,106.45 | 119.61 | 801.92 | 728.2 | 569 | 348 | 226.2 | 406.015 |
| **SWS** | 290.05 | 643.31 | 5625.79 | 4866.36 | 3979 | 12201 | 3332.7 | 1809.792 |
| **WCNP** | 661.53 | 779.71 | 3877.54 | 1359.61 | 1714 | 2242 | 447.8 | 3335.784 |
| **Total** | 12,640.23 | 9,526.54 | 53,647.79 | 45,788.61 | 21,402.00 | 24,124.00 | 13,760.20 | 13,249.59 |

Forest fire is another forest disturbance factor affecting the forest carbon stored in PAs. On an average, about 696.91 ha of the forest area was damaged by fire between 2017 to 2022 inside PA. Table 10 shows area of forest affected by forest fire from 2017 to 2022 (AFS and Forestry Facts and Figures from 2017 to 2022).

Table 9: Volume of firewood supplied ($m^3$)

| Office | 2022 | 2021 | 2020 | 2019 | 2018 | 2017 | 2016 | 2015 |
|---|---|---|---|---|---|---|---|---|
| **BWS** | 1,746.38 | 575.43 | 2,930.19 | 2,622.00 | 247.00 | 3,387.00 | 1,967.60 | 9,588.92 |
| **JDNP** | 1,988.74 | 10,680.00 | 10,422.16 | 4,237.00 | 2,810.00 | 3,084.00 | 1,334.00 | 1,632.92 |
| **JKSNR** | 1,450.51 | 175.91 | 15.10 | 57.00 | 0.00 | | | |
| **JSWNP** | 259.65 | 135.39 | 109.33 | 360.00 | 474.00 | 1,174.00 | 820.20 | 552.76 |
| **JWS** | 299.94 | 1,584.86 | 1,646.67 | 628.00 | 191.00 | 648.00 | | |
| **PWS** | 0.00 | 0.00 | 113.33 | 120.00 | 40.00 | 59.00 | 0.40 | |
| **PNP** | 2,612.43 | 1,863.44 | 7,532.48 | 2,196.00 | 3,615.00 | 2,344.00 | 12,192.00 | 1,289.92 |
| **RMNP** | 854.04 | 547.46 | 234.32 | 178.00 | 139.00 | 686.00 | 488.00 | 65.02 |
| **SWS** | 1,882.22 | 109.32 | 3,389.29 | 3,041.00 | 2,086.00 | 3,144.00 | 20,570.00 | 1,733.69 |
| **WCNP** | 4,300.91 | 485.56 | 1,706.67 | 703.00 | 1,313.00 | 1,859.00 | 1,044.00 | 1,236.35 |
| **Total** | 15,394.82 | 16,157.37 | 28,099.54 | 14,142.00 | 10,915.00 | 16,385.00 | 38,416.20 | 16,099.57 |

Table 10: Forest area damaged by forest fire (ha)

| Year | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|
| **Area damaged (ha)** | 28.82 | 547.37 | 2.11 | 16.56 | 0.87 | 3585.74 |

### 3.5 $CO_2$ Emission from PAs of Bhutan

$CO_2$ emission in the PAs of Bhutan is the result of land use change, timber and firewood harvesting and forest fire. The total average emission from 2015 to 2023 is 1,948,443.34 t $CO_2$ per annum. Table 11 shows the total emission from different sources. Further, the total emission from timber and firewood removal is underestimated as disaggregated data on timber and firewood removals from BCs are not available.

Table 11: Carbon stock loss and emission in PAs

| Carbon Pool/Activity | Carbon stock loss[1] (C t) | $CO_2$-e (t) |
|---|---|---|
| Deforestation | 500,958.98 | 1,836,849.58 |
| Delayed emission from soil | 4,055.72 | 14,870.98 |
| Timber and firewood removal | 18,123.1 | 66,451.33 |
| [2]Non-$CO_2$ emission from forest fire | | 30,270.45 |
| Total | | 1,948,443.34 |

[1] Estimated as equivalent carbon stock from emission

[2] CO2 emission is not included in the emission from forest fire as it is assumed that all damaged tree is converted into timber or firewood to avoid doubling count. Otherwise, the estimated CO2 emission from forest fire is 0.29 million tonnes of CO2 per annum.

The average non-$CO_2$ emission (CO, $CH_4$ and $N_2O$) from 2015 to 2022 in PAs due to forest fires is 30,270.45 t $CO_2$-e annually.  The average annual $CO_2$ emission from timber and firewood removal from PAs from 2015 to 2023 is 66,451.33 tonnes. Accounting for the considerable amount of emission from PA, the net carbon sequestration in the PA is 3.93 million tonnes of $CO_2$ per annum.

# 4 Discussion

Globally, it is imperative to explore the role of PAs in carbon sequestration, as this understanding can bolster their effectiveness in mitigating climate change impacts. Numerous studies have recently investigated PAs contributions to carbon storage and sequestration. For instance, Tian et al. (2023) examined terrestrial PAs role in carbon sequestration in China, Laing et al. (2023) evaluated PAs' effectiveness in conserving AGB density in Tanzania, and Zheng et al. (2013) studied PAs in the United States.  All studies found that the PA store and sequester more carbon than similar ecosystem without formal protection.

Our analysis estimated the total carbon stock (including both forest and non-forest areas), forest carbon sequestration, and emissions within PAs. We found that PAs serve as net carbon sinks, removing approximately 3.93 million tonnes of $CO_2$ equivalent annually. However, they also emit significant greenhouse gases, totalling 1.95 million tonnes of $CO_2$ equivalent. These emissions stem from activities such as deforestation, timber harvesting, firewood extraction, and non-$CO_2$ emissions from forest fires.

## 4.1 Carbon Stock of the PAs

BFL anticipated a net annual forest carbon sequestration of 2.51 million tonnes of $CO_2$ from 2018 to 2031. This projection indicates an accumulation of approximately 34.8 million tonnes of $CO_2$, supplementing the existing carbon stock of 206 million tonnes within the PA by 2031. This addition arises primarily from tree AGB and BGB growth, with a minor contribution of 0.3 million tonnes through forest restoration efforts. These findings underscore the positive performance of PAs in carbon storage, with a total carbon stock of 139.86 million tonnes (equivalent to 512.98 million tonnes of $CO_2$) stored in aboveground and belowground tree biomass. Additionally, 3.41 million tonnes (12.50 million tonnes of $CO_2$) are present in aboveground and belowground sapling biomass, 0.9 million tonnes (3.3 million tonnes of $CO_2$) in aboveground shrub and herb biomass, 16.94 million tonnes (62.11 million tonnes of $CO_2$) in dead organic matter (litter and dead wood), and 85.36 million tonnes (312.98 million tonnes of $CO_2$) in soil. Consequently, the BFL project document significantly underestimates the carbon stored in Bhutan's PAs, as highlighted in the funding proposal, which notes that the estimates are conservative. PAs in Bhutan store more than 47% of the total forest carbon stock (523.87 million tonnes) of Bhutan, despite only 42.48% of the forest area falling within their boundaries. This trend aligns with findings from studies conducted in various regions such as Brazil, Tanzania, southeast Asia, China, and Italy, which consistently demonstrate that PAs store more carbon compared to unprotected areas. The carbon density in the PA is higher than the carbon density outside PA which is estimated to be 183.39 t C $ha^{-1}$.

The non-forested area within PAs makes a substantial contribution to the overall carbon stock, harbouring 71.5 million tonnes of carbon. Notably, the carbon density of shrubs, herbs, litter, and CWD carbon pools is higher in non-forest areas compared to forested regions within Bhutan's PAs. This highlights the significant potential of non-forest lands, which collectively hold a considerable amount of carbon. This observation aligns with the findings of Jones and Donnelly (2004), who noted the high carbon sequestration potential of grassland ecosystems through changes in management practices. Consequently, it's essential to separately consider the conservation and management of non-forest areas within PAs to fully understand their role in carbon storage and mitigation of climate change.

### 4.2 Carbon Emission and Removal

The carbon emission and removal are substantial in PAs of Bhutan. Carbon sequestration rate is estimated to be 5.17 t $CO_2$ $ha^{-1}$ with total annual carbon sequestration of 5.88 million tonnes of $CO_2$. The forest carbon sequestration rate in PA is 25% higher compared to average forest carbon sequestration rate (4.18 t $CO_2$ $ha^{-1}$) (FMID, 2023) in Bhutan and twice as much as in community forest (2.57 t $CO_2$ $ha^{-1}$) (Sigyel et al., 2024).

On the other hand, PA has emitted 1.95 million tonnes of $CO_2$ per annum since 2016. The emission is mainly contributed by conversion of forest land to non-forest land followed by emission from timber and firewood harvesting and forest fire, which constitute deforestation and forest degradation. The net carbon sequestration in the PA is 3.93 million tonnes of $CO_2$ per annum and if all of the forest area conserved, PA can accumulate an additional 35.97 million of $CO_2$-e by 2031. It is interesting to note that the emission from the PA constitute approximately 80% of total greenhouse gas emission reported in biennial update report of Bhutan (BUR) (2.72 million tonnes of $CO_2$-e for the inventory year 2020 (NEC 2021). Therefore, it indicates that there is substantial increase in GHG emission in forest in general.

### 4.3 Land Cover and Land Use Change

The forest land in the PA underwent a major change from 2016 to 2022, where forest losses far exceed the forest gains. On an average, about 4674.68 ha of forest inside the PA were converted into non-forest land annually. This is more than 0.4% deforestation rate inside the PA compared to overall deforestation rate 0.2% in the country based on forest area of 2022 and annual average forest loss of 6060.1 ha per annum from 2016 to 2022.

The forest loss may be attributed to allotment of SRF land for different purposes such as land lease, *kidu* land, land substitute, transmission lines, road construction, etc., for socio-economic development and recultivation of forested private registered land by clear felling. However, it is interesting to note that 94.69% of forest land were converted into grassland and collectively less than 6% is converted into cropland, settlement, wetland and other land. Further, only about 3,551.75 ha of SRF land were allotted annually for various developmental activities from 2015 to 2023 including area outside PA. In accordance with existing legal framework in practice, forested land is generally not allotted for development activities and based on the land allotment inside PA in 2023, only 378 ha of area were forested against the overall land allotment of 694 ha.

While the drivers of deforestation are not clear, if the trend continues, there is a risk of losing the existing carbon stock from the forest and there is reputational risk of high deforestation inside PA. Therefore, a proper assessment and studies needs to be conducted in determining the suitability and impact of land allotted on forest and forest carbon inside PAs.

# 5 Conclusion and Recommendation

The PA of Bhutan store huge quantity of carbon in different carbon pools and aid in climate change mitigation efforts as part of NDC. However, there is also substantial emission in PA resulting from deforestation, timber and firewood removal as well as forest fire. The rate of deforestation in PA (0.4 %) is recorded higher than areas outside the PA (0.2 %). Further, carbon stock and net sequestration in the PA is close to 250% and 150% higher respectively than the BFL estimate. Therefore, there is gross underestimate in the carbon stock inside the PA in BFL project proposal document.

In view of the findings, we recommend following interventions

1. Identify the driver of deforestation in the PA and revalidate the rate of deforestation using better resolution satellite imageries or improved field validations
2. Re-estimate the mitigation impacts in BFL landscape
3. Monitor the land use and land cover change in the PAs
4. Strengthen the land use inside the PA to avoid any reputational risk and achieve the mitigation impacts of BFL.

# 6 Limitation

The forest loss and gains are estimated using the already published LULC and forest cover data and no new data is generated. We acknowledge the spatial inconsistency between LULC 2020 developed using Sentinel 2 data with 10 m resolution; and LULC 2016 and forest cover map 2022 developed using Landsat data (30 m resolution). These three data sets were made consistent and comparable by rasterizing the shape files to 10 m resolution for change detection in QGIS 3.22 and further analysis were performed under same resolution.

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