ABSTRACT

Carbon sequestration is the extraction of atmospheric carbon dioxide (CO\textsubscript{2}) and its storage in terrestrial system for a very long period of time – may be thousands of years. Forests offer certain potential to be managed as a sink, which is to promote net carbon sequestration. A sink is the activity which removes Greenhouse Gases (GHGs) from atmosphere. The sacred groves are traditionally conserved areas under the name of certain deity. These are the virgin patches of the natural forest communities. Therefore, estimation of carbon sequestration potential of such virgin forest patches will be of great help to understand the natural rate of carbon sequestration. Therefore, the sacred groves may have high carbon sequestration potential. To evaluate carbon pool of such sacred groves as compared to open forest the present study has been undertaken from Bhor Tahsil area which comes under Western Ghat region of Maharashtra.

Ravindranath (1996, 1997) published a paper on carbon flows in climate change and reported that the standing biomass (as above and below ground biomass) in India is estimated to be 8375 million tones for the year 1986 of which carbon storage would be 4178 million tonnes. The total carbon stored in forests, including soil is estimated to be 9578 mt. on the other hand, carbon emission from fossil based energy production and consumption activities in India have been estimated at 152-205 mt. per year. Trees are important sinks for atmospheric carbon i.e. carbon dioxide, CO\textsubscript{2}, since 50% of their standing biomass is carbon itself (Ravindranath et.al 1997). Importance of forested areas in carbon sequestration is already well accepted and well documented (Tiwari and Singh, 1987).

Sacred groves from Pune district are surveyed for multidimensional aspects by several workers. Gadgil and Vartak (1981) made inventory of sacred groves from Maharashtra state in general and recorded 11 sacred groves from Bhor Taluka. Waghmare et.al (2006) recorded 14 sacred groves from Parinche Valley of Pune district for their cultural and ecological point of view. Kulkarni and Sindikar (2005) made plant diversity evaluation of Shirkai sacred groves situated at village Shirkoli from Bhor Taluka. Kulkarni and Nipunage (2009) reported floristic diversity and ecological evaluation of Dhup-rahah sacred groves situated in Bhor region of Pune district. This sacred groves is specially known as Dhup-Rahat due to magnificent trees of Dhup i.e. Canarium strictum Roxb. Sacred groves from Bhor Taluka are under control of Devasthan.
committees and that are monitored by forest department, Maharashtra Government. The sacred groves are under threat because of anthropogenic pressure and developmental activities like Bhatghar, Nira Devoghar and Gunjawani damps. The present work is the first attempt of carbon sequestration of sacred groves.

**STUDY AREA:**

The present study deals with the carbon sequestration potentials of selected sacred groves from Bhor, Taluka, Dist-Pune, India. Pune district is situated between 17.5° to 19.2° North latitude and 73.2° to 75.1° East longitudes. Bhor Taluka is located in hilly and remote Western Ghat region covering an area about 892.0 Sq. Km. The Bhor town is located 55 Km south of Pune City and between 18°.45’ N latitude and 73°-15’ E longitude. Elevation of Bhor from mean Sea level is 591.43 meters.

The four sacred groves namely i) SomjaichiRai at village Nandghur ii) Nivgunjaich Rai at village Nivgun iii) Maulidevichi Rai at village Varvand iv) Umberjaichi Rai at village Parhar, are selected to study their biodiversity and carbon sequestration potentials.

**AIM AND OBJECTIVES:**

The main aim of the study is the documentation of selected sacred groves from Bhor Tahsil and assessment of carbon sequestration potential of trees (vegetation) and environmental factors associated with conservation in general plant resources and biodiversity.

**Objectives:**

- To document plant diversity in selected sacred groves from Bhor Taluka.
- To study diversity of sacred groves in three seasons using suitable method.
- To evaluate carbon sequestration potentials in vegetation and soils from sacred groves and adjacent areas.
- To compare carbon sequestration potentials between various vegetation including sacred groves.

The thesis has been arranged in the following chapters:
1. **Introduction:** This chapter narrates the meaning of carbon sequestration, need and importance of carbon sequestration, meaning of sacred groves and their importance; the role of sacred grove forest in carbon sequestration and their importance.

2. **Review of Literature:** The literature is reviewed considering two aspects as carbon sequestration and the status of sacred groves at the Global, National and Regional levels.

3. **Materials and Methods:** This chapter narrates the study area location, its climatic conditions, vegetation and names of selected sacred groves and area of each sacred grove. Plant diversity of each sacred grove has been documented in each season. The methodology includes i) the appropriate number of sampling locations has been selected in the field based on land use criterion. ii) The field measurements had taken for these locations. The parameters like GBH, height of trees, regeneration status of plants. iii) Estimation of carbon pool for above and below ground biomass. iv) Deadwood and leaf litter biomass. v) Soil organic carbon estimation. vi) The qualitative and quantitative estimations of vegetation quadrate and transect methods.

4. **Plant diversity in sacred groves:** Floristic composition of each sacred grove includes, trees, shrubs, herbs, grasses, climbers has been documented and compared for variations studies.

5. **Assessment of Carbon Sequestration Potentials of Four Selected Sacred Groves:** In this chapter the assessment of Above ground Biomass (AGB), Below ground Biomass (BGB), Total Biomass, Deadwood and Leaf Litter Biomass, Soil Organic Carbon, the species found in sacred groves and the Total Carbon Sequestrated in the respective areas of Four sacred groves and the total carbon sequestrated in the respective adjacent areas of sacred groves have been narrated.

   Among the four selected sacred grove, Somjaichi Rai has sequestered highest amount of aboveground and below ground carbon i.e. 342.4 tonnes/50000 m², after extrapolation. The dominant plant species were *Terminalia bellirica* (Gaertn.) Roxb, *Ficus amplissima* J. F. Smith, *Mangifera indica* L, *Pongamia pinnata* (L.) Pierre, *Syzygium cumini* (L.) Skeels , *Ficus recemosa* L sequestrating 121.73, 37.31 , 37.18 , 24.89, 23.46, 22.96 tonnes respectively. The other plant species like *Dendrocalamus strictus* (Roxb.) Nees, *Dalbergia lanceolaria* L.f., *Lagerstroemia microcarpa* Wt, were sequestrating the biomass carbon in the range of 12 to 13 tonnes. The remaining plant species were sequestrating biomass carbon below 10.00
tonnes/50000 m$^2$. Total tree, climber and shrub biomass carbon was estimated for 1661 individuals belonging to 31 plant species.


The biomass (AGB+BGB) carbon sequestered in Maulidevichi Rai was 292.104 tonnes/20000 m$^2$ after extrapolation. The dominant plant species contributing to the carbon sequestration were *Dendrocalamus strictus* (Roxb.) Nees., *Memecylon umbellatum* Burm. f., *Mangifera indica* L., *Syzygium cumini* (L.) Skeels., *Artocarpus heterophyllus* Lam sequestrating 67.88, 48.91, 32.18, 29.96, 27.75 tonnes of carbon/20000 m$^2$ repectively. The other plant species like *Terminalia alata* Heyne. ex. Roth, *Terminalia chebula* Retz, *Bombax ceiba* L., *Bridelia retusa* (L.) Spreng sequestrating carbon in the range 2.0 to 5.0 tonnes/species per 20000 m$^2$. The least carbon sequestrating species were *Allophylus cobbe* (L.) Raeusch and *Eucalyptus globusus* Lab having 0.0336 and 0.0332 tonnes/species respectively. The more abundant plant species was *Memecylon umbellatum* Burm.f with 647 individuals. The total tree, shrub, climber biomass carbon was estimated for 2517 individuals.

The total Biomass (AGB+BGB) carbon sequestered in the comparable adjacent area of Maulidevichi Rai was 11.712 tonnes/20000 m$^2$. The plant species found in the adjacent area were *Bridelia retusa* (L.) Spreng, *Bombax ceiba* L. *Acacia concinna* DC, *Carissa congesta* Wt, *Erythrina varigeta* L, *Dendrocalamus strictus* (Roxb.) Nees, *Mangifera indica* L, *Memecylon umbellatum* Burm.f, *Syzygium cumini* (L.) Skeels., *Terminalia chebula* Retz, *Terminalia alata* Heyne.ex. Roth. For adjacent area of Maulidevichi Rai the total tree, climber and shrub biomass carbon has been estimated for 378 individuals belonging to 11 plant species.

The total biomass (AGB+BGB) carbon in Nivgunjaichi Rai was 276.801 tonnes/10000 m$^2$ after extrapolation. The major plant species contributing to the carbon sequestered were *Terminalia bellirica* (Gaertn.) Roxb. (63.62 tonnes), *Ficus racemosa* L. (48.89 tonnes), *Mangifera indica* L. (43.89 tonnes), *Syzygium cumini* (L.) Skeels (36.32 tonnes) of carbon, and
Ficus amplissima J.F. Smith (30.43 tonnes of carbon). The other plant species like, Dendrocalamus strictus (Roxb.) Nees, Terminalia chebula Retz were sequestrating carbon in the range 17.0 to 15.0 tonnes/10000 m$^2$. The more abundant species found in Nivgunjaichi Rai was Syzygium cumini (L.) Skeels having 166 individuals. The Nivgunjaichi Rai has high carbon sequestration potential through having smaller area compared with the areas of Somjaichi Rai and Maulidevichi Rai.

The carbon sequestered in the adjacent area of Nivgunjaichi Rai was 15.32 tonnes/10000 m$^2$ after extrapolation. The plant species found in the outside area were Bridelia retusa (L.) Spreng, Carissa congesta Wt, Dendrocalamus strictus (Roxb.) Nees, Erythrina varigeta L., Cassia fistula L, Syzygium cumini (L.) Skeels., Mangifera indica L, Terminalia bellirica (Gaertn.) Roxb, Terminalia chebula Retz. For adjacent area of Nivgunjaichi Rai, the total tree, shrub, climber biomass carbon has been determined for 352 individuals.

The total biomass (AGB+BGB) carbon sequestered in Umberjaichi Rai was 52.85 tonnes/4000 m$^2$ after extrapolation. The major plant species contributing to the carbon sequestration were Lagerstroemia microcarpa Wt, Diospyros montana Roxb, Memecylon umbellatum Burm. F, Terminalia chebula Retz, Terminalia bellirica (Gaertn.) Roxb sequestrating 8.26, 7.85, 7.65, 6.87, 5.48 tonnes of carbon/4000m$^2$ repsectively. The least dominant species was Clematis gauriana Roxb.ex DC having 0.0122 tonnes of carbon/4000 m$^2$. The more abundant plant species was Memecylon umbellatum Burm.f having 453 individuals. The Umberjaichi Rai had least carbon sequestration potential among the selected four sacred groves.

The total biomass carbon sequestered in adjacent area of Umberjaichi Rai was 6.77 tonnes per 4000 m$^2$. The plant species found in adjacent area of Umberjaichi Rai were Acacia concinna DC, Bridelia retusa (L.) Spreng, Carissa congesta Wt., Catunaregam spinosa (Thunb.) Tirveng., Ficus recemosa L, Lagerstroemia microcarpa Wt., Mangifera indica L, Memecylon umbellatum Burm.f., Syzygium cumini (L.) Skeels., Terminalia alata Heyne. ex. Roth etc.

The total aboveground and belowground carbon sequestered in four selected sacred groves was 963.52 tonnes.

The total aboveground and belowground carbon sequestered in adjacent areas of four sacred groves was 51.67 tonnes.
Aboveground biomass is an important pool for all land use categories for national greenhouse gas inventory, carbon mitigation projects, particularly tree based projects, and roundwood production programmes. The above ground carbon sequestration of standing trees in any ecosystem plays the most important role in sequestration of carbon dioxide. The below ground carbon sequestration was estimated from an equation since destructive methods were not applied in all study areas. India has very good green sequestration potential i.e. sequestrating more than 116 million tonnes of CO$_2$ per year which is equal to 32 million tonnes of carbon sequestration, contributes to reduce atmospheric carbon of the globe (SFR, 2009; Jasmin and Birundha, 2011). This is due to the fact that India has considerable natural and man-made forests all over the country.

The total soil organic carbon estimated in the Somjaichi Rai at the Nandghur village was 331.26 tonnes/50000 m$^2$ after extrapolation. This was due to the larger area of this Rai. Thus, maximum soil organic carbon was found in this sacred grove. The carbon sequestered in the form of SOC in the adjacent area of Somjaichi Rai was 173.6 tonnes/50000 m$^2$ after extrapolation.

The study area number 2 Maulidevichi Rai had sequestered 131.77 tonnes of carbon in the form of SOC in 20000 m$^2$. The comparable adjacent area of Maulidevichi Rai had sequestered 115.2 soil organic carbon.

The total soil organic carbon found in study area number 3 Nivgunjaichi Rai was 139.2 tonnes/10000 m$^2$ after extrapolation. The soils of this sacred grove were very rich due to very dense vegetation. The adjacent area of Nivgunjaichi Rai (scared grove) has sequestered 49.6 tonnes/10000 m$^2$ of carbon in the form of SOC.

Umberjaichi Rai (sacred grove) has sequestered 44.24 tonnes/4000 m$^2$ tonnes of SOC. This sacred grove was found to have lowest soil organic carbon due to less area of the grove. The adjacent area of Umberjaichi Rai was found to have 21.49 tonnes/4000 m$^2$ of SOC. It has been observed that the contribution of soil organic carbon to the total carbon sequestered is approximately 50%. The total soil organic carbon estimated in 4 sacred groves was 646.47 tonnes.

The total soil organic carbon in the comparable adjacent areas of sacred groves was 359.89 tonnes. The soil organic carbon found in adjacent area was very much more than that of biomass carbon found in the same area.
The contribution of deadwood carbon to the total carbon sequestered is only about 1-10%. Deadwood carbon sequestered in Somjaichi Rai was 7.8 tonnes/50000 m² after extrapolation. The adjacent area of Somjaichi Rai had 2.2144 tonnes/50000 m² of carbon.

The deadwood carbon sequestered in Maulidevichi Rai was 7.77 tonnes/20000 m². The deadwood carbon sequestered in adjacent area of Maulidevichi Rai was 3.01 tonnes/20000 m² after extrapolation.

The deadwood carbon found in Nivgunjaichi Rai was 5.847 tonnes/10000 m² after extrapolation. 1.4 tonnes of carbon was found in the adjacent area of Nivgunjaichi Rai in 10000 m² area.

The deadwood carbon found in Umberjaichi Rai was 2.5368/4000 m² after extrapolation. The deadwood carbon in adjacent area of Umberjaichi Rai was very much less i.e. 0.747 tonnes/4000 m² after extrapolation. The total deadwood carbon sequestered in all 4 sacred groves was 23.95 tonnes. The total deadwood carbon sequestered in adjacent area of 4 sacred groves was 7.37 tonnes.

The total leaf litter carbon sequestered in all 4 sacred groves was 10.65 tonnes. The total leaf litter carbon sequestered in the adjacent area of 4 sacred groves was 2.7484 tonnes.

Total carbon sequestered = Biomass carbon (AGB+BGB) + Deadwood carbon + Leaf litter carbon+ Soil organic carbon

Total carbon sequestered in four selected sacred groves =
= 964.155 + 23.9578 + 10.6512 + 646.47
= 1645.234 tonnes.

Total carbon sequestered in the adjacent areas of four sacred groves =
= 51.6873+7.1256+2.745+359.89 = 421.448 tonnes.

The carbon sequestered in selected sacred groves is nearly four times more than the carbon sequestered in the adjacent areas of sacred groves. This indicates that the sacred groves have greater potentials of carbon sequestration which can help to reduce the concentration of CO₂ in the atmosphere.

6. Results and Discussion: This chapter narrates the discussion and comparison of results obtained in the study areas.

7. Summary and conclusion: This includes the summary of present work and conclusion.
Bhor region in Pune district has climax vegetation and moderate climatic conditions. The area has different types of vegetation pattern like evergreen, moist deciduous, dry deciduous and thorny forest. Among these vegetation patterns some relic forest patches are conserved by local people on religious grounds. These patches like Somjaichi Rai at Nandghur, Maulidevichi Rai at Varvand, Nivgunjaichi Rai at Nivgun, Umberjaichi Rai at Parhar were selected for plant diversity evaluation and carbon sequestration. The standard methods reported for diversity and carbon sequestrations were used and intensive field visits were arranged for soil sample collection, leaf litter and tree biomass collection. GPS readings were taken for each sacred grove to understand its exact location.

Plant diversity in each sacred grove was very different in inside and outside sacred groves. Some common species in all sacred groves are Acacia concinna Dc., Bridelia retusa (L. Spreng), Cassia fistula L., Mangifera indica L., Erythrina varigeta L., Meyna laxiflora Robyns., Syzygium cumini (L.) Skeels. and Terminalia chebula Retz. Some rarely occurring plants like Entada rheedei Spreng, Zingiber cernum Dalz and Zingiber neesanum (Grah.) Raman. Exotic plant Peltophorum petrocarpum (DC. Baker ex Heyne. Present in Maulidevichi rai. Family wise each sacred groves showing difference Nivgunjaichi rai has 34 families, 52 genera inside sacred grove and 17 outside. Somjaichi rai has maximum families 48 and having 73 genera inside and 13 outside. Maulidevichi rai has 33 families and 42 genera inside and 10 outside. Umberjaichi rai has 29 families and 31 genera inside and 16 outside. Somjaichi rai has rich in species diversity and Umberjaichi rai has only 34 species. Tree species are more in Maulidevichi rai 32 and minimum in Navunjaichi rai. 15 trees. Dendrocalamus strictus only found in three sacred groves. Plant diversity data is very useful for carbon sequestration of each sacred grove.

The present work focused on potentials of carbon sequestration of selected four natural preserved forest patches protected by local communities under religious ground. This work initiated to know the natural rate of carbon sequestration and importance of preservation of the sacred groves to maintain environmental balance for the welfare of biodiversity and human society. Four sacred groves were assessed for Above-Ground Biomass (AGB), Below-Ground Biomass (BGB), soil organic carbon (SOC), deadwood & leaf litter biomass and total carbon sequestered in each selected sacred grove and in comparable adjacent area. Carbon stokes from different pools were estimated using standard methods.
The study concluded with following points:

1) Carbon sequestration potential on sacred groves has been carried out for the first time in the western Ghat of Maharashtra.

2) Remnant vegetation of old trees in selected sacred groves had more carbon sequestration potentials.

3) Soil organic carbon estimated in the sacred grove has direct relationship with vegetation. Dense vegetation has higher amount of soil organic carbon. Carbon rich soils are suitable for regeneration of vegetation.

4) Sacred groves will help to know the importance of carbon sequestration for longer period. Plant diversity in sacred grove is unique due to microclimate exist when compared with outside region of sacred grove.

5) It will provide a new contribution on comparative carbon sequestration potentials of sacred groves and adjacent non-sacred groves areas.

8. Bibliography – This includes selected references mentioned in the thesis.