Department of Forest and Soil Sciences

Institute of Silviculture

Inst. Head/Supervisor: Univ. Prof. Dipl.-Ing. Dr. Hubert Hasenauer

SUSTAINABLE FOREST MANAGEMENT STRATEGIES OF BROADLEAVED FORESTS IN BHUTAN

Dissertation to obtain the doctoral degree (Dr. Nat. Techn.) at the University of Natural Resources and Life Sciences (BOKU), Vienna, Austria.

Submitted by:

Jigme Tenzin,

Institute of Silviculture, Vienna, Austria, November 2016

Preface

We carried out this study within the framework of the project "Climate change adaption potential of forests in Bhutan-building human capacities and knowledge base (BC-CAP)" with funding from the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management (BMLFUW-UW.1.3.2/0124.V/4/2013).

This is a cumulative dissertation consisting of two parts. The first part (section 1 to 8) is an extended summary which provides the framework demonstrating the links between all three papers in their accomplishment towards a larger research goal. Detailed information on methodologies, results and discussions can be found in the individual research paper of Appendix 9.1. to 9.4.

The second part (Appendix) consists of three first authored papers of which two have been published in peer reviewed international journals. One paper is accepted with revision for publication in the Forestry International Journal of Forest Research. Additionally, one peer reviewed paper presented at an international conference is also included. The formatting of the individual papers varies due to the individual style of the journals.

Any citations from this work should be referred to as: Tenzin, J., 2016. Sustainable forest management strategies of broadleaved forests in Bhutan. PhD Dissertation. University of Natural Resources and Life Sciences, Vienna, Austria, p. 104 or by reference of the individual papers.

List of Papers

1. **Tenzin J**, Hasenauer H, 2016. Tree species composition and diversity in relation to anthropogenic disturbances in broadleaved forests of Bhutan. International Journal of Biodiversity Science, Ecosystem Services & Management 12, 274-290

2. **Tenzin, J.**, Wangchuk, T., Hasenauer, H., 2016. Form factor functions for nine commercial tree species in Bhutan. Forestry 89. Available at: forestry.oxfordjournals.org/content/early/2016/09/09/forestry.cpw044.short?rss =1

3. **Tenzin, J.**, Tenzin, K., Hasenauer, H., 2016. Individual tree basal area increment models for broadleaved forests in Bhutan. Forestry (accepted with revision) International Journal of Forest Research.

Other papers:

4. **Tenzin, J.**, Hasenauer, H., 2016. Assessing the forests dynamics of broadleaved forests ecosystems of Bhutan. Conference on International Research on Food Security, Natural Resource Management and Rural Development. Vienna, Austria. TROPENTAG, p.5.

Abstract

In Bhutan, broadleaved forests provide various ecosystem services to about 80 % of the population. In order to ensure the sustainable management of these forests, correct and accurate assessments of growing stock in combination with forest growth prediction from growth models are essential. Currently, no such information exists for the broadleaved forests of Bhutan. The aim of this study was to (i) assess the current state of forest resources as a response to disturbances and management impacts, (ii) develop accurate and consistent volume estimation methods and (iii) calibrate an individual tree basal area increment model for predicting tree growth. The assessment of forest resources revealed a reduction in diversity and change in species composition with increasing disturbances and accessibility. The selective felling leads to the removal of only valuable timber species and the regeneration was dominated by non-valuable species in the forests. To improve existing volume estimation methods in the country, form factor functions were chosen, as volume estimation is more accurate if the form of a tree can be determined accurately. The form factor functions of Pollanschütz, which was calibrated from the data of 395 felled trees, provided consistent and unbiased predictions. Due to the large number of tree species, species groups were created using cluster analysis, to calibrate individual tree basal area increment models for the four species groups. Tree basal area increment is mainly driven by DBH, crown length and the competition within a forest stand. Distance dependent competition indices showed higher correlation than the distance independent competition indices. The resulting increment model provided consistent and unbiased estimates. We demonstrate that the basal area increment models can be used to predict tree growth by species group according to different stand density conditions.

Keywords: Bhutan; broadleaved species; diversity; form factor functions; individual tree increment model; species richness; sustainable forest management.

Zusammenfassung

Die bhutanischen Laubwälder dienen in verschiedenster Weise einem Großteil der Bevölkerung. Damit diese wertvollen Wälder nachhaltig genutzt werden können, bedarf es einer verlässlichen Erfassung der Holzvorräte und einer realistischen Abschätzung der Zuwachsleistung über Waldwachstumsmodelle. Diese Informationen fehlten in der Vergangenheit. Die Ziele dieser Studie waren daher, (I) den aktuellen, durch Störungen und Forstwirtschaft geprägten Waldzustand in Bhutan zu erheben, (II) genaue und konsistente Volumsfunktionen zu entwickeln, und (III) ein Einzelbaumwachstumsmodell zu kalibrieren.

Die Erhebung des Waldzustandes brachte eine Abnahme bzw. Veränderung der Baumartendiversität mit der Erhöhung der Störungsintensität und der Aufschließung ans Tageslicht. Wertvolle Baumarten werden selektiv entnommen, wohingegen weniger wertvolle Baumarten im Wald verbleiben und sich verjüngen. In Bhutan verwendete Volumsfunktionen wurden verbessert, indem Formzahlfunktionen in die Volumsberechnung integriert wurden. Die Formzahlfunktion von Pollanschütz wurde kalibriert anhand von Daten 395 gefällter Bäume und lieferte danach konsistente und unverzerrte Schätzwerte. Die Kalibrierung des Einzelbaumgrundflächenzuwachsmodells wurde aufgrund der hohen Baumartenvielfalt für vier über Clusteranalyse bestimmte Baumartengruppen vorgenommen. Der Grundflächenzuwachs zeigte die stärkste Abhängigkeit von BHD, Kronenlänge und Konkurrenz. Abstandsabhängige Konkurrenzindizes zeigten höhere Korrelation mit dem Zuwachs als abstandsunabhängige Indizes. Das so entwickelte Grundflächenzuwachsmodell kann für die vier Artengruppen dichteabhängige konsistente und unverzerrte Schätzungen für das Waldwachstum liefern.

Keywords: Bhutan, Laubbaumarten, Diversität, Formzahlfunktion, Einzelbaumwachstumsmodell, Artenvielfalt, Nachhaltige Waldwirtschaft