CONTENTS

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Peter **Zhelev** – University of Forestry, Sofia, Bulgaria

FORESTRY IDEAS, 2016, vol. 22, No 2 (52): 113-126

NEW RECORDS AND DATA ON HYPOGEOUS ECTOMYCORRHIZAL FUNGI IN BULGARIA

Teodor Nedelin[1]*, Melania Gyosheva[2], Kaloyan Kostov[3], and Slavcho Savev[1]

[1]Department of Silviculture, Faculty of Forestry, University of Forestry, 10 St. Kliment Ohridski Blvd., 1797 Sofia, Bulgaria. *E-mail: teodor_nedelin@hotmail.com
[2]Department of Plant and Fungal Diversity and Resources, Institute of Biodiversity and Ecosystem Research, BAS, 23 Acad. G. Bonchev Str., 1113 Sofia, Bulgaria
[3]AgroBioInstitute, Agricultural Academy, 8 Dragan Tsankov Blvd., 1164 Sofia, Bulgaria

Received: 05 June 2016 Accepted: 26 July 2016

Abstract

In this article, new data on species diversity of hypogeous macrofungi in Bulgaria are reported. Three species: *Tuber rufum*, *Gautieria graveolens* and *Lactarius stephensii* were recorded for first time in the country. New localities of noteworthy fungi *Tuber excavatum* and *Gautieria morchelliformis* are also reported. A DNA sequencing for most studied hypogeous fungi and detailed phylogenetic analysis for *T. excavatum* were performed. Results confirmed that representatives of *T. excavatum* group have a very high intraspecific genetic variability.

Key words: ascomycetes, basidiomycetes, Bulgaria, fungal conservation, hypogeous fungi, phylogenetic analysis.

Introduction

Almost all of hypogeous macrofungi (ascomycetes and basidiomycetes) are ectomycorrhizal species, living in symbiotic relationship with roots of trees. Because of their cryptic, subterranean fruit bodies, they are often overlooked and neglected in different studies until now, when a rapidly development of molecular tools takes main part of scientific research. The design and construction of specific primers can be used as an easier and more sensitive tool for the identification of truffle species in any stage of their life cycle, including the mycorrhizal phase (Bertini et al. 1999).

Many hypogeous fungi, for instance truffles, are pioneer species. They are often reported in present studies as one of the main components of ectomycorrhizal associations in various forest ecosystems under particular ecological conditions (Benucci et al. 2011). Truffles generally grow in calcareous soils, but some of them are well adapted to slightly acidic soils (Jaillard et al. 2014, Pacioni and Comandini 1999). Most of them have a relatively wide plant partners range and also growing conditions and only a few number is restricted to particular ones.

The Balkan Peninsula and the western parts is still insufficiently explored regarding hypogeous fungi, including ’true‘ truffles of the genus *Tuber* (Gyosheva et al. 2012a, Marjanović et al. 2010, Dimitrova and Gyosheva 2008).

Geographic position of Bulgaria and

respectively the great diversity of ecological conditions let to assume that the large number of hypogeous ectomycorrhizal fungi could be found in the country. We can expect slightly genotype difference for some known species because of particular conditions in a process of adaptation to their plant partners.

Eleven hypogeous ascomycetes (truffles and truffles-like fungi) have been published until now from Bulgaria: *Choiromyces meandriformis* Vittad., *Elaphomyces granulatus* Fr., *Hydnotrya cerebriformis* Harkn., *H. tulasnei* (Berk.) Berk. & Broome, *Stephensia bombycina* (Vittad.) Tul., *Tuber aestivum* Vittad., *T. brumale* Vittad., *T. borchii* Vittad., *T. excavatum* Vittad., *T. macrosporum* Vittad., *T. puberulum* Berk. & Broome (Dimitrova and Gyosheva 2008, 2009; Gyosheva et al. 2012a,b; Lacheva 2012; Peev et al. 2015).

There is a great species diversity of larger basidiomycetes in Bulgaria and up-to-date more than 1500 species are recorded (Denchev and Assyov 2010). Some of them from genera *Gautieria* Vittad., *Hymenogaster* Vittad., *Macowanites* Kalchbr., *Melanogaster* Corda, *Octaviania* Vittad. and *Rhizopogon* Fr. are hypogeous and ectomycorrhizal.

Hypogeous macrofungi are with high conservation value. Ten species (5 ascomycetes and 5 basidiomycetes) were included in the Red List of Fungi in Bulgaria (Gyosheva et al. 2006) and also in the Red Data Book of the Republic of Bulgaria (Peev et al. 2015). All species are from categories Critically Endangered (CR) – 1 and Endangered (EN) – 9.

This paper presents three species of hypogeous fungi: *Tuber rufum* Picco, *Gautieria graveolens* Vittad. and *Lactarius stephensii* (Berk.) Verbeken and Walleyn, recorded for first time in Bulgaria. New data for the distribution of *Tuber excavatum* and *Gautieria morchelliformis* Vittad are also presented. Most of fungal specimens are DNA sequenced. Phylogenetic analyses have been done for *T. excavatum* and *T. fulgens* Quél. Recent molecular studies have shed some light on complex diversity among closely related *Tuber taxa.* Molecular and phylogenetic studies on well-known species *T. excavatum* are insufficient until now (Alvarado et al. 2012; Bonito et al. 2010a,b,c; Zampieri et al. 2009; Chen and Liu 2007; Wang et al. 2006, etc.).

Materials and Methods

The investigated specimens were harvested in several localities in Bulgaria in 2014–2015. Some information concerning their habitats was recorded – habitat type, nearby trees, soil structure and type (where data are available). One permanent plot (3×3 m) in the area near Gradets village was chosen on a productive site for periodical observation and ecological studies (at least 1 time per month from September to April).

Morphological observation of main character features of fungal specimens was studied on fresh specimens using Carl Zeiss Jena Citoval stereo microscope. Micromorphological characters were observed under Amplival, Leitz Laborlux Phase-contrast microscope and Zeiss light microscope. As mounting medium deionized water was used. For better observation and for important diagnosing chemical reactions some colorizing reagents were used – KOH, Congo Red in ammonia solution, Cotton Blue in lactophenol, and Melzer’s reagent. The microphotographs were taken by AmScope MA1000, 10 MP× camera. Measurement of asci, spores and peridium were performed by Piximetre 5.8 software (http://ach.log.free.fr/Piximetre/).

Scanning electron microscopy (SEM) was carried out at the Institute of Physical Chemistry, Bulgarian Academy of Sciences. Specimens were examined on JSM-5510 scanning electron microscope at 10 kV.

All studied specimens are kept at the Mycological Collection of the Institute of Biodiversity and Ecosystem Research, Bulgarian Academy of Sciences, Sofia (SOMF).

The nomenclature of hypogeous fungi follows Kirk et al. (2001). The author's abbreviations of fungi are according to Kirk and Ansell (2004). Hypogeous fungi were identified following Riousset et al. (2012), Dissing (2000), Montecchi and Sarasini (2000), Montecchi and Lazzari (1993), Pegler et al. (1993), Breitenbach and Kränzlin (1984), Trappe (1979), Dennis (1978) and Moser (1963). The threat status follows the Red List of Fungi in Bulgaria (Gyosheva et al. 2006).

For DNA analysis was used only properly dried material (5–6 h, 55–60 °C) stored in freezer at – 20 °C. For DNA extraction, was followed and modified Dellaporta et al. (1983) protocol for plant tissue isolation. PCR amplification was performed with the primers ITS1 and ITS4 (White et al. 1990, Gardes and Bruns 1993) for the ITS regions. After gel-electrophoresis, successful DNA fragments were visualized and cleaned using GeneMATRIX Basic DNA Purification Kit. Samples were sequenced at GATC biotech laboratory in Germany.

The results were compared with their closest relatives obtained with BLAST algorithm. Phylograms are constructed for *T. excavatum* and *T. fulgens*. Sequences were first aligned in CLC Genomics workbench 8.0 and then corrected manually. Dendrogram was constructed and analyzed for best fit model – lowest-scoring maximum likelihood tree. To obtain this, several tests were used: hierarchical likelihood ratio test (hLRT), BIC test (Bayesian information criterion) – $BIC = -2\ln(L) + K\ln(n)$, where $\ln(L)$ = loglikelihood of the best tree found, K = number of parameters and AIC Model test – $AIC = -2\ln(L)+2K$, where $\ln(L)$ = loglikelihood of the best tree found and K = number of parameters.

Results and Discussion

New records of hypogeous macrofungi for Bulgaria

Ascomycota
Pezizales
Tuberaceae

Tuber rufum Picco, Meleth. Bot.: 80 (1788)

Ascomata hypogeous or semihypogeous, irregular, lobed and very rare subglobose (Fig. 1a), 1.5–4 cm in diameter, yellow-brown to reddish-brown, fine warted and areolate, cartilaginous. Warts are fine and almost pyramidal. **Peridium** is very thick (380–480 μm) and two layers can be distinguished – outer, which is composed by 3–5 rows of thick-walled large hyphae and inner layer, which is paler and almost white, forming pseudoparenchymatous tissue (Fig. 1b). **Gleba** of interwoven to parallel hyphae is more loosely structured than the inner layer of peridium, hard and solid, initially whitish, than yellowish, ochre to olive-brown or olive-gray at maturity, with a close network of whitish meandering and translucent veins. **Odor:** relatively strong, not specific and unpleasant. **Taste** is mild. **Asci** 50–70 × 80–100 μm, clavate to almost globose (depending of spore position and view – Fig. 1d), short-stalked

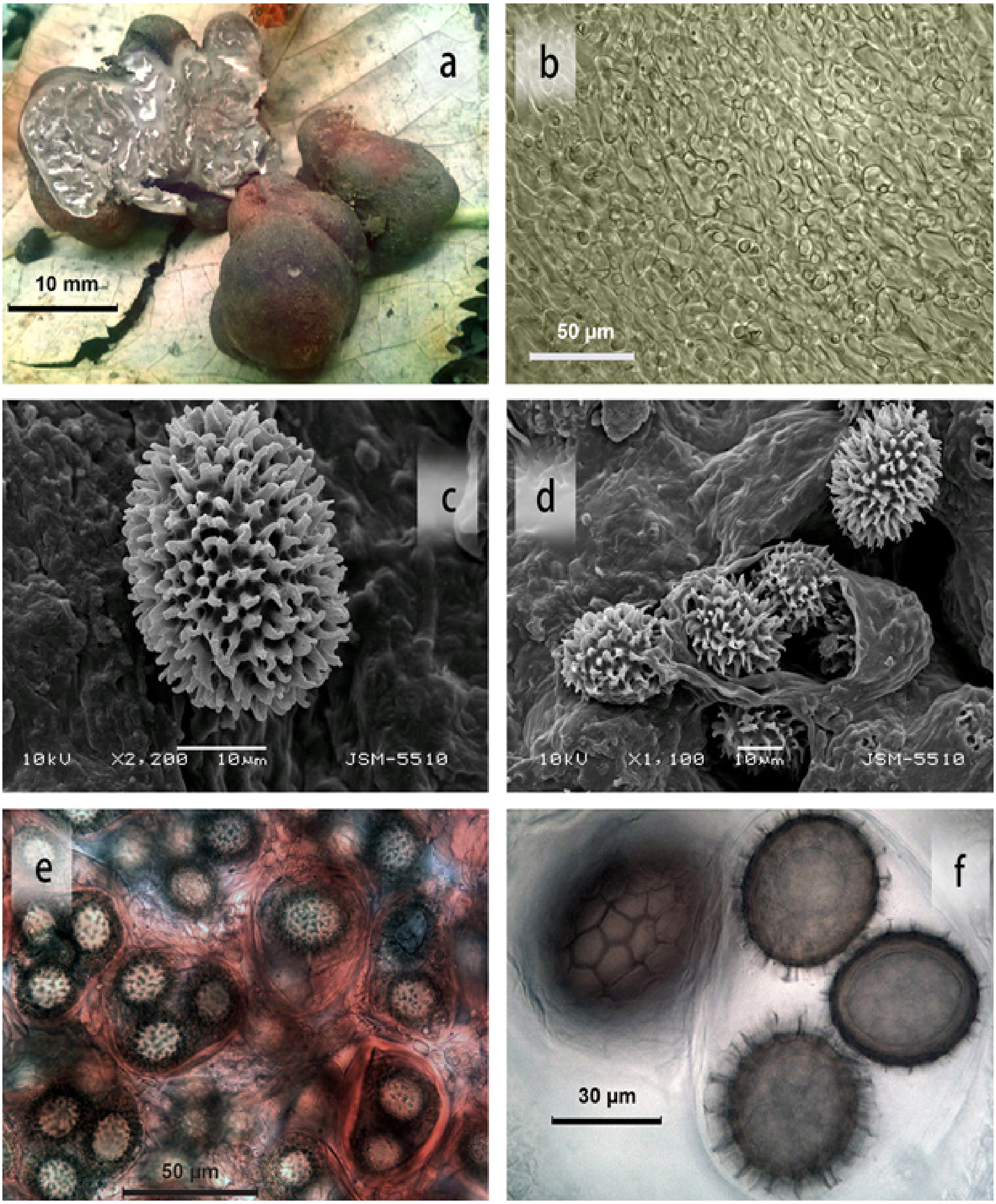

Fig. 1. ***Tuber rufum*** **(BG13AG10): a – general view; b – inner layer of pseudoparenchymatous tissue of peridium in Melzer's reagent; c– SEM detail view of spore; d – SEM general view; e – asci with ascospores in Congo red; f –** ***Tuber excavatum*** **(BG13AG06) – ascospores.**

(10–25 µm) (Fig. 1e), usually 3–4-spored. **Ascospores** 27.1 [32.9; 34.8] 40.7 × 20.2 [24.6; 26.1] 30.5 µm; Q = 1.0 [1.3; 1.4] 1.6; N = 50; C = 95 % M_e = 33.9 × 25.4 µm; Q_e = 1.3, broadly ellipsoid, ornamented with conical spines (Fig. 1c), 2.5–3.5 µm high, initially translucent, yellow – ochre tobrownish at maturity (Fig. 1e).

Habitat. This species is relatively widespread associated with deciduous trees and conifers, ascomata maturing during late summer and autumn (Pegler et al. 1993).

Specimens examined. Western Forebalkan, near Belotintsi village, buried in humus layer of soil, partially on the surface, near *Tilia tomentosa* Moench artificial plantation, 14.09.2014, leg. T. Nedelin, det. M. Gyosheva (SOMF 29671; BG13AG10).

Comments. Although there are several species with similar features, according to Pegler et al. (1993) main differences in close related ones can be observed in type and colour of peridium, its cell organization and structure, also in consistency of gleba. *T. rufum* was also reported recently from Turkey (Türkoğlu and Castellano 2014). Due to its high intraspecific variability a set of specific primers were developed – Ru1f/Ru2f-ITS4 (Iotti et al. 2007). Our result of DNA sequencing matches 100 % for this species in GenBank, with standard fungal primers – ITS1/ITS4, but using specific primers is recommended, because the detection can be more sensitive and it is possible for only 0.2 mg of this truffle to be identified successfully. It is especially important when mycorrhizal tips are used, instead of fungal tissue from ascoma. According to the same authors *Tuber ferrugineum* Vittad. is a morphological form of *T. rufum* characterized by a rusty coloured peridium and spores with long spiny ornamentations.

Basidiomycota
Gomphales
Gomphaceae

Gautieria graveolens Vittad., Monographia Tuberacearum (Milano), p. 27, 1831.

Basidiomata hypogeous or semi-hypogeous, irregularly subglobose, often wrinkled, with small depressions, 2–4 cm in diameter, ochre to reddish-brown. At the base with whitish mycelial tuft of strands (hyphae). **Peridium** is thin (220–330 μm – Fig. 2a) and can be seen only in immature stage and through the development disappear. **Gleba** with a labyrinthine-like elongate or near roundish cavities, situated near ochre, reddish – brown or grayish branches which often enlarge toward the base and forming white or whitish **columella**. **Odor** very strong and unpleasant. **Taste** undefined. **Basidia** 13–20 × 8–10 μm, broadly clavate, usually 2-spored (rare 4-spored). **Cystidia** clavate and hyaline. **Basidiospores** 16–19 × 11.5–13 μm, Q range = 1.3–1.6, broadly ellipsoid, brownish at maturity. **Spore** ribs are smooth and apiculus is rounded (Fig. 2c).

Habitat. In soil, in coniferous and deciduous forests (mainly under oak), from late summer to late autumn.

Specimens examined. Tracian Lowland, near Haskovo town, in the Park 'Kenana', buried in organic layer of soil, under *Quercus* sp., 14.09.2014, leg. T. Chokova and E. Nankova, det. M. Gyosheva (SOMF 29672; BG13AG07).

Comments. *G. graveolens* was recorded in Greece in forests of *Quercus frainetto* Ten. (Konstantinides 2006). It is also reported from some other European countries and also from North America (Benedek and Pál-Fám 2001, Zeller and Dodge 1918, etc.). There is insufficient data of exact host range of tree species forming ectomycorrhiza with this hypogeous fungus. It can be easily recognized from *Gautieria morchelliformis* (Fig. 2b) by its smaller spores and clear visible peridium in early stages of development.

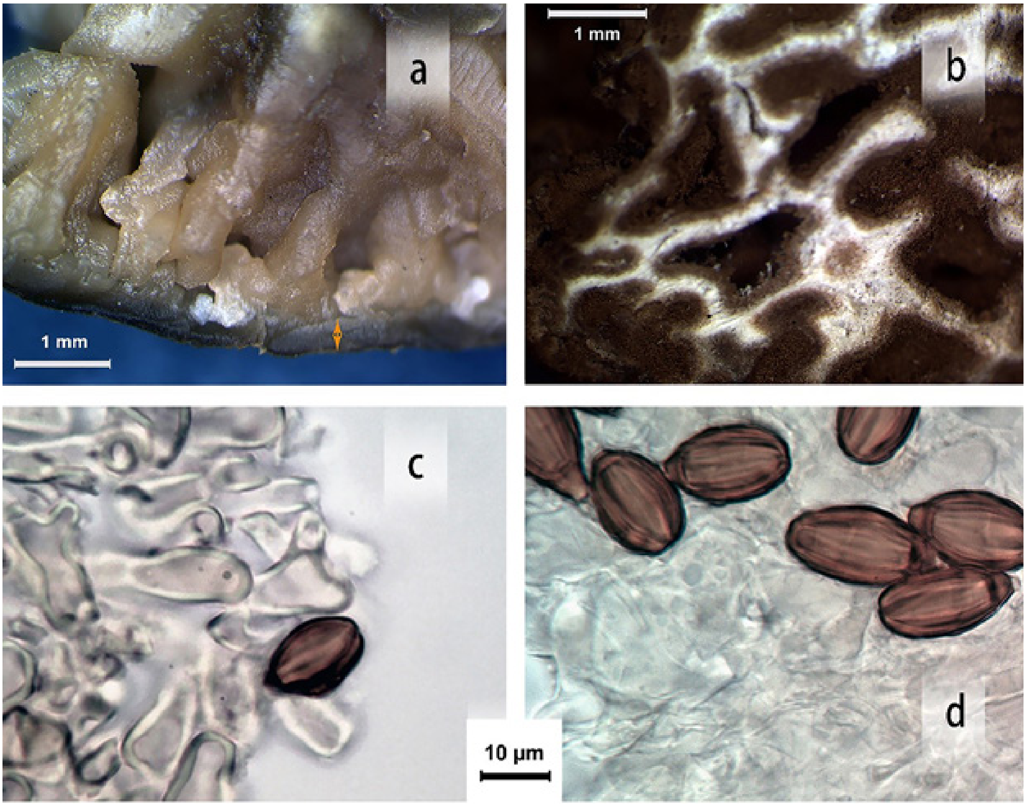

Fig. 2. ***Gautieria graveolens*****: a – immature fruitbody with clear visible peridium (orange arrows); b – section view of *Gautieria morchelliformis*; c – *Gautieria graveolens* – spore and paraphyses; d – *Gautieria morchelliformis* – spores.**

Russulales

Russulaceae

Lactarius stephensii (Berk.) Verbeken & Walleyn, in Nuytinck, Verbaken, Delarue & Walleyn, Belg. Jl Bot. 136 (2): 151 (2004) [2003]

Basidiomata hypogeous or semihypogeous 1.0–2.5 cm in diameter (Fig. 3a), mostly irregular or subglobose, lobbed with distinctive radial ridges at the base, together with thin, mycelial cords arising from a minutely projecting sterile base. **Peridium** at first pale ochraceous to orange-red, finally darkreddish-brown, dull, smooth, viscid, easily detached – 150–200 µm total, two layers – 50–80 µm of peridiopellis (Fig. 3b). **Gleba** whitish to pale orange or pinkish, discoloring reddish on exposure after cutting, labyrinthic, with irregularly elongated chambers (Fig. 3c). **Columella** cannot be seen. **Odour** very strong, specific, fruity. **Taste** very strong, fruity, and specific, even in dry specimens. **Basidia** broadly clavate to almost globose, short-stalked, with 3–4-spores. **Basidiospores** 10.91 [12.20; 12.56] 13.84 × 10.37 [11.36; 11.64] 12.62 µm; Q = 0.97 [1.06; 1.09] 1.18; N = 64; C = 95 %; M_e = 2.38 × 11.50 µm; Q_e = 1.08 (excluding ornaments) (Figures 3d, e), globular, ornamented with conical spines rounded apically with length 1.2–1.8–(2.2)

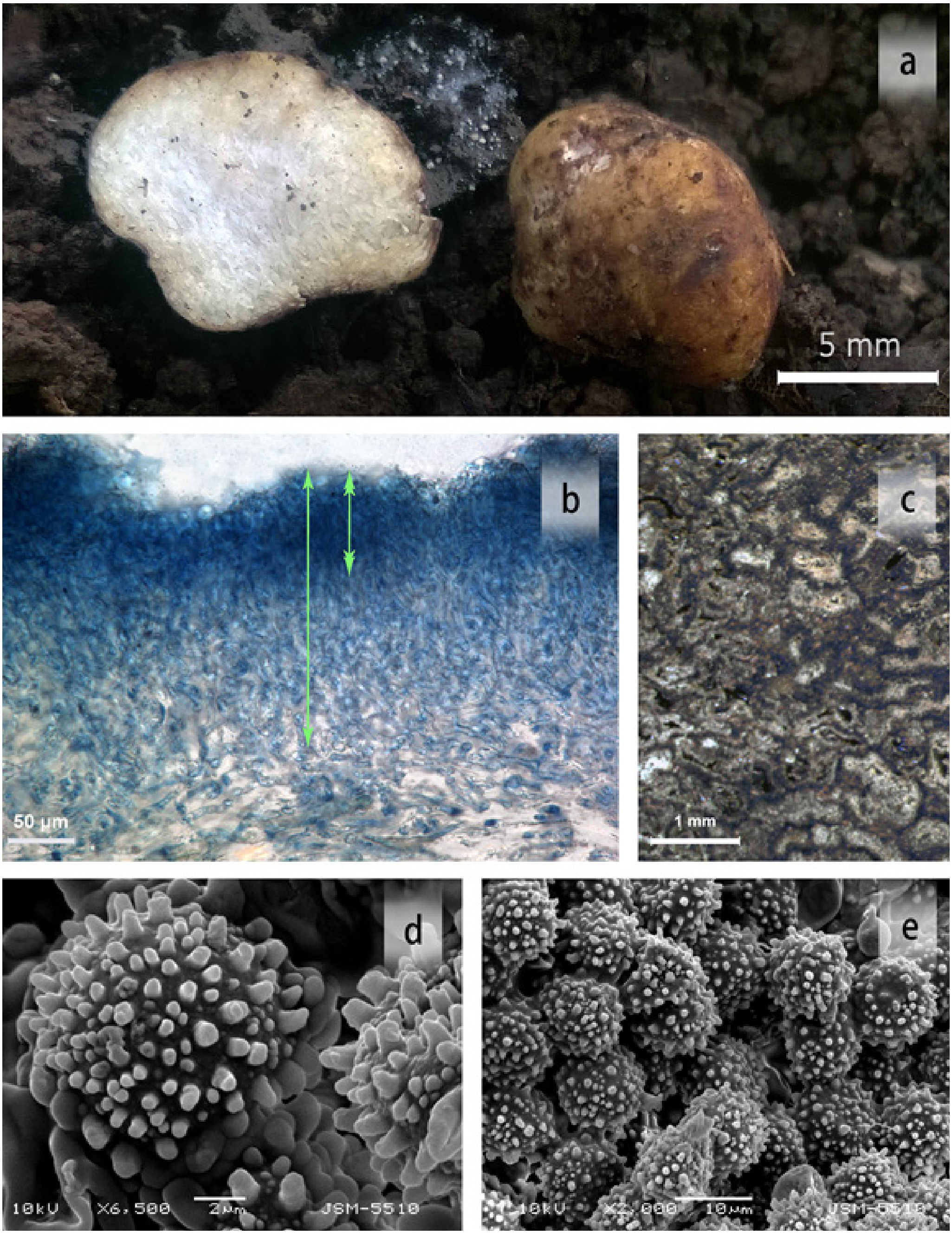

Fig. 3. ***Lactarius stephensii*** **(BG13AG08): a – general view; b – two layers of peridium (green arrows) – outer is with doubled green arrows (≈80 µm); c – detail section view of mature fruit body; d, e – SEM of spores at different magnifications.**

µm, initially translucent, yellow-ochre to brownish at maturity.

Habitat. Usually gregarious, under humus, with ectomycorrhizal hosts from genera *Corylus* L., *Carpinus* L., *Fagus* L., *Populus* L., *Quercus* L., *Tília* L. (Vidal 2004).

Specimens examined. Western Balkan Mts., near Gradets village, buried in organic layer of soil, near *Carpinus betulus* L., 03.09.2014, leg. & det. T. Nedelin (SOMF 29673; BG13AG08).

Comments. Two genera of sequestrate fungi related with genus *Lactarius* Pers. are well recognized presently: *Arcangeliella* Cavara and *Zelleromyces* Singer et A. H. Sm. First of both is secotioid and contrarily, *Zelleromyces* is nonsecotioid and sessile. In Europe only 6 species from second are known (Vidal 2004).

New localities of hypogeous fungi in Bulgaria

Ascomycota

Tuber excavatum Vittad.

Specimens examined: BG13AG05 – Northeast Bulgaria, near Razgrad town, buried in organic layer of soil (1–5 cm under litter), near *T. tomentosa* artificial plantation, 13.11. 2013, leg. K. Kyose, det. T. Nedelin (SOMF 29674); BG13AG06 – Western Stara Planina Mts., near Gradets village, buried in organic layer of soil (1–5 cm under litter), near *Carpinus orientalis* Mill., 30.10.2014, leg. &. det. T. Nedelin (SOMF 29675).

The species was reported previously in Bulgaria also from Northeast Bulgaria – Razgrad Hills (Dimitrova and Gyosheva 2008) and from Western Rhodopes Mts., near Ravnogor village (Lacheva 2012).

Comments. *T. excavatum* group is well recognized from other truffles because of their usually well-developed basal cavities. This group seems to have a great intraspecific diversity and a dozen of varieties, subspecies and forms were described (Riousset et al. 2012, Gross 1991). For instance the colour of peridium in *monticellianum* form is olive brown. Fischer (1923) distinguishes varieties with small spores (*brevisporum*) and other with larger spores (*longisporum*). Most species have been shown a very close intraspecific ITS to interspecific ITS sequence variation and sometimes overlapped gaps can be recognized (Bonito et al. 2010c). Thus requires comprehensively morphological and phylogenetic studies, especially in case, where degree of variability between examined specimens is higher and there are significant differences in ecological aspects (host plant and period of maturing in respect to geographical latitude). Several samples from each *T. excavatum* locality were compared and macro- and micro-morphologically studied, and were found some slightly distinct features. BG13AG05 has more wrinkled surface (Fig. 4a) and paler colours in the peridium, also its basal cavities are narrowed (Fig. 4c). In BG13AG06 the basal cavities are enlarged, especially in young stage of development (figures 4b and 4d). It has finely papillose peridium, contrary to BG13AG05 which peridium is generally smooth. The colour of its gleba is dark purple to pinkish purple and dark purple to purple brown in BG13AG06 (Fig. 4d), without pink tints in the last. Asci have no significant differences in their morphology or size, but spore ratio (Q) for Razgrad samples is 1.0 [1.2; 1.3] 1.4 (Fig. 4e) and respectively for Gradets village samples – 1.2 [1.4] 1.6 (Figures 1f and 4f). Both specimens (BG13AG05, BG13AG06)

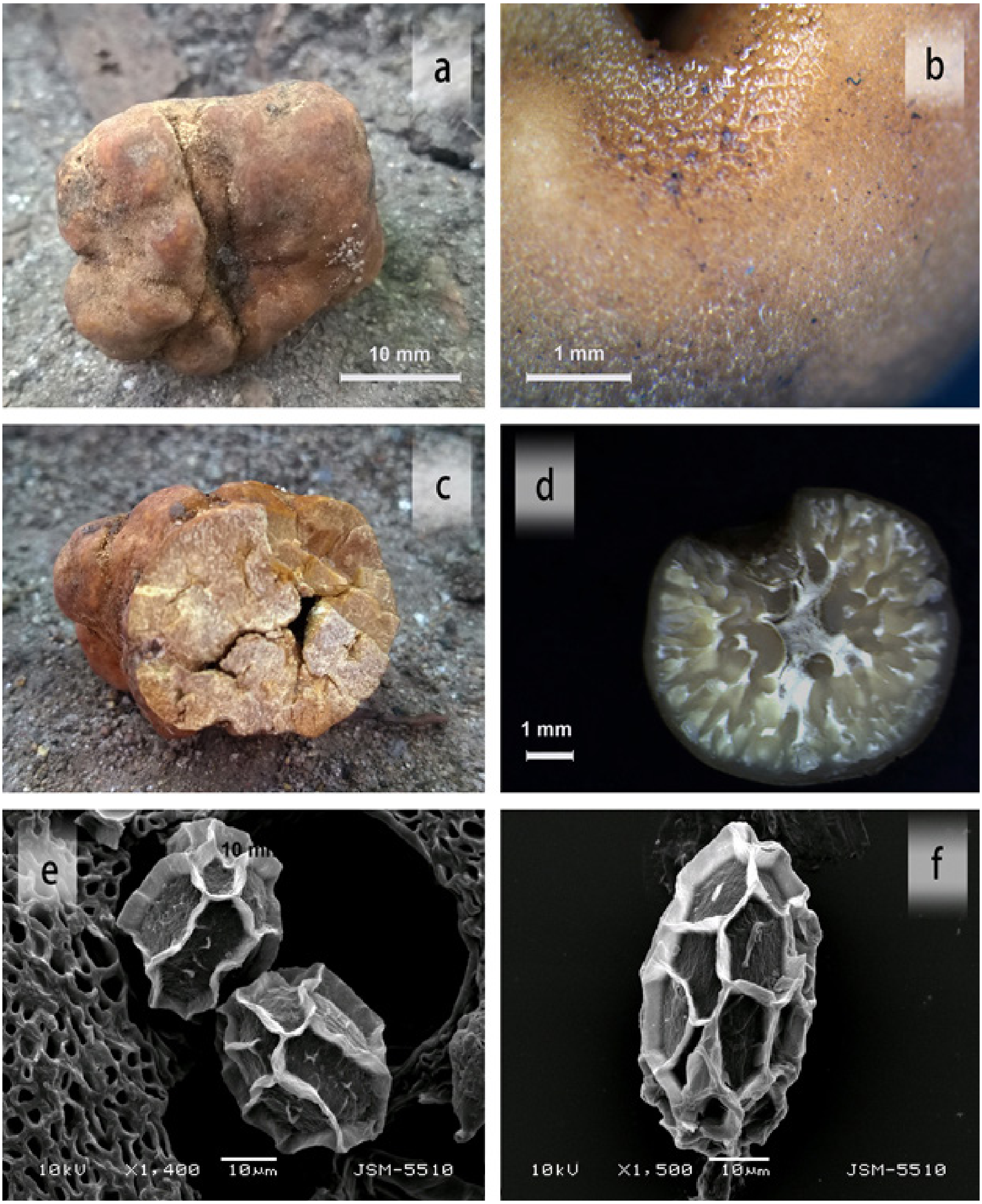

Fig. 4. *Tuber excavatum*: a – general view (BG13AG05); b – detailed view of peridium BG13AG06); c – section (BG13AG05), d – section (BG13AG06); e – SEM, BG13AG05; f – SEM, BG13AG06.

have different tree hosts and there is a great possibility that this might be the most important factor in addition to soil structures, type and climate condition for the ecological plasticity of *T. excavatum* group.

Basidiomycota

Gautieria morchelliformis Vittad.
(Fig. 2d).

Specimens examined. Western Stara Planina Mts., above the village of Buhovo, semihypogeous in soil, near *Quercus* sp., 25.11.2014, leg. A. Goranov, det. M. Gyosheva (SOMF 29677).

This species was reported only once for Bulgaria from Southern Black Sea coast – Ropotamo Reserve (Kuthan and Kotlaba 1981). It is also found in Greece, under *Quercus ilex* L. (Konstantinides 2006) and in forests of *Pinus nigra* Arn. (Diamandis and Perlerou 2008).

Results from DNA analysis

According to various authors (Rioussett et al. 2012, Montecchi and Sarasini 2000, Pengler et al. 1993) the closest taxonomically species to *T. excavatum* is *T. fulgens*, which differs from it for its brighter, orange-brown colour and its subglobous spores. The phylogram on Fig. 5 is constructed for most *T. excavatum* and *T. fulgens* samples in the GenBank, compared with their identical ITS regions. It was obtained in CLC Genomic Benchmark 8.0 after (computer and then manual) alignments analysis of parallel ITS sequences after several tests for construction of best tree model.

Two major clades clearly emerge with several subgroups amongst them, which can be distinguished also without molecular studies. It was found that in the first group intraspecific variation is slightly below 6 % and in the second slightly above 12 %. This corresponds within the borders accepted by Bonito et al. (2010a) – for intraspecific variation <14.7 % and interspecific variation >9.2 %. *T. excavatum* is the only species from their study, which shows lower interspecific to intraspecific variation and overlaps and we confirm this.

T. excavatum samples from Gradets village are genetically closer to *T. fulgens* than to *T. excavatum* group I. The comparison of BG13AG05 and BG13AG06 is shown in Fig. 6. More symmetric lines correspond to more similarity in their nucleotide basis.

Conclusion

The data of carried out morphological and molecular studies of *Tuber excavatum* samples confirmed the great genetic variability amongst this group. Using specific primers, especially for the group of white truffles, would bring further clarity in their diversity. The dramatic and constant decrease of whole genome sequencing cost price since 2008 (from 100 million USD in 2001 to 1000 USD in 2015 at Illumina HiSeq X10) and establishment of the Next-Gen Sequencers (Bahassi and Stambrook 2014) will make direct sequencing of the entire genome in near future more accessible – up-to-date the most reliable method to determine species. All this, however, must be accompanied by the most possible detailed morphological, anatomical, physiological and other studies of hypogeous fungi from different habitats to determine borders of their ecological plasticity.

All reported hypogeous fungi in the paper are uncommon or threatened in Europe and should be estimated according to IUCN criteria at the next update of Red List of Fungi in Bulgaria.

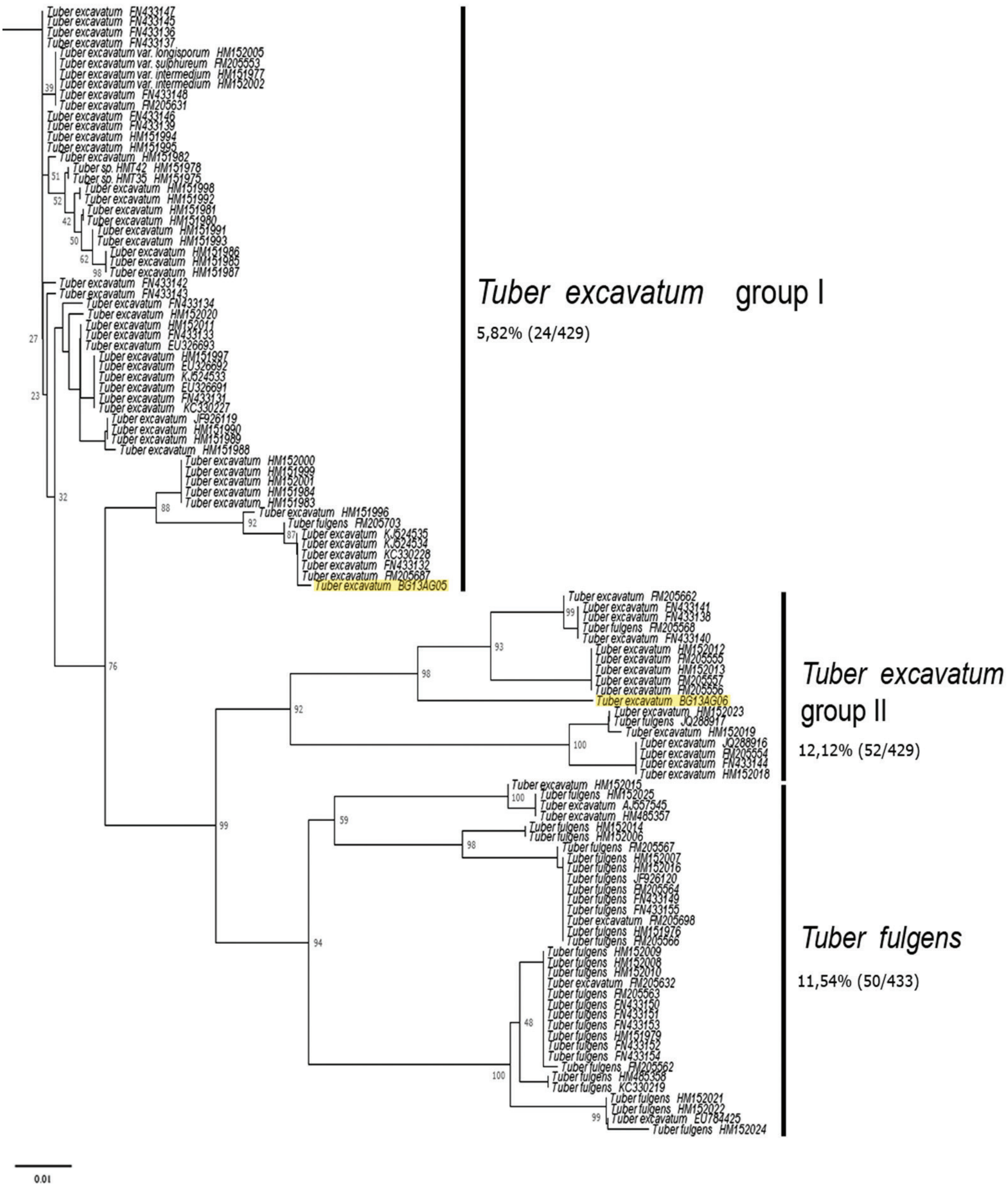

Fig. 5. Phylogenetic tree of *Tuber excavatum* and *Tuber fulgens* specimens from public database.

Acknowledgements

This work was supported by the Swiss Enlargement Contribution in the framework of the Bulgarian-Swiss Research Programme, project IZEBZO_143109. The work of M. Gyosheva is carried out within the framework of the project

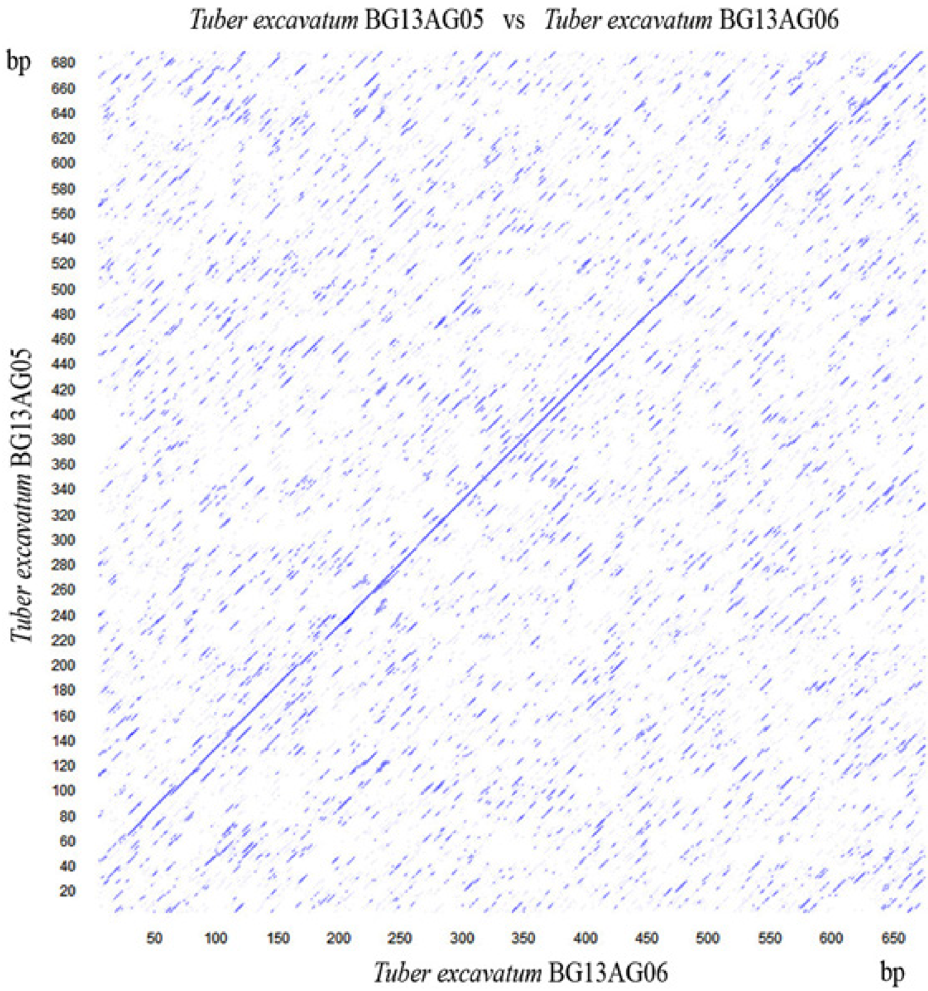

Fig. 6. Dot-plot diagram of both Bulgarian *Tuber excavatum* specimens (BG13AG05, BG13AG06).

'Taxonomy, conservation and sustainable use of fungi'.

The authors would like to thank Prof. G. Pacioni and Assoc. Prof. S. Slavov for their valuable advices during the preparation of this manuscript.

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FORESTRY IDEAS, 2016, vol. 22, No 2 (52): 127–136

DIVERSITY OF PTERIDOPHYTES IN THE SURROUNDINGS AND DAM SUBMERGENCE AREAS OF HYDROELECTRIC PROJECTS IN KULLU DISTRICT OF HIMACHAL PRADESH, INDIAN HIMALAYA

Pankaj Sharma[1*] and Sher Singh Samant[2]

[1]Himachal Pradesh State Biodiversity Board, H. P. State Council for Science, Technology & Environment, 34, SDA Complex, Kasumpti, Shimla-171009, Himachal Pradesh, India.
*E-mail: spankaj80@gmail.com
[2]G.B. Pant Institute of Himalayan Environment and Development, Himachal Unit, Mohal-Kullu-175126, Himachal Pradesh, India

Received: 04 May 2016 Accepted: 02 August 2016

Abstract

The Himalayan Region in India is very unique and globally known for its unique topography, large altitudinal range, climate and diverse habitats. The pteridophytes are important from evolutionary point of view, as they show the evolution of vascular system and reflect the emergence of seed habitat in the plants. Due to rich biodiversity of Himachal Pradesh, the pteridophytic flora is also interesting in its diversity and distribution, however, little is worked out on the economic aspects of these plants. Therefore, present communication pertains to the diversity of ferns in the surroundings and dam submergence areas of three hydroelectric projects of Himachal Pradesh. Overall, 63 species of pteridophytes, belonging to 15 families and 29 genera, were recorded. Maximum species (56 spp.) were found in forest habitat, followed by riverine/watercourse (48 spp.), shadymoist (42 spp.), bouldary (21 spp.), dry (17 spp.), degraded (12 spp.), submergence area (12 spp.), landslide and near crop field/orchards (4 spp. each), waste place/road side (1 sp.). Large scale deforestation and increasing anthropogenic activities have caused elimination of the habitats, which is posing a serious threat to the pteridophytes of the Himalayan region. Several conservation measures and management programmes have been taken up in various regions for the angiosperms, but very little attention has been given to the conservation of pteridophytes. Therefore, it is important to formulate and implement a detailed scientific study with aim of conservation of pteridophytes to ensure their long term conservation.

Key words: distribution, diversity, ferns, habitat, Himachal Pradesh, hydroelectric project.

Introduction

The Himalayan Region, one among the 34 global biodiversity hotspots, is the richest source of biological diversity and very well known for its unique topography, valleys and hills, climate, large altitudinal range, diverse habitats and network of rivers and streams (Sharma 2013). These unique features of the Himalaya support diverse species, communities and ecosystems (Samant et al. 1998, Singh 2006). The Indian Himalayan Region (IHR) includes about 8,000 species of angiosperms

(40 % endemic), 44 species of gymnosperms (16 % endemic), 600 species of pteridophytes (25 % endemics), 1737 species of bryophytes (33 % endemic), 1,159 species of lichens (11 % endemic) and 6,900 species of fungi (27 % endemic) (Singh and Hajra 1996, Samant et al. 1998, Sharma et al. 2014). In addition to these, it is also a rich repository of pteridophytic plant wealth. The pteridophytes form a conspicuous element of the Earth's vegetation and are important from evolutionary point of view as they show the evolution of vascular system and reflect the emergence of seed habitat in the plants (Das and Nath 2012). About 250 million years ago, they formed the dominant part of Earth's vegetation, but in the current scenario, flora has been largely replaced by the seed bearing plants. About 12,000 species of pteridophytes occur in the world flora of which more than 1000 species are distributed in different biogeographical regions of India with the main centers of the Himalayas. They are widely distributed to the wetter parts of the country, but are much less common, or even absent from very dry or severely cold regions (Benniamin 2012). They occur in abundance in tropical, subtropical, temperate and moist-deciduous forests of India and their life cycle is based on the existence of the forests. However, large scale deforestation and increasing anthropogenic factors have caused the elimination of the habitats, which is posing a serious threat to the pteridophytes of the Himalayan region. In the recent years, though the pteridological studies have picked up in various parts of the country, many questions regarding the pteridophytic wealth of the North Western remain unanswered and hence, more studies are required for developing *in situ* and *ex situ* conservation strategies for this wonderful and important group of plants.

Himachal Pradesh (30°22′40" to 33°12′40" N latitudes and 75°45′55" to 79°04′20" E longitudes, area 55,673 km^2), one of the states of IHR, covers parts of Trans and North West Himalaya (10.54 % of the Himalayan landmass). Of the total geographical area, 66.45 % is under forests and of the total forest, 20.45 % area is under protected area network and 3.41 % area under reserve forests. The state is represented by tropical, temperate, sub-alpine and alpine vegetation (Samant et al. 2007). It supports 32 wildlife sanctuaries; 02 national parks and 01 recently notified cold desert biosphere reserve (CDBR) (Samant et al. 2012). The vegetation comprises of sub-tropical, temperate, sub-alpine and alpine types and supports a representative, natural, unique and ecologically and economically important biodiversity. Like other states, the peteridophytic diversity of the Himachal Pradesh is facing tremendous pressure due to anthropogenic activities, such as construction of roads, hydroelectric projects, industrialization, urbanization, etc. The constructions of hydroelectric projects have caused a great loss of peteridophytic diversity, inspite of the environmental management plans (EMP) and catchment treatment plans (CAT). Therefore, the present attempt has been made to assess the pteridophytic diversity of three hydroelectric projects i.e., Sainj, Parbati Stage II and Malana II, so that information on pteridophytic diversity of hydro-electric projects areas in Kullu district of Himachal Pradesh could be obtained.

Material and Methods

Study area

The present study has been conducted in Sainj (100 MW), Parbati Stage II (800 MW) and Malana II (100 MW) hydro-electric projects in Kullu district of Himachal Pradesh. The study areas fall in Kullu district (31°25' to 32°35' N Latitudes and 76°09' to 77°09' E Longitudes) of Himachal Pradesh. The Kullu district is bounded by Lahaul-Spiti and Kangra districts on north and north-east, Kinnaur and Shimla districts on its east and south-east. It is one of the richest districts in terms of biodiversity and supports one national park (i.e., Great Himalayan National Park) and six wildlife sanctuaries (i.e., Manali, Kanawar, Khokhan, Kais, Sainj and Tirthan) (Singh et al. 1990). The study areas are approximately 25–75 km from the district headquarters, Kullu. The areas fall under the Seraj Forest Division and Parbati Forest Division. These areas are very well known for their diverse habitats, microclimatic conditions and rich biodiversity including flora and fauna. These project areas are mainly inhabited by Raila, Suind, Niharni, Neuli, Sangad, Sainj, Barsaini, Garsha, Manhiar, Majhan, Barsaini, Tosh, Pulga, Tulga, Kalga, Rasol and Malana villages. The inhabitants of the area largely depend on the forests for wild edibles, medicinal plants, fuel, fodder, timber, making agricultural tools, fiber, religious, livestock grazing and various other purposes.

Geology and pedology

The study areas fall within the Lesser Himalayan ranges characterized by rugged topography of the northwest Himalaya. The different hydroelectric project areas are in the geological domain of the Larji Rampur tectonic window zone. This window zone exposes two granitoid complex bodies, the Bandal granitoid gneiss in the northwest and the Jeori-Wangtu granitoid gneiss in the southwest. The Bandal granitoid gneiss is considered equivalent to the Jeori-Wangtu gneiss complex in tectonic position, lithology, and chronology of rocks. The Bandal gneiss complex, spread over 500 km^2, is exposed in Garsha valley in the northwest to the Sainj valley in southeast, where it has reportedly been enveloped by the Manikaran quartzite. The Bandal granitoid gneiss with litho trend along the north-northwest-south-southeast comprises porphyroclastic, as well as medium-to coarse-grained gneiss, and mylonitic gneiss. The Rampur group presents an association of metabasalts and metasediments (Sharma 2008). The major part of the study areas is constituted by Khokhan Formation of the Kullu Group. The Khokhan Formation comprises of mainly quartzites, quartz schists, quartz chlorite and quartz biotite schists, slates, phyllites and garnetiferous schists. Locally, amphibolites appear associated with the metasediments. The other formations of the Kullu group exposed in the study area are Gahr and Khamrada Formations. Gahr Formation is characterized in the area by streaky and banded gneisses, while Khamrada Formation is characterized by carbonaceous slates, phyllite, quartzite and lenticular limestone (Srikantia and Bhargava 1998).

Climate

With increase or decrease in altitude the climate of the region varies to a greater extent. The climate of the study areas is typically sub-tropical, temperate, sub-alpine and alpine types, and consists of mainly four distinct seasons; summer (April–July), rainy (August–September), autumn (Oct–Nov) and winter season (Dec–March). The higher reaches of Malana, Tosh, Sainsar, Sangad, Majhan and Manhihar villages are snow covered during the winter season. From climatic point of view the area is unique. Temperature ranged between -2 °C to 39 °C in the study area during the study period. Average annual rainfall was about 878, 836, 805 and 783 mm/year in 2008, 2009, 2010 and 2011, respectively. Average maximum temperature was recorded in monsoon (23 °C) and summer (23 °C), minimum in winter (11 °C), whereas relative humidity was maximal in monsoon (77 %) and minimal in winter (58 %). Frequent snowfall during winter occurs from December to March (Sharma 2013, Sharma and Samant 2016).

Survey, sampling and identification of the species

Frequent surveys were conducted seasonwise during 2008 to 2012 in and around three hydroelectric project areas, i.e. Sainj, altitude ranges from 1400 to 2600 m a.s.l., Parbati Stage II, altitude ranges from 1300 to 2600 m a.s.l. and Malana II, altitude ranges from 1800 to 3400 m a.s.l.. Sainj, Barsaini, Gadsa and Malana areas were thoroughly explored. The rapid sampling was done for the pteridophytic diversity inventory. The habitats were identified based on the physical characters and dominance of the vegetation. The sites facing high anthropogenic pressure were considered degraded habitats and sites having closed canopy with high percent of humus and moisture were considered moist habitat, whereas low percent of the same as dry habitat. The sites having >50 % boulders of the ground cover were considered bouldery habitat. Samples of each species were collected, information on altitudinal range, habitat/s, occurrence, distribution, etc. was gathered. Species were identified with the help of flora (Chowdhery and Wadhwa 1984; Dhaliwal and Sharma 1999; Khullar 1994, 2000; Singh and Rawat 2000; Pande and Pande 2002, 2003).

Results

A total of 63 species (Sainj: 47; Parbati Satge II: 52; and Malana II: 45) of pteridophytes belonging to 15 families and 29 genera were recorded from different hydro-electric projects areas (Table 1). Dryopteridaceae (12 spp.); Athyriaceae (10 spp.); Polypodiaceae (9 spp.); Pteridaceae and Thelypteridaceae (5 spp., each); Adiantaceae and Aspleniaceae (4 spp., each); Hemionitidaceae and Sinopteridaceae (3 spp., each); Cryptogrammaceae and Equisetaceae (2 spp., each) were the dominant families; 4 families (Davalliaceae, Ophioglossaceae, Osmundaceae and Selaginaceae were monotypic (Fig. 1).

Table 1. Diversity, altitudinal range, habitat/s, occurrence and distribution of pteridophytes in three Hydroelectric Projects (HEPs) areas in Kullu district, Himachal Pradesh, India.

Taxa	Altitudinal Range, m	Habitats	Occurrence in HEPs	Distribution
Adiantaceae				
Adiantum capillus-veneris L.	2000–3400	1, 2, 3, 4, 6, 8	A, B, C	Europ Occ et Austr Afr As Temp Himal
A. edgeworthii Hk.	1300–2600	1, 4, 8	A, B, C	China Ind
A. lunulatum Burm.	1700–2500	1, 4, 8	A, B	Afr As Austr Polyn Trop Amer Centr

A. venustum D. Don	1700–3000	1, 2, 3, 4	A, B, C	Afghan Ind Bor
Aspleniaceae				
Asplenium dalhousiae Hk.	1300–2700	1, 2, 3, 5	A, B, C	Afghan Ind Kash Nepal Pakistan Afr
A. ensiforme Wall. ex Hk.	2000–2600	1, 2, 3	A, B, C	Ind Yun
A. varians Wall. ex Hk.	1600–3000	1, 3, 6	A, B, C	Japon China Ceyl Afr Austr Ins Hawaii
A. yoshinagae Mak.	2200–2600	1, 3, 5, 6	A	Japon As
Athyriaceae				
Athyrium anisopterum Christ.	1700–2600	1, 2, 3, 4, 5	A, B, C	As Merid
A. atkinsonii Bedd.	2200–2500	2, 3, 4, 5	B, C	Himal
A. attenuatum (Wall. ex Cl.) Tagawa	2000–3000	1, 2, 3, 5	A, B, C	Kash China
A. fimbriatum Moore	2100–3300	3, 4, 6	B, C	Himal Yun
A. rubricaule (Bl.) Moore	2000–3300	1, 2, 6	C	Kash China
A. rupicola (Edgew. ex Hope) C. Chr.	2300–2500	2, 3	B	Ind Bor
A. schimperi Moug. ex Fee	2000–2700	2, 3, 5	B, C	Abys Ind Bor
Diplazium esculentum (Retz.) Sw.	1300–2700	1, 2, 3, 5	A, B, C	As Temp As Trop
D. spectabile (Wall. ex Mett.) Ching	1600–2500	2, 3, 5, 8	B	Yunn Ind Nepal
Lunathyrium allantodioides (Bedd.) Ching	1700–3400	1, 6, 9	A, B, C	As
Cryptogrammaceae				
Onychium contiguum Wall. ex Hope	1500–2700	1, 2, 3, 4, 5, 8, 9	A, B, C	As
O. fragile Verma et Khullar	1600–2500	1, 3, 7	A, B	Himal
Davalliaceae				
Araiostegia beddomei Hope	2200–3400	1, 4, 6	A, B, C	Ind Bor
Dryopteridaceae				
Cyrtomium caryotideum (Wall. ex Hk. & Grev.) Presl.	1700–2500	1, 2, 10	A, B, C	Ind As
Dryopteris cochleata (D.Don) C.Chr.	1700–2500	1, 2, 3, 4, 5	A, B, C	Ind Bor et Austr
D. juxtaposita Christ.	1700–3300	1, 2, 4, 5, 8	A, B, C	Yunn
D. panda (Cl.) Christ.	2000–2700	1, 2, 3, 4	A, C	Ind Bor As Austr et Occ
Polystichum nepalense (Spreng.) C.Chr.	1700–2600	1, 2, 3	A, B	Ind Bor As
P. piceopaleaceum Tag.	1500–2600	1, 2, 4	A, B	Yun Afghan Ind Japon Kash
P. lonchitis (L.) Roth	1700–2400	1, 2, 5, 6	A, B	Europ As et Amer Arct et Temp Himal
P. longipaleatum Christ	1700–2500	1, 2, 3	A, B, C	Yun
P. lachenense (Hk.) Bedd.	2700–3400	1, 2, 5	C	Himal As
P. setosum Schott.	1500–3200	1, 2, 10	A, B, C	Japon South Kor
P. squarrosum (D. Don) Fee	1300–3000	1, 2, 4	A, B, C	Ind As
P. stimulans (Kunze ex Mett.) Bedd.	2000–2500	1, 2, 3	B	Ind Bor As Merid

Equisetaceae				
Equisetum arvense L.	2000–2600	1, 2, 10	B, C	Arct Temp Europ North Amer As
E. diffusum L.	1700–2500	1, 2, 3	A	Yunn Ind Japon Kash As
Hemionitidaceae				
Coniogramme fraxinea (Don) Diels	1700–2500	1, 2, 3, 5	A, B	Ind Bor Malaysia Ins Philipp
C. intermedia Hieron. var. *glabra* Ching	1700–3000	1, 2, 5	A, B, C	Ind Bor As Japon
Gymnopteris vestita (Wall. ex Moore) Underw.	2000–2600	1, 5	C	China Ind Bor
Ophioglossaceae				
Ophioglossum petiolatum Hk.	2100–2600	1, 2, 10	A, C	As Amer
Osmundaceae				
Osmunda claytoniana L.	2000–3000	1, 2, 6	A, C	Amer Bor Atlant Himal As
Polypodiaceae				
Drynaria mollis Beddome	2000–2600	1, 2, 6, 8	A, C	Himal As Merid
Lepisorus nudus (Hk.) Ching	2000–3300	1, 4, 5	A, B, C	As Yun
Phymatopteris malacodon (Hk.) P. Serm.	2100–2600	1, 3	A, B	Himal As Merid
P. stracheyi (Ching) P. Serm.	2200–3200	1, 3, 6	A, B, C	As China
Polypodium polypodioides L. Watt.	1700–2700	1, 5, 2	A, B, C	Mex
Polypodiastrum argutum (Wall. ex Hk.)	1700–2600	2, 3, 5, 8	B	Yun As
Polypodiodes amoena (Wall. ex Mett.)	2000–2500	1, 2, 3	A, B, C	Ind Bor As
P. microrhizoma (Cl. ex Baker) Ching	2000–2700	1, 3	A, B, C	Himal Yun
P. subamoena (Cl.) Ching	2200–3300	2, 3, 5	B, C	As Merid Himal
Pteridaceae				
Pteris cretica L.	1300–3300	1, 2, 3, 8, 9	A, B, C	Trop Subtrop
P. biaurita L.	1300–2000	1, 3, 4, 5, 9	A, B, C	As Ind Subcont As Trop
P. vittata L.	1700–2400	1, 2, 3	A, B, C	Afr As Europ Trop et Subtrop Austr Polynes Trop
P. wallichiana Ag.	1700–2500	1, 2, 3	A, B, C	Ind Bor Java Celebes Ins Philipp
Pteridium aquilinum (L.) Kuhn.	1700–2700	1, 2, 3, 4	A, B, C	Afr As Trop As Temp Europ N Amer
Selaginaceae				
Selaginella chrysoleuca Spring	2000–2700	1, 2, 3, 8	A, C	Peru
Sinopteridaceae				
Cheilanthes albomarginata Cl.	1500–2700	1, 2, 3,	A, B, C	Himal Ind Austr
C. dalhousiae Hk.	2000–2500	1, 2, 3	B, C	As Ind
C. subvillosa Hk.	2100–2600	1, 2, 3, 6	A, B	Himal
Thelypteridaceae				
Phegopteris punctata (Thunb.) Bedd.	1700–2200	1, 3, 8	B	Hawaii

Pseudophegopteris distans (D. Don) Mett.	1500–2600	1, 2	A, B	As Ind China
P. levingei (Cl.) Ching	2500–3300	1, 2, 3	C	Ind As
Stegnogramma mollissima (Kunze) Fras.-Jenk.	1700–2600	1, 2, 3, 8	A, B	Ind Ceyl Jappon Kor
Thelypteris palustris (Salisb.) Schott.	1700–2600	1, 2, 3	B	Canada

Abbreviations used: HEPs – Hydroelectric projects; A – Sainj HEP; B – Parbati Satge II HEP; C – Malana II HEP; 1 – Forest; 2 – Riverine/Watercourse; 3 – Shadymoist; 4 – Dry; 5 – Bouldary; 6 – Degraded; 7 – Waste place/Road side; 8 – Dam submergence area; 9 – Land slide; 10 – Near crop field/orchards; Europ – Europe; Occ – Occidetalis; Austr – Australia; As – Asia; Afr – Africa; et – And; Temp – Temperate; Abys – Abyssinia; Arct – Arctica; Amer – America; Afghan – Afganistan; Atlant – Atlantica; Bor – Boreal; Centr – Central; Ceyl – Ceylon; Himal – Himalayan; Ins – Insular; Ind – Indian; Japon – Japan; Kash – Kashmir; Kor – Korea; Mex – Mexico; Merid – Meridian; Philipp – Philippines; Polyn – Polynesia; Subcont – Subcontinental; Subtrop – Subtropical; Trop – Tropical; and Yun – Yunnan.

Among the genera, *Polystichum* (8 spp.); *Athyrium* (7 spp.); *Adiantum*, *Asplenium* and *Pteris* (4 spp., each); *Dryopteris*, *Polypodiodes* and *Cheilanthes* (3 spp., each); *Diplazium*, *Equisetum*, *Coniogramme*, *Phymatopteris* and *Pseudophegopteris* (2 spp., each) were dominant genera (Table 1). 63 species were reported in the altitudinal zone 1800 to 2800 m, followed by 36 species in the altitudinal zone 1300 to1800 m and 19 species were present in the altitudinal zone >1800 m. Maximum species (56 spp.) were found in forest habitat followed by riverine/watercourse (48 spp.), shadymoist (42 spp.), bouldary (21 spp.), dry (17 spp.), degraded (12 spp.), submergence area (12 spp.), landslide and near crop field/orchards (4 spp. each), waste place/road side (1 sp.) (Fig. 2).

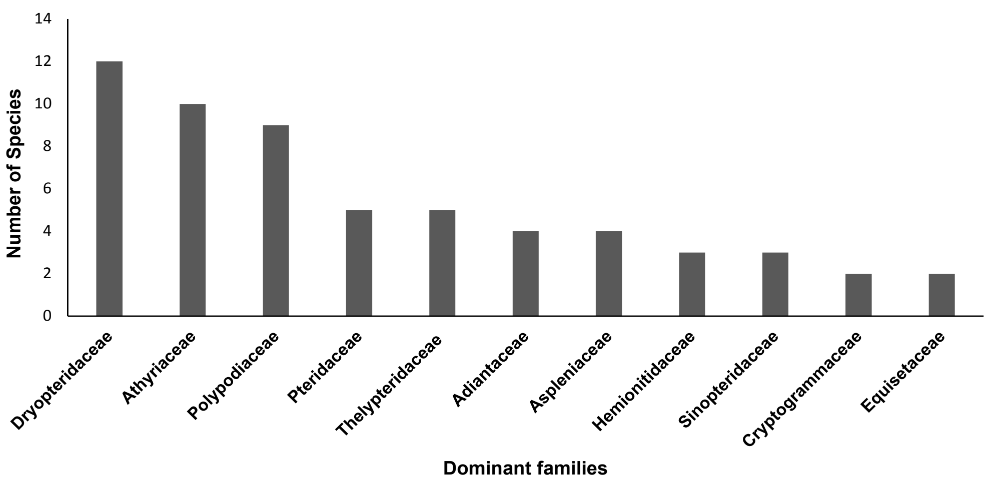

Fig. 1. Dominant families for peteridophytes in three Hydroelectric Projects areas in Kullu district, Himachal Pradesh, India.

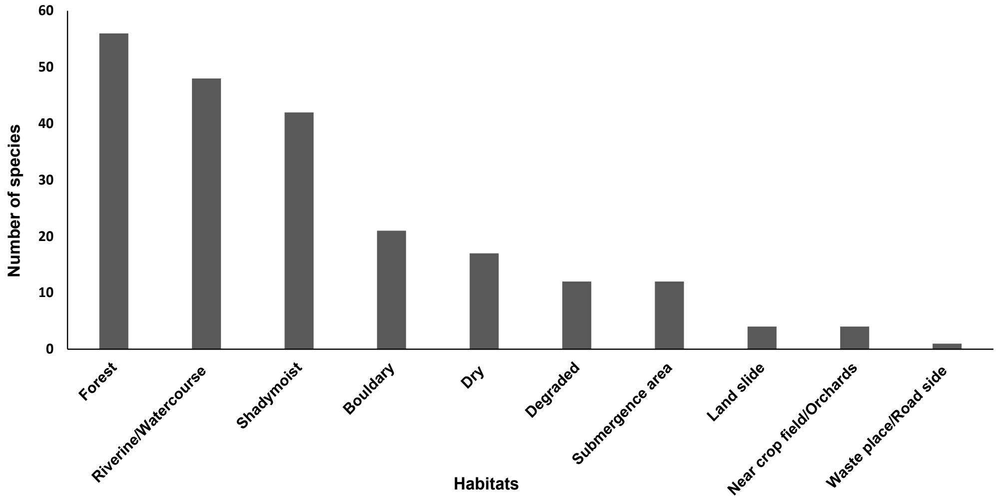

Fig. 2. Habitat wise distribution of peteridophytes in three Hydroelectric Projects areas in Kullu district, Himachal Pradesh, India.

Discussion and Conclusions

The pteridophtes are very well known and used in various ways by mankind from ancient times. They are seedless vascular plants and had a very flourishing past in dominating the vegetation on the Earth about 280–230 million years ago (Mehra and Bir 1964; Bir 1987, 1993). Although they are now largely replaced by the seed bearing vacular plants in the extant flora today, yet they constitute a fairly prominent part of the present day vegetation of the world. India, with a highly variable climate, has a rich diversity of its flora and Pteridophytic flora greatly contributes to its diversity (Bir 1987). According to a recent census, the Pteridophytic flora of India comprises of 67 families, 191 genera and more than 1,000 species (Dixit 1984, Dixit and Kumar 2002) including 47 endemic Indian ferns, less than 10 % of those reported previously and 414 species of Pteridophytes (219 at risk, of which 160 critically endangered, 82 near-threatened and 113 rare), constituting 41–43 % of the total number of 950–1000 Pteridophytes of political India. Chandra (2000) recorded 34 families, 144 genera and more than 1100 species of ferns with about 235 endemic species from Indian region. Analysis of the fern flora (Western Himalaya), Dhir (1980) recorded 264 species, Khullar (2000) recorded 360 species, Khullar (1988) documented 246 species from Uttrakhand, Khullar (1988) recorded 258 species from Garhwal Himalaya, 341 species reported from Kumaon Himalaya by Pande and Pande (2003). In the present scenario many different ecological niches are under tremendous threat due to various anthropogenic activities, creating severe problems for the persistence of ferns in the area. Increase in human population, expansion of agricultural land, harvesting of fuel wood and timber, exploitation of non-timber forest products (NTFPs), selective removal of species and other developmental activities are continuing at the verge of natural flora/ fauna. In addition to these, construction of hydroelectric projects, roads, urbanization, construction of buildings, etc. in the areas are all examples of direct assaults on nature resulting in the loss of the pteridophytic diversity of the areas. The huge decrease in forest cover indicates a danger for many epiphytic ferns, climbing ferns and many other shade loving ferns, which cannot survive in the absence of forest cover.

The state Himachal Pradesh represents one of the richest zones of vegetation wealth in India. Pteridophytic flora is also interesting for its diversity and distribution, however, little is worked out on the economic aspects of these plants. The occurrence of 63 species of pteridophytes species in the area indicates that its environmental conditions, particularly, shady moist and forest habitats, are suitable for growth and development of such species. Therefore, present communication pertains to the diversity of ferns in the surroundings and dam submergence areas of different hydroelectric projects in Kullu district of Himachal Pradesh, India and based on frequent field trips to various remote localities and collecting the information from the local inhabitants. Several conservation measures and management programmes have been taken up in various regions for the angiosperms, but very little attention has been given to the conservation of pteridophytes even though they have ecological value and a good potential for academic, medicinal, ritualistic, food and ornamental uses. In view of this it is important to formulate and implement a detailed scientific study with aim of in situ, as well as ex situ conservation of pteridophytes in target localities with a high value at district and state level has been sugested. In a nutshell, to ensure the long term conservation of pteridophytes in Himachal Pradesh proper strategy and policy dealing with conservation management for this important group of plants should be formulated, so that effective management of forests could be achieved in posterity.

Acknowledgements

The authors are thankful to the Director, G. B. Pant Institute of Himalayan Environment & Development, Kosi-Katarmal, Almora, Uttrakhand for providing facilities and encouragement. Authors greatly acknowledge the support and cooperation received from the local inhabitants of the area during field surveys. Help from Mr. Karam Dass Thakur and Mr. Vikram Jeet during field surveys is also acknowledged.

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FORESTRY IDEAS, 2016, vol. 22, No 2 (52): 137–152

DOCUMENTATION AND UTILIZATION OF MEDICINAL PLANTS USED BY RURAL PEOPLE OF GARHWAL HIMALAYA, INDIA

Purna Jana

H.N.B. Garhwal University, Srinagar, Garhwal, Uttarakhand – 246174, India.
E-mail: purnajana1986@gmail.com

Received: 28 January 2016 Accepted: 06 August 2016

Abstract

The present study provides the information about medicinal plants in Garhwal Himalaya, Uttarakhand, India. The objective of the study was to document the available important medicinal plant species and their use in several different health issues of rural people. Numerous ethno-medicinal surveys were conducted in the villages of Chamoli, Pauri and Rudraprayag districts during 2014. Data on different aspects of medicinal plants were collected by interviewing the local communities, following a simple random sampling method with at least 5 % sampling from each village. During survey, a total of 66 important plant species were recorded, from most of which roots (40 %) are used. Maximum number of species was recorded from the family Asteraceae (5 species). In present study area, due to over exploitation and unsustainable harvesting, several important commercial medicinal plants are facing great threats and need to be conserved properly. Moreover, lack in interest of present generation about the use of medicinal plants augments the threat. Therefore, suitable conservation planning is strongly recommended to conserve medicinal plants including biomedical research, transfer of technology to harvest the existing medicinal plants sustainably, organization of educational and awareness programmes among local communities.

Key words: conservation, medicinal plants, traditional knowledge.

Introduction

Since ancient times, plants are serving human being several useful purposes starting from food, shelter, wear, amusement, medication, etc. India is a country worldwide renowned due to its rich natural resources, biological diversity and cultural heritage (Bisht and Sharma 2005, Singh 2008). Due to its variety of altitudinal zones and long coastlines with various ecological habitats, India has beautiful gift of nature rich in floristic wealth. Though several alternative ways have been ascended along with time, still in several circumstances the contribution of plants are considered inevitable like in medication. Still as the primary health care traditional herbal remedies are recognized by the rural and tribal communities of the world (Taylor et al. 1995, Singh 2008). As per estimation of World Health Organization, 80 % of world's population for primary health care relies mainly on herbal medicines (Farnsworth 1994, Mukherjee and Wahil 2006, Singh 2008). Medicinal plants are supposed to be possible link between sustainable economic development, affordable health care and conservation of the biodiversity (Dhar et al. 2002). Worldwide more than 50,000 plants are under use for medicinal purposes (Schippmann et al. 2002, Tejesvi and Pirttila 2011), which is 11.85 % of total reported flowering plants from the world (Govaert 2001). In India, about 8000 plant species (44.12 % of total reported higher plants) have been recorded having medicinal values (Kumar and Katakam 2002, Vidyarthi et al. 2013, Kanwal and Joshi 2015).

The Indian Himalayan Region (IHR), having quite large geographical area, provides the home for 3.8 % of total population of the country (Mukherji 2010) including many tribal and rural communities solely depending upon several plant species to meet the needs of their daily life (Samant and Dhar 1997). The region, being supported by the diverse agro-climatic conditions, turns into a major repository of medicinal as well as aromatic plants. Samant et al. (1998) reported 1748 species of medicinal plants being supported by the region, of which 25.3 % are endemic for Himalaya (Singh 2008). Ved et al. (1998) reported that more than 90 % of medicinal plants of this region are harvested from wild and are used directly or indirectly by the industries (Vidyarthi et al. 2013).

Uttarakhand, one of the states of this region, due to its unique geographical, as well as varied climatic conditions, is well recognized for having rich plant diversity with medicinal value (Gaur 1999, Kala 2004, Kurele et al. 2015). Out of total medicinal plants used in all over India, about 9.33 % medicinal plants are being used in traditional system of medicine only in Uttarakhand state (Kanwal and Joshi 2015).

In recent years, in order to assess both global and local environmental changes, an emphasis has been given to recognition of biological diversity. Climate change, deforestation, overexploitation, globalization, constructions, growing human population, industrialization, etc. to a great extent have enhanced the threat to biological diversity (Walther et al. 2002, Singh 2008). Currently population deterioration of several high value medicinal plant species (FAO 2003) have been reported as a result of substantial habitat loss due to continuous exploration of medicinal plants from the wild over last few decades (Kala 2003, Singh 2008). In India, 90 % raw materials of medicinal plants for herbal industry is drawn from natural habitat (Gupta et al. 1998, Ved et al. 1998, Singh 2008) and, as per world trade figures in exporting raw material of a number of medicinal plants, India ranks next to China in the world (Lange 1997, Singh 2008). Due to over extraction, different categories of threat have been faced by 14 % of total Red Data plant species and 3.5 % of the total medicinal plants of Indian Himalaya (Singh 2008). Therefore, there is an urgent need to investigate medicinal plants extensively, as well as to document the indigenous practices of medicinal plants systematically in order to check the huge natural population destruction, which is the result of unsustainable and excessive harvesting of medicinal plant resources by the pharmaceutical industries (Behrens 1991, Bodeker 1997, Hamilton 2004, Kurele et al. 2015, Sharma et al. 2012). There is a strong need to set up necessary conservation measure in order to stop the threats (Behrens 1991, Kurele et al. 2015). As in recent years, due to increasing developmental activities and modernization, the over century's developed traditional wisdom is rapidly vanishing (Huntington 1971, Seters 1997). Moreover, the centuries-old traditional knowledge, which was mostly orally transferred from one generation to other without any permanent record, needs to be secured. From this point of view the current study was undertaken in order to document the present medicinal plant diversity status, as well as the existing traditional knowledge of native people on medicinal plants in this region.

Material and Methods

The present study was conducted as preliminary survey in the villages of Pauri, Rudraprayag and Chamoli districts of Garhwal Himalaya, Uttarakhand, India, viz. Malari, Pipalkoti, Chamoli, Karnprayag, langasu of Chamoli district, Srinagar, Parindic, Chamella, Rera, Juginya,Wadda, Banina, Bandun, Jhangorya, etc. of Pauri district and Thapla, Pabau, Bhaiswara, Rail, Tyori, Bansu, Khumera, Barasu etc. of Rudraprayag district. The study area lies between latitude 29°50′30" N to 30°34′15.7" N and longitude 78°47′31.6" E to 79°2′43.9" E (Fig. 1). The relevant information and data for study were collected mainly by conducting extensive and frequent field survey during June to November, 2014, in different villages of the study areas. Interviews were conducted in Hindi and Garhwali (dialect) directly by researcher herself with the presence of one local fellow with the full consent of the respondent. However, some information (origin/nativity and botanical name) also has been collected from secondary sources available in publications and reports of various academic institutions. The altitudinal range of study area was between 500 m to 3500 m above sea level. In the surveyed area mainly four ethnic groups are presented viz. Rajput, Brahmin, Tribal and Schedule caste. In this area people communicate mainly with the help of Garhwali and Hindi. Main sources of income here are agriculture, wage labour and different jobs (governmental and private). Detail information on medicinal plants, including both plant parts used in several medicinal practice and related indigenous knowledge, were

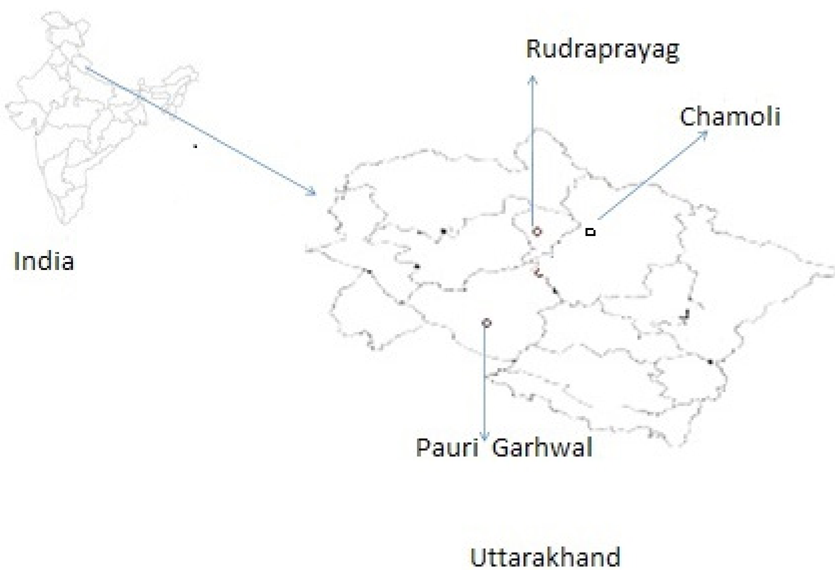


Fig. 1. Map of the study area.

collected by interviewing local habitants of the study area, mainly elderly and knowledgeable persons.

The respondents are of varying age, i.e. starting from 19 to 85. They have various education levels, i.e. from illiterate to higher education (master's level). Most of respondents are engaged in several occupations like education, agriculture, wage labour, job, business, etc. However, some respondents are engaged in Ayurveda treatment of villagers by using medicinal plants and the rest, due to their old age (≤ 80), do nothing. Consultations with traditional healer/vaidya also were done to know the additional medicinal properties, uses of plant species and finally existing literature were consulted in order to correct the collected information, as well as to know the vernacular/local name of the used species (Samant et al. 1998, Kala 2004).

Result and Discussion

Total 50 species were identified and recorded in the current study, which belongs to 28 families (Fig. 2). Maximum number of species has been recorded in the family Asteraceae and Lamiaceae (4 spp. each), followed by Ranunculaceae, Polygonaceae, Liliaceae, Rosaceae, Solanaceae and Pinaceae (3 spp. each), Achyranthaceae, Anacardiaceae, Apiaceae, Berberidaceae, Caesalpiniaceae, Ericaceae Liliaceae, Linaceae, Meliaceae, Moraceae, Scro-phulariaceae and Solanaceae (2 spp. each). The notable important species were *Centella asiatica*, *Angelica glauca*, *Saussurea obvallata*, *Tinospora sinensis*, *Nardostachys grandiflora*, *Sinopodophyllum hexandrum*, *Mentha longifolia*, etc. (Table 1).

Local village dwellers use several parts of plant species to prepare herbal medicine. In medicine preparation, mostly roots (34.85 %) are used, followed by leaves (27.27 %), whole plants (25.76 %), bark (16.67 %), stem (12.12 %), flower (9.09 %), fruit (9.09 %), seed (6.06 %), resin (4.55 %) and rhizome (1.52 %) of the plant (Fig. 3). Village dwellers use those medicinal plants to cure several common diseases like cough, cold, fever, urinary disorder, skin disease, wounds, sore, eye inflammation, diarrhoea, kidney stone, diabetes, toothache, stomach ache,

Table 1. Details of available medicinal plants in study area

Family	Botanical name	Local Name	Part/s used	Use	Life form	Origin/ Nativity
Acanthaceae	*Adhadota vasica* Nees.	Basinga	Leaf	Cough, cold and fever	Shrub	Tropical Asia
Achyranthaceae	*Achyranthes aspera* Linn.	Latjira	Whole plant	Ring worm, facilitating delivery, toothache, asthma, boils, bronchitis, dropsy, colic, cough, cold, dog bite, dysentery, headache, renal complaints, pneumonia, leucoderma, snake and scorpion bite	Herb	Tropical Gerontia

Anacardiaceae	*Spondias pinnata* (L.f.) Kerz	Amra	Fruit, Bark, Root	Stomach ache, dysentery, diarrhoea, articular and muscular rheumatism, gonorrhoea, menstrual regulation, dyspepsia, sore throat, bowels and ear complaints	Tree	Tropical Asia
	Rhus javanica L.	Tungla	Fruit	Gastric complaints and body swelling	Tree	Himalayan region, Sandvich
Apiaceae	*Angelica glauca* Edgew	Choru, Chora	Root	Gastric trouble, flatulence, Swelling, cough, cold, fever	Herb	Himalayan region
	Centella asiatica (L.) Urban	Brahmi	Whole plant	Brain tonic, scleroderma, psoriasis, wounds, skin disease, blood purifier	Herb	Tropical and sub-tropical region
Apocynaceae	*Rauvolfia serpentina* Benth.	Sarpgandha	Root	Anxiety, Insomnia, high BP, fever, cough, nervous and intestinal disorder	Shrub	Indian Oriental, Java
Araceae	*Arisaema jacquemontii* Blume	Saperi mausi	Root, Fruit	Antidote for snake bite	Herb	Himalayan region
Asteraceae	*Artemisia vulgaris* L.	Kunja	Whole plant	Malarial fever, headache, cuts, wounds and ear complaints	Shrub	Temperate region, Borealis
	Artimisia capilaris Thunb	Pati	Leaf	Ear complaints, tonic for worms	Herb	Japan
	Saussurea costus (Falc.) Lipsch	Koot	Root	snake bite, jaundice, toothache and gum complaints	Herb	Himalayan region
	Taraxacum officinalis Weber. Dudhar	Kanphul	Whole plant	Rheumatism, kidney and liver trouble, mouth ulcer, blisters, boils, diabetes, burnt body parts, blood purifier	Herb	Temperate region, Borealis, Australia
Berberidaceae	*Berberis aristata* DC	Chatru	Root, Bark	Anticancer, snake and rodent bite, ulcer and eye complaints	Shrub	Indian Oriental
	Berberis lycium Royle	Kilmora	Root, Bark, Stem, Fruit	Diabetes, piles, skin disease, eye and ear complaints	Shrub	Himalayan region
	Sinopodophyllum hexandrum (Royle) T.S.Ying	Bankakri	Root	Cancer, asthma, constipation, blood purifier, skin disease, cut and wounds	Herb	Himalayan region
Betulaceae	*Betula utilis* D.Don	Bhojpatra	Bark, Leaf	Fever, nose bleeding, cough, cold, rheumatism	Tree	Himalayan region, Japan

Caesalpiniaceae	*Bahunia variegata* L.	Guriyal	Bark, Stem, Flower	Cough, boils, skin disease, dysentery	Tree	Indian Oriental, Burma, China
	Cassia tora L.	Chakunda	Leaf, Root, Fruit	Stomach ache, cough, cold	Herb	Tropical Cosmopolitan
Cannabaceae	*Cannabis sativa* L.	Bhang	Leaf, Seed, Flower	Ulcer, bronchitis, cuts, fever, sedative	Shrub	Central Asia
Chenopodiaceae	*Chenopodium album* L.	Bathua	Seed, Leaf	Skin disease	Herb	Temperate and Tropical region
Cuscutaceae	*Cuscuta reflexa* L.	Amer bel	Whole plant	Inflammation, swelling, rheumatic pain, skin disease	Herb	Indian Oriental
Ericaceae	*Lyonia ovalifolia* (Wall.) Drude	Anyar	Whole plant	Ulcer, cut, itching	Tree	Himalayan region, Japan
	Rhododendron arboreum Sm	Burans	Flower, Leaf	Heart tonic, dysentery, digestive, blood pressure, fever, headache, rheumatism	Tree	Himalayan region, Indian Oriental
Euphorbiaceae	*Emblica officinalis* Gaertn.	Amla	Whole plant	Stomach-ache, blood purifier, source of vitamin C, hair tonic, digestive	Tree	tropical Asia
Fabaceae	*Astragalus condolleanus* Royle ex Benth	Rudravanti	Root	Skin complaints, blood purifier	Herb	Persia
Gentianaceae	*Swertia angustifolia* Buch.-Ham. ex D.Don	Chirotu	Whole plant	Fever, malarial fever, blood purification	Herb	Himalayan region
Juglandaceae	*Juglans regia* L.	Akhrot	Bark, Leaf, Fruit	Rheumatism, toothache, eczema, swelling in between two fingers, leaf used as insecticide and fungicide	Tree	Asia, Occidentalis, Himalayan region
Lamiaceae	*Leucas cephalotes* Roth Sreng.	Gumba	Whole plant	cut, pain and snake bite	Herb	Indian Oriental
	Mentha longifolia L.	Pudina	Whole plant	Digestive, stomach-problems, indigestion	Herb	Borealis Temperate region
	Ajuga parviflora Benth.	Neelkanthi	Whole plant	Stomach ache, malaria	Herb	Himalayan region
	Origanum vulgare L.	Bantulsi	Whole plant	Whooping cough, bronchitis, diarrhoea, cough and cold	Herb	Europe, Asia and Africa Tropical
Lauraceae	*Litsea glutinosa* (Lour.) Robins	Maida lakri	Bark	Bone fracture, joint pain reliever	Tree	Himalayan region

Liliaceae	*Allium stracheyi* Baker	Jambu	Leaf	indigestion, stomach-complaints, flatulence	Herb	Himalayan region
	Gloriosa superba L.	Kali hari	Root, Leaf	Skin disorder, painful delivery	Herb	Asia Tropical
	Asparagus racemosus Wild.	Sataver, Jhirna	Root	Urinary complaints	Shrub	Indian oriental, African tropical, Australia
Linaceae	*Reinwardtia indica* Dumort	Phinuli	Leaf, Flower	Wounds, cut, paralysis	Herb	Indian Oriental
Meliaceae	*Azadirachta indica* Juss.	Neem	Stem, Leaf, Flower	Skin disease, antiseptic, toothache, diabetes	Tree	Indian Oriental
	Toona ciliata M. Roem.	Toon	Leaf, Stem	Ulcers, sore	Tree	Australia
Menispermaceae	*Tinospora cordifolia* (Willd.) Miers	Giloe	Leaf, Stem	Fever, leprosy, urinary complaints of domestic animal	Herb	Indian Oriental
Moraceae	*Ficus palmata* Forsk	Bedu	Fruit, Leaf	Indigestion, dysentery	Tree	Africa Tropical Arabia Indian Oriental
	Ficus religiosa L.	Pipal	Stem, Bark	Swelling, rheumatism, bronchitis	Tree	Indian oriental
Myricaceae	*Myrica esculenta* Buch. -Ham ex Don	Kaphal	Bark	Fever, headache	Tree	Asia tropical and sub-tropical
Myrtaceae	*Syzgium cumini* (L.) Skeels	Jamun	Whole plant	Kidney stone, diabetes	Tree	Asia and Australia Tropical
Orchidaceae	*Dactylorrhiza hatagirea* (D.Don) Soo	Hatajari	Root	Impotency, leucorrhoea, diarrhoea, kidney pain, cut, wounds	Herb	
Oxalidaceae	*Oxalis corniculata* L.	Khattibuti	Whole plant	Jaundice, insect bite, skin complaints, pimple, indigestion, cut, wound, cough, cold	Herb	Amphigaea Temperate and Tropical
Pinaceae	*Cedrus deodara* (Roxb.) Loud	Deodar	Resin, Stem	Joint pain and joint stiffness, piles, skin Itching, boils	Tree	Himalayan region
	Pinus roxburghii Sarg.	Chir	Resin, Stem	Asthma, bronchitis, bone fracture, skin disease, ulcer	Tree	Himalayan region
	Pinus wallichiana A.B. Jacks	Kail	Resin, Bark	Ulcer, joint pain, dislocation joints	Tree	Himalayan region
Plantaginaceae	*Plantago depressa* Willd.	Isabgol	Leaf, Seed	Piles, gastric, indigestion	Herb	Sibir
Poaceae	*Cynodon dactylon* (L.) Pers	Dub	Whole plant	Headache, nose bleeding, dysentery, cramps, cut, puking	Herb	Cosmopolitan Tropical

Polygonaceae	*Rumex hastatus* D.Don	Almora	Whole plant	Skin complaints, cut and wounds	Herb	Himalayan region
	Fagopyrum dibotrys (Don) Hara	Bathu	Root	Insect bite, vermicide	Herb	Himalayan region, China
	Rheum australe D.Don	Dolu	Root	Bone ache, joint pain, muscular pain, internal wound	Herb	Himalayan region
Ranunculaceae	*Aconitum ferox* Wall.	Meetha bish	Root	Paralysis, joint pain, arthritis, fever	Herb	Himalayan region
	Aconitum heterophyllum Wall.	Ateesh	Root	Typhoid, tuberculosis, diarrhoea, fever, body pain, cough, gastric trouble	Herb	Himalayan region
	Thalictrum foliosum DC.	Mamiri Or makhan ghas	Root	Fever, stomach ache, eye sore	Herb	Himalayan region
Rosaceae	*Rosa macrophylla* Lindl.	Ban gulab	Flower	Bowel complaints, cut, wound, skin disease	Shrub	Himalayan region, China
	Potentilla fulgans Hook.	Bajradanti	Root	Pyorrhoea, gum trouble and toothache	Herb	Himalayan region
	Rubus ellipticus Sm.	Hinsar	Shoot, Root	Stomach complaints, skin disease, dysentery	Shrub	Indian oriental
Saxifragaceae	*Bergenia ligulata* Engl.	Silphaara	Root	Kidney stone, indigestion, swellings, diabetes	Herb	Himalayan region
Scrophulariaceae	*Picrorhiza kurrooa* Royle	Kutki	Root	Jaundice, fever, stomach complaints, laxative, dysentery, cold	Herb	Himalayan region
Solanaceae	*Withania somnifera* Dunal	Ashwagandha	Root	Fever, joint pain, urinary complaints	Shrub	Regional Mediterranean
	Solanum nigrum L.	Makoi	Whole plant	Liver complaints, jaundice, diarrhoea, eye complaints, fever	Herb	Venezuela
	Datura stramonium L.	Datura	Leaf, seed	Asthma, bronchitis, joint pain, stomach ache, cough	Herb	Indian Oriental
Taxaceae	*Taxus baccata* L.	Thuner	Bark, Leaf	Cancer, bone fracture, cough, cold	Tree	Regional Borealis temperate
Zingiberaceae	*Hedychium spicatum* Buch.-Ham ex Sm.	Banhaldi	Rhi-zome	Asthma, tuberculosis, cough, cold, menstrual pain, indigestion	Herb	Himalayan region

N.B. Botanical name and origin/nativity have been collected by reviewing literatures.

Achyranthes aspera

Saussurea costus

Berberis aristata

Rhus javanika

Artemisia vulgaris

Angelica glauca

Artemisia capilaris

Bahunia variegata

Fig. 2. Some of important medicinal species found in study area.

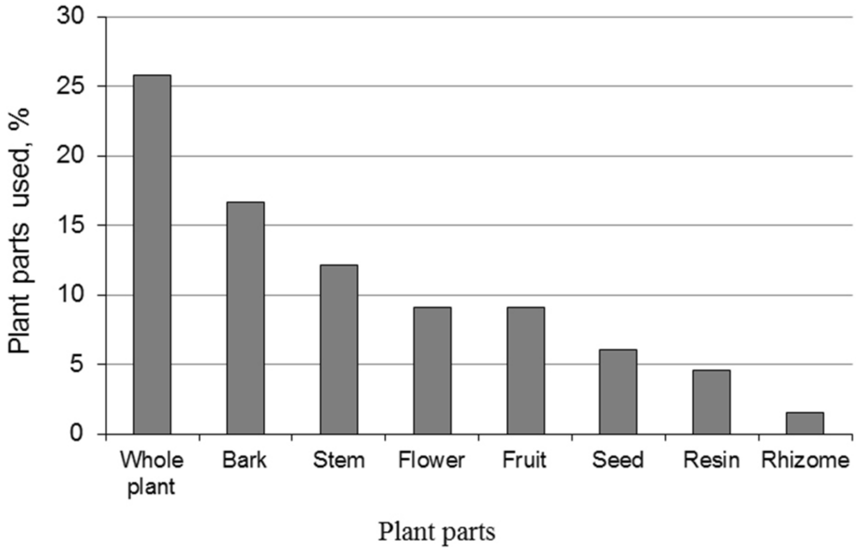


Fig. 3. Percentage of plant parts used in medicine preparation purpose.

indigestion, headache, swelling, body pain, joint complaints, gastric trouble, etc. Among the listed plants, *Allium stracheyi* and *Picrorhiza kurrooa* have been recorded under vulnerable threat category in the Red Data Book of Indian plants.

According to CAMP-2003 criteria, among the listed species *Aconitum heterophyllum*, *Dactylorhiza hatagirea* and *Picrorhiza kurrooa* have been recorded under the category critically endangered; *Saussurea obvallata*, *Sinopodophyllum hexandrum* and *Angellica glauca* have been categorized as endangered species. *Allium stracheyi*, *Gloriosa superba* have been placed under vulnerable category. As per IUCN status, *Dactylorhiza hatagirea* has been categorized as endangered species.

Aconitum ferox, *Angellica glauca* and *Allium stracheyi* are identified as endemic species, which are restricted to Indian Himalayan Region. On the other hand, *Aconitum heterophyllum*, *Arisaema jacquemontii*, *Arnebia benthami*, *Berberis aristata*, *B. lycium*, *Dactylorhiza hatagirea*, *Rheum australe*, *Potentilla fulgens, Bergenia ligulata* and *Hedychium spicatum* are restricted to Indian Himalayan region and neighbouring Himalayan countries and so they have been brought under category near endemics.

The study shows that inhabitants have pretty much idea regarding medicinal plants and their uses in curing several diseases. Belief on treatment by using medicinal plants varies based on types of area, i.e. whether it is village or town. In village, 70.27 % respondents have belief in medicinal plant use but only 48.23 % respondents in town showed interest in use of medicinal plants in treatment (Fig. 4). Moreover, belief on medicinal plants also varies with the age of respondents. In this study, 69.38 % old respondents believe in medicinal plant use, whereas it is only 46.57 % in the case of young respondents (Fig. 5). Evidently, study shows that

77.45 % old respondents (age ≥ 40) in village and 55.17 % in town believe in effect of medicinal plants. In village 54.34 % and only 33.33 % young respondents in town believe in usefulness of medicinal plants (Fig. 6). In several villages dwellers are forced to use traditional medicines due to remoteness and inconvenience to avail modern medicinal facilities. In the study area, based on distance from main road, use or believe on medicinal plant and its use in treatment also differ. Study shows that 70.09 % old respondents and 50.84 % young respondents, who live away from the road, believe on use of medicinal plants in treatment, whereas the belief is 67.44 % in case of old and only 28.57 % for young respondents who live near the main road and can avail the modern medicinal facilities (Fig. 7). Belief on use of medicinal plants also depends on caste. In the study area, 61.53 % Brahmin, 62.24 % Rajput, 62.66 % SC and 50 % ST respondents believed in medicinal plants use (Fig. 8). Only few people have drastic knowledge regarding medicinal plants and their implement in important complicated disease like cataract, cancer, kidney stone, snake bite, asthma, piles, etc. Presently the study shows that this knowledge is being depleted day by day due to migration of village dwellers to urban areas seeking for better livelihood, lack of interest of youth generation on traditional medicine and its uses as they think that it is time consuming procedure than modern medicinal facilities (Fig. 6 and 7).

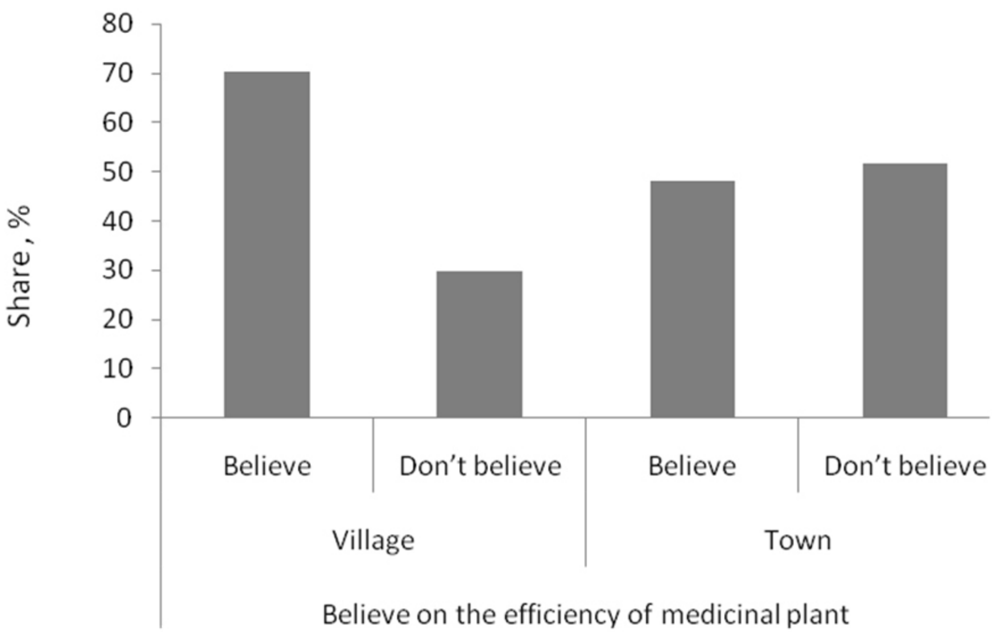


Fig. 4. Share of belief on the efficiency of medicinal plants based on type of area.

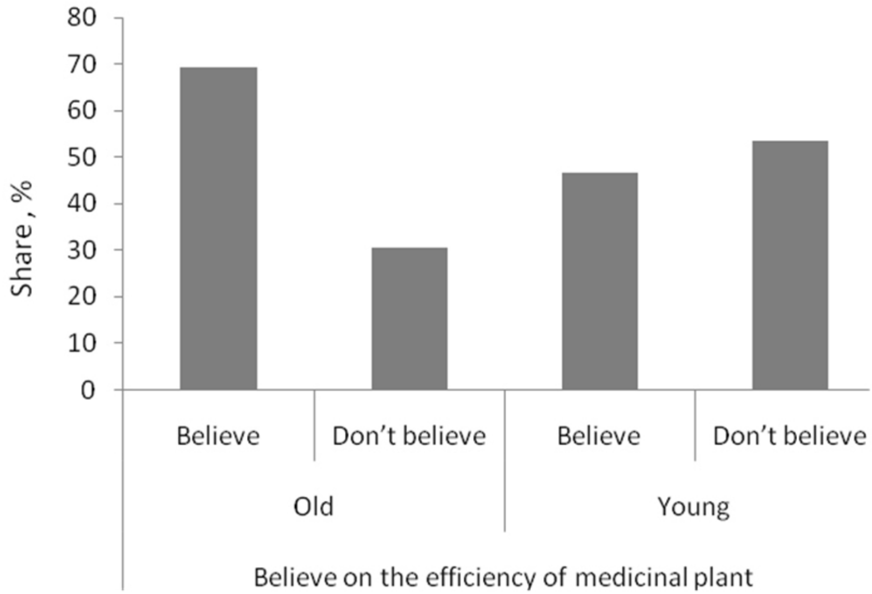


Fig. 5. Share of belief on the efficiency of medicinal plants based on age group.

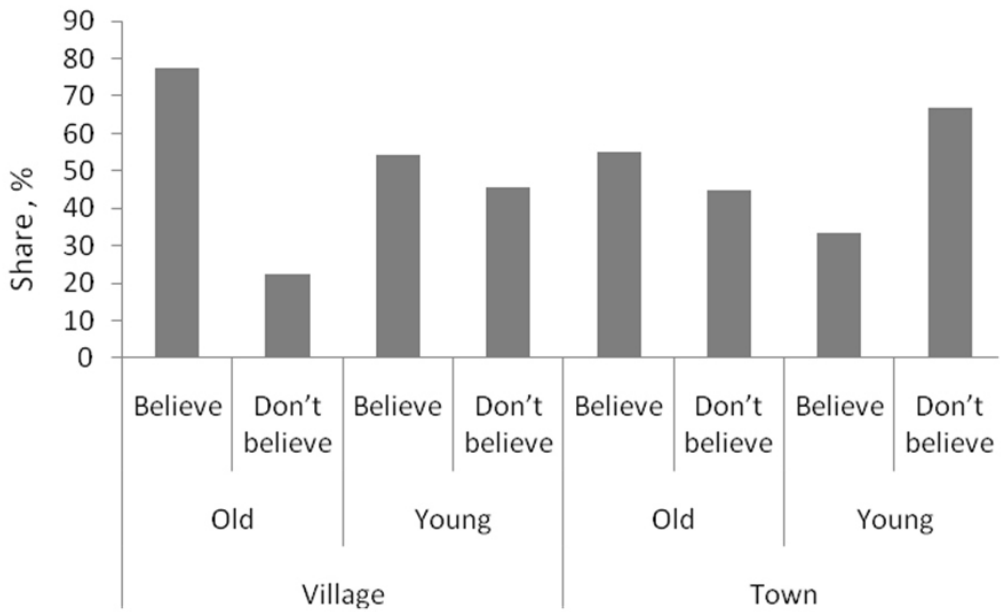
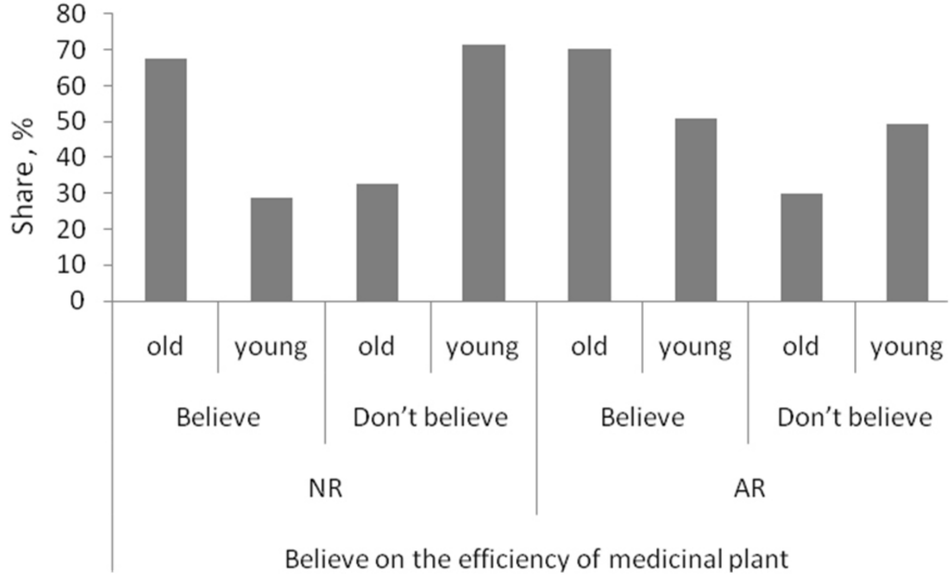
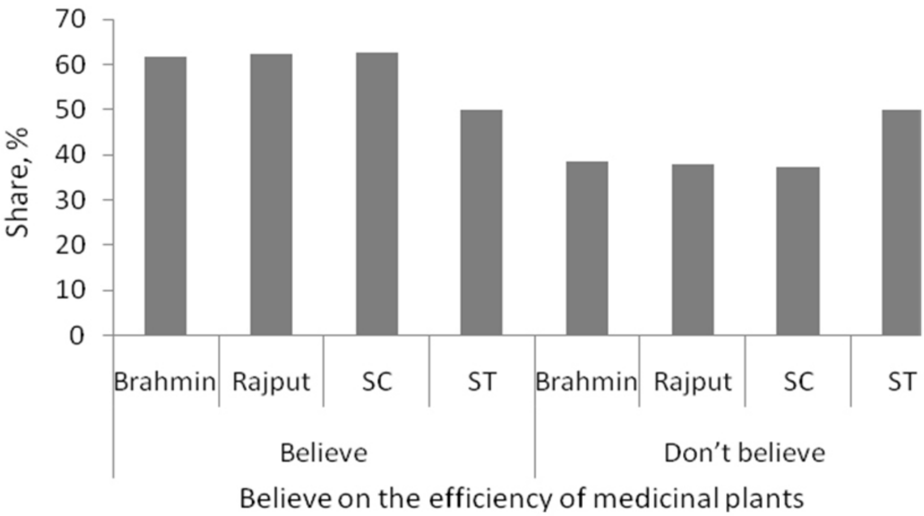


Fig. 6. Share of belief on the efficiency of medicinal plants based on type of area and age group.



Note: AR – away from road, NR – near road.

Fig. 7. Share of belief on the efficiency of medicinal plants based on distance from main road and age group.



Note: SC – schedule caste, ST – schedule tribe.

Fig. 8. Share of belief on the efficiency of medicinal plants based on castes.

Conclusion

It is worth to notify that the knowledge is being depleted day by day due to migration of village dwellers to urban areas seeking for better livelihood, lack of interest of youth generation on traditional medicine and its uses as they think that it is time consuming procedure than modern medicinal facilities. Hence, there is an urgent requirement of available indigenous knowledge documentation has been felt strongly to save all those important knowledge. Tafesse and Mekonnen (2001) and Regassa (2013) also mentioned the facts stated above as the reason of knowledge depletion. Giday et al. (2009) also mentioned that acculturation of young generation is one of the major threat to the continuation of traditional medicinal knowledge.

Moreover, medicinal plants are continuously exploited unsustainably. Egharevba et al. (2015) also reported the fact. Same statement has been given in the report of planning commission (2000) Govt. of India and Sharma et al. (2012). This fact, together with anthropogenic pressure, climate change, habitat degradation becomes the reason of rapid depletion of several important medicinal plants (Kanwal and Joshi 2015). In present study area such threats have been faced by *Aconitum heterphyllum*, *Arnebia benthami*, *Dactylorhiza hatagirea*, *Picrorhiza kurrooa*, *Angelica glauca*, *Sinopodophyllum hexandrum*, *Allium stracheyi*, *Gloriosa superba* etc. Therefore, there is an urgent requirement of documentation of all available indigenous knowledge (WHO, IUCN & WWF 1993).

Only in this way we can save all those important knowledge to let people know about the importance of plants in curing difficult diseases, as well as to conserve those plants facing threats by forming strong management strategies. For this reason, a suitable conservation planning is strongly required including advance biomedical research, transfer of technology to local communities for the sake of proper sustainable harvest of existing medicinal plants, organization of educational and awareness programmes among local communities to encourage them in conservation of medicinal plants. Same also has been recommended in the report of planning commission (2000), Govt. of India.

Finally, based on this, a comprehensive and long term conservation and management of all existing medicinal plant species is also essential. Same also has been advised in the report of planning commission (2000), Govt. of India. All of them could be achieved by involving several stakeholders for the wellbeing and well management of the huge medicinal treasure of this area but most important part is, the ecosystem needs to be preserved in its intact form and so the area must be conserved locally by the name of sacred grove, which is community based forest protection and proved to be quite strong way in order to give complete protection to the productive ecosystem, which is also very prominent in the study area. Kurela (2015) also mentioned about sacred grove concept in the context of protection for the ecosystem.

Acknowledgements

The author is thankful to Department of Forestry & NR of HNB Garhwal University for facility and encouragement. The author is also thankful to local dwellers to share and provide valuable information on medicinal plants and hospitable co-operation during field work.

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FORESTRY IDEAS, 2016, vol. 22, No 2 (52): 153–170

CLONE-SPECIFIC BIOMETRIC MODELS FOR ABOVEGROUND DENDROMASS OF SINGLE-STEM AND COPPICED BLACK POPLAR CLONES DIFFERING IN AGE AND SPACING

Tatiana Stankova*, Hristina Hristova, Emil Popov, and Ivaylo Tsvetkov

Forest Research Institute of the Bulgarian Academy of Sciences, 1756 Sofia, Bulgaria.
*E-mail: tatianastankova@yahoo.com

Received: 26 April 2016 Accepted: 30 August 2016

Abstract

The main objective of this study was to investigate the allometry of aboveground dendromass of both single-stem and coppiced black poplar hybrids at an early growth stage and to examine the potential of the variables age, growth space and number of sprouts as covariates in diameter-based (basal, d_0 or breast-height, *dbh*) power form models. Our investigation developed clone- and tree form-specific equations for the aboveground tree dendromass of the clones 'Agathe', 'I 45/51', 'NNDV' and 'BL', grown in a spacing trial in North-Western Bulgaria. All equations, which were derived as the best per clone×tree form combination, revealed high accuracy and predictive power, except for the equation of coppiced 'Agathe' trees. The clone-specific aboveground dendromass models for single-stem saplings showed higher goodness-of-fit than those of the coppices, where more significant dissimilarity of dendromass trends among the clones was also noticeable. Honer transformed variable model was the most adequate to describe monostem 'Agathe' and 'BL' biomass, while the simple *dbh*-based allometric equation was selected for monostem 'NNDV'. A d_0-based allometric model, in which the slope parameter was expanded by a power function of tree age predicted best the dendromass of the single-stem 'I 45/51'saplings. All models derived for the coppiced poplars included the number of sprouts as a second predictor variable. The clone-specific dendromass models, which possessed the higher goodness-of-fit within each tree form category, manifested also significantly improved prediction power as compared to the generic dendromass models for black poplar hybrids.

Key words: allometric models, biomass equations, Euro-American poplars, Nelder wheel design, *Populus deltoides* × *P. nigra*, short-rotation plantations.

Introduction

Biomass utilization for energy was established as a priority in Bulgaria through the National long-term strategy promoting biomass usage in the period 2008–2020 (Ministry… 2008), and wood was recognized as one of the main sources of biomass. Two principal dendromass suppliers have been identified: the remains from timber harvesting and wood-processing industry, and short-rotation crops from fast-growing tree species. The latter is given higher priority in Europe (Ericsson and Nilsson 2006). Bulgarian forests comprise a range of fast-growing species and genotypes, appropriate for short-rotation crops. Comprehensive research has been carried out (Kolarov 1974; Tsanov 1986; Krastanov et al. 2004a, b; Tsakov 2009), and intensive plantations of selected poplar and willow clones, and black locust progenies have been established, mainly for timber and cellulose production.

Cultivation of short-rotation crops usually involves estimation of the total lignified biomass production, which is based on individual plant mass and plantation density. Tree biomass has been found to vary with species, genotype, population density, growth stage, management, topography and site characteristics (Sileshi 2014), and therefore generic models with multiple predictors are often preferred for quantifying biomass at larger scales. Biologically plausible and statistically sound generalized biometric models have been developed (Stankova et al. 2015, 2016) for estimation of dendromass and aboveground biomass of juvenile black poplar hybrids (*Populus deltoides* × *P. nigra*), traditionally cultivated for timber and cellulose production, using the breast height tree diameter, total tree and mean stand heights as predictor variables.

Some of the hybrid black poplar clones (*Populus deltoides* × *P. nigra*) are described as having thin branches (‘I 45/51‘, ’Agathe‘, ’Luisa Avanzo‘, ’BL‘), while thicker branches are characteristic of other clones (e.g. ’I 214‘, ’NNDV‘) (Tsanov and Mikov 1997). A study by Sixto et al. (2014) showed that clone ’I 214‘ and particularly ’MC‘ are characterized by relatively low branchiness. These observations suggest that the biomass allometry of hybrid black poplars might be clone-specific. Previous research on other species has shown that biomass allocation may depend also on age (Bond-Lamberty et al. 2002, Porté et al. 2002, Shaiek et al. 2011) and stand density (*sensu* Burkhart and Tomé 2012). The level of model generalization, when investigated, is usually determined by analysis of co-variance (ANCOVA), which either leads to model differentiation according to the significant covariates (Arevalo et al. 2007; Paul et al. 2013a, b) or to inclusion of these covariates as additional predictors in the models (Bond-Lamberty et al. 2002).

Biomass models for aboveground compartments of individual trees commonly utilize two principle tree dimensions as predictor variables: diameter at breast height (*dbh*, cm) and total tree height (*h*, m) (Clutter et al. 1983, Burkhart and Tomé 2012), but the change of the tree form to shrub-like, which is done by coppicing, suggests that instead of single-stem equations, multiple-stem-models might also be considered (Menéndez-Miguélez et al. 2013). Predictors needed for such models often include diameter at root collar instead of the breast-height diameter, total height, number of stems and perhaps crown width (*sensu* Burkhart and Tomé 2012).

Energy crops have been defined as short-rotation, high-density systems of selected genotypes grown under specific cultural regimes (Ceulemans and Deraedt 1999). Planting densities ranging from 2500 up to 100,000–300,000 plants per hectare have been investigated (DeBell et al. 1993), but the density range most often studied spans from 5000 to 40,000 stems per hectare (Cañellas et al. 2012). Ceulemans and Deraedt (1999) reported that optimum rotation time and plantation density for poplar energy plantations are generally 4 years and 2500 to 10,000 plants per hectare, respectively. An experimental plantation was established in the spring of 2013 in North-Western Bulgaria using the Nelder wheel design with 4 hybrid black poplar clones and 11 nearly-square spacings, which accounted for initial densities from 870 to 10,000 saplings per hectare. It was exposed to consecutive partial coppicing in 2014 and 2015. The experiment was designed to study the effect of genotype, spacing and rotation length on the biomass production. The main objective of this study was to examine the potential of variables age, growth space and number of sprouts as biomass predictors and to develop clone- and tree form-specific models for aboveground tree dendromass of investigated black poplar hybrids.

Materials and Methods

Experimental plantation and data collection

The experimental plantation was established in the spring of 2013 on the territory of Galovo nursery of Oryahovo Forest Range in North-Western Bulgaria (43º39´48.31˝ N, 24º05´44.11˝ E). The nursery is situated in the valley of Danube at altitude 25 m a.s.l. The climate is temperate continental, with average annual temperature 11.5–12 °C and average amount of annual precipitations of 515−630 mm. The soil is Haplic Kastanozem of high bulk density, low nitrogen, but high phosphorus and potassium content, and is poorly stocked with soil organic matter (Kaveko … 2006). The level of the underground water is close to the surface, the growth period lasts 6–7 months, with summer maximum of the precipitations, which provide conditions relatively favourable for poplar cultivation. The Nelder wheel experimental design (Nelder 1962, Namkoong 1965) was adopted with 4 hybrid black poplar (*Populus deltoides* × *P. nigra*) clones and 11 nearly-square spacings ranging from 1.0 to 11.5 m^2 (Fig. 1, Table 1). The clones were arranged in alternating spokes, grouped in sectors by 8, which were separated by two border spokes of the clone ’Panonia‘ (Fig. 1). Planting densities varied along the spokes, forming 13 concentric circumferences, with the innermost and the outermost circumferences playing the role of borders. Standard hardwood cuttings (18–20 cm) were used for plantation establishment and due to the limited cultivation activities the rooting rate was low and the percentage of under-sized saplings was high at the end of the first growth period. In accordance with the requirement of this specific design, adapted to study the genotype- and density-dependent tree growth (Namkoong 1965), replacement of the plants shorter than 1.3 m and replanting of the empty planting spots were done during the winter of 2013–2014 with standard 1-year-old saplings from the same clones, according to the scheme. The saplings of eight spokes (12–19) were coppiced in the same winter. Data collection took place in the autumn of 2014 and in 2015 by measuring of all trees from 2 sectors (16 spokes) each time. The trees of spokes 12–19 and 22–29 were harvested in 2014 and provided dendromass data from 2-year-old single-stem plants (spokes 22–29) and from coppiced plants of 2-year-old roots and 1-year-old shoots (spokes 12–19). Sampling of spokes 22–29 and 32–39 was done after the third growth period in 2015, which assured leafless biomass data from 3-year-old single-stem saplings (spokes 32–39) and from coppiced plants of 3-year-old roots and 1-year-old shoots (spokes 22–29) (Fig. 1, Table 1).

Each sample tree was cut to the ground at 5 cm maximum stump height. Stem length (to the nearest 1.0 cm), basal and breast-height tree diameters (to the nearest 0.1 cm) were measured for the single-

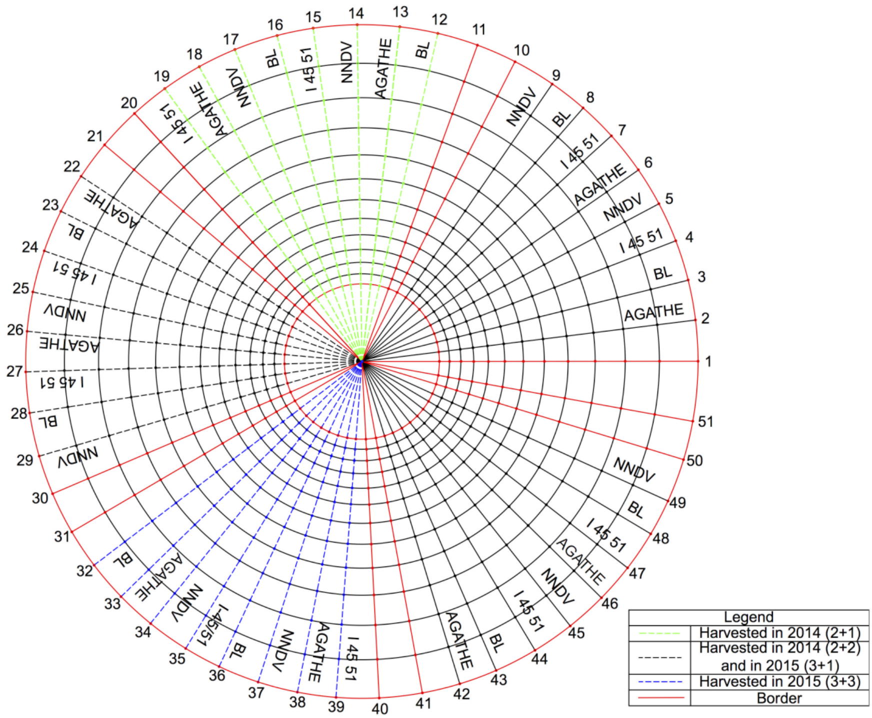

Fig. 1. Design of the experimental plantation.

stem saplings, while length, basal and breast-height diameters of the main stem and the number of stems were determined for the coppiced plants. The stems and the branches of each tree were separated and weighted *in situ*, to the nearest 0.005 kg. One stem and 1 branch samples (of around 100–200 g each) per tree were obtained from 3 saplings along each spoke. The collected woody parts were cut into 10–12 cm-long pieces, a size appropriate for oven-drying, and the fresh weight of all samples was measured in the field. They were packed in paper bags, transported to the laboratory and oven-dried at 105 °C to constant weight, which was measured to the nearest 0.001 kg. Proportions of dry to fresh weight were estimated for all samples. For each tree fraction (stem or branches) separately, these proportions were averaged from the respective samples obtained within the spoke. The calculated mean dry mass proportions were used to estimate the dry mass of the entire fractions of each tree in the spoke, using the respective fresh weights measured in the field. All allometric models derived in this study refer to the dry weight of aboveground woody fractions of the individual saplings.

Model development

We developed allometric models for estimation of the total tree dendromass (stem+branches), differentiated by clone and tree form (single-stem vs. coppiced).

Table 1. Description of experimental data used to derive aboveground dendromass models.

Clone	Root age +stem age	Number of trees	[a] Spacing, m²	[b] d_0, cm	[b] *dbh*, cm	[b] *h*, m	[b] *w*, kg	[b] Number of stems
Agathe	2+1	15		3.7 (2.0–5.6)	1.9 (1.0–3.1)	3.5 (2.2–4.9)	0.649 (0.095–2.122)	3 (1–5)
Agathe	2+2	21		3.5 (2.6–7.0)	2.1 (1.6–3.5)	3.7 (3.0–4.8)	0.576 (0.272–1.901)	1
Agathe	3+1	17	1.0	3.2 (1.9–4.5)	1.9 (0.9–3.1)	3.5 (2.0–4.6)	0.676 (0.152–1.691)	3 (1–10)
Agathe	3+3	22	1.3	6.3 (3.5–9.9)	4.3 (2.5–7.0)	5.8 (3.5–7.7)	2.961 (0.572–7.697)	1
BL	2+1	13	1.6	4.2 (2.6–6.3)	2.3 (1.4–2.9)	3.8 (2.7–4.6)	0.978 (0.234–1.993)	3 (1–5)
BL	2+2	22	2.1	4.6 (2.6–8.7)	2.6 (1.5–4.7)	4.0 (3.0–5.7)	0.943 (0.242–2.888)	1
BL	3+1	21	2.7	3.1 (1.3–9.3)	1.6 (0.6–2.3)	3.1 (1.7–4.0)	0.591 (0.050–1.509)	3 (1–12)
BL	3+3	22	3.4	6.3 (2.8–9.7)	4.2 (1.9–7.0)	5.7 (3.5–7.0)	2.508 (0.311–6.968)	1
I 45/51	2+1	13	4.3	4.1 (2.6–6.7)	2.2 (1.2–4.0)	3.1 (2.1–4.0)	0.725 (0.189–1.875)	3 (1–5)
I 45/51	2+2	21	5.5	3.6 (2.6–6.6)	2.2 (1.4–3.4)	3.2 (2.5–4.2)	0.482 (0.246–1.327)	1
I 45/51	3+1	17	7.1	3.4 (1.4–5.3)	1.9 (0.6–2.9)	3.0 (1.5–3.9)	0.613 (0.049–1.407)	2 (1–13)
I 45/51	3+3	22	9.0	5.8 (4.1–8.1)	4.0 (2.6–5.9)	4.9 (2.5–6.3)	2.144 (0.728–3.965)	1
NNDV	2+1	16	11.5	3.8 (3.0–4.9)	2.3 (1.4–3.5)	3.9 (3.1–4.6)	0.881 (0.274–1.479)	4 (1–6)
NNDV	2+2	19		3.9 (2.4–5.5)	2.2 (1.5–3.1)	3.8 (3.1–4.7)	0.665 (0.274–1.360)	1
NNDV	3+1	20		2.8 (1.6–3.8)	1.7 (0.6–2.4)	3.4 (1.6–4.2)	0.677 (0.059–1.766)	3 (1–9)
NNDV	3+3	22		6.1 (3.7–8.7)	4.2 (2.3–5.8)	5.8 (4.5–7.4)	2.449 (0.801–5.297)	1

Abbreviations: *dbh* – breast-height tree diameter; d_0 – basal tree diameter; *h* – total tree height; *w* – dry weight of the aboveground tree dendromass.
Note: [a] – The planting schemes are presented in all Clone-Age combinations (columns 1 and 2); [b] – Mean and minimum – maximum variable values in brackets are presented.

In regard with the number of observations per clone-tree form combination (Table 1), we restricted the models to one- and two-predictor-equations and considered either the basal (d_0, cm) or the breast height tree diameter (*dbh*, cm) as the principal predictor.

We used the power function of diameter (either basal or breast height), which is known as the allometric equation (Huxley 1972) and which is linearized in the log-transformed form, and performed analysis of covariance (ANCOVA) to test the factors spacing, age (root age in the case of the coppiced plants) and number of sprouts (for the coppiced plants) for inclusion in the model as predictor variables. In case of proven significant influence of the covariate on the intercept and/or the slope of the allometric equation, we tested the model with the respective functional components expressed as linear or power function of the covariate. The superiority of the expanded model forms to the simple allometric equations was further assessed by the extra sum of squares method and χ^2-test of Lakkis and Jones (Barrio-Anta et al. 2006, Picard et al. 2012). In addition, we examined 5 principal biometric models, based on tree diameter (basal or breast-height) and total tree height, which are used to model tree volume and biomass: combined variable, constant form factor, logarithmic, generalized logarithmic and Honer transformed variable (Clutter et al. 1983, Burkhart and Tomé 2012).

Prior to the analyses, we excluded the measurements of the trees, which are adjacent to missing plants and for which the available spacing is compromised and does not correspond to the design. All regression models tested were fitted in log-transformed form to the logarithm of total tree dendromass. The goodness-of-fit of the examined models was assessed by a set of nine criteria for adequacy (details are shown in the footnotes of Tables 4 and 5), e.g. tests for normality, homoscedasticity, unbiasedness, derived from Gadow and Hui (1999), Parresol (1999), Picard et al. (2012) and Sileshi (2014), and according to the requirement for biologically-logical model behaviour, by the adjusted coefficient of determination ($R_{adj.}$), the root mean squared error (RMSE) and Akaike information criterion (AIC), which were used also to select the best models. To convert the predicted values to arithmetic, untransformed units, the ratio correction for bias (Snowdon 1991) was applied (formula shown in the footnote of Table 4). Finally, we compared the newly derived clone and tree form-specific models with the generic biomass models for aboveground dendromass of hybrid black poplars, derived by Stankova et al. (2016), employing the estimation of model efficiency (*ME*) and the absolute relative error (*ARE*%) (formulae shown in the footnote of Table 6). Model efficiency (*ME*) is a relative measure of model performance analogous to the coefficient of determination, but of ideal value equal to zero (Gadow and Hui 1999). Mean value, 25th, 50th and 75th percentiles of *ARE*% were estimated, which indicate the range and the magnitude of prediction errors relative to predicted dendromass. In addition, we tested whether the biomass values predicted by the generic and the specific models differ significantly from each other by paired-samples non-parametric test (Sign test).

Results

With a few exceptions, the investigated covariates did not affect concomitantly the slope and the intercept of the allometric models, but either of them (Table 2). The ANCOVA results for the factor 'spacing' were ambiguous, while age was proven as a significant covariate of the d_0-based allometric models of all single-stem clones, but did not influence significantly the allometric equation parameters of coppiced poplars (except for the intercept of d_0-based model of 'Agathe'), where it corresponded to root age alone. A strong covariate effect in this case was manifested by the stem number, which was found to significantly contribute for the improved predictability of both types of allometric models of all coppiced clones (Table 2). The ANCOVA indicated stronger differentiation of the dendromass allometric models according to alternative tree forms than by clone.

One-predictor allometric models did not prove adequate for all clones and tree forms. Expanded models of d_0-based allometric equation were derived for 4 clone×tree form combinations, while allometric equation of *dbh* was only expanded

Table 2. Tests for spacing, age and number of stems as covariates of tree diameter in estimating aboveground tree dendromass.

Type of plant	Model		Significant covariates according to clone			
			Agathe	BL	I 45/51	NNDV
Single stem	$\ln w = b_0 + b_1 \ln dbh$	Intercept b_0	-	-	Age	Spacing
		Slope b_1	-	-	Age	Spacing
		Slope b_1 and Intercept b_0	-	-	-	-
	$\ln w = b_0 + b_1 \ln d_0$	Intercept b_0	Spacing Age	Spacing Age	Age	Spacing Age
		Slope b_1	Spacing Age	Spacing Age	Age	Spacing Age
		Slope b_1 and Intercept b_0	-	-	-	-
Coppiced	$\ln w = b_0 + b_1 \ln dbh$	Intercept b_0	Stem number	Spacing Stem number	Spacing Stem number	Spacing Stem number
		Slope b_1	Stem number	Spacing Stem number	-	Spacing Stem number
		Slope b_1 and Intercept b_0	-	-	Spacing	Stem number
	$\ln w = b_0 + b_1 \ln d_0$	Intercept b_0	Age Stem number	Stem number	Stem number	Spacing Stem number
		Slope b_1	Stem number	Stem number	Stem number	Spacing Stem number
		Slope b_1 and Intercept b_0	-	Stem number	Stem number	Stem number

Abbreviations: *dbh* – breast-height tree diameter; d_0 – basal tree diameter.

with the stem number for coppiced 'BL' saplings dendromass (Table 3). The two-predictor formulations in these cases proved to be significantly better than the reduced model forms, which was indicated by the Extra sum of squares and the Lakkis-Jones tests. Two-predictor models including basal diameter and age were mainly derived for the single-stem black poplar trees and adequate dependencies of height and diameter were also developed for all clones. Dendromass models, which included the number of sprouts as an independent variable, were developed for all coppiced clones that confirmed its predictive power (Table 3). Two-predictor dendromass models involving spacing were suggested for the single-stem 'Agathe' and for the coppiced 'BL' and 'NNDV' (Table 3).

Clone-specific aboveground dendromass models derived for the single-stem saplings showed higher goodness-of-fit than those of the coppices (Table 4), where more significant dissimilarity of dendromass trends among the clones was also noticeable (Fig. 2).

All equations, which were derived as the best per clone×tree form combination, revealed high accuracy and predictive power, except that for coppiced 'Agathe' trees (Tables 4 and 6). Honer transformed

Table 3. Aboveground dendromass models for the investigated poplar clones.

Clone		Single-stem trees		Coppiced trees
Agathe	**R**	$\ln w = b_0 + b_1 \ln d_0$	**R**	$\ln w = b_0 + b_1 \ln d_0$
	E1	$\ln w = b_0 Spacing^{b_1} + b_2 \ln d_0$	**E, B**	$\ln w = b_0 + b_1 SN \ln d_0$
	E2	$\ln w = b_2 + b_0 Spacing^{b_1} \ln d_0$		$\ln w = b_0 + b_1 \ln SN \ln d_0$
	E3	$\ln w = b_0 + b_1 \ln Spacing + b_2 \ln d_0$		$\ln w = b_0 + Age + b_1 \ln d_0$
	E4	$\ln w = b_0 + b_1 Age + b_2 \ln d_0$		
	E5	$\ln w = b_0 Age^{b_1} + b_2 \ln d_0$		
	E6	$\ln w = b_0 + \left(b_1 + b_2 Age\right) \ln d_0$		
	E7	$\ln w = b_0 + \left(b_1 Age^{b_2}\right) \ln d_0$		
	E8	$\ln w = b_0 + b_1 \exp(Age) + b_2 \ln d_0$		
	E9	$\ln w = b_0 + b_1 \ln Age + b_2 \ln d_0$		
		$\ln w = b_0 + b_1 \exp(Age) \ln d_0$		
		$\ln w = b_0 + b_1 \ln Age \ln d_0$		
		$\ln w = b_0 + b_1 \ln dbh$		
	B	$\ln w = \ln dbh^2 - \ln(b_0 + b_1 / h)$		
BL		$\ln w = b_0 + b_1 \ln dbh$	**R**	$\ln w = b_0 + b_1 \ln dbh$
		$\ln w = \ln\left(b_0 + b_1 \ln dbh^2\right)$	**E1**	$\ln w = b_0 + b_1 SN + b_2 \ln dbh$
	B	$\ln w = \ln dbh^2 - \ln(b_0 + b_1 / h)$	**E2, B**	$\ln w = b_0 SN^{b_1} + b_2 \ln dbh$
			E3	$\ln w = b_0 + (b_1 + b_2 SN) \ln dbh$
				$\ln w = b_0 SN^{b_1} \ln dbh$
			E4	$\ln w = b_0 + b_1 \ln SN + b_2 \ln dbh$
			E5	$\ln w = b_0 Spacing^{b_1} + b_2 \ln dbh$
				$\ln w = b_0 + Spacing^{b_1} \ln dbh$
			E6	$\ln w = b_0 + b_1 \ln Spacing + b_2 \ln dbh$
				$\ln w = b_0 + b_1 \ln d_0$
I 45/51		$\ln w = b_0 + b_1 \ln d_0 + b_2 h$	**R**	$\ln w = b_0 + b_1 \ln d_0$

		$\ln w = \ln b_0 + 2\ln d_0 + \ln h$	**E1, B**	$\ln w = b_0 + b_1 SN + b_2 \ln d_0$
		$\ln w = b_0 + b_1 Age \ln d_0$	**E2**	$\ln w = b_0 + b_1 \exp SN + b_2 \ln d_0$
	B	$\ln w = b_0 + Age^{b_1} \ln d_0$		$\ln w = \ln b_0 + 2\ln d_0 + \ln h$
		$\ln w = b_0 + b_1 \ln Age + b_2 \ln d_0$		$\ln w = b_0 + SN^{b_1} \ln dbh$
		$\ln w = b_0 + b_1 \exp Age \ln d_0$		
		$\ln w = b_0 + b_1 \ln Age \ln d_0$		
		$\ln w = b_0 + Age + b_1 \ln d_0$		
NNDV	**B**	$\ln w = b_0 + b_1 \ln dbh$		$\ln w = b_0 + b_1 SN + b_2 \ln dbh$
	R	$\ln w = b_0 + b_1 \ln d_0$	**B**	$\ln w = \ln(b_0 + b_1 SN) + b_2 \ln dbh$
	E1	$\ln w = b_0 + b_1 Age + b_2 \ln d_0$		$\ln w = b_0 SN^{b_1} + b_2 \ln dbh$
	E2	$\ln w = b_0 Age^{b_1} + b_2 \ln d_0$		$\ln w = b_0 + SN^{b_1} \ln dbh$
	E3	$\ln w = b_0 + (b_1 + b_2 Age)\ln d_0$		$\ln w = b_0 + b_1 SN + b_2 \ln dbh$
	E4	$\ln w = b_0 + b_1 \exp Age + b_2 \ln d_0$		$\ln w = \ln(b_0 + b_1 Spacing) + b_2 \ln dbh$
	E5	$\ln w = b_0 + b_1 \ln Age + b_2 \ln d_0$		$\ln w = b_0 + b_1 Spacing^{b_2} \ln dbh$
		$\ln w = b_0 + Age^{b_1} \ln d_0$		$\ln w = b_0 + b_1 \ln Spacing \ln dbh$
		$\ln w = b_0 + b_1 \exp Age \ln d_0$		$\ln w = \ln b_0 + 2\ln d_0 + \ln h$
		$\ln w = b_0 + b_1 \ln Age \ln d_0$		
		$\ln w = \ln b_0 + 2\ln d_0 + \ln h$		

Abbreviations: **E** – expanded model; **R** – reduced model; **B** – the best model for the clone; *SN* – number of stems; *dbh* − breast-height tree diameter, cm; d_0 – basal tree diameter, cm; *h* − total tree height, m; *w* – dry weight of the aboveground tree dendromass, kg.

variable model was the most adequate to describe the biomass of the monostem ’Agathe‘ and ’BL‘, while the simple *dbh*-based allometric equation was selected for ’NNDV’ clone. A d_0-based allometric model, in which the slope parameter was expanded by a power function of tree age, predicted best the dendromass of single-stem ’I 45/51’ saplings (Tables 4 and 5, Fig. 2a). All best models for the coppiced poplars included the number of sprouts as a second predictor variable (Table 4, Fig. 3). The breast-height diameter was principal predictor in the equations of ’BL‘ and ’NNDV’ clones, which intercepts were expanded with power (‘BL’) or linear (‘NNDV’) functions of stem number. Expanded forms of d_0-based allometric equation were derived for the coppiced ’Agathe‘ and ’I 45/51‘ where linear

Table 4. Adequacy tests for the best aboveground dendromass models.

Type of plant	Clone	Model	CF	R^2adj	RMSE	AIC	Mean error [a]	A-D [b]	B-P [b]	Model bias [c]	CN [d]	SR (%) [e]	LP (%) [e]	IP (%) [e]
Single stem	Agathe	$\ln w = \ln dbh^2 - \ln(b_0 + b_1/h)$	1.00	0.980	0.145	-164.0	0	0.343	0.122	0.068	7.26	4.65	0	2.33
	BL	$\ln w = \ln dbh^2 - \ln(b_0 + b_1/h)$	0.99	0.990	0.088	-211.7	0	0.332	2.123	0.287	2.24	2.27	2.27	4.55
	I 45/51	$\ln w = b_0 + Age^{b_1} \ln d_0$	1.03	0.936	0.222	-127.4	5.10×10^{-11}	0.522	5.748	1.79×10^{-4}	4.28	4.65	0	2.33
	NNDV	$\ln w = b_0 + b_1 \ln dbh$	1.01	0.970	0.139	159.9	0	0.498	1.036	4.72×10^{-27}	6.02	2.44	2.44	2.44
Coppiced	Agathe	$\ln w = b_0 + b_1 SN \ln d_0$	1.09	0.402	0.518	-40.2	0	0.241	3.059	1.62×10^{-28}	3.03	6.25	3.13	9.38
	BL	$\ln w = b_0 SN^{b_1} + b_2 \ln dbh$	1.02	0.936	0.216	-101.4	-1.57×10^{-4}	0.620	0.197	1.42×10^{-5}	4.00	5.88	5.88	8.82
	I 45/51	$\ln w = b_0 + b_1 SN + b_2 \ln d_0$	1.02	0.893	0.285	-72.5	0	0.333	2.318	0.078	9.05	10	6.67	10
	NNDV	$\ln w = \ln(b_0 + b_1 SN) + b_2 \ln dbh$	1.01	0.870	0.267	-92.3	0	0.399	4.934	4.46×10^{-5}	4.59	2.78	5.56	5.56

Note: [a] – Mean errors are not significantly different form zero in all cases; [b] – Null hypotheses for normality (Anderson-Darling test) and homoscedasticity (Breusch-Pagan test) of errors are accepted in all cases, as P>0.05; [c] – Null hypothesis for slope equal to 1 and zero intercept of the linear regression relating observed and predicted values is accepted in all cases, as P>0.05; [d] – Defined as a criterion for multicollinearity and must obtain values below 30; [e] – Outliers in the response variable are assessed by the percentage of Studentised residuals $\in[-2; 2]$. Leverage points are outliers with respect to the predictors and are compared to a reference value estimated as: 2(k+1)/n, where k is the number of predictors and n is the sample size. The influential points (Cook's D) are predictor combinations with unusually large weights in determining regression coefficients and are compared to a reference value estimated as: 4/n, n – sample size. The percentage of the influential observations, exceeding the reference values, must obtain value below 10 %. Abbreviations: *dbh* – breast-height tree diameter, cm; d_0 – basal tree diameter, cm; *h* – total tree height, m; *w* – dry weight of the aboveground tree endromass, kg; *CN* – condition number; *CF* – bias-correcting coefficient: $CF = \frac{\sum y_i}{\sum \exp(\overline{\ln y_i})}$ and $\hat{y}_i = CF \exp(\overline{\ln y_i})$, where $y_i, \hat{y}_i$ are experimental and predicted biomass values of the *i*-th measurement, and $\overline{\ln y_i}$ is the predicted value of the log-transformed biomass of the *i*-th measurement, RMSE – root mean squared error, kg; R^2_{adj} – adjusted coefficient of determination; AIC – Akaike Information Criterion; A-D – Anderson-Darling test statistics; B-P – Breusch-Pagan test statistics; SR – Studentised residuals; LP – Leverage points; IP – Influential points.

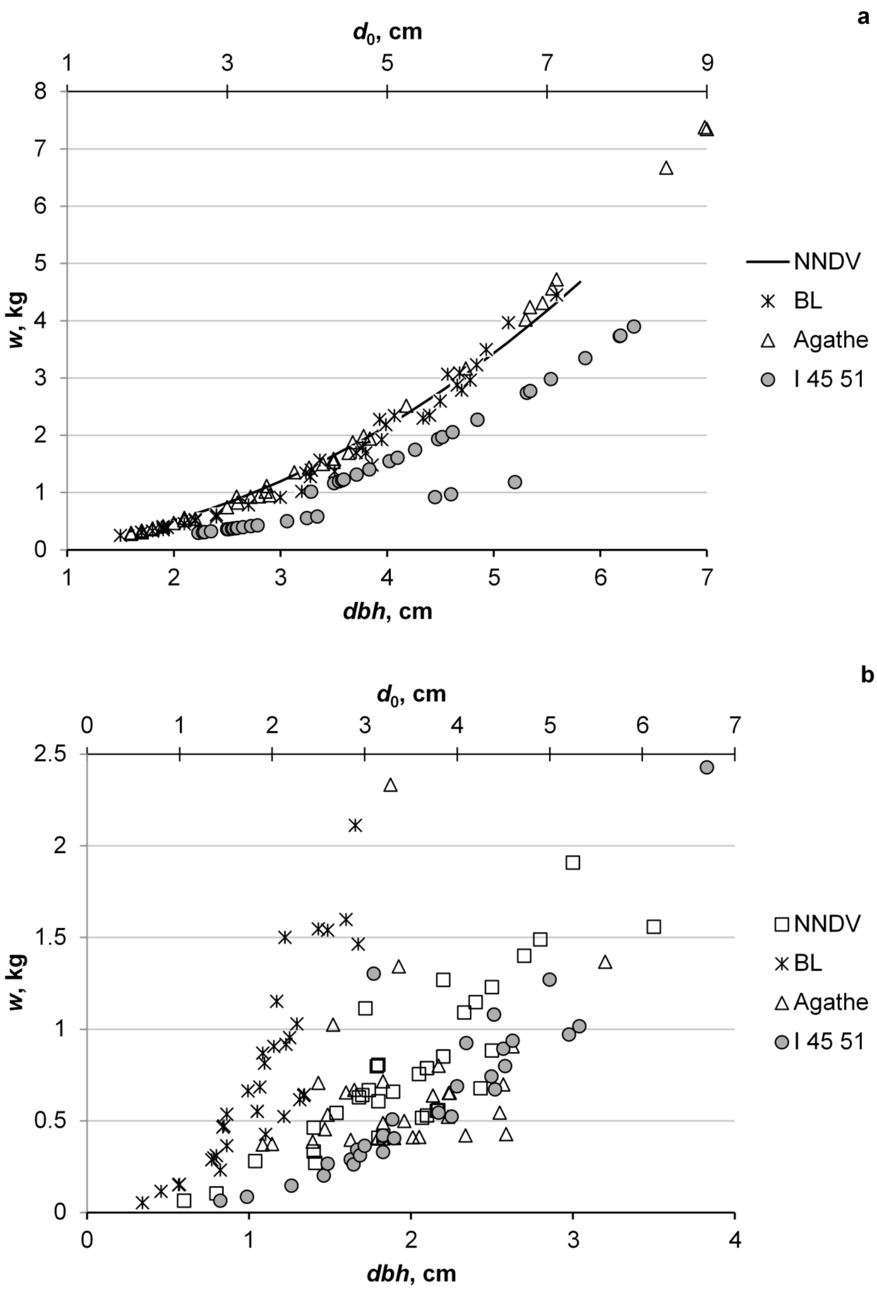

Fig. 2. Predicted aboveground dendromass by clone: a – Single-stem trees; b – Coppiced trees.

Abbreviations: *dbh* – breast-height tree diameter, cm; d_0 – basal tree diameter, cm; *w* – dry weight of the aboveground tree dendromass, kg.

Table 5. Parameter estimates for the best aboveground dendromass models.

Type of plant	Clone	Parameter	b_0	b_1	b_2
Single stem	Agathe	Estimate	4.695	14.451	
		SE	0.639	2.901	
		PRSE % [a]	13.61	20.08	
	BL	Estimate	4.808	16.102	
		SE	0.436	2.046	
		PRSE %	9.06	12.70	
	I 45/51	Estimate	-2.731	0.605	
		SE	0.076	0.027	
		PRSE %	2.80	4.46	
	NNDV	Estimate	-2.100	2.063	
		SE	0.067	0.057	
		PRSE %	3.19	2.78	
Coppiced	Agathe	Estimate	-1.188	0.164	
		SE	0.154	0.035	
		PRSE %	12.97	12.41	
	BL	Estimate	-2.259	-0.250	2.101
		SE	0.093	0.036	0.104
		PRSE %	4.13	14.38	4.93
	I 45/51	Estimate	-3.824	0.120	2.212
		SE	0.209	0.023	0.159
		PRSE %	5.45	19.07	7.21
	NNDV	Estimate	0.112	0.036	1.689
		SE	0.017	0.008	0.135
		PRSE %	15.38	20.74	7.97

Abbreviations: SE − standard error; PRSE % − Parameter Relative Standard Error, %; PRSE = 100×SE/|parameter|.
Note: [a] PRSE % was defined as a criterion for stability of parameter estimate and must obtain values below 30 %.

function of the stem number was incorporated in the slope (‘Agathe’) or the intercept (‘I 45/51’) of the model (Tables 4 and 5, Fig. 2b).

The clone-specific dendromass models, which possessed the higher goodness-of-fit within each tree form category (monostem ’Agathe‘, ’BL‘ and multistem ’BL‘, ’I 45/51‘), manifested also significantly improved prediction power as compared to the generic dendromass models for black poplar hybrids (Table 6). In the assessment of single-stem aboveground dendromass, the generalized models revealed error range and model efficiency of very similar magnitude to that, estimated for the specific models. The new specific biometric models appeared most beneficial for the clone ‘BL’ regardless of its form (Table 6).

Discussion

The high stocking rate required for establishment of short-rotation crops can be achieved by either closely spaced monostem plantings or by coppicing; the priority to coppicing should be given when the average of mean annual increments of coppice harvests is greater than the maximum mean annual increment of single ro-

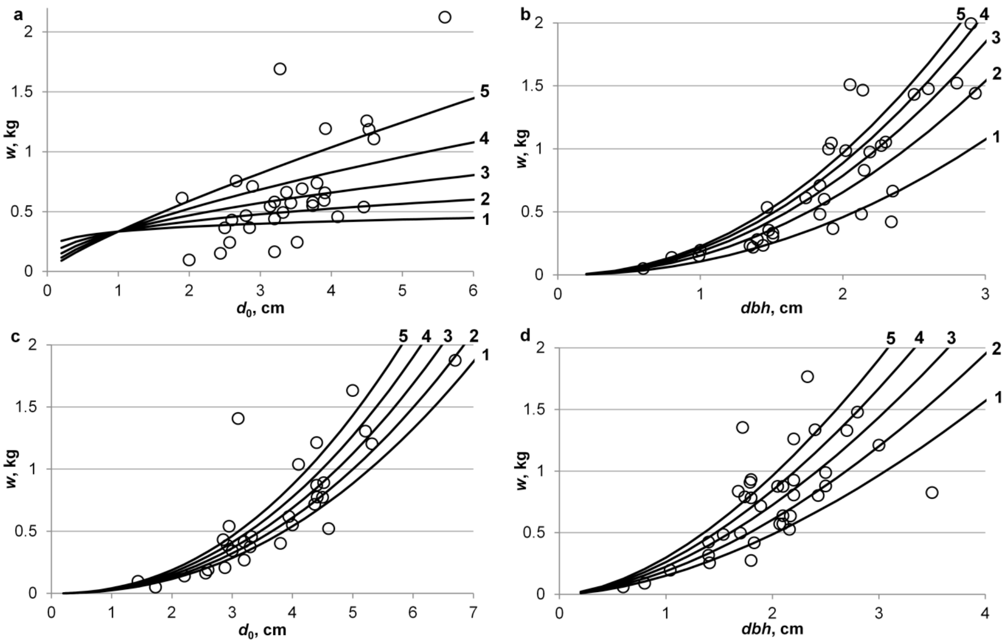

Fig. 3. Aboveground dendromass prediction trends for coppiced hybrid poplars according to tree diameter and number of sprouts (1, 2, 3, 4, 5): a – Agathe; b – BL; c – I 45/51; d – NNDV.

Abbreviations: *dbh* – breast-height tree diameter, cm; d_0 – basal tree diameter, cm; *w* – dry weight of the aboveground tree dendromass, kg.

tation (Ribeiro and Betters 1995). The investigated experimental plantation allows to study in parallel both single-stem and coppiced poplar saplings and we aimed at development of reliable clone-specific biometric relationships to enable fast estimation and comparison of aboveground dendromass productivity of particular genotypes. Plant biomass allometry studies have been conducted by either direct modeling of total tree biomass or by development of additive systems of equations for different plant compartments (Laureysens et al. 2005; Zianis et al. 2005; Fajman et al. 2009; Menéndez-Miguélez et al. 2013; Stankova et al. 2015, 2016). Our study developed clone-specific biometric models for aboveground tree dendromass assessment to address the need of fast, simple and easy calculation for practical purposes. The comparison with the previously derived generic additive models (Stankova et al. 2016) revealed that both model types were adequate for the single-stem juvenile poplars. As expected, the same manner of application of the generalized models to coppiced plants was not very appropriate since the resultant estimates reflected more the dendromass of the main sprout alone rather than the dry mass of the entire stool. Alternatively, the generic dendromass model can be applied individually to each shoot on the stump, but such calculation would be rather complicated and the breast-height diameter may not be an adequate predictor, because of the smaller size of secondary shoots.

Table 6. **Comparison between specific and generic dendromass models.**

Type of plant	Clone	Sign test statistic [a]	Generalized model					Specific model				
			ME	MARE %	Perc25	Perc50	Perc75	ME	MARE %	Perc25	Perc50	Perc75
Single stem	Agathe	10.5***	0.090	0.18	0.08	0.19	0.26	0.021	0.11	0.04	0.09	0.16
	BL	13.0**	0.098	0.14	0.05	0.15	0.20	0.024	0.07	0.03	0.05	0.11
	I 45/51	-1.5^{ns}	0.180	0.19	0.07	0.14	0.27	0.063	0.17	0.05	0.12	0.24
	NNDV	3.5^{ns}	0.121	0.13	0.03	0.11	0.21	0.050	0.12	0.06	0.11	0.16
Coppiced	Agathe	2.0^{ns}	0.712	0.32	0.12	0.33	0.47	0.566	0.48	0.12	0.31	0.55
	BL	21.0***	0.839	0.35	0.18	0.42	0.49	0.071	0.16	0.04	0.10	0.22
	I 45/51	4.5**	0.629	0.38	0.24	0.39	0.49	0.157	0.24	0.11	0.23	0.33
	NNDV	10.0^{ns}	0.978	0.32	0.17	0.32	0.46	0.410	0.21	0.08	0.15	0.34

Abbreviations: *ME* – model efficiency; $ME = \frac{\sum (y_i - \hat{y}_i)^2}{\sum (y_i - \overline{y})^2}$; *ARE*% – absolute relative error; $ARE\% = \frac{|y_i - \hat{y}_i|}{y_i} 100$, where $y_i, \hat{y}_i$ are experimental and predicted biomass values of the *i*-th measurement and $\overline{y}$ represents the mean observed biomass value; *MARE* % - mean absolute relative error; Perc25, Perc50 and Perc75 denote the 25th, 50th and 75th percentile of the absolute relative errors, respectively.

Note: [a] – the null hypothesis tests that the median of the paired differences distribution equals zero. Level of significance: *** - *P*<0.001, ** - *P*<0.01, ^{ns} – *P*>0.05.

The majority of the studies on coppiced plantations use the general allometric equation (Huxley 1972), by relating dry biomass weight of each individual shoot on the stump to a power function of its diameter at a certain height above ground and evaluate the total plant mass per stump or unit area by summing up the individual shoot weights (Laureysens et al. 2003, 2005; Paris et al. 2011; Ghaley and Porter 2014; Verlinden et al. 2015). Proe et al. (1999), on the other hand, employed as a predictor in their allometric equations the individual shoot basal area, while the sum of the basal areas of the sprouts on a stump was used in the models by Razakamanarivo et al. (2012). To provide a quick estimate of biomass by measuring only some stems in a stool, Menéndez-Miguélez et al. (2013) attempted in modeling the whole-stool dendromass of coppiced chestnut the same approach as our for coppiced poplars. The size (diameter and height) of the biggest shoot was not derived as a good predictor of coppiced chestnut plants in their study and they employed instead the mean shoot diameter and the basal area of stool together with the number of sprouts on the stump (Menéndez-Miguélez et al. 2013). Diameter (basal or breast-height) of the principal sprout was proven as a good predictor of poplar dendromass at stump level in our study and the best biometric models including diameter and number of shoots explained more than 85 % of the variation in the stool biomass of 3 of the investigated clones. Ceulemans and Deraedt (1999) emphasized that there was a great deal of genotypic variation in the number of sprouts after coppicing and Laureysens et al. (2003) found significant correlation between the number of shoots and stool biomass. In an investigation on coppiced willows Bergkvist and Ledin (1998) also found strong correlation between biomass and number of shoots, but the authors pointed out that the variability in shoot number increased with age leading to decreased influence of the shoot number as a covariate. This finding suggests that the results of our study can be further extended and conclusions would be strengthened by inclusion of data for 2- and 3-year-old shoots.

Numerous studies investigate the influence of stand density on biomass production (*sensu* Cañellas et al. 2012), but very few address its effect on the biomass allometry. Our results on the influence of spacing as a predictor of aboveground dendromass were not unequivocal and significant relationships were established for two coppiced (‘BL’ and ‘NNDV’) and one single-stem (‘Agathe’) clones only. Although inclusion of the independent variable ‘spacing’ significantly improved the predictability of diameter-only equations, the two-predictor models based on the other tested covariates showed higher goodness-of-fit. In line with the allometry investigations of other species of monostem tree form (Bond-Lamberty et al. 2002, Porté et al. 2002, Shaiek et al. 2011), we also derived age-dependent dendromass models for the single-stem ‘Agathe’, ‘I 45/51’ and ‘NNDV’. However, the biometric relationships of coppiced poplars in regard with various root-shoot age combinations is of particular interest and requires further investigation.

Conclusions

Clone-specific as well as the generalized allometric models applied to the particular poplar clones revealed high accuracy and predictive power in estimation of aboveground tree dendromass of individual stems. The whole-stump dendromass of coppiced poplars can be reliably assessed by employing models based on either basal (‘Agathe’, ‘I 45/51’) or breast-height (‘BL’, ‘NNDV’) diameter of the main sprout and the number of shoots per stump. Further investigation on the allometry of coppiced poplars is envisaged by inclusion of data for 2- and 3-year-old shoots and in regard with various root-shoot age combinations.

Acknowledgements

We thank the forestry officers from Oryahovo Forest Range for their cooperation and logistic support in carrying out the experimental work and data collection. We are grateful also to the Executive Forest Agency that provided financial support for this work through the project ’Establishment of experimental plantation from perspective poplar clones (*Populus* sp.) for comprehensive assessment of their potential for biomass production‘ (Contract N108, 2013).

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FORESTRY IDEAS, 2016, vol. 22, No 2 (52): 171–187

SOCIO-ECONOMICS AND STATUS OF TWO NON-TIMBER FOREST PRODUCTS (*IRVINGIA* FRUIT AND KERNEL) IN A CHANGING ENVIRONMENT IN CROSS RIVER STATE, NIGERIA

Agbaeze Umazi Udeagha[1,2*], Enefiok Sunday Udo[1], and Opeyemi Olajide[1]

[1]Department of Forestry and Natural Environmental Management,
University of Uyo, Uyo, Akwa Ibom State, Nigeria
[2]Department of Forestry Technology, Hussaini Adamu Federal Poytechnic, Kazaure,
Jigawa State, Nigeria. *E-mails: aumazi@yahoo.co.uk; uumazi@gmail.com

Received: 20 June 2016 Accepted: 06 October 2016

Abstract

Irvingia fruit and kernels are valuable socio-economic non-timber forest products in South Eastern Nigeria. The dried kernels have long been used in the kitchen as a condiment for the preparation of local dishes and the market continues to expand, because of its contributions to household income and dietary needs. The study focused on the socio-economics and status of *Irvingia* fruits and kernels, in two local government areas (LGAs) within the rainforest of Cross River State, South Eastern Nigeria. A multi-stage sampling technique was employed for the study. Two hundred households in 8 villages were interviewed using semi-structured questionnaire and other participatory methods for data collection. The data collected were analysed using descriptive statistics and Likert type scale. The results of study revealed that 78.5 % of the respondents prioritised the kernels and fruits as a very important source of income and food for their households. Also, 91.5 % of the respondents claimed that the abundance of the fruit and kernel has decreased over time due to extreme changes in the environment. The results of the Likert scale analysis rated perceived effect of changes in the environment on the overall abundance of *Irvingia* fruit and kernel economic and culinary value to be high and positive ($\overline{X}$ = 4.02), which implies that the sustainable availability of *Irvingia* fruits and kernels and their contributions to local household dietary needs and income is not guaranteed. It is imperative to intensify both *in-situ* and *ex-situ* conservation of this valuable tree species.

Key words: Abundances, environmental changes, fruits, *Irvingia* species, kernels, perception.

Introduction

Non-timber forest products (NTFPs) are of enormous socio-economic, cultural and ecological importance in sub-Saharan Africa; the essence of which are extensively documented (Agustino et al. 2011, Ambrose-Oji 2003, Asaah et al. 2003, Ayuk et al. 1999, Bharucha and Pretty 2010, Ermias et al. 2014, Heubach 2012, Heubes et al. 2012, Heubach et al. 2013, Nkwatoh et al. 2010, Shomkegh et al. 2013, Vihotogbe 2012, Vihotogbe et al. 2015, Shomkegh et al. 2016). In fact, across sub-Saharan Africa, wild foods gathered from the forests and other natural or modified ecosystems, are vital for supplementing agricultural production by contributing to improve food availability, food security and equally plays an essential role in foreign exchange earnings (Ayuk et al. 1999, Bharucha and Pretty 2010, Heubach et al. 2011, Vinceti et al. 2013, Shackleton 2014). NTFPs are especially crucial in years of low agricultural productivity, usually as a result of extreme climate events such as drought, flood, disease and pest outbreak and other natural disasters (Shackleton 2014, Takasaki 2011, Bharucha and Pretty 2010, Fentahun and Hager 2009, Jumbe et al. 2008, Mojeremane and Tshwenyane 2004).

Generally, NTFPs offer a potentially critical role in buffering against food stress caused by changing environmental conditions (Bharucha and Pretty 2010, Shackleton 2014). NTFPs in times of stress can thus be viewed as an effective coping mechanism for dealing with threats to food security (Shackleton 2014, Shackleton et al. 2011, Fentahun and Hager 2009) because of their innate resilience to changing environment by assisting communities to cope in adverse situations (Msalilwa et al. 2013, Shackleton 2014). Furthermore, NTFPs are numerous and versatile (Ambrose-oji 2003, Ahenkan and Boon 2011, Agustino et al. 2011, Shackleton 2014) but this study is considering only one of the most important socio-economic NTFPs found in South-Eastern Nigeria, which have contributed immensely to household income and dietary needs overtime. *Irvingia* species (*Irvingia wombolu* Verm. and *Irvingia gabonensis* Baill.) are highly valuable and extensively utilised tropical African trees and have been identified as very high priority tree species (Ainge and Brown 2001, Nkwatoh et al. 2010). They are among the most important multipurpose indigenous food tree species in West and Central Africa because of its continuous high income share and dietary contribution to rural households (Agbor 1994, Ainge and Brown 2001, Asaah et al. 2003, Ayuk et al. 1999, Babalola and Agbeja 2009, Ewane et al. 2009, Lowe et al. 2000, Nkwatoh et al. 2010, Sunderland 2001, Sunderland et al. 2003, Vihotogbe 2012) and with a market value of about US$ 260,000 per annum across West and Central Africa (Asaah et al. 2003, Nkwatoh et al. 2010, Sunderland et al. 2003). The dried kernels have long been used in the kitchen as condiment for the preparation of local dishes such as “ogbono soup” and other sauce, and the market continues to expand because of its big contributions to households’ income and dietary needs. The soup-thickening quality is enhanced by viscosity and drawability, which varies by tree species and by geographical location (Asaah et al. 2003, Lowe et al. 2000, Vihotogbe et al. 2015).

In Nigeria, it is generally perceived that *Irvingia* kernels has more drawability or viscosity properties than any other viscous food condiment and these has increased the priority place on the *Irvingia* species in terms of its preference to culinary value, conservation and contribution to household income. Albeit, the abundances of these NTFPs can be seriously affected by changes in the environment through the evidences of past and future climate simulations in Nigeria and other West-African counties (Abiodun et al. 2013; IPCC 2013, 2014, Heubes et al. 2013; NEST 2011; Shackleton 2014). However, it could be expected that under predicted environmental change, particularly the increase in frequency and intensity of extreme events, the likelihoods of people resorting to consumption of wild foods and sales of NTFPs as a coping strategy may expand (Bharucha and Pretty 2010, Heubes et al. 2012, Shackleton 2014, Shackleton et al. 2010, Woittiez et al. 2013, Vihotogbe 2012).

Evidently, little is known about how environmental changes, interacting with other drivers of change will impact the forest, more particularly, the range of products and resources the people rely on (Bharucha and Pretty 2010, Nkem et al. 2010, Shackleton 2014). More so, limited research has been undertaken to consider how changes in climate may affect the distribution, productivity or availability of the wild species especially NTFPs that people use for food and other purposes (Shackleton 2014). In order to ensure a viable and sustainable production system of *Irvingia* species in Nigeria, there is need for further understanding of the socio-economics of *Irvingia* in Nigeria (Ladipo 1999), since research initiatives in this direction are still scarce and hindered by poor sampling in quantitative and comparative studies over the entire distribution range of *Irvingia* species and other NTFPs in West Africa (Heubach et al. 2013, Vihotogbe 2012). There is, therefore, a need to examine the perceived socio-economic factors that affect the trends of abundance and status of *Irvingia* fruits and kernels in a changing anthropogenic environment. It is anticipated that the findings of this study may serve as an incentive to safeguard its protracted use and consequent conservation.

Material and Methods

Study area

This study was carried out in Akamkpa and Etung local government areas (LGAs) of Cross River State, Nigeria (Fig. 1). The study area occupies a land area of 7,908.47 km^2 or 42.80 % of the total land area spanning the tropical high forest areas of Cross River State (CRS) at 5°20’ and 6°20’ N and longitudes 8°05’ to 8°45’ E (Oyebo et al. 2011). The rainy season commences in the area around March and extends to November, while dry season occurs between December and February, reaching its peak in January, when the harmattan wind sweeps across the entire area. However, the time of commencement, cessation of rainy season and changes in other weather events are recently becoming very irregular and unpredictable. The annual average rainfall is between 2233.33 mm in Etung and 2977.21 mm in Akamkpa with an average temperature for Etung 32.03 °C and 30.90 °C for Akamkpa and an average wind speed of 93.89 knots for Akamkpa and 28.97 knots for Etung in the past 32 years (Udeagha 2015). The arable land in the area is predominantly used for the cultivation of perennial crops, such as plantain and banana, cash crops (cocoa) and other arable crops. Bush fallow cultivation is clearly dominant as it engages about 84 % of the population (Bisong 2004).

Multi-stage sampling technique was employed for this study. The first stage involved purposive selection of two local government areas (LGAs), identified as having forest resources and proximity to forest reserves, national parks and market access from the list of 18 LGAs in Cross River State. In the second stage, four rural villages were selected randomly from each of the two LGAs with emphasis on villages identified as having forest resources, located adjacent to the forest, accessible to market, access roads or water transport and extent of NTFPs in the area, representativeness and accessibility. In all, 8 villages were randomly selected for the study, namely: Nsofang, Abijang, Mkpot and Itaka in Etung LGA: Mfaminyen, Ojok,

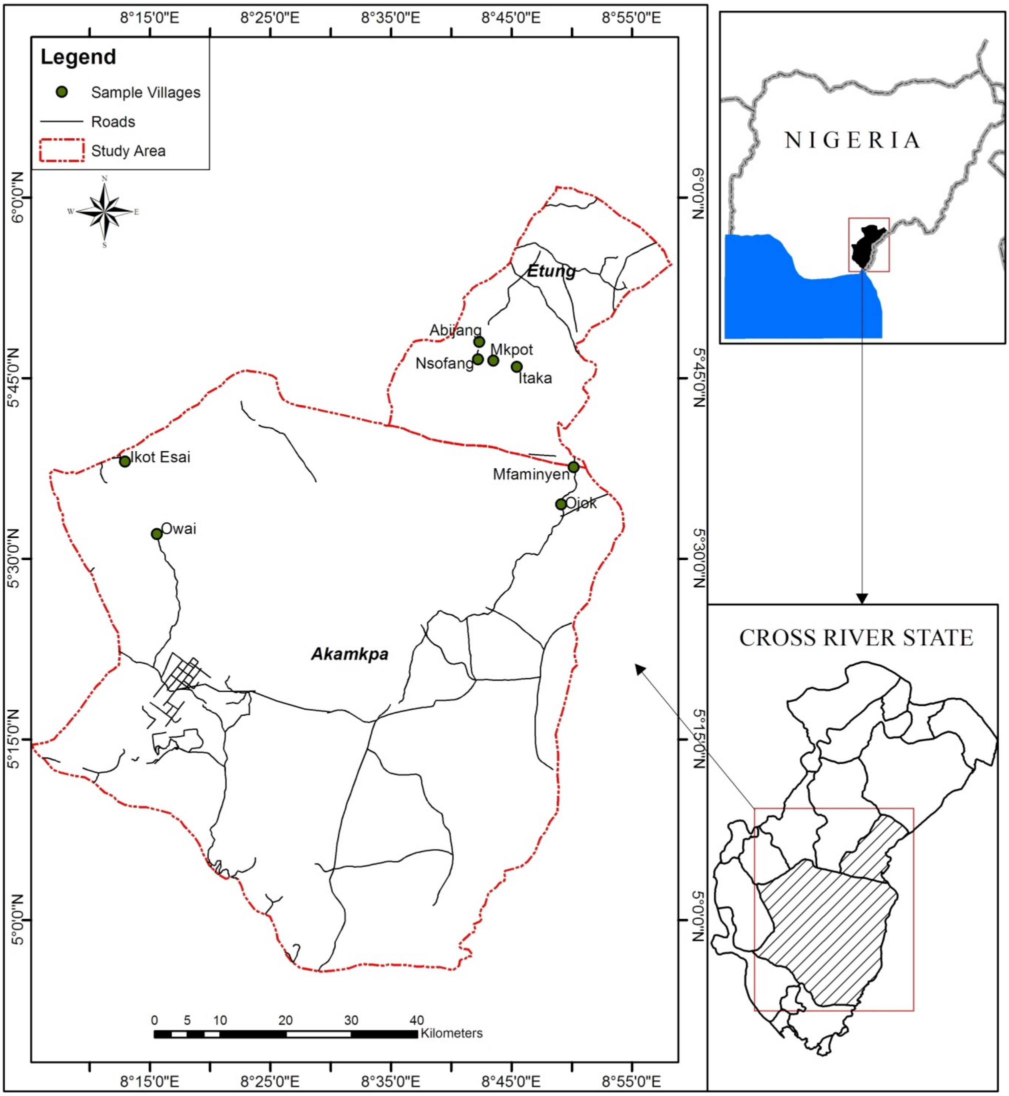

Fig. 1. Map of the study areas showing selected local government areas and sampled villages.

Owai and Iko Esai in Akamkpa LGA (Table 1). In the third stage, sample households were selected using lottery method. The list of sampled households in each village was obtained with the assistance of community leaders and their councils. The household's involvement in NTFP-related livelihood activities and access to the forest was used as yardstick while selecting the sample households. Each household identified to be involved in NTFP-related activity in each of the selected villages was assigned a number on paper, which was then put in a box.

The numbers were drawn from the lottery box without replacement until a sam-

Table 1. Local government areas, villages, number of households and sample size used.

LGAs	No of villages*	Sampled villages	No of households	No of sampled households
Akamkpa	63	Mfaminyen	365	25
		Ojok	371	25
		Owai	267	25
		Iko Esai	425	25
Etung	14	Nsofang	496	25
		Abijang	432	25
		Mkpot	412	25
		Itaka	374	25
	78	8	3142	200

Note: * – Source Cross River State traditional ruler's council audit of villages (1976).

ple size of 25 households was reached in each village (Angelsen et al. 2011), corresponding to 5–10 % of households in the villages. In order to ensure comparison, variation and representativeness in the selection of geographical sub-units (villages) in a study, Angelsen et al. (2011) stipulated, as the rule of thumb, a minimum sample size of 25–30 households from each village as appropriate for a village ranging in size from 100–500 households (Table 1).

Both primary and secondary data were collected. Primary data was collected from the study area through the combination of both qualitative and quantitative tools using a semi-structured questionnaire, supplemented by other participatory approaches such as focus group discussions (FGDs), among others for the data collection. The questionnaire was developed based on the reconnaissance survey, consultation with different experts on socio-economic issues and reference to literature. Individuals, who had lived in the area for a long time and had good experience of the uses and trade in *Irvingia* fruits and kernels, were selected for the FGDs. FGDs were conducted by forming small groups (4–6 members) with extractors and brokers sharing similar background and who have experience and ample knowledge of utilization of the species. In all, a total sample size of 200 households in 8 villages was selected and used for administering the semi-structured questionnaire.

Data Analysis

The data collected was analysed using IBM Statistical Package for Social Science version 20 and Excel 2007. Descriptive statistics such as percentages, tables, frequencies, standard deviation and graphs, as well as inferential statistics such as Likert type scale, were employed in analysing the socio-economic characteristics of the households and the trends in perception of the abundance of *Irvingia* fruits and kernels in the past 10 years, respectively. The Likert type scale for the determining the household perceived impact of changing environment on the availability of *Irvingia* fruits and kernel as follows:

The mean scores of respondents' responses to the questions were used to assess the impacts of climate change. The mean scores (weighted mean) were derived from a five point Likert scale question (Impact statement): “Strongly agreed” = 5, “Agreed” = 4, “Undecided” = 3, “Disagreed” = 2, and “Strongly disagreed” = 1. To determine the possible impacts of changing environmental conditions on the abundance of *Irvingia* fruits and kernels as perceived by the households, the values on the Likert-type scale were summed to get 15, and then divided by 5, to get a mean score of 3. The overall mean was calculated by dividing the sum of mean score by the number of impact statements. The equation is expressed as specified by (Likert 1932, Denis and Dormody 1994, Sullivan and Artino 2013, Belachew and Zuberi 2015) in Eqn. 1.

$$\frac{\sum \bar{X}}{N} \quad (1),$$

where:

$\sum \bar{X}$ – Summation of the mean score from each impact statement;

N – Number of impact statement.

Decision rule: Any impact statement mean score of ≥ 3.00 was taken as significant, positive and ‘agreed’ decision that changing environmental conditions had been impacting on the availability of *Irvingia* species (fruits and kernel) over time, while mean score of < 3.00 was regarded as a negative and disagreed decision, implying that changing environmental conditions had no impact on the availability of *Irvingia* species (fruits and kernels) in the study area. A grand mean (overall mean) of > 3.00 was regarded as ‘agreed’, indicating that the respondents perceived impact of changing environment on availability of *Irvingia* fruits and kernels as significant, positive and high, while any grand mean score of < 3.00 was regarded as ‘disagreed’, indicating that the households perceived changing environmental impact on the abundance of *Irvingia* fruits and kernels was negative and low.

Results and Discussion

Socio-economics characteristics of households involved in the gathering/extraction of *Irvingia* fruits and kernels

The socio-economic characteristics of the households presented in Table 2 revealed that the ages of the sampled household heads ranged between 28 and 75 years, with an average of 48.51 years. This implies that the respondents have a lot of experience with regard to changes in their environment and gathering of *Irvingia* fruits and kernels and could be in a better position to make inference on the trends of abundance of *Irvingia* fruits and kernel. This agreed with the findings of Akponikpe et al. (2010), Awe et al. 2011 and Msalilwa et al. (2013) that age had an influence on the accumulation of knowledge on environmental changes and variability and gathering of NTFPs of a particular locality. Overall, 82 % of the household heads were between 25 and 59 years (Table 2). This demonstrated that majority of the household heads were still there in productive and active working age, which is below 60 years, and are still actively involved in the gathering and collection of *Irvingia* fruits and kernels for their household needs.

Among the respondents, 73 % and 27 % were male and female household heads, respectively. About 30 % of the respondents did not have formal education, while the rest had primary (34.5 %), secondary (25 %) and tertiary (10.5 %) education, respectively. This high rate of literacy among the respondents could positively influence their perception of environmental changes and variability. This agreed with the findings of Msalilwa et al. (2013) and Fonta and Ayuk (2013) that educational level influenced the people's perception of changes in environment and variability. Majority of the respondents (94 %) were native to the area, thus this implies that they are very much aware of changes in the environment and would be in the position to tell their own story about the trend in changing climate and their level of involvement in collection and gathering of *Irvingia* fruits and kernels, while the rest (6 %) were migrants/settlers from other places, who came for trade in *Irvingia* fruits and kernels or as migrant labourers who also help local households in the gathering, collection and processing of kernels of these NTFPs. Ermias et al. (2014) and Msalilwa et al. (2013) affirmed that how long a person lived in an area helps the individual to accumulate experience and knowledge on the changes in the environmental condition and their participation in forest related (mainly NTFPs) activities of that particular locality. A large proportion (97 %) of the households engaged in crop and livestock production, as well as trading in *Irvingia* fruits and kernels to supplement their source of livelihood because these could serve as a supplementary and alternative sources of food and income especially crucial in years of crop failure, usually as a result of extreme weather event (See Shackleton 2014, Woittiez et al. 2013). This also agreed with the findings of Belachew and Zuberi (2015), Blench (2003) and Kurukulasuriya and Mendelsohn (2008), who asserted that mixed cropping and crop switching helped farmers to cope and adjust to prevailing environmental condition like climate change.

Forest land is an important fixed asset to the households upon which cultivation of agricultural crops, rearing of livestock and collection of NTFPs depend. The result shows that (87.5 %) of the households had their land, while (12.5 %) did not have their own land (Table 2). Among those who had their own land, majority (72 %) got theirs' through open access to land acquisition. Open access is a means of land acquisition whereby an individual or household claim portion of forested land through own clearance (Fonta and Ayuk 2013). This practice was found to be prevalent in the study area where land was cleared in order to give way for the expansion of agricultural activities, especially for the cultivation of cocoa tree (*Theobroma cacao* L.) alongside with *Irvingia* species. However, the *Irvingia* trees function as shade to the cocoa trees and equally provides additional income and food for the farmers. This practice was observed to be a very high surrogate income generation for the households in the study area. The remaining (23.5 %) of the respondents got their land through inheritance, while 4.5 % got theirs through lease or rent.

The family size ranged from 1 to 15 persons, with the majority (46 %) of the households having 7 to 9 persons with an average of 8 persons per household (Table 2). The high household size implies that the household's involvement in the collection and gathering of *Irvingia* fruits and kernels could be high in order to supplement both their food and other household's needs. Accordingly, Anyanwu (2013) indicated that following micro-economic arguments in Nigeria, children are considered as an essential part of the household's work force to generate household income, and as insurance against

Table 2. Distribution of households based on their demographic and socio-economic characteristics.

Variables	Frequency, N	Share, %
Age:		
28–35	19	9.5
36–43	52	26.0
44–51	56	28.0
52–59	37	18.5
60–67	27	13.5
68–75	9	4.5
Household headship by gender:		
Male-headed	146	73.0
Female-headed	54	27.0
Educational Status of households:		
Non-formal	60	30.0
Primary	69	34.5
Secondary	50	25.0
Tertiary	21	10.5
Residence:		
Born where respondent resides	188	94.0
Migrated	12	6.0
Household's primary occupation:		
Trading in NTFPS/crop/livestock	194	97.0
Trading/ civil servant	6	3.0
Land ownership:		
Yes	175	87.5
No	25	12.5
Methods of Land Acquisition:		
Open access	144	72.0
Inherited	47	23.5
Lease/rent	9	4.5
Household size:		
≤3	12	6.0
4–6	50	25.5
7–9	92	46.0
10–12	45	22.5
13–15	1	0.5
Household heads' years of occupational experience:		
≤12	22	11.0
13–20	71	35.5
21–28	42	21.0
29–36	41	20.5
37–44	18	9.0
45–52	6	3.0

old age. About one third (35.5 %) of the household heads had between 13–20 years of occupational experience, while 21 % and 20.5 % had 21–28 and 29–36 years of occupational experience, respectively (Table 2). The average number of years of occupational experience was 24 years for the sampled households. This result indicated that the respondents were highly experienced in their various occupations and, therefore, were in a good position to make reasonable livelihoods from it, while also being aware, to a large extent, of the changes in the environment. Maddison (2007) and Gbetibouo (2009) reported that farmers with high level of farming experience were more likely to notice environmental changes than those with less farming experience. This result also indicated that the households were aware of the salient implications of changing environment on their livelihoods. This concurred with the findings of Maddison (2007) in eleven African countries that farming or working experience increased households' perception of environmental changes in a particular locality.

Household's prioritisation of uses of *Irvingia* fruits and kernels in the past 10 years

Majority (78.5 %) of the respondents prioritised *Irvingia* fruits and kernels as a very important source of income and subsistence use for their households, while 21.5 % considered it to be important in the last ten years (Fig. 2). Most of the sampled households (97 %) placed very high priority on the kernel rather than on the edible pulp since the kernel was the 'gold', which brought the much needed income. Trade in the kernel of *Irvingia* species played a very important role in contributing to rural household economy, thus helping the rural households to meet both their food and other household's needs (Ayuk et al. 1999, Sunderland et al. 2003, Ewane et al. 2009, Babalola and Agbeja 2009, Nkwatoh et al. 2010).

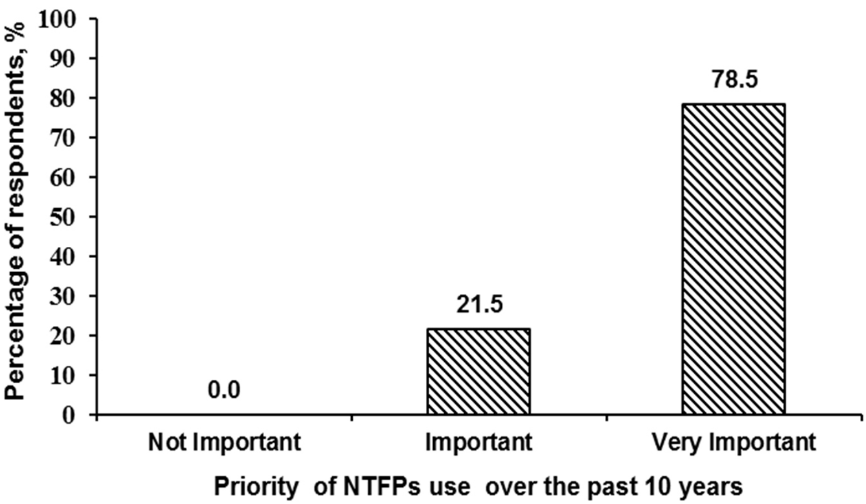

Fig. 2. Ranking of uses of *Irvingia* fruits and kernels.

Local perception on past and present abundance of *Irvingia* fruits and kernels ($1= ₦198)

Majority (91.5 %) of the respondents reported that *Irvingia* fruits and kernels were becoming rarely abundant recently. This implied that its abundance had decreased over the years, while 8.5 % maintained that *Irvingia* fruits and kernels were still abundant (Fig. 3). Sixty percent (60 %) of the respondents believed that *Irvingia* fruits and kernels were becoming less abundant in the past five years; 33.5 % maintained that they were still abundant, while few (5.5 %) believed that the fruits and kernels were becoming more abundant in the last five years (Fig. 3). Fifty-five percent (55 %) of the households affirmed that *Irvingia* fruits and kernels were more abundant ten years ago; 32 % affirmed that *Irvingia* fruits and kernels were much more abundant about ten years ago, while 13 % believed that they were less abundant ten years ago (Fig. 3). The respondents reported that the demand for *Irvingia* fruits and kernels has increased significantly in the last 10 years, because of their decreasing supply due to environmental changes, hence non-abundance as before. This increase in demand became more intense in the 2012–2013 season, judging from the high number of brokers (buyers) who came to their villages in search of these NTFP. This was suggestive of the high economic value placed on the NTFP in terms of contributions to household economy. According to the sampled households, they were in the position to bargain for the selling price of *Irvingia* fruits and kernels from ₦ 3500 last season to ₦ 7000 this season for 6.5 kg measure of the kernels of the wet season species (*Irvingia gabonensis*). In the last season, the selling price for a 6.5 kg of kernels of the dry season species (*Irvingia wombolu*) was higher (₦ 8000) than the price (₦ 5000) in the subsequent season. This indicated that the supply was low, perhaps because *Irvingia* fruits and ker-

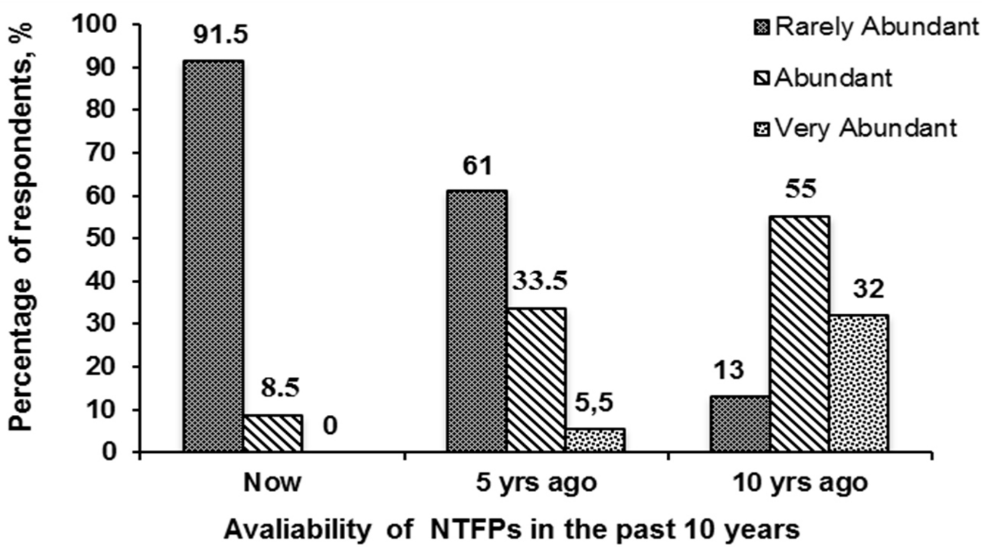

Fig. 3. Trend of abundance of I*rvingia* species in the past ten years.

nel were becoming less abundant than used to be the case in the past 10 years, thereby creating a supply gap by making the overall demand to exceed supply. Sunderland (2001) and Sunderland et al. (2003) had earlier reported that during the period of low supply both the wholesale and retail prices of *Irvingia* fruits and kernels could increase by up to 300 %.

Reasons for decrease in abundance of *Irvingia* species in the past 10 years

The reasons for the low abundance and diversity of *Irvingia* species across the study area could be attributed to lack of proper seed dispersal mechanism as reported by 89 % of the respondents, and its inability to withstand short-term changes in the environment due to extreme weather events (Vihotogbe, 2012). Humans and wild animals do not normally feed on *Irvingia wombolu* fruits because of the bitter pulp and juice (endocarp). Because of this, it is difficult for it to be properly dispersed and this invariably has reduced its diversity and abundance (Vihotogbe et al. 2014b). *Irvingia wombolu* fruits mature during the dry season when rainfall is inadequate to trigger germination or to create enabling environment to support germination (Vihotogbe 2012; Vihotogbe et al. 2014c; Vihotogbe et al. 2015). Ninety five percent (95 %) of the respondents strongly believed that the current climatic conditions had not favoured the increase in abundance of *Irvingia* spp. because they had continued to experience increase in extreme weather events in the past 10 years, which included damping of the flowers due to recent excessive rainfalls, shrinking of the flowers due to increase in heat intensity, and blowing way flowers by increase in wind speed according to them these would reduce the abundance of the fruits at maturity. Invariably this had contributed to overall decrease in the abundance of *Irvingia* spp over time.

Impact of decreased abundance of *Irvingia* fruits and kernels on rural household economic and food needs

Majority (71.5 %) of the respondents strongly believed that if the availability of *Irvingia* fruits and kernels kept decreasing, it would have significant impacts on its contribution to the overall household income and food needs (Fig. 4). For example, the NTFPs would lose their safety-net function in time of financial shortfall or environmental crisis such as crop failure, among others (Heubes et al. 2012, Shackleton 2014). On the other hand, only 20 % of the sampled households indicated that the decrease in the abundance of *Irvingia* fruits and kernels would have some impacts on its overall contribution to their wellbeing. However, 8.5 % of the households indicated that the decreasing availability of *Irvingia* fruits and kernels would have very little impact on its contribution to their overall wellbeing.

Perceived impact of changing climate on the abundance of *Irvingia* fruits and kernels economic and culinary value

The perception of changing climate survey using five point Likert scale (Table 3), has shown that the current changes in the environment was impacting on the abundance of *Irvingia* species economic and culinary values. All the respondents (100 %) strongly agreed that environmental changes were causing positive and significant reduction in the availability of *Irvingia* fruits and kernels, confirming the findings of Deryng et al. (2014), Shackleton (2014). Regarding reduction

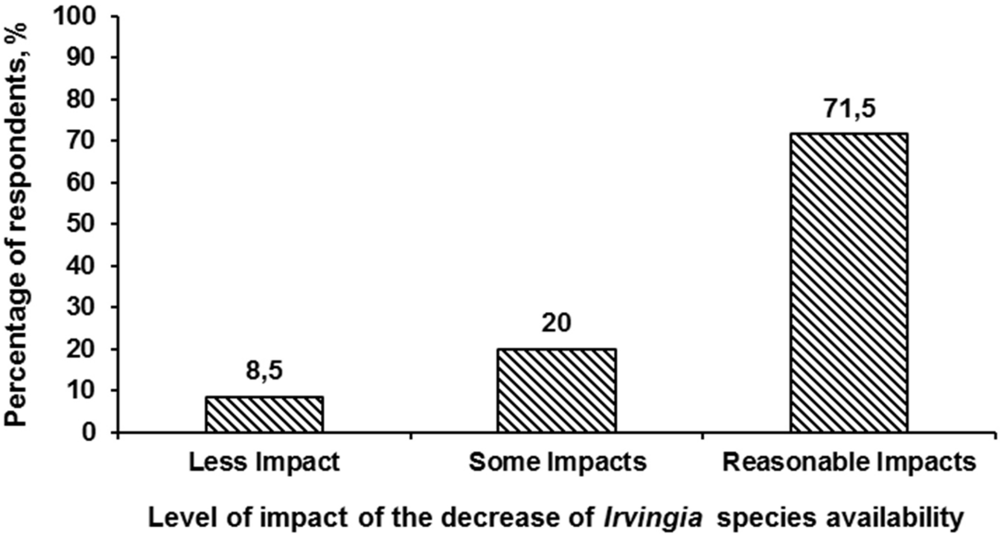

Fig. 4. Level of impacts of the decrease in *Irvingia* fruits and kernels abundances on household economy.

in quantity of collected *Irvingia* fruits and kernels, 87 % strongly agreed to the statement, while 13 % were undecided. Nearly 79.5 % agreed with statement reduction in income generated from the kernels. Also 45.5 % strongly agreed with the statement reduction in food availability and abundance, while 22 % strongly disagreed. About 48 % strongly agreed with statement that changing climate had not started inducing conflict over forest resource management with 25 % strongly disagreeing. However, 57.5 % of the households strongly agreed with the impact statement that changing climate had started triggering out-migration, thereby reducing availability of labour, while 16 % strongly disagreed. For all the response the most common rating was the "Strongly Agreed", the weighted mean was above ($\bar{x}$ = 3.7) for all except one ($\bar{x}$ = 2.37), showing the high level of awareness / perception of environmental changes and its impacts on the abundance of *Irvingia* fruits and kernels. Overall increasing impact of environmental changes on the abundance of *Irvingia* fruits and kernels was high and positive, thus implying that most rural households would not be in the position to continuously rely on *Irvingia* fruits and kernels for their dietary and income needs.

Conclusions

The study revealed that the abundance of *Irvingia* fruits and kernels was decreasing over time due to the perceived changing climate conditions. This could affect the sustainable availability of the *Irvingia* fruit and kernels and their contributions to local household dietary needs and income. It is, therefore, very pertinent for policy makers especially at the local level to formulate policies and design strategies aimed at sustaining the future availability of *Irvingia* fruits and kernels through a consolidated community based forest management and other conservation measures using modern approaches and techniques that would

Table 3. Mean distribution of rural households rating of impact of environmental changes on the abundances of *Irvingia* fruits and kernels economic and culinary values.

Impact statement	Strongly agreed	Agreed	Undecided	Disagreed	Strongly disagreed	Sum of responses	Mean score	SD
Reduction of the abundances Irvingia fruits and kernels	154(77.0)	46(23.0)	-	-	-	954	4.770*	1.67
Reduction in quantity collected of Irvingia fruits and kernels	131(65.5)	43(21.5)	26(13.0)	-	-	905	4.525*	1.37
Reduction income generation from Irvingia fruit and kernels	159(79.5)	31(15.5)	7(3.50)	-	3(1.5)	943	4.715*	1.71
Reduction in the availability of foods	91(45.5)	52(26.00)	12(6.0)	1(0.5)	44(22.00)	745	3.725*	0.94
Increase in conflicts over the of forest resources	50(25.0)	8(4.0)	3(1.5)	43(21.5)	96(48.0)	473	2.365	0.47
Out-migration thereby reducing the availability of labour	115(57.5)	46(23.0)	2(1.0)	4(2.0)	33(16.5)	806	4.030*	1.21
Overall mean							4.022*	
Number of respondents							200	

Note: * – Positive and agreed rating, SD – Standard Deviation. Figures in parenthesis are percentage distributions of the household rating.

ensure more domestication of *Irvingia* species in public, government and private lands. This would create more access to *Irvingia* fruits and kernels gathering and extraction for cultural and economic uses while increasing the resilience of the rural households to adjust to changing environmental conditions. Additionally, this would enhance the genetic diversity of this invaluable forest resource and conserve its innate resilience to the changing anthropogenic environment.

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FORESTRY IDEAS, 2016, vol. 22, No 2 (52): 188–197

COMPARATIVE STUDY ON PHYSIOLOGICAL POTENTIAL OF *PINUS SYLVESTRIS* L. AND *PINUS BUNGEANA* ZUCC. EX ENDL. TO GROW IN BULGARIAN URBAN PARKS

Svetoslav Anev

Department of Dendrology, Faculty of Forestry, University of Forestry,
10 Kliment Ohridski blvd., 1797 Sofia, Bulgaria.
E-mail: svetoslav.anev@gmail.com

Received: 11 September 2016 Accepted: 25 November 2016

Abstract

Pinus bungeana Zucc. ex Endl. is a picturesque multi-trunked pine tree native to north-eastern and central China with symmetrical crown and grey-green, mottled, exfoliating bark. This species is already introduced into European urban parks, although there is still limited information about its appearance when full grown. The first *P. bungeana* tree in Bulgaria was planted in the arboretum of the University of Forestry in Sofia. The aim of this study is to compare needle gas exchange in this tree and *Pinus sylvestris* L. Both experimental trees are at similar age and grow out of their natural range of distribution. The net photosynthesis (A_N) in response to various air temperatures and light conditions was analyzed in both *P. bungeana* and *P. sylvestris* needles. Temperature and light responses of photosynthesis obtained in this study show insignificant differences between *P. bungeana* and *P. sylvestris*. The established features are sings for higher tolerance of *P. bungeana* to shade and cold, than *P. sylvestris*. Therefore, it can be assumed that *P. bungeana* has physiological potential to grow in Bulgarian urban parks, similar to *P. sylvestris*.

Key words: light curve, photosynthesis, temperature response.

Introduction

As an integral component of urban green infrastructure, park trees selection is crucial to successfully shaping a better urban environment (Li et al. 2011). An important requirement for high aesthetics of urban parks is enrichment of tree species diversity. But the general picture is that a few species make up a large proportion of the urban park tree population. An issue concerns preferences for or against native trees versus non-indigenous species. Most planting sites in communities are quite different from natural forests to which trees are genetically adapted. But certain species can tolerate compacted soils and pollutants better than others, and some of these are native to distant, analogous climatic regions. Therefore, some non-indigenous species can withstand urban stresses better than some “native species”, and these should not be excluded just because they are classified as exotic (Gerhold and Porter 2006).

Arboreta, by displaying and distributing trees, have been very influential in the choice of species used in designing urban forests (Gerhold 2006). Botanic gardens were planted to showcase rare or interesting species. Many of exotic species causing problems in our vegetated areas escaped from these gardens (Koch 2000). Designers of urban landscapes, who specified which trees were to be planted and where, depended first on gardeners, and later on horticulturists, arborists, and foresters for the cultivation and care of the trees. Miller et al. (2015) proposed a model with three groups of factors for selecting species for urban uses: the site factors, economic factors and social factors. Clark and Kjelgren (1989) recommended rigorous site analysis when making species selections, especially relative to radiation load, temperature, the availability of water and soil properties. Trees in the urban environment are subjected to a number of stresses which are very different from those suffered by trees in typical rural conditions. On the other hand, through proper planning, design, and management, urban trees can mitigate many of the environmental impacts of urban development by moderating climate, reducing building energy-use and atmospheric carbon dioxide, improving air quality, lowering rainfall runoff and flooding, and reducing noise levels (Nowak and Dwyer 2006). Design qualities, longevity, ease of cultivation, and mass propagation were identified as the main criteria for the selection of tree species by Pauleit (2003). However, the physiological potential for adaptation of species to specific conditions in an urban territory still missed in set of criteria for selection of park species.

The aim of this study is to evaluate the physiological potential of *Pinus bungeana* Zucc. ex Endl. to grow in Bulgarian urban parks. For this purpose, specific responses of *P. bungeana* and *P. sylvestris* photosynthesis to various light and temperature conditions were compared.

P. bungeana is a picturesque multi-trunked pine tree native to northeastern and central China with symmetrical crown and grey-green, mottled, exfoliating bark. This species occurs in mountains, often on limestone rocks and on south-facing slopes, scattered and mixed with angiosperms. Its altitudinal range is probably between 500 m and 2150 m a.s.l. It is a light demanding species and therefore is usually restricted to sites less suitable for other trees, especially angiosperms. *P. bungeana* was introduced to England in 1843 but is still not very common in gardens and parks of Europe (Luscombe 2013). *P. sylvestris* was chosen for comparison due to its well-studied biological characteristics for the Bulgarian mountains and similar to *P. bungeana*’s light and temperature requirements within their natural ranges of distribution.

According to Shelford’s “Law of tolerance” (Shelford 1931) plant responses to temperature can be expressed in terms of three cardinal temperatures: the minimum and maximum temperatures at which the process ceases entirely, and the optimum range of temperature over which the highest rate can be maintained, assuming that temperature is limiting factor (Fitter and Hay 2012). An alternative approach has been to apply the Arrhenius equation (from chemical kinetics) to plant processes. The recent variants of this law for photosynthesis (Medlyn et al. 2002) and for respiration (Tjoelker et al. 2001, Smith and Dukes 2013) include energy for activation and energy for deactivation of these processes. Various peak functions are suggested as an alternative by some eco-physiologists (Kattge and Knorr 2007, Friend 2010). One of the most suitable equations for the photosynthesis response to temperature is proposed by June et al.

(2004) and his model was used in this article. Theoretical causes for photosynthetic light-response curve were raised by Blackman (1905) and were improved by many authors subsequently (Rabinowitch 1951, Thornley 1976, Prioul and Chartier 1977, Leverenz and Jarvis 1979, Marshall and Biscoe 1980). At low light intensities, AN increases linearly with irradiance, with the light-driven electron transport limiting photosynthesis. The initial slope of the light-response curve based on absorbed light (quantum yield) describes the efficiency with which light is converted into fixed carbon. This mathematical description is useful because it contains variables with a clear physiological meaning that can be derived from light-response curves and used to model photosynthesis. The recent variant of this non-rectangular hyperbola, proposed by Norman et al. (1992), was used in this article.

The optimal temperature for net photosynthesis can vary with species, ecotype, site, and time of the year (Larcher 2003). Respiration is especially sensitive to temperature, with a temperature coefficient Q_{10} of approximately 2 (respiration doubles when the temperature rises by 10 degrees), whereas the Q_{10} values of the electron transport and enzyme reactions of photosynthesis are 1 and 2–3, respectively (Fitter and Hay 2012). As a result, the light-saturated rate of net photosynthesis for most conifer species during the growing season is greatest at approximately 20 °C and is depressed below 10–15 °C and above 30 °C (Stenberg et al. 1995). Freezing temperatures increase the sensitivity of conifer photosynthesis to photoinhibition, even in hardened tissues and under low irradiance levels (Öquist and Huner 1991). Photoinhibition is detected by a reduction in quantum yield and, in many cases, the light-saturated rate of net photosynthesis (Powles 1984). Leverenz and Öquist (1987) established that in *P. sylvestris* the quantum yield during the winter season is consistently lower than during the growing season. At high irradiance, photosynthesis becomes light saturated and is limited by carboxylation rate, which is governed by some combination of CO_2 diffusion into the leaf and carboxylation capacity (Lambers et al. 2008). Photosynthetic efficiency in the intermediate light range (curvature parameter) provides information for adaptation (acclimatization) of the plant to light regime (Ögren 1993).

Materials and Methods

Site description

The experiment was conducted in the arboretum of the University of Forestry in Sofia, Bulgaria (42° 39’ 09” N, 23° 21’ 30” E, 590 m a.s.l.). This urban site is unnatural both for *P. sylvestris* (in relation to altitude) and *P. bungeana* (in relation to longitude and altitude). Sofia is located in the North Temperate Zone and characterized with moderate hydro-thermal regime. During the last two decades (1996–2015) the average annual temperature for Sofia region has increased with 0.98 °C (+10 %) in comparison to referent period (1961–1990) on a background of 0.58 °C (+5 %) for the overall country. For the same period precipitation sum in Sofia increased with 96.4 mm·yr^{-1} (+17 %), but the likelihood for pouring rain (> 100 mm/day) increased with 30 % (Alexandrov et al. 2004, NOAA 2016). These tendencies showed that climate change in Sofia is exacerbating and therefore enhances abiotic risks for plants.

Plant material and gas exchange measurements

For the physiological measurements, two conifer species: *Pinus sylvestris* L. and *Pinus bungeana* Zucc. ex Endl. were chosen. Two experimental trees are approximately the same age and grow near each other in the arboretum of the University of Forestry in Sofia.

Gas exchange measurements were acquired using a LI-6400 portable infrared gas analyzer (LI-COR Ltd., Lincoln, Nebraska, 68504 USA) seven times within the period December 2015 – May 2016 in clear sky days with varied air temperatures. Data were taken after a minimum 30-minute calibration period (LiCor 2012). To determine the temperature dependence on net photosynthesis (A_N), incident air temperatures (T_A) were recorded during the measurements. Four branches with different geographical exposition were selected in the middle parts of the crowns both of the sample trees. Randomly chosen six mature needles of these branches were used for measurements. Five values for each parameters at each branches were recorded when gas exchange was stable as indicated by: (a) visually stable intercellular CO_2 concentration and net CO_2 assimilation rates values, (b) a total coefficient of variation (CV) – calculated as the sum of CO_2 and H_2O CV % – of less than 0.5 %. (Broadbent 2012).

Before budburst of the two experimental trees, measurements for constructing the photosynthetic light-response curves were made in April 2016. The measurements were conducted in two levels within the crowns (sun and shade) by standard protocol according to Evans and Santiago (2012) at 2000, 1000, 500, 250, 100, 50, 25 and 0 µmol · m^{-2} · s^{-1} intensity of PAR.

The projected area of the needles was determined with an open source software ImageJ (Abramoff 2004) to recalculate measured photosynthesis.

Data analysis

Temperature dependence of A_N was determined by the equation (1), suggested by June et al. (2004):

$$A_N(T_A) = A_{To} \cdot e^{-\left(\frac{T_A - T_O}{w}\right)^2} \quad (1),$$

where: A_N is the net photosynthesis; T_A is the ambient air temperature (independent variable); T_O is the optimal temperature for A_N; A_{To} is the photosynthetic rate at T_O; and w is the width of the temperature tolerance of the photosynthesis.

Light curve of photosynthesis was fitted by the function (2) of Norman et al. (1992).

$$A_N(I_A) = \frac{q \cdot I_A}{\left[1 + \left(\frac{q \cdot I_A}{A_{Max}}\right)^p\right]^{1/p}} - R_D \quad (2),$$

where: I_A gives the absorbed quanta per unit leaf area in the chamber, q is the photochemical efficiency at low light levels, A_{Max} is the assimilation rate at light saturation, R_D is the dark respiration rate, and *p* is a photosynthetic efficiency in the intermediate light range (curvature parameter).

The differences between regressions parameters both for temperature and light curves of *P. sylvestris* and *P. bungeana* for each studied physiological parameters were assessed with Z-test according Clogg et al. (1995) – equation (3).

$$Z = \frac{|C_1 - C_2|}{\sqrt{SE_{C_1}^2 + SE_{C_2}^2}} \quad (3),$$

where: C_1 and C_2 are the same regression parameters for *P. sylvestris* and *P. bungeana* responses and SE_{C1} and SE_{C2}

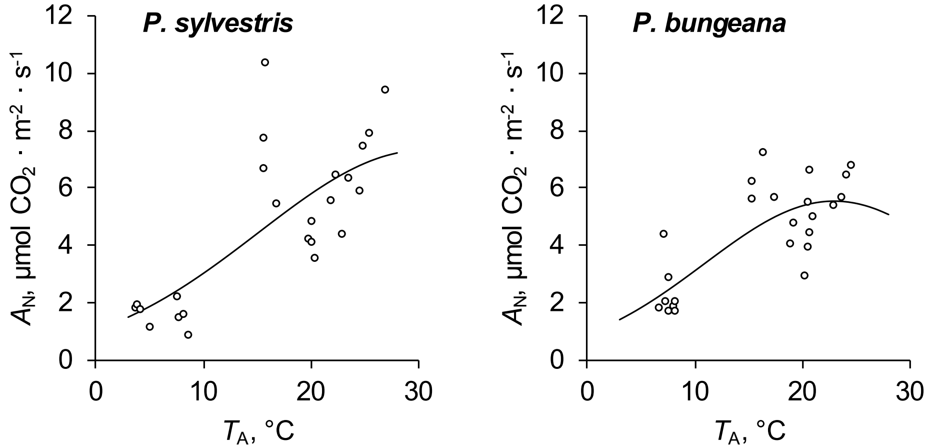

Fig. 1. Regression between ambient air temperatures (T_A) and net photosynthetic rate (A_N) in *P. sylvestris* and *P. bungeana* needles.

Note: Mean values (n = 5) for every case of measurements (N = 24) are shown with ○; Equation (1) regression lines are shown with —.

are standard errors of C_1 and C_2, respectively.

All regression lines were fitted to the data applying the least-squares approach of the Microsoft Excel Solver routine using the Newton algorithm.

Results

A_N increased significantly with increase of air temperatures both in *P. sylvestris* and *P. bungeana* needles (Fig. 1).

The regression analysis identified moderate relations between the net photosynthetic rate and air temperature both in *P. sylvestris* and *P. bungeana* needles (Table 1).

A_N have greater variation in *P. sylvestris* needles by comparison with *P. bungeana* due to lower photosynthesis in winter and higher photosynthesis in spring. Furthermore, A_N in *P. bungeana* reaches saturation at temperature, within the measured range, whereas A_N in *P. sylvestris* increase constantly. The opti-

Table 1. Regression statistics: T_A-response of A_N.

	A_{To}	±SE	T_O	±SE	w	±SE	R^2	F-value	df	P-value
P. sylvestris	7.32	1.04	**30.58**	6.01	21.90	4.87	0.560	13.35	23	<0.001
P. bungeana	5.54	0.19	**22.94**	2.01	17.06	2.32	0.578	14.36	23	<0.001
Z statistics	Z-test	P-value	Z-test	P-value	Z-test	P-value				
	0.899	0.184	1.680	0.046	1.205	0.114				

Note: Statistically significant different (Z-test, P-value < 0.05) regression parameters are shown in bold.

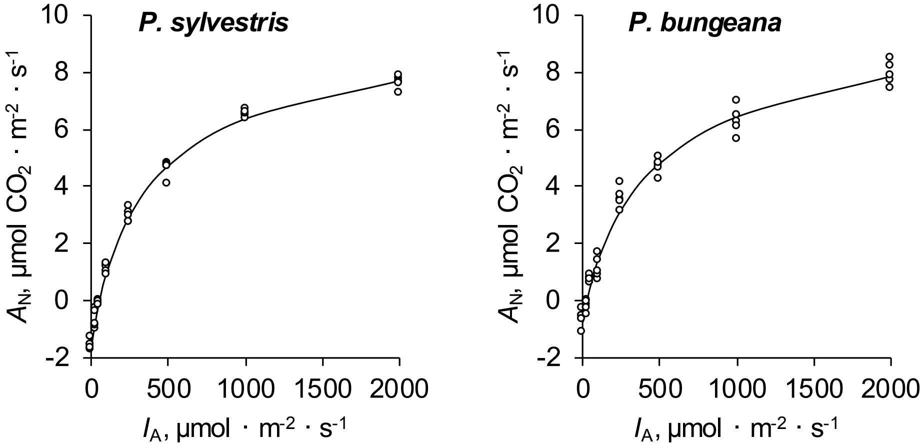

Fig. 2. Regressions between incident light intensity (I_A) and net photosynthetic rate (A_N) in *P. sylvestris* and *P. bungeana* sun needles.

Note: Mean value of A_N (n = 5) at each rate of I_A (N = 8) are shown with ○; Equation (2) regression lines are shown with —.

mal for photosynthesis temperatures (T_O) is the only significant different (P-value = 0.046) parameter of the temperature dependence of photosynthesis in both species. Strong relationships between A_N and incident light (I_A) are observed both in sun and shade parts of crowns of P. sylvestris and *P. bungeana* (Fig. 2 and Fig. 3).

A rising photosynthesis is observed both in *P. sylvestris* and *P. bungeana* sun needles in high light intensity, which is a sign for high demand of light both in two studied species.

Except R_D, all other regression parameters in light curves of sun needles of *P. sylvestris* and *P. bungeana* are statistically insignificantly different (Table 2).

P. bungeana photosynthesis has higher variation at each level of incident light than *P. sylvestris* photosynthesis, which reflect on coefficient of determination (R^2 = 0.995 and R^2 = 0.983 in *P. sylvestris* and *P. bungeana* regression line respectively).

P. bungeana shade needles have higher A_{Max} and reach light saturation at higher

Table 2. Regression statistics: I_A-response of A_N in sun needles of *P. sylvestris* and *P. bungeana*.

	A_{Max}	±SE	R_D	±SE	p	±SE	q	±SE	R^2	df	P-value
P. sylvestris	11.82	0.69	**1.55**	0.09	0.04	0.01	0.80	0.08	0.995	39	<0.001
P. bungeana	11.87	1.69	**0.73**	0.16	0.03	0.01	0.74	0.16	0.983	39	<0.001
Z statistics	Z-test	P-value	Z-test	P-value	Z-test	P-value	Z-test	P-value			
	0.03	0.49	4.47	<0.01	0.45	0.33	0.33	0.37			

Note: Statistically significant different (Z-test, P-value < 0.05) regression parameters are shown in bold.

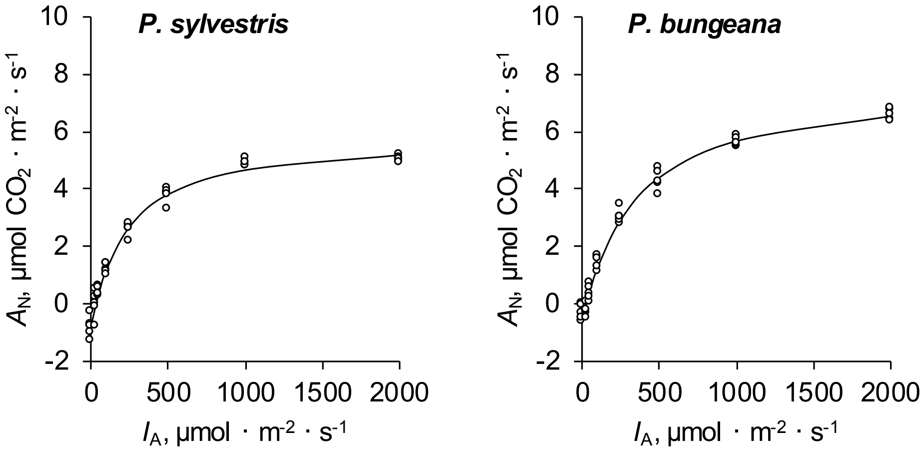

Fig. 3. Regressions between incident light intensity (I_A) and net photosynthetic rate (A_N) in *P. sylvestris* and *P. bungeana* shade needles.

Note: Mean value of A_N (n = 5) at each rate of I_A (N = 8) are shown with ○; Equation (2) regression lines are shown with —.

level of I_A than *P. sylvestris* (Fig. 3).

Except A_{Max}, the other three regression parameters in light curves of shade needles in experimental species are statistically insignificantly different (Table 3).

Discussion

Temperature and light responses of photosynthesis in P. Bungeana, obtained in this study, have small differences with same ones in *P. sylvestris*. The established lower optimal for photosynthesis temperature is probably because *P. bungeana* is more cold hardy (Peng and Bo 2007), but also might be an indication for better adaptation of *P. sylvestris* to the local climate.

The values of A_{Max} and R_D in needles of *P. sylvestris*, calculated by light curves regressions is close to values, which are observed for the same species by James et al. (1994) in Scotland tree line (around 600 m a.s.l.) and higher than established by Anev et al. (2016) for other three species from genus *Pinus*. Less intensive R_D

Table 3. Regression statistics: I_A-response of A_N in shade needles of *P. sylvestris* and *P. bungeana*.

	A_{Max}	±SE	R_D	±SE	p	±SE	q	±SE	R^2	df	P-value
P. sylvestris	**6.47**	0.39	0.73	0.11	0.03	<0.01	1.09	0.18	0.98	39	<0.001
P. bungeana	**8.07**	0.54	0.51	0.11	0.02	<0.01	1.08	0.18	0.99	39	<0.001
Z statistics	Z-test	P-value	Z-test	P-value	Z-test	P-value	Z-test	P-value			
	2.41	0.01	1.37	0.09	0.60	0.27	0.02	0.49			

Note: Statistically significant different (Z-test, P-value < 0.05) regression parameters are shown in bold.

in *P. bungeana* sun needles is probably because both lower rate of growth (and therefore lower requirements of energy) and better shade tolerance. The last claim is confirmed with higher A_{Max} in the shade needles of *P. bungeana* than the same in *P. sylvestris*.

Quantum use efficiency (*p*) varied slightly both in sun and shade part of the crowns in *P. sylvestris* and *P. bungeana* trees. As a light demanding species (Stefanov and Ganchev 1953, Luscombe 2013), *p* is low in two experimental trees probably due to thin crowns (Gilman and Watson 1994, Durrant et al. 2016, YiMing et al. 2006) and low chlorophyll concentration (Broadmeadow and Jackson 2000) in the needles of *Pinus* species. For *P. sylvestris* Leverenz and Öquist (1987) established similar values of *p* in April (0.017) and much higher value in July (0.057).

The close to 1.0 values of *q* both in sun and shade needles in two experimental species confirms the conclusions of Leverenz (1988) that even if within-leaf variation in light acclimation is big, the same whole-leaf variation is small.

Conclusions

P. bungeana has response to variation in air temperature and incident light intensity similar to *P. sylvestris*. The established small differences between examined physiological parameters are indications for higher tolerance of *P. bungeana* to shade and low temperature. Therefore, it can be assumed that *P. bungeana* has a comparable to *P. sylvestris* physiological potential to grow in Bulgarian urban parks and even has the potential to withstand more extreme low air temperature and incident light.

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FORESTRY IDEAS, 2016, vol. 22, No 2 (52): 198–205

NON-DESTRUCTIVE ALLOMETRIC METHOD FOR ESTIMATION OF LEAF AREA IN COMMON BEECH (*FAGUS SYLVATICA* L.)

Svetoslav Anev[1*], Petya Dimitrova-Mateva[2], Sabah Lamlom[3], Ganka Chaneva[4], and Nikolina Tzvetkova[1]

[1]Department of Dendrology, Faculty of Forestry, University of Forestry, 10 Kliment Ohridski blvd., 1797 Sofia, Bulgaria
[*]E-mail: svetoslav.anev@gmail.com
[2]South-West State Forest Company, Ministry of Agriculture, 1 Antim I Str., 1000 Sofia, Bulgaria
[3]Faculty of Natural Resources and Environmental Sciences, University of Omar Al-Mukhtar, Al Baida, Libya
[4]Faculty of Biology, Sofia University 'St. Kliment Ohridski', 8 Dragan Tzankov Blvd., 1164 Sofia, Bulgaria

Received: 26 October 2016 Accepted: 15 December 2016

Abstract

A model for leaf area (L_A) determination in Common beech (*Fagus sylvatica* L.) was developed by using leaves from two different elevation sites. The leaf mass (L_M), lamina width (L_W), lamina length (L_L), and L_A were all measured after excision of leaves from the plants in an open source software ImageJ. Best subsets regression analysis for relations between L_A and different combinations of L_W and L_L was performed. The proposed best-fit L_A-estimation model is: $L_A = 2.40 \cdot L_L + 6.65 \cdot L_W - 23.77$. The established highly significant relation ($R^2 = 0.98$, P-value < 0.001, d.f. = 177) between L_A and leaf width and length allows this mathematical model to be used for simple non-destructive field calculation of L_A in Common beech, which can thus be tremendously time saving without compromising on accuracy.

Key words: allometry, best-fit model, field measurements.

Introduction

Leaf area index is a significant variable in monitoring and modeling forest condition and growth and consequently it is essential for foresters and environmental scientists to determine leaf area regularly and precisely (Coops et al. 2004). The leaf area (L_A) estimation in field experiments is a long and complicated task. There are several direct (Shaban and Vassev 1983, Daughtry 1990, Bartelink 1997, Ferment et al. 2001) and indirect (Welles 1990, Chen 1996, Chen et al. 1997) methods for determination of L_A in the field. The majority of the direct methods, involving physical removal of leaves or other structures from the plants, are called destructive or laboratory methods (Jonckheere et al. 2004). After collection of leaves, L_A can be calculated using planimetric techniques (Daughtry 1990). There are different planimeters on the market for this purpose. The scanning ones (e.g. LI-3000C Area Meter from Li-Cor, Lincoln, USA) utilize an electronic method of rectangular approximation. The portable scanning planimeters (e.g. CI-203 Handheld Laser Leaf Area Meter from CID Bio-Science, Inc., Camas, USA and LI-3100C Portable Area Meter from Li-Cor, Lincoln, USA) are appropriate merely for small plants with few leaves but require the removal of leaves from the plant. All of these are expensive and also use particular software for data preparation.

ImageJ is an open source JAVA application distributed by the National Institutes of Health (NIH, Bethesda, MD, USA), which can find out leaf area by scanned or photographed leaf. The very 'friendly' graphical user interface assists users to manage and edit plant images. The online material as handbooks (Broeke et al. 2015), wikis (Rasband 2016), and plugins leads users through a variety of functions, providing hints about potential new applications. Fiji is one of the most current image processing distribution of ImageJ, bundling many plugins, which help scientific image analysis (Schindelin et al. 2012).

Regardless of the different non-destructive techniques used to estimate leaf area (Lu et al. 2004), the most widespread approach is to develop ratios and regression estimators by using simply measured leaf parameters such as length (L_L) and width (L_W). Such relations can provide researchers with many advantages in physiological experiments (Rouphael et al. 2007). Furthermore, the equations allow researchers to perform L_A measurements on the same plants throughout the plant growth period and may give rise to decreased experimental variability (Serdar and Demirsoy 2006). Various combinations of measurements and various equations relating L_L and L_W to leaf area have been used largely in some horticultural plants (Shaban and Vassev 1983, Stewart and Dwyer 1999, Schwarz and Kläring 2001, Chanda and Singh 2002, Blanco and Folegatti 2003, Tsialtas and Maslaris 2005, Rouphael et al. 2006, Rouphael et al. 2007) and considerably less often in trees (Demirsoy et al. 2004, Serdar and Demirsoy 2006).

The aim of this study was to develop a reliable equation that will allow the non-destructive estimation of Common beech (*Fagus sylvatica* L.) leaves' area through linear measurements.

Materials and Methods

Site description and plant material

Common beech leaves were collected from two sample plots with different elevation in the West Stara Planina mountain region (Table 1).

A total of 178 leaves (89 per sample plot) from two levels of tree crowns were randomly selected and analyzed. They

Table 1. Sites descriptions and plant material.

Site characteristics	Petrohan	Shirine
Altitude, m a.s.l.	1425	600
Latitude	43° 07' 27.2"	43° 10' 34.5"
Longitude	23° 07' 27.6"	23° 09' 28.1"
Aspect	E	E
Slope, °	17	22
Mean trees age, years	20	18
Diameter of breast height (DBH), cm	2.8	4.4
Mean tree height, m	6.2	6.4

were collected during May-August in 2015 and 2016. After leaf detachment, L_M was measured with a portable electronic scale (precision: 0.01 g), and leaves were scanned with portable scanner (Canon Lide 110, Canon Inc., Japan) at 600 dpi resolution in PNG colour mode format.

Leaf allometry and area measurements

Leaf Area Index (LAI) was defined such as the total one-sided area of leaf tissue per unit ground surface area (Watson 1947). According to this definition, LAI is a dimensionless quantity characterizing the canopy of an ecosystem. Leaf allometry and area measurements were performed with open source software ImageJ v.1.51 64-bit (NIH, Bethesda, MD, USA). The scanning scale was set as proportion of dpi/(px/cm), which is 1dpi = 0.393701 px/cm or 600 dpi = 236.2206 px/cm. A rectangular selection tool was used for L_L and L_W measurement and a polygon selection tool was used for L_A determination (Fig. 1).

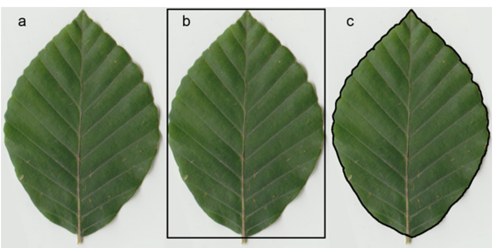

Fig. 1. Leaf allometry processing: a) original image; b) rectangular selection tool for measuring of L_L and L_W; c) polygon selection tool for measuring of L_A.

’Area‘ and ’bounding rectangle‘ options were marked in set measurements dialog window. All results were exported in csv format for data preparation and analysis.

Data analysis

Normality test (Shapiro-Wilk) was used for evaluation of the normal distribution of data within each group. Two-tailed Student’s t-test was used to detect differences between means of allometric scaling of leaves from Petrohan and Shirine sites. The relationship between L_A as a dependent variable and (1) L_L, (2) L_W, (3) $L_R = L_L \cdot L_W$ or (4) L_M, as independent variables, was determined using linear regression analysis, and two-factorial relationship between L_A as a dependent variable and combination of (5) L_L, L_W and (6) L_L, L_W, L_M as independent variable was determined using multiple linear regression. According to Anev et al. (2013) the six regressions were assessed by values of: coefficient of determination (R^2), adjusted coefficient of determination (AdjR^2), mean absolute error (MAE), root-mean-square error (RMSE) (Zar 2010, Bolboaca and Jäntschi 2013), coefficient of aggregation (W), Akaike information criterion (AIC) and Bayesian information criterion (BIC) (Burnham and Anderson 2004) between measured L_A and modeled with each models L_A. For validation of the models, we used the calculated and measured L_A dataset, to which we fitted a linear equation. The slope and intercept were tested with Z-test (Clogg et al. 1995) to see if they were significantly different from the slope and intercept of the 1:1 correspondence line. All statistical calculations were performed with MS Excel (Microsoft Corp., Redmond, WA) and specially created visual basic user defined functions.

Results

Normality test (Shapiro-Wilk) of all series indicates that the data matches the

Table 2. Leaf dimensions.

Leaf dimension	Petrohan	Shirine
Width (L_W), cm	5.02 (0.10) a	4.94 (0.06) a
Length (L_L), cm	7.15 (0.15) a	7.44 (0.10) a
Rectangle (L_R), cm^2	36.98 (1.44) a	37.10 (0.86) a
Area (L_A), cm^2	27.64 (1.01) a	26.05 (0.59) a
Mass (L_M), g	0.259 (0.011) a	0.309 (0.012) b

Note: Values shown are means (Standard errors of means are shown parenthetically). The same letters on each row indicate that there is no statistically significant difference (Two-tilted t-test, *P*-value < 0.05) between means in both sample plots.

pattern expected if the data was drawn from a population with a normal distribution. Except of L_M, there is no statistically significant difference between allometric scales of leaves from both sample plots (Table 2).

The higher L_M of leaves from Shirine is probably due to greater water content in these leaves in comparison to leaves from the higher altitude sample plot (Petrohan).

The six models for calculation of L_A by allometric scales of leaves are described in Table 3.

The best-fit is model 5, which includes L_L and L_W as factors and was prepared by multifactorial regression analysis (Fig. 2).

Only model 4, which calculates L_A by L_M as a factor, is insignificant and should not be used for L_A modeled. In model 6, the regression coefficient of L_M is statistically insignificantly different from zero, which is evidence that leaf mass is inconsequential as factor in this model and the calculation of L_A is unnecessarily complicated. Therefore, it will not be included in the model assessments and comparison.

All the indicators, used for assessment of models, confirm the conclusion that model 5 is the best-fit among the assessed ones. However, the slope of it is close, but different (*P*-value = 0.044) from the slope of 1:1 regression (Table 4).

Model 3 also has good fit indicators, but both the intercept and the slope in it are statistically significantly different from the same of 1:1 regression (*P*-value is 0.038 and 0.032 for intercept and slope respectively).

Table 3. Descriptions and statistics of allometric models for determining leaf area (LA).

Model number	Model equation	AdjR^2	ANOVA-F	ANOVA-P
1	$L_A(1) = 5.58 \cdot L_L - 13.88$	0.765	576	0.033
2	$L_A(2) = 9.42 \cdot L_W - 20.04$	0.904	1671	0.020
3	$L_A(3) = 0.69 \cdot L_R + 1.40$	0.962	4535	0.012
4	$L_A(4) = 49.60 \cdot L_M + 12.77$	*0.471*	*159*	*0.063*
5	$\mathbf{L_A(5) = 2.40 \cdot L_L + 6.65 \cdot L_W - 23.77}$	**0.968**	**5350**	**0.011**
6	$L_A(6) = 2.42 \cdot L_L + 6.68 \cdot L_W - \underline{0.53} \cdot L_M - 23.77$	0.968	5354	0.011

Note: The best-fit model is bolded. The insignificant models are presented in italic. The insignificant different from zero (Two-tilted t-test, *P*-value < 0.05) regression coefficients are underlined.

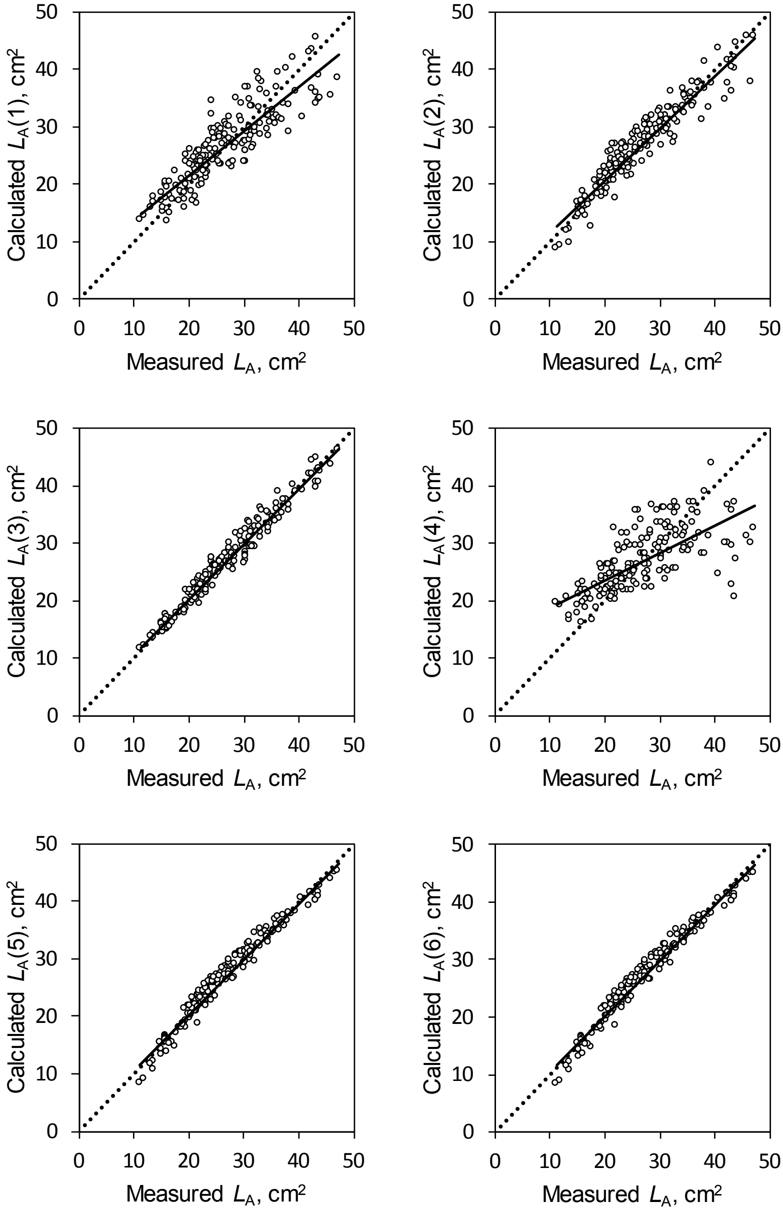

Fig. 2. Regression between measured in ImageJ leaf area (L_A) and calculated by corresponding model leaf area – L_A (N).

Note: *N* is the number (from 1 to 6) of each model, described in Table 3.

Table 4. Descriptions and statistics of allometric models for determining leaf area (LA).

Statistical indices	Model number				
	1	2	3	4	5
Coefficient of determination (R^2)	0.766	0.905	0.963	0.474	**0.968**
Adjusted coefficient of determination (AdjR^2)	0.765	0.904	0.962	0.471	**0.968**
Mean absolute error (MAE)	3.096	1.835	1.238	4.113	**1.176**
Root mean square error (RMSE)	3.781	2.412	1.511	5.668	**1.395**
Akaike information criterion (AIC)	428.0	297.7	142.1	486.7	**114.7**
Bayesian information criterion (BIC)	431.2	300.9	145.2	489.9	**117.9**
Coefficient of aggregation (W)	0.930	0.974	0.990	0.795	**0.992**
Intercept (b_0)	***	**	*	***	**n.s.**
Slope (b_1)	***	**	*	***	*

Note: In the best-fit model, R^2, AdjR^2 and W must be maximal and close to 1, MAE, RMSE, AIC and BIC must be minimal. For the intercept (b_0) and the slope (b_1) are shown significance of difference (Z-test, P-value <: * 0.05; **0.01; ***0.001) from the same of 1:1 regression line.

Discussion

Leaf area is a valuable variable for the majority of physiological studies, concerning plant growth, light interception, photosynthetic efficiency, evapotranspiration and response to fertilizers and irrigation (Blanco and Folegatti 2003). It is known that (Bréda 2003) allometric relationships are site and species dependent or in some cases – year dependent. By Bidlake and Black (1989), Maguire and Bennett (1996) estimating allometric relationships through destructive sampling is a reliable method to assessing LAI for a given experimental sites but remains year-dependent. The findings of this evaluation of the six non-destructive methods for leaf area determination of Common beech, indicate that closest to the measured areas are those calculated by two-factor model 5 including the length and width of the leaves. As recommended by other authors (Blanco and Folegatti 2003, Peksen 2007, Rouphael et al. 2007, Ravi et al. 2010), model 3, including the product of length and width of the leaves, also has good fit indicators, but both intercept and slope are statistically significantly different from the same of 1:1 regression. This calls into question of its accuracy for leaf area determination in species with highly variable leaf size (L_L and/or L_W). The models which include only one dimension of the leaf (whether width, height or especially mass) are with insufficient precision and will not be recommended for scientific experiments. The unnecessarily complicated calculation of L_A with including of more than two dimensions does not improve the models. The validation of model 5, which is of the type $L_A = a \cdot L_L + b \cdot L_W + c$, showed that

Common beech leaf area could be measured quickly, accurately, and non-destructively by using the simple allometric leaf dimensions.

Conclusions

In this study, a fast and simple model was developed to predict the leaf area of Common beech. The use of this equation would enable researchers to make non-destructive or repeated measurements, which can thus be tremendously time saving without compromising on accuracy.

The approach for constructing and validation of the model could be used for estimation of leaf area in other plant species. However, it has been considered that prediction equation developed for the present region may need to be adjusted (validated) for diverse environmental conditions.

Acknowledgements

This study was supported by the scientific project No 93/2015 of the University of Forestry, Bulgaria.

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FORESTRY IDEAS, 2016, vol. 22, No 2 (52): 206–213

HEIGHT STRUCTURE OF COPPICE OAK (HUNGARIAN, SESSILE AND TURKEY) STANDS

Rumen Petrin and Ivaylo Markoff

Forest Research Institute, Bulgarian Academy of Sciences, 1756 Sofia, Bulgaria.
E-mail: lesni4eja2014@gmail.com

Received: 12 May 2016 Accepted: 18 December 2016

Abstract

The study has intended to reveal the height structure of relatively even-aged coppice stands of Hungarian oak (*Quercus conferta* L.), Sessile oak (*Quercus petraea* Liebl.) and Turkey oak (*Quercus cerris* L.) according to thickness levels in terms of curve forms, and to look for the general regularities occurring with these. Based on a total of 59 sample plots, the height curves have been investigated for the three groups of stands according to tree species. The height curves have been transformed into relative height curves and multiplied by the respective numbers of trees in order to obtain the complex relative height curves. Due to the numbers of trees, the complex relative height curves obtain paraboloid shape, and these have been investigated for finding out their asymmetry in terms of breast-height diameter, i.e. the natural thickness level of 1.0. The complex height curves have been investigated while using a special coefficient of asymmetry (C_{as}). As a result of the investigations, the distribution of sample plot numbers according to height structure asymmetry for the three investigated aggregates is almost the same. The average curves' values of the normal numbers have been calculated for the three aggregates through the natural indicators' method of Douhovnikov (1966), and the average curves have been compared with the uniform average curve of normal numbers by Tyurin. Extreme similarities of the curves' aspects have been found, which confirms that the tree species does not have substantial influence upon the height structure of stands.

Key words: asymmetry type, average curves of normal numbers, height structure, oak stands.

Introduction

It is important to permanently improve the normative and reference data about forests, including the models and tables for evaluating the growing stock volume. For this reason, it is always necessary for scientists to improve their knowledge of the regularities in the growth and structure of forest stands.

In 1965, the total area of coppice stands of Hungarian, Sessile and Turkey oak in Bulgaria amounted to 489 314 ha, and in 2000 it increased to 623 629 ha (Petrov 2008). Because of this, it is currently important to study the thickness structure of these stands.

A number of authors have carried out studies of forest stand's structure (i.e. Tyurin 1938; Tretyakov 1927, 1952; Sirakov 1947; Nedyalkov 1964, 1967; Mihov et al. 1996; Dimitrov 2003; Tonchev 2007). The more important inferences the above and other authors have made from their studies of stand structure according to height are as follows:

Tyurin (1938) used in his studies not the absolute height for the particular thickness levels but the relative one, which is obtained by dividing each particular tree height by stand average one. He also introduced the natural level of thickness instead of the absolute one. Tyurin found out that the height curves for homogenous, pure, even-aged stands resembled one another in their shape regardless tree species and site quality. Only tree age and forest management can alter the curve shape. This gave him the reason for calculating an average general curve of relative heights for all major tree species.

Tretyakov (1927, 1952) carried out a detailed study of the regularities in the structure and variation of some dendrobiometric characteristics in pure even-aged stands and in mixed uneven-aged ones of complex forms. He established that forest structure always has a constant nature, regardless of stocking, age, tree species and growth conditions, even though these might pertain as to normal stands so to complex mixed ones. Thus he formulated a Law about the Unity of Stand Structure.

Dimitrov (1978) demonstrated the ability for analytical expression curve heights as a link height-diameter spruce based on 3-4 altitudes of any degree of thickness. Dimitrov (2003) pointed out that the relative heights, alias reduction number, in Tyurin's general curve of relative heights needs to be specified.

Mihov et al. (1996) identified three types of structure in thickness and height – positive (left maximum of the average diameter curve) asymmetry, negative (with right maximum) asymmetry and normal or symmetric type.

Mihov (2005) showed the necessity of approximating the height curves by means of a parabola equation while using a polynomial raised to a certain power, or a logarithmic function. This approximation has successfully been applied into the present study.

For the structure of uneven-aged spruce stands in thickness Nedialkov (1964, 1967) established various distribution curves for different generations. For different age generations distribution curves have bell- or parabolic shape and aggregate curve – exponential form.

Tonchev (2007), comparing the average curve of relative heights for the coppice common beech growing stocks investigated with Tyurin's average general curve, and found differences indicative of a specificity proceeding from the tree species and the origin of stands.

An investigation has been carried out of the height structure of natural beech stands (Petrin et al. 2014). Using the natural indicators' method, the steepness of height curves was investigated and found that stand height structure does not depend on tree age and that it is possible to create common, order curves of the heights for more than one tree species.

The investigations of the above-mentioned and other authors have provided the methodological background for our study.

Purpose of the study

The purpose of the present study is to investigate the height structure of coppice stands by Hungarian, Sessile and Turkey oak with a view to solving the following tasks:

1. Find out the different types of height structure of Hungarian, Sessile and Turkey oak stands by investigating the asymmetry, of the complex height structure curves.

2. Compare the average curves of the normal numbers of the height structure of the investigated stands with the uniform

average curve Tyurin developed for all tree species for finding-out similarities in the curves' aspects, which would be the basis of important inferences.

Objects and Methods

The present investigation pertains to coppice Hungarian, Sessile oak and Turkey oak stands in the Balkan Range (near Elena, Kotel and Sliven towns), in the Rhodopes (near Topolovgrad and Elhovo towns), and near the cities of Varna, Staro Oryahovo and Bourgas.

A total of 59 sample plots (SPs) have been established, 25 of these being in Hungarian oak stands, 26 – in Sessile and 8 – in Turkey oak.

Average stand age vary from 40 to 80 years, i.e. premature and mature stands, taking into account various rotation time from 60 to 100 years.

The natural levels of thickness have been calculated for each sample plot after Tyurin (1938), and these have been obtained by dividing the absolute levels of thickness by breast-height diameter, the results being relative, not round, levels of thickness, or relative diameters as, for example, 0.56, 0.67, 0.76, etc. up to 1.43. Further on, the height curves have graphically been approximated and the heights corresponding to the relative levels of thickness, which have been called 'natural levels of thickness', have been reported. The natural thickness-level values' interval for reliably investigating the curves is from 0.6 to 1.4. The absolute values of the heights are in their turn converted into relative heights by dividing them by height corresponding to natural thickness level of 1.0, i.e. by the average height of the even-aged stand. After this, the values for the relative heights' curves, in these aspects of theirs, are multiplied by the percentage number of trees, thus resulting in the complex, or generalised, curves of the heights for each thickness level. As the complex curves of the heights contain in their values the number of trees in percentages, they obtain paraboloid aspects and are investigated like thickness structure – the asymmetry of the curves is investigated in terms of the natural thickness level of 1.0, which corresponds to the average breast-height diameter of the stand. The right-hand asymmetry of the curves means that the parabola's maximum is on the right, and it reveals the availability of a larger volume of wood in the respective stand as it suggests the prevalence of taller and thicker trees. It is just the opposite with the left-hand asymmetry – the stand contains less wood because its trees are thinner and lower.

As it is seen from the above, the notion 'asymmetry of the structure curves according to height, and thickness,' does not mean the same as 'statistical asymmetry', which is calculated in terms of the maximum value of paraboloid curve. For measuring the asymmetry of the complex curves of heights, a special coefficient of asymmetry has been introduced, which can be expressed by means of the equation:

$$C_{as} = \frac{N_{0,x1} + N_{0,x2} + \ldots + N_{0.8} + \sum(N_{0.9} + N_{1.0} + N_{1.1})}{2},$$

where:

$N_{0,x1}$, $N_{0,x2}$ etc., $N_{0,8}$ are the complex relative heights corresponding to the thickness levels ranging up to 0.8, in percentages, and

$\Sigma (N_{0.9} + N_{1.0} + N_{1.1})$ is the sum of the complex relative heights for each of the three central levels of thickness, in percentages.

When C_{as} is less than 49 %, the curves have a right-hand asymmetry, more than

51 % – a left-hand asymmetry, and within the range from 49 % to 51 % we have assumed to consider them symmetric.

Further on, the values of the normal numbers's curves are calculated, as the values of the heights for the respective thickness levels are divided by the value of height corresponding to that of rightmost point on the abscise, i.e. the thickness level of 1.4. This is how all the normal numbers's curves are obtained through the natural indicators' method of Douhovnikov (1966) and, after this, the average curve of the normal numbers (q_{xav}) is calculated for the particular aggregates of curves, depending on the tree species.

While comparing our average curves of the normal numbers with the uniform average curve of Tyurin, the correlation coefficients have been calculated as well as other indicators of the conformity or proximity of the curves, such as the standard deviation, the coefficient of variation, and the error with the mean value.

Results and Discussion

Types of asymmetry of the complex relative heights curves

We have completed the distribution of the sample plots into three groups, on the basis of asymmetry coefficient values (C_{as}) for the height structure, thus forming three types of stand height structure according to the asymmetry of respective curves in terms of vertical imaginary line raised from the uniform average breast-height diameter 1.0. All the three types of asymmetry are available, namely left-hand, right-hand, and symmetric one. On figures 1, 2 and 3, these three types have respectively been illustrated for Hungarian, Sessile and Turkey oak coppice stands.

Figures 1, 2 and 3 reveal that the high

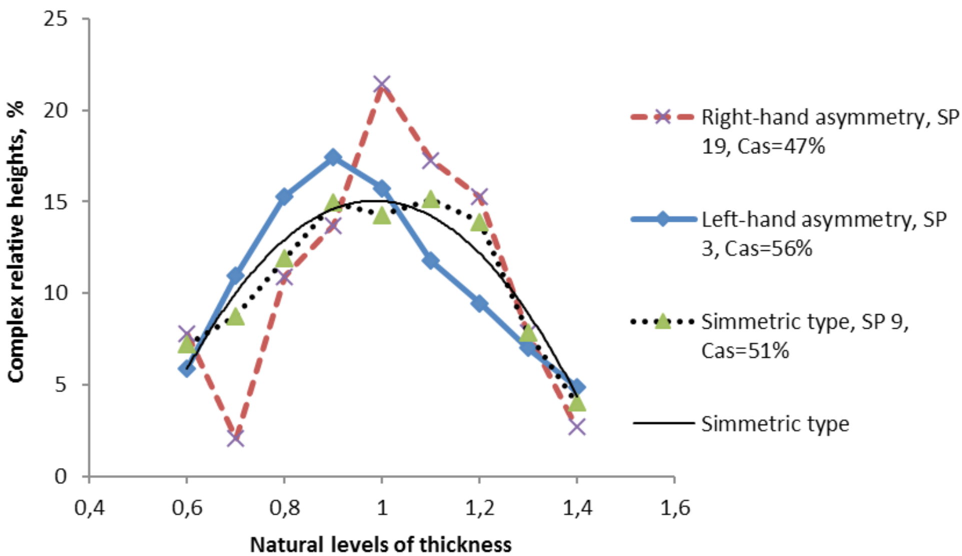

Fig. 1. Three types of curves according to the asymmetry of the generalised curve of heights for coppice Hungarian oak stands.

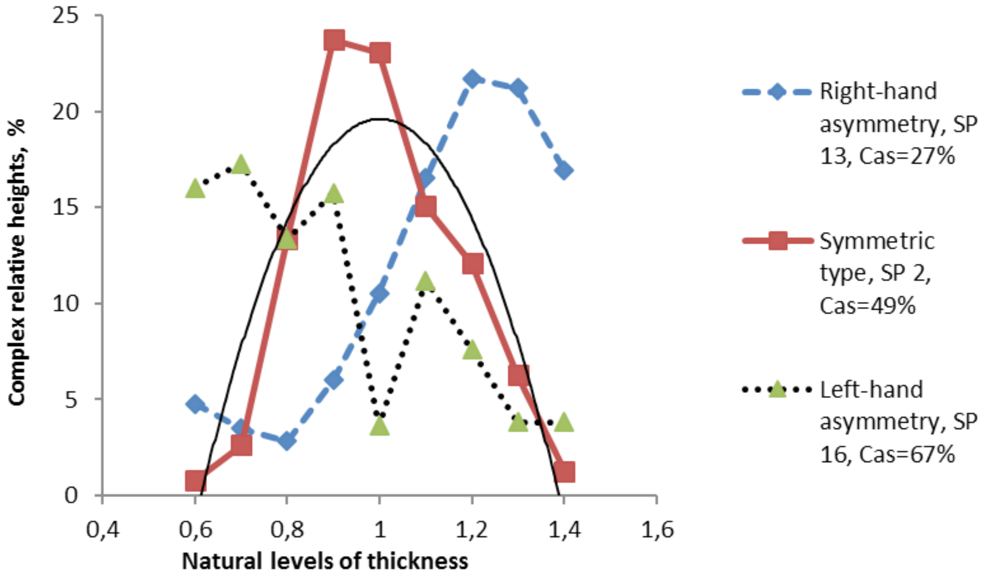

Fig. 2. Three types of curves according to the asymmetry of the generalised curve of heights for coppice Sessile oak stands.

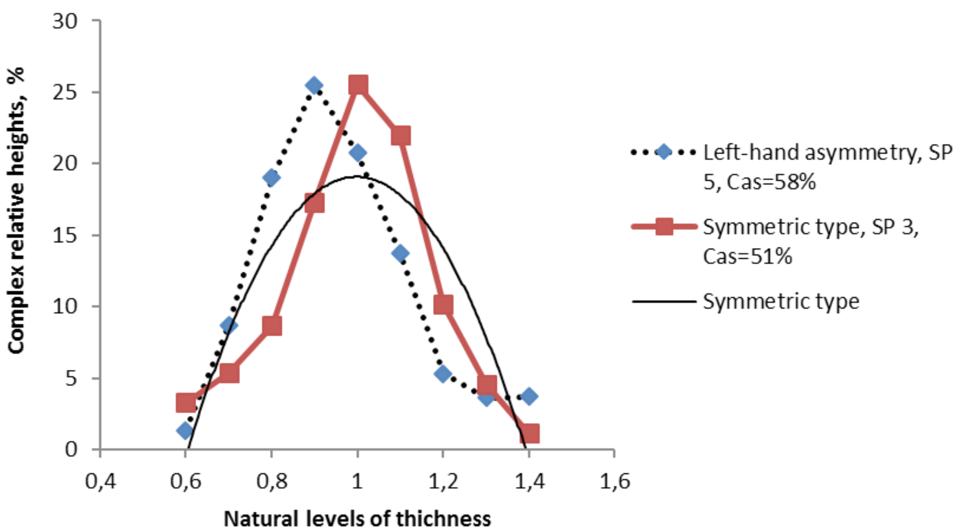

Fig. 3. Two types of curves according to the asymmetry of the generalised curve of heights for coppice Turkey-oak stands.

values of C_{as} (SPs 3, 16 and 5) stand for a clearly expressed left-hand asymmetry of generalised curves of the three tree species height structure, respectively. This means that thinner and lower trees prevail, hence, the availability of lower volume of wood. The lower values of C_{as} (SPs 19 and 13) stand for curves of a right-hand asymmetry, which means that thicker and taller trees prevail and the wood volume are higher and, when C_{as} is about 50 % (SPs 9, 2 and 3), the curves are symmetric, i.e. they occupy an intermediate position.

The distribution of the sample plots according to types of asymmetry has been presented for the three groups of stands in Table 1.

Table 1. Distribution of coppice stands according to types of asymmetry of the generalised curves.

Types of asymmetry according to height	Number of sample plots according to tree species						Total number of sample plots	Share, %
	Hungarian oak	Share, %	Sessile oak	Share, %	Turkey oak	Share, %		
Left-hand	13	52	13	50	3	43*	29	50
Right-hand	5	20	6	23	-	-	11	19
Symmetric	7	28	7	27	4	58*	18	31
Total	25	100	26	100	7	100	58	100

Note: * – SP distribution do not ensure reliability of results for Turkey oak.

Table 1 reveals similarity and conformity in terms of the sample plots distribution of Hungarian and Sessile oak according to asymmetry types. This pertains also to their total distribution, as the percentage is almost the same. The left-hand asymmetry is seen to prevail, about 50 %, next followed by the symmetric type, about 30 %, and the right-hand asymmetry – about 20 %. The prevalence of the left-hand asymmetry suggests prevalence of thinner and lower, or medium-high trees with the formation of total wood volume in the stands, and the close proximity of sample-plot distribution for Hungarian and Sessile oaks suggests conformity in their height structure, as this same could quite probably be said about the Turkey oak, if the sample plots were more. Therefore, it can be assumed that the first two, or even the three, of the tree species have the same height structure or similar one.

In Table 2 is presented the comparison between our average relative curves of heights (or the average curves of the normal numbers) and Tyurin's uniform curve of relative heights, which pertains to all the tree species.

Table 2 shows similarity of all three tree species and Tyurin's average data. The height structure normal-number rows of coppice Hungarian, Sessile and Turkey oak stands are similar not only for these three species, but also for other, so it is possible to elaborate a common model of height structure.

Conclusions

Three types of height structure have been found with Hungarian, Sessile and Turkey oak stands: with a right-hand asymmetry, a left-hand asymmetry, and a symmetric type. Same trend has been observed for all three oak species stands in the distribution of their sample plots according to asymmetry types. For this reason, studying them either separately or as a whole in terms of their height structure does not affect their distribution according to asymmetry types.

The comparison between the average curves of the normal numbers (quality indicators) of the height structure of investigated coppice oak stands and Tyurin's average curve of normal numbers has shown close proximity of the curves'

Table 2. Comparison of average height curves with Tyurin's uniform average curve of normal numbers.

Belonging of the curve	Natural Levels of Thickness									Indicators of similarity			
	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	Correlation coefficient	Standard deviation	Variation coefficient, %	Error of average, %
	Average complex curves of the normal numbers ($q_{xav.H}$) for height structure												
Hungarian oak	0.69	0.76	0.81	0.86	0.90	0.94	0.96	0.99	1	0.997	0.04	3.9	1.3
Sessile oak	0.69	0.75	0.8	0.84	0.89	0.92	0.95	0.98	1	1.000	0.04	4.4	1.5
Turkey oak	0.68	0.74	0.8	0.84	0.89	0.92	0.95	0.98	1	1.000	0.04	4.8	1.6
Tyurin's uniform average curve of normal numbers ($q_{xav.H}$)	0.77	0.81	0.85	0.88	0.91	0.94	0.96	0.98	1	-	-	-	-

aspects, and this convincingly proves the possibility of developing common models of their wood volumes and assortment structure, as long as these depend on height structure.

The proximity of the studied medium curves normal numbers to total average curve of Tyurin, designed for all tree species, showed the possibility of developing common diluted curves heights oak and other tree species such as Scots pine, beech, etc.

Acknowledgements

We wish to gratitude Prof. Ivan Mihov from University of Forestry in Sofia, for providing his sample plots data, thanks to which this study became possible.

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FORESTRY IDEAS, 2016, vol. 22, No 2 (52): 214–220

FOREST-FIRE PROTECTION INFRASTRUCTURES IN NATURAL PROTECTED AREAS WITH MANAGEMENT BODIES IN GREECE

Konstantinos S. Tsiolis[1*] and Georgios Sp. Efthimiou[2]

[1]Forester, Fire Brigade Officer, 43100 Karditsa, Greece. [*]E-mail: kostaskard@hotmail.com
[2]Department of Forestry and Natural Environment Management, Technological Educational Institute of Sterea Hellas, 36100 Karpenissi, Greece.
E-mails: gefthi@yahoo.gr, efthimiou@teiste.gr

Received: 12 March 2015 Accepted: 19 December 2016

Abstract

The recent global climate change has already increased the risk of fire in Mediterranean forests, including protected natural areas. The adaptation options for fire protection that are related to forest fires and to climate change contain measures, which are relative to the management of biomass, the prevention and fighting of fires with proper infrastructure and, above all, with public sensitization. This research endeavours to examine the current situation of the above measures and to evaluate the 28 Management Bodies (M.B.) that are responsible for the corresponding 28 protected areas of Greece. As a research tool, the questionnaire method was used, in order to record and to evaluate the views of the land-use managers and scientists in each of the 28 Protected Areas (P.A.). The survey reveals differences among the various national parks with regard to fire-protection measures, as well as to the effectiveness of fire-fighting and public commitment, which were estimated to be more important than the management of fuel biomass. The results were evaluated in the light of a critical review of measures used in preventing and managing fires.

Key words: activity of the M.B., fire-fighting, fire prevention, fire-protection measures, Mediterranean forests, national parks.

Introduction

The Mediterranean region is intrinsically linked to fires (Tsagari et al. 2011). Their intensity and recurrence make them the root cause of the degradation and shrinkage of Mediterranean forest ecosystems. Besides the forest fires, Mediterranean forests are very vulnerable and fragile to other numerous threats, such as over exploitation, deforestation and degradation. These threats are currently accentuated within the context of climate and land-use changes (Palahi et al. 2008). The fireproof protection, as a mean of prevention, constitutes an important measure in protecting and conserving natural ecosystems, diversity of the Mediterranean landscape and biodiversity.

Handling forest fires in Greece constitutes an acute problem, because, on the one hand, fires are the main threat to the country's forests, and in combination with overgrazing, are the main cause of the desertification of mountainous and semi-mountainous regions. On the other hand, climatic and meteorological conditions are key factors for both the occurrence and development of forest fires.

Material and Methods

The study started with a survey on the international bibliography on issues concerning protected areas and especially fire protection (prevention and suppression of fires) of national parks.

The 28 Protected Areas of Greece that are managed by a corresponding number of Management Bodies constitute the object of this study, as shown in Figure 1.

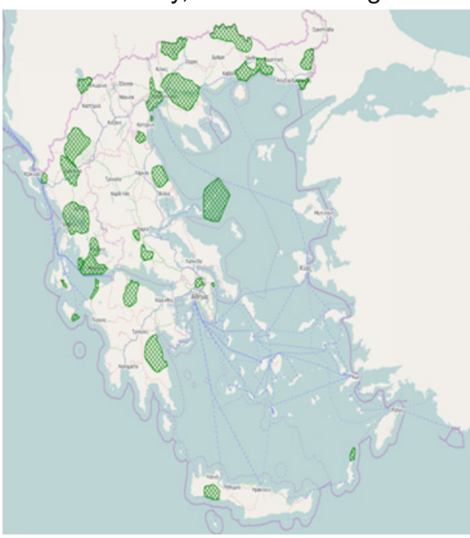

Fig. 1. Map of Greeks protected areas with Management Body (YPEKA 2015).

Research was carried out by means of a questionnaire that was prepared and sent to the 28 active Management Bodies by electronic mail. The information of the completed questionnaires was recorded electronically and processed statistically. This survey was conducted from October 2011 to April 2012.

Descriptive statistics was applied for data analysis using the software SPSS 19.0.

Results and Discussion

The questionnaires that were completed by all 28 of the Management Bodies in Greece (see Table 1) and filed electronically revealed the following data about each Management Body:

a) Documentation of each Management Body's existing firewall infrastructure (Table 2);

b) Grouping of fire-protection operations in the Protected Areas with M.B. (Table 2);

c) Cataloguing of the Management Bodies that use new technologies for fire safety (e.g. the use of satellite data) (Table 2).

The results of processing the questionnaires could be summarized as follows:

1) With regard to issues of infrastructure and agencies, 71.4 % of Management Bodies (MB) have drafted a protection or guard plan in the protected area of their administrative territory, while all M.B. must draft such a plan immediately. On the contrary, only two M.B. had drafted a study for fire protection during the time period when the survey was conducted.

2) 64.3 % of M.B. apply new technologies, such as satellite data, while only the M.B. of the National Forest of Samaria uses electronic system (E/T) or models of forest-fire management (Tsiolis and Efthimiou 2014).

3) 33 % of the MB report that they have no involvement in the management of forest fires. The M.B. of the National Park of Olympus introduces implementation programs of fire management. Furthermore, only two M.B. (Olympus and Samaria) use fuel maps.

Table 1. The 28 Management bodies (M.B.) of the protected areas in Greece.

Plot, No	Name of Management Body
M.B. 1	M.B. of the National Park of Olympus
M.B. 2	M.B. of the National Park of Parnassos
M.B. 3	M.B. of the National Park of Parnitha
M.B. 4	M.B. of the National Park of Samaria
M.B. 5	M.B. of the National Park of Vikos, Aoos and Pindos
M.B. 6	M.B. of the National Park of Prespa
M.B. 7	M.B. of the National Park of Ainos
M.B. 8	M.B. of the National Park of Iti
M.B. 9	M.B. of the National Park of Evros Delta
M.B. 10	M.B. of the Forest of Dadia
M.B. 11	M.B. of the lake of Kerkini
M.B. 12	M.B. of the lagoon of Messolonghi
M.B. 13	M.B. of the Delta of AxiosLoudias-Aliakmona
M.B. 14	M.B. of the lakes of Koronea-Volvi
M.B. 15	M.B. of the National Marine Park of Alonissos, Northern Sporades
M.B. 16	M.B. of the Nestos Delta, Vistonida, Ismarida
M.B. 17	M.B. of the Mount of Parnona and of the Wetland of Moustos
M.B. 18	M.B. of the lake of Pamvotida
M.B. 19	M.B. of the Amvrakikos wetlands
M.B. 20	M.B. of the wetland of Kotychi, Strofylia
M.B. 21	M.B. of the Strait & Estuaries Acheron & Kalama
M.B. 22	M.B. of the Chelmos, Vouraikos
M.B. 23	M.B. of the Mountain Chain of Rhodope
M.B. 24	M.B. of the Karpathos, Saria
M.B. 25	M.B. of Ecodevelopment Area of Karla, Mavrovouni, Kefalovriso, Velestino of Karla
M.B. 26	M.B. of the National Marine Park of Zakynthos
M.B. 27	M.B. of the National Park of Schinia, Marathon, Attica
M.B. 28	M.B. of the National Park of Tzoumerka, Peristeri and gorge of Arachthos

4) The majority of MBs participate in meetings with other agencies regarding fire-protection issues. Nevertheless, only 32.1 % of M.B. have analogous activities and collaboration with Rescue Teams. Only 32 % of M.B. have fire protection. Only 35.7 % of M.B. perform joint patrols with other agencies.

5) Only one third of M.B. have progressed with regard to informing citizens about fire-prevention/fire-protection issues.

6) 14.3 % of M.B. have fire-fighting vehicles. The M.B. of the National Park of Parnitha has the largest number of fire-fighting vehicles (Tsiolis and Efthimiou 2014).

7) Ten out of the 28 M.B. (only 35.7 %) have water-intake points (taps). The M.B. of the National Park of Parnitha has the largest number of water-intake points (141).Nine out of 28 M.B. (only 32.1 %) have cisterns (Tsiolis and Efthimiou 2014).

Table 2. Management bodies' infrastructure actions and agencies for fire protection.

Management body (M.B.)	Protection plan or guard plan	Studyoffireprotection	Meetings with bodies on fire protection subjects	Cooperation with Rescue teams and Fire protection	Joint patrols with other bodies	Informing citizens about prevention – Fire protection	Use of satellite data	Using of the electronic system (E/T) or models of the forest fire management	Use of fuel maps
M.B. of Olympus	√		√	√	√		√		√
M.B. of Parnassos	√						√		
M.B. of Parnitha	√	√	√		√	√	√		
M.B. of Samaria	√	√	√	√	√		√	√	√
M.B. of Vikos-Aoos	√		√			√			
M.B. of Prespa	√		√			√			
M.B. of Enos	√			√			√		
M.B. of Iti									
M.B. of Evros Delta	√		√						
M.B. of Dadia			√	√					
M.B. of Kerkini			√				√		
M.B. of Messolonghi			√		√		√		
M.B. of Axios, Loudias					√		√		
M.B. of Koronea-Volvi	√			√	√		√		
M.B. of Alonissos	√		√			√			
M.B. of Nestos Delta	√		√		√				
M.B. of Parnona			√	√		√	√		
M.B. of Pamvotida	√						√		
M.B. of Amvrakikos wetlands									
M.B. of Kotychi-Strofylia	√		√		√		√		
M.B. of Acheron & Kalama	√						√		
M.B. of Chelmos-Vouraikos	√		√			√	√		
M.B. of Rhodope	√		√				√		
M.B. of Karpathos, Saria	√			√					
M.B. of Karla, Mavrovouni	√		√	√	√	√	√		
M.B. of Zakynthos	√		√				√		
M.B. of Schinia, Marathon	√		√	√	√	√			
M.B. of Tzoumerka, Peristeri						√	√		
Total, number	20	2	18	9	10	9	18	1	2
Share, %	71.4	7.1	64.3	32.1	35.7	32.1	64.3	3.6	7.1

8) The M.B. of the National Park of Parnitha has the largest number of tanks (68), followed by the M.B. of the National Park of Olympus (16) (Tsiolis and Efthimiou 2014).

9) Twelve out of the 28 M.B. (42.9 %) stated that they have fire observatories. However, it has not been ascertained if

these observatories are manned.

10) With regard to fire-fighting in forests and fire-fighting in general, it has been ascertained that only one out of four M.B. take part actively.

11) With regard to fire-prevention and infrastructure resources, the M.B. of the National Park of Parnitha has more resources and infrastructures than the other M.B. and is better organized with regard to materials and instruments. There is a trans-national cooperation among Mediterranean and European countries on issues of mutual assistance in circumstances of major fires and exchange of fire-fighting equipment, education and technology (Martinez et al. 2006, NKUA 2012).

The use of the fireproof method was applied also in Greece, when the fighting of forest fires was among the Forest Service's responsibilities (Law 2612/1998).

It has been stated that Switzerland only manages forest fuels, whereas France carries out land cleaning by means of animal grazing (NKUA 2012).

In Greece, several laws related to forest protection, forest fire-fighting and fire-protection infrastructures have been issued, amended and replaced.

Similarly, we can also refer to the European legislative framework, such as the Council for the EU Forestry Strategy, which, in its resolution of December 15, 1998, called on the Commission to proceed to a constant evaluation, to an improvement of the effectiveness of the European surveillance system regarding forest health and to a consideration of all potential impacts on forest ecosystems. It also called on the Commission to pay special attention to the development of the Community-system information regarding forest fires, which allows a better assessment of the effectiveness of fire-protection measures (Regulation EC No 2152/2003).

The protection of forests against fires is an issue of particular importance and urgency, in order to combat, among other things, desertification and to avoid the negative effects of climate change. It is crucial to avoid any interruption of operations on behalf of the Member States under Regulation (EEC) No 2158/1992, which has expired. Therefore, Regulation (EC) No 2152/2003 of the European Parliament should cover preventive measures, which are not covered by Regulation (EC) No 1257/1999 and are not included in the national or the regional development programs for rural areas.

According to the Resolution of the European Parliament (2010), fires comprise a source of destruction for forests, agricultural crops, and residential areas as well. Because forests are important for timber production, conservation of biodiversity, prevention of floods, avalanches and erosion, management of underground water resources and carbon sequestration, the fires should be an issue of concern for all Member States. Therefore, the European Parliament (EP) requests that the Commission, in cooperation with Member States, implement legislative proposals and initiatives in the field of forest protection and fire prevention. The EP maintains that plans for afforestation/reforestation should be strengthened, preferably on native species and mixed forests, for the benefit of biodiversity and for greater resistance to fires, storms and pests, as well as for the constant collection and use of residual forest biomass, which is a renewable source of energy.

The purpose of this study was to record and to evaluate fireproofing measures of Management Bodies that have been established and set up in Greece by virtue of Law 3044/2002 for the management and protection of the Protected

Areas within their jurisdictions. Presently, 28 Management Bodies are operating in Greece (Table 1), which manage a corresponding number of national parks in the country, as provided by the Laws 2742/1999 & 3044/2002 (Efthimiou 2015).

Conclusion

The results of this study revealed that there are weaknesses and deficiencies in the Management Bodies' agencies and equipment. The immediate registration and demarcation of Protected Areas in Greece is essential, along with the drafting of forest maps. Fire-protection plans must be drafted for Protected Areas and implemented, in order to protect biodiversity as well.

Further research is needed, in order to create a database and an organized Geographic Information System (GIS, use of new technologies, etc.) in all Management Bodies of Protected Areas. In this way, a more effective management of forests can be achieved.

Therefore, it is necessary to consider the results of this study, in order to estimate right the risk of forest fires in Greece. For the protection of national parks, however, the implementation of fire-prevention measures is critical, especially during the summer season.

Finally, from the survey conducted with the Management Bodies of Greece, it appears that there is a general need of the improvement and supply with equipment and instruments and for the implementation of fire-protection measures.

Acknowledgment

The authors wish to thank all Management Bodies of Protected areas of Greece, for their participation in our survey.

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FORESTRY IDEAS, 2016, vol. 22, No 2 (52): 221–227

EXISTING AGROFORESTRY SYSTEM AND ITS COMPONENT IN TEHRI DISTRICT OF GARHWAL HIMALAYA

Kundan K. Vikrant[1*], Dhanpal S. Chauhan[1], and Raza H. Rizvi[2]

[1]Department of Forestry & NR, HNB Garhwal University, Srinagar, Garhwal, Uttarakhand – 246174, India. [*]E-mail: kundankumarvikrant@gmail.com
[2]Central Agroforestry Research Institute, Jhansi, Uttar Pradesh – 284003, India

Received: 01 June 2015 Accepted: 12 January 2017

Abstract

The present study was conducted to investigate the existing agroforestry system and its component along altitudes in traditional agroforestry systems in Tehri district Garhwal Himalaya, India. Three different altitudes were considered: lower (286–1200 m), middle (1200–2000 m) and high altitude (2000–2800 m). All agroforestry components along altitudes were presented including trees, fruit trees and crops. The proportion of trees, fruit trees, and crops were 45.8 %, 22.9 % and 31.2 %, respectively. Total 22 forest tree species, 11 fruit tree species, and 15 crops species were recorded in the study area. The agri-silviculture, agri-horticulture and agri-hortisilviculture were the common agroforestry systems recorded in the region.

Key words: agro-climatic zone, altitudes, crops, *Grewia oppositifolia*, multipurpose tree.

Introduction

Agroforestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence. In agroforestry systems there are both ecological and economical interactions between the different components (Lundgren and Raintree 1982). Agroforestry plays a vital role in the improvement of Indian economy through tangible and intangible benefits. In Garhwal Himalaya, agroforestry is permanent feature of agriculture landscape (Semwal and Maikhuri 1996, Bhatt and Todaria 1999). It forms integral relationships with the farmer community to supplement fuel, fodder, fruits and fibers, on the one hand and balance the environment on the other. Farmers have common practice to integrate crops, trees, and livestock to solve the problem of acute shortage of fuel, fodder and other goods (Bhatt 2002). The farmers have little opportunities to select the tree species, and therefore, they accept whatever is available on their land (Bhatt et al. 2010). The assortment of trees on the edges of the agricultural field is farmer friendly and compatible. Selection of intercrops depends mainly on edapho-climatic conditions of the area, farmer's need and resource availability (Saroj and Dadhwal 1997). The present investigation is an effort to examine the existing traditional agroforestry system and its components across different altitude in the Garhwal region of the Central Western Himalaya of Uttarakhand, India.

Materials and Method

The study was conducted in Tehri district of Garhwal Himalaya. The district lies between 30°3’ and 30°53’ N and 77°56’ and 79°04’ E, having geographical area of 3,642 km^2 (FSI 2011) (Fig. 1). The area has been divided into three main agro-climatic zones: Sub-tropical zone (300–1200 m), Sub temperate zone (1200–2000 m) and Temperate zone (2000–2800 m), depending on the topography, altitude and temperature condition (Singh and Singh 1992). The study was carried out in the agricultural fields, mostly dominated by trees. Out of nine developmental blocks, six were selected in the district, representing three altitudes.

Total thirty villages were included in the present study. They are situated in six developmental blocks: six villages in

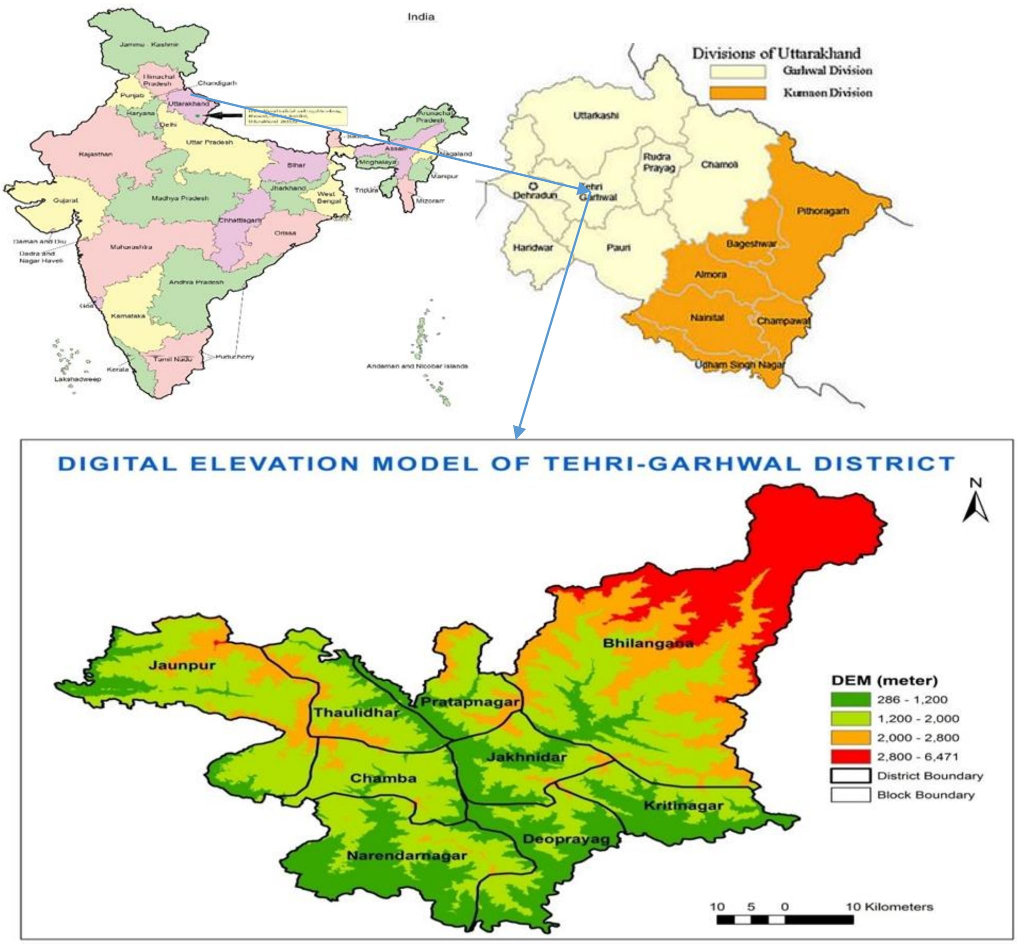

Fig. 1. Geographical location of study area.

Devprayag, Kritinagar, Chamba and four villages in Thauldhar, Jakhnidhar and Pratapnagar, respectively. Regarding the altitude, thirteen villages were within 286–1200 m (designated as lower altitude) and range 1200–2000 m (middle altitude) and four villages – within the range 2000–2800 m (high altitude) (Tables 1 and 2). Field survey was conducted in Kritinagar, Devprayag, Chamba, Jakhnidhar, Pratapnagar and Thaulidhar blocks in July, 2014 (Table 1). The useful information like name of the village, altitude, GPS location, existing agroforestry system, tree species, and crops was also recorded. In each village, 10 sample plot of 20×10 m^2 were marked randomly for detailed study in the agroforestry field.

Table 1. Surveyed blocks/villages.

Blocks	Altitudes, m		
	286–1200	**1200–2000**	**2000–2800**
Devprayag	Bagi, Grothikhanda, Palisen	Langur, Dungi	Jurana
Kritinagar	Maikhandi, Jakhand, Dhaulangi	Timal gaon, Dagar, Riskoti	-
Chamba	Kyari, Pali	Guldi, Purshal	Saur, Chopriyal gaon
Thauldhar	Dharwal, Jaspur	Indra, Sonara	-
Jakhnidhar	Raswari, Undoli	Manthal, Chah	-
Pratapnagar	Bausari	Kothaga, Kandakhal	Kualgarh

Results and Discussion

Based on the field survey, the common existing agroforestry systems in Garhwal Himalaya appeared to be agrisilviculture (trees and agricultural crops), agrihorticulture system (edible fruit trees and agriculture crops), and agrihortisilviculture system (trees including edible fruit trees, forest trees and agricultural crops) (Table 2). In the Himalayan region, a number of indigenous agroforestry systems have been known from Himachal Pradesh and Uttarakhand (Atul and Khosla 1990) out of which agrihortisilviculture, agrisilviculture and agrihorticulture are very frequent. Dadhwal et al. (1989) and Toky et al. (1989) have recognized these three agroforestry systems with their multifarious benefits.

Table 2 indicates that the proportion of forest trees, fruit trees, crops are found 45.8 %, 22.9 % and 31.2 % respectively. Total 22 forest tree species, 11 fruit tree species, and 15 crops were recorded in the study area. At middle Himalayan altitude, tree species like *Grewia oppositifolia* Roxb., *Celtis australis* L., *Melia azedarach* L., *Morus alba* L., *Prunus cerasoides* D. Don, *Musa paradisiaca* L., *Celtis australis* L., *Ficus palmata* Forssk., *Pinus roxburghii* Sargent, *Bauhinia variegata* L., *Mangifera indica* L. were common along 1200–2000 m. In lower Himalayan altitude, *Adina cordifolia* (Roxb.) Hook. f. ex Brandis, *Mangifera indica*, *Citrus limon* (L.) Burm. f., *Artocarpus heterophyllus* Lam., *Anogeissus latifolia* (Roxb. ex DC.) Wallich ex Richard, *Cassia fistula* L., *Melia azedarach, Bauhinia variegata*, *Ficus palmata*, *Syzygium cumini* (L.) Skeels were common along 286–1200 m. *Grewia oppositifolia* was one of the species thriving in the diverse altitudinal range. In high Himalayan altitude, species like *Quercus leucotrichophora* A. Camus., *Malus domestica* Borkh., *Myrica esculenta* Buch.-Ham., *Juglans regia* L., *Prunus persica* (L.) Batsch., *Grewia oppositifolia* found along 2000–2800 m. In crops, *Echinochloa frumentacea* Link., *Glycine max* (L.) Merr., *Cajanus cajan* (L.) Millsp., *Cur-*

cuma longa L., *Zea mays* L. these are common crops which are cultivated in the field of farmer's along diverse altitudinal range.

Table 2. Existing agroforestry system and its component.

Village	Blocks	Altitudes, m	Agroforestry system	Tree species	Crops
Dungi	Devprayag	1200–2000	Agrisilvi, Agrihorti	*Quercus leucotrichophora, Grewia oppositifolia, Melia azedarach, Rhododendron arboreum* Sm., *Celtis australis, Toona ciliata* M. Roem.	*Echinochloa frumentacea*
Bagi	Devprayag	286–1200	Agrihortisilvi, Agrihorti, Agrisilvi	*Adina cordifolia, Mangifera indica, Citrus limon, Artocarpus heterophyllus*	*Echinochloa frumentacea*
Langur	Devprayag	1200–2000	Agrisilvi, Agrihortsilvi	*Grewia oppositifolia, Celtis australis, Pyrus communis* L., *Ficus roxburghii* Wall., *Prunus cerasoides, Musa paradisiaca*	*Glycine max, Brassica campestris* L., *Solanum melongena* L., *Colocasia antiquorum* L.
Gorthikanda	Devprayag	286–1200	Agrisilvi, Agrihortisilvi	*Grewia oppositifolia, Anogeissus latifolia, Cassia fistula, Melia azedarach, Psidium guajava* L.	*Vigna mungo* (L.) Hepper, *Cajanus cajan*
Palisen	Devprayag	286–1200	Agrisilvi, Agrihortisilvi	*Grewia oppositifolia, Adina cordifolia, Morus alba*	*Cajanus cajan*
Jurana	Devprayag	2000–2800	Agrisilvi	*Quercus leucotrichophora*	*Zea mays, Brassica campastris*
Timal gaon	Kritinagar	1200–2000	Agrisilvi, Agrihortisilvi	*Grewia oppositifolia, Toona ciliata, Syzygium cumini, Mangifera indica*	*Amaranthus spinosus* L., *Glycine max, Zea mays, Echinochloa frumentacea*
Dagar	Kritinagar	1200–2000	Agrihortisilvi	*Ficus bengalensis* L., *Melia azedarach, Citrus sinensis* (L.) Osbeck, *Prunus cerasoides, Juglans regia, Toona ciliata, Musa paradisiaca*	*Echinichloa frumentacea, Vigna mungo, Curcuma longa*
Maikhandi	Kritinagar	286–1200	Agrisilvi, Agrihortisilvi	*Grewia oppositifolia, Toona ciliata, Celtis australis, Melia azedarach, Musa paradisiaca, Bauhinia variegata, Ficus palmata*	*Curcuma longa, Vigna mungo, Echinochloa frumentacea*

Riskoti	Kritinagar	1200–2000	Agrisilvi, Agrihortisilvi	*Grewia oppositifolia, Ficus roxburghii, Prunus cerasoides, Bauhinia variegata, Celtis australis, Mangifera indica*	*Vigna mungo, Glycine max, Zea mays, Amaranthus spinosus*
Jakhand	Kritinagar	286–1200	Agrisilvi, Agrihortisilvi	*Celtis australis, Toona ciliata, Grewia oppositifolia, Citrus limon, Psidium guajava, Celtis australis*	*Vigna mungo, Glycine max, Zea mays, Amaranthus spinosus*
Dhaulangi	Kritinagar	286–1200	Agrisilvi, Agrihortisilvi	*Ficus roxburghii, Pinus roxburghii, Syzygium cumini, Celtis australis, Toona ciliata, Melia azedarach*	*Amaranthus spinosus*
Kyari	Chamba	286–1200	Agrisilvi, Agrihortisilvi	*Grewia oppositifolia, Celtis australis, Prunus cerasoides, Quercus leucotrichophora*	*Vigna mungo, Echinochloa frumentacea, Zea mays*
Purshal	Chamba	1200–2000	Agrisilvi, Agrihortisilvi	*Grewia oppositifolia, Celtis australis, Prunus cerasoides, Quercus leucotrichophora*	*Vigna mungo, Echinochloa frumentaacea, Zea mays*
Chaupriyal Gaon	Chamba	2000–2800	Agrihortisilvi	*Quercus leucotrichophora, Malus domestica, Pyrus communis*	*Echinochloa frumentacea*
Pali	Chamba	286–1200	Agrihotisilvi	*Juglans regia, Prunus armeniaca* L., *Prunus persica*	*Echinochloa frumentacea*
Guldi	Chamba	1200–2000	Agrihortisilvi	*Celtis australis, Grewia oppositifolia, Ficus palmata, Morus alba*	*Vigna mungo, Zea mays*
Saur	Chamba	2000–2800	Agrihortisilvi	*Malus domestica, Myrica esculenta, Juglans regia*	*Vigna mungo*
Dharwal	Thauldhar	286–1200	Agrihortsilvi, Agrisilvi	*Grewia oppositifolia, Ficus roxburghii, Bauhinia variegata, Melia azedarach*	*Echinochloa frumentacea, Glycine max*
Jaspur	Thauldhar	286–1200	Agrisilvi	*Grewia oppositifolia, Pinus roxburghii, Pyrus pashia*, Buch.-Ham. ex D. Don**.**	*Brassica campestris, Colocasia antiquorum* Schott
Indra	Thauldhar	1200–2000	Agrisilvi	*Melia azedarach, Celtis australis, Albizia lebbeck,* L., *Ficus auriculata* Lour.	*Vigna mungo, Zea mays, Amaranthus spinosus*
Sonara	Thauldhar	1200–2000	Agrisilvi	*Pinus roxburghii, Celtis australis, Albizia lebbeck, Ficus auriculata*	*Vigna mungo, Zea mays, Glycine max, Amaranthus spinsous*

Raswari	Jakhnidhar	286–1200	Agrisilvi	*Pyrus pashia, Celtis australis, Grewia oppositifolia, Melia azedarach, Prunus cerasoides*	*Glycine max, Amaranthus spinosus, Zea mays, Echinochloa frumentacea*
Undoli	Jakhnidhar	286–1200	Agrisilvi	*Melia azedarach, Ficus auriculata, Celtis australis*	*Echinochloa frumentacea*
Manthal	Jakhnidhar	1200–2000	Agrisilvi	*Grewia oppositifolia, Melia azedarach, Celtis australis*	*Amarenthus spinsous*
Chah	Jakhnidhar	1200–2000	Agrisilvi, Agrihorti	*Grewia oppositifolia, Celtis australis*	*Amaranthus spinosus*
Kaulgarh	Pratapnagar	2000–2800	Agrisilvi, Agrihorti	*Grewia oppositifolia, Malus domestica, Juglans regia, Prunus persica*	*Zea mays, Pisum sativum, Sesamum orientale*
Kotagha	Pratap nagar	1200–2000	Agrisilvi	*Grewia oppositifolia, Pyrus pashia, Melia azedarach*	*Echinochloa frumentacea*
Kandakhal	Pratap nagar	1200–2000	Agrisilvi	*Grewia oppositifolia, Melia azedarach*	*Echinochloa frumentacea*
Bausari	Pratap nagar	286–1200	Agrisilvi	*Grevia oppositifolia, Pyrus pashia, Melia azedarach*	*Echinochloa frumentacea*

Conclusion

The varying topography of the Tehri district affects its species diversity, composition and structure along the altitudes, even at small distances. Moreover, the exposition in the hilly topography also plays an important role in the vegetation pattern. The studies showed that agroforestry systems consist predominantly of multipurpose tree species and horticulture tree species. The present study compiles the list of such tree species including crops, which are present in the agriculture fields of the farmers along variable altitudinal range. The documentation of these multipurpose trees and agroforestry practices may be helpful for introducing them in other areas in the same agro-climatic zone.

Acknowledgements

I would also like to show our gratitude to the Prof. N. P. Todaria, Head of Department of Forestry and Natural Resources for encouragement throughout the study period and also thanks the Ministry of Social Justice & Empowerment for providing the financial assistant as a Rajiv Gandhi National Fellowship to conduct this study. The farmers of the Tehri Garhwal who facilitated during the study are also acknowledged.

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